# STVDIA GEOLOGICA

## XIV

NUMERO EXTRAORDINARIO CON LAS COMUNICACIONES
PRESENTADAS A LA REUNION INTERNACIONAL
DEL PROYECTO M. A. W. A. M.

(I. G. C. P.)

EDICIONES UNIVERSIDAD DE SALAMANCA

1979

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# EL COMPLEJO ESQUISTO - GRAUVAQUICO Y LOS MATERIALES ORDOVICICOS AL SE. DE CIUDAD RODRIGO (SALAMANCA - ESPAÑA)

M.ª D. RODRÍGUEZ ALONSO*

RESUMEN.—Se ha estudiado una zona situada al SW de la provincia de Salamanca de la que se presenta: una cartografía geológica y estructural, una descripción estratigráfica y petrográfica del Complejo esquisto-grauváquico y de los materiales ordovícicos y un estudio tectónico del área.

Desde el punto de vista estratigráfico, se señala la existencia de una serie monótona de esquistos y grauvacas entre los que se intercalan niveles de conglomerados y mixtitas; sobre ellas se superpone una sucesión de esquistos carbonosos y grauvacas muy oscuras y localmente un tramo carbonatado de calizas impuras, grauvacas y conglomerados.

Sobre estos materiales y sin discordancia importante, se encuentra una serie intermedia en la base de la Cuarcita Ordovícica formada por limolitas, arenas arcillosas, areniscas y conglomerados.

El estudio tectónico revela la existencia de dos fases principales de deformación hercínica. La primera es la responsable de las estructuras cartografiables y lleva asociada una esquistosidad de flujo que afecta a los materiales del Complejo esquisto-grauváquico y a los Ordovícicos.

SUMMARY.—Some pre-Ordovician and Lower Ordovician metasediments in southwestern part of Salamanca province (Spain) have been studied.

From the stratigraphic point of view it is pointed the existence of a monotonous series of schists and graywackes with some conglomerate and mixtite levels interbedded.

A very dark schists and graywackes sequence is overlaying them. Locally a carbonated level with siliceous limestones, carbonated graywackes and conglomerates appears.

Over those materials and under the Ordovician Quartzite, without important disconformity between them, a intermediate series with siltstones, shaly sands, sandstones and conglomerates is found.

The structural study reveals the existence of two main phases of Hercynian deformation. The older one is responsible of the main mappab'es folded structures. This fo'ding yield an axial-plane cleavage that affects the Complex of schists and graywackes and also the Ordovician materials.

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## INTRODUCCION

El objeto de este trabajo ha sido el estudio de una zona situada en el SE de Ciudad Rodrigo (provincia de Salamanca), en la que pueden observarse las relaciones entre los materiales del Complejo esquisto-grauváquico y las series superiores.

Desde el punto de vista geológico y estructural, abarca una amplia estructura sinclinal de dirección NW-SE, constituida por materiales ordovícicos que se sitúan, sin discordancia apreciable en este caso, sobre los materiales del Complejo esquisto-grauváquico que afloran al sur de ella.

## ANTECEDENTES

La zona es poco conocida en su aspecto geológico. SCHMIDT THOME (1950), considera Cámbricas y/o Algónquicas las formaciones del Complejo esquisto-grauváquico del sur de la provincia de Salamanca, sobre los que se sitúa el Arenig con un conglomerado basal de aparición local y la Cuarcita Armoricana.

L. C. GARCÍA DE FIGUEROLA (1970), y L. C. GARCÍA DE FIGUEROLA y J. M. UGIDOS MEANA (1971), señalan en el Complejo esquisto-grauváquico la presencia de pliegues de dirección extraña con respecto a las estructuras generales que se observan en la provincia (ya citada por SCHMIDT THOME (op. cit.), dirección que él consideró como *Erzgebírguica*), y la existencia de materiales diversos, como pizarras bandeadas y grauvacas, pizarras negras, calizas y conglomerados calcáreos, cuarcitas y pizarras grises.

F. MINGARRO MARTÍN, E. MINGARRO MARTÍN y M.ª C. LÓPEZ DE AZCONA (1971), presentan la cartografía geológica a escala 1/50000 de la hoja n.º 526, Serradilla del Arroyo.

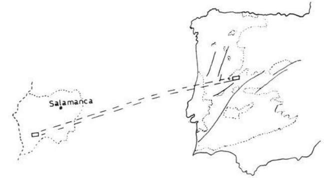
P. RÖLZ (1972), presenta una cartografía general de una extensa zona al E. de la estudiada, aportando una serie estratigráfica semejante a las descritas por los autores anteriormente citados.

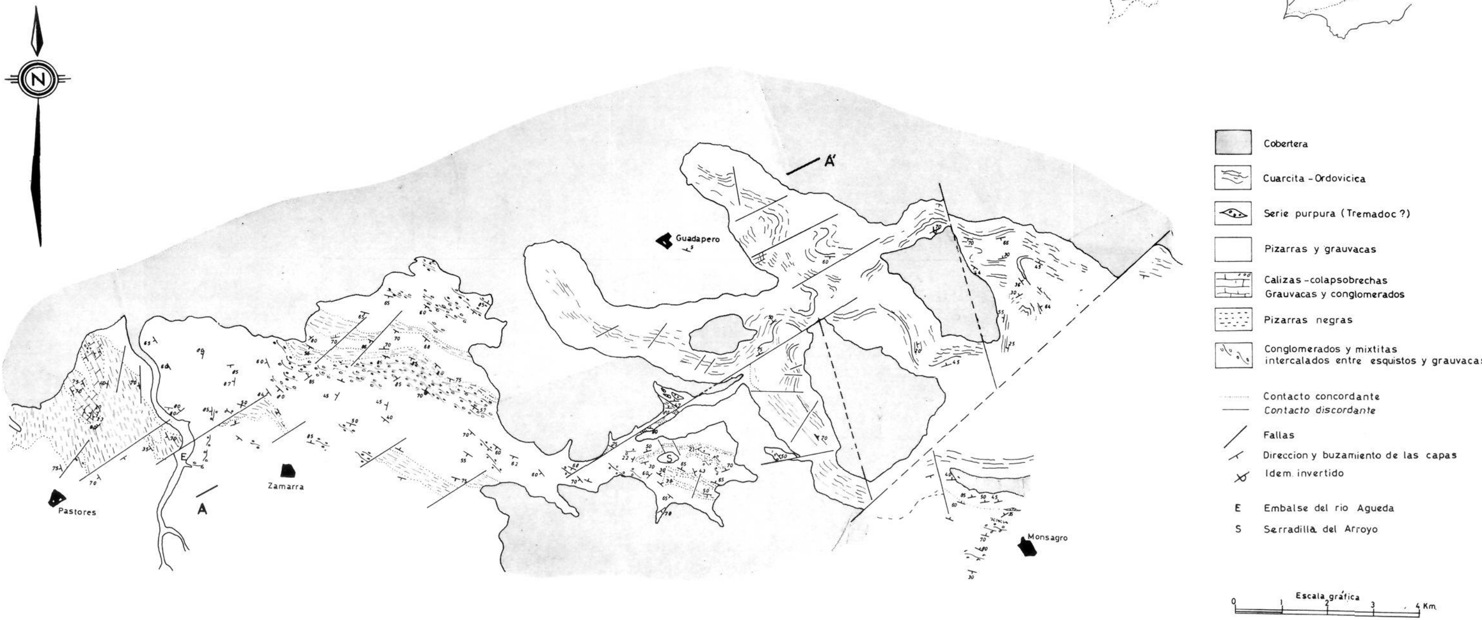
## ESTRATIGRAFIA

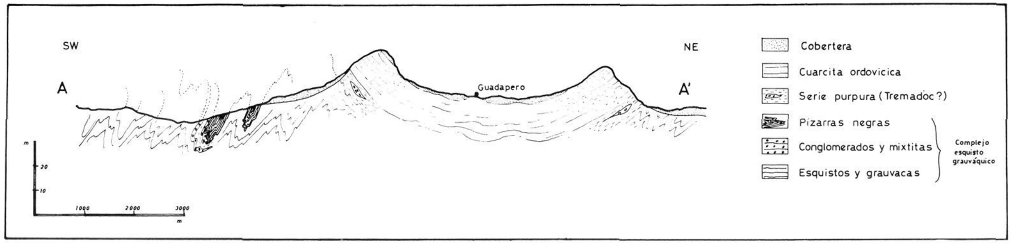
Se han establecido dos series estratigráficas locales: Serie de Pastores y Serie de Monsagro-Serradilla del Arroyo (detalladamente descritas por M.

# MAPA GEOLOGICO DEL S.E. DE CIUDAD RODRIGO (SALAMANCA, ESPAÑA)

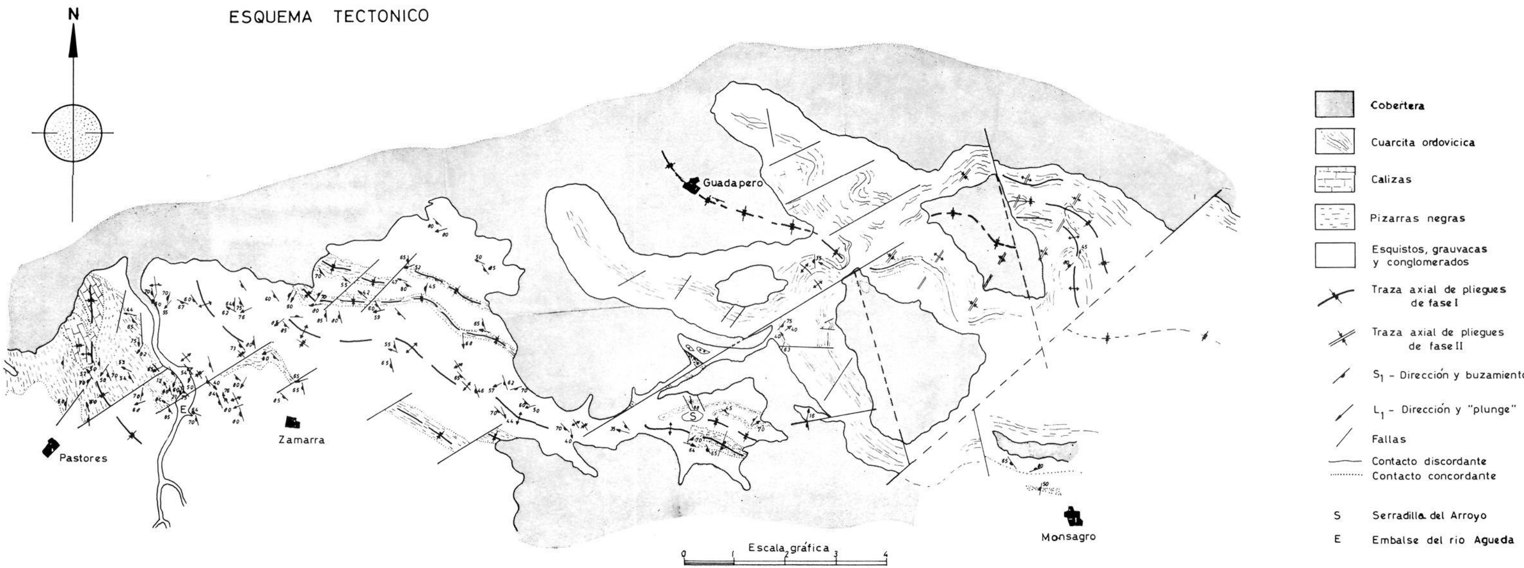
Maria Dolores Rodriguez Alonso – 1976






ESQUEMA TECTONICO



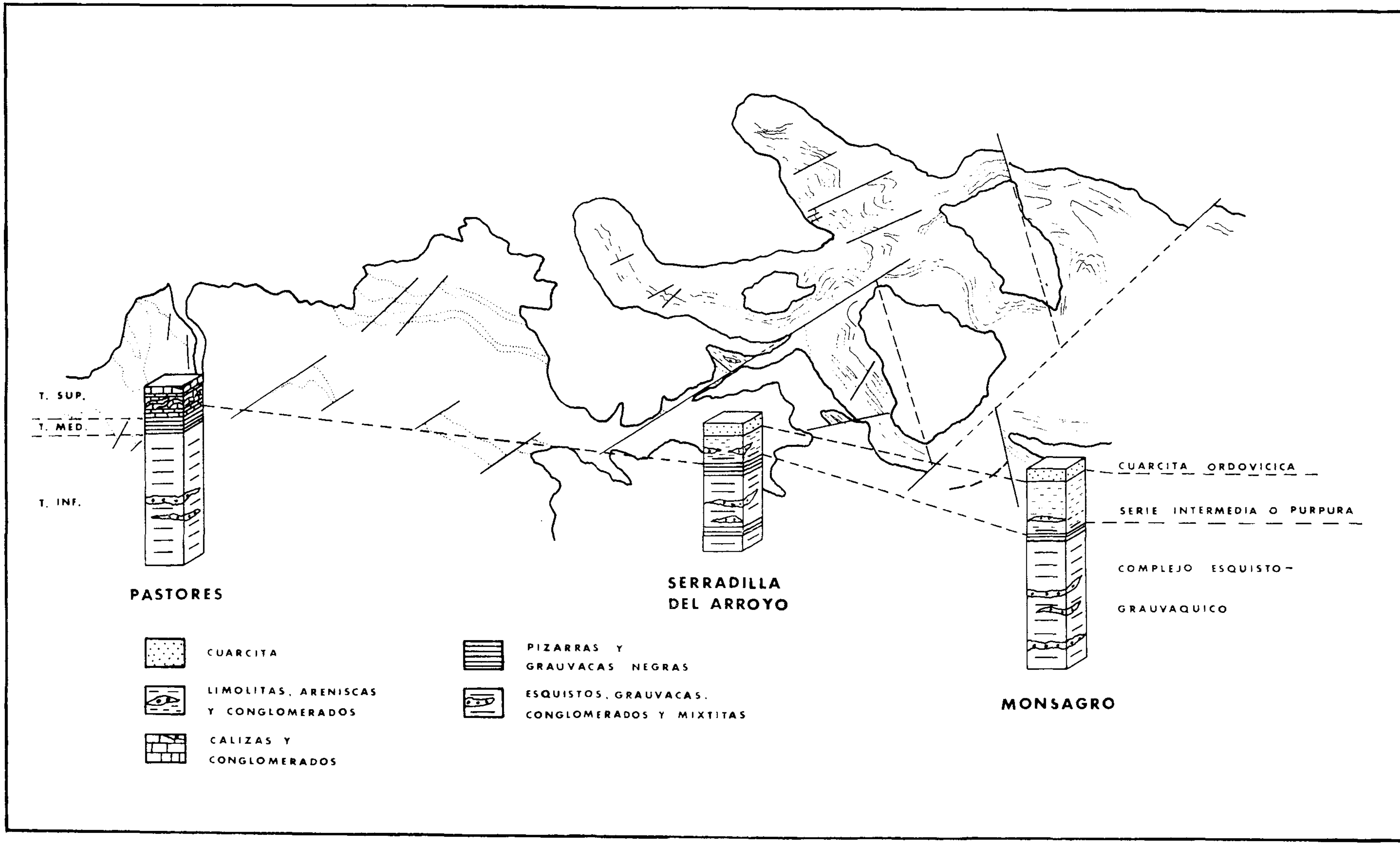



FIG. 1. *Situación geográfica de las columnas estratigráficas del Complejo esquisto-grauváquico y Ordovícico inferior*

D. Rodríguez-Alonso, 1976), en las que se han definido globalmente diferentes tramos (Fig. 1):

— Cuarcita ordovícica.

— Serie Intermedia de base de la cuarcita, que se ha llamado Serie Púrpura por posible correlación con las definidas en los Montes de Toledo, Alta Extremadura, Alcudia y Despeñaperros.

— Complejo esquisto-grauváquico.

En el complejo esquisto-grauváquico se han distinguido tres tramos característicos, cuyos espesores son difíciles de calcular debido al replegamiento sufrido.

El tramo inferior, se caracteriza por presentar una alternancia de esquistos grises bandeados y grauvacas en sentido amplio (Fig. 2), entre los que se intercalan en algunas zonas, niveles de conglomerados y mixtitas de espesor variable.

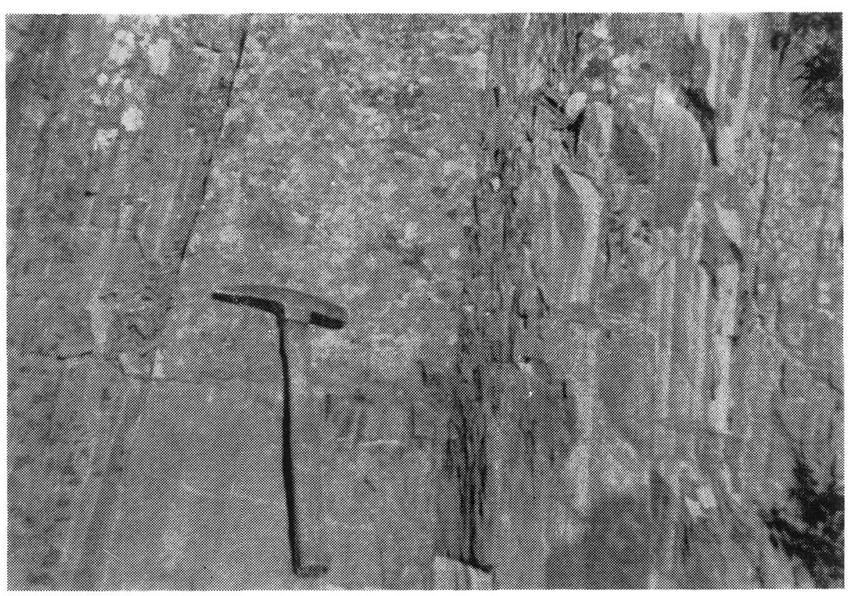


Fig. 2

*Alternancia de esquistos y grauvacas. Carretera de Serradilla del Arroyo a Serradilla del Llano*

Los esquistos son grises, de grano fino a medio, sericíticos y cuarzo-sericíticos, presentando frecuentemente laminaciones paralelas claras y oscuras, según el predominio de material cuarcítico o pelítico y de opacos. Presentan además, otras estructuras sedimentarias como estratificaciones cruzadas, ripple marks y wavy laminated bedding (Figs. 3 y 4).

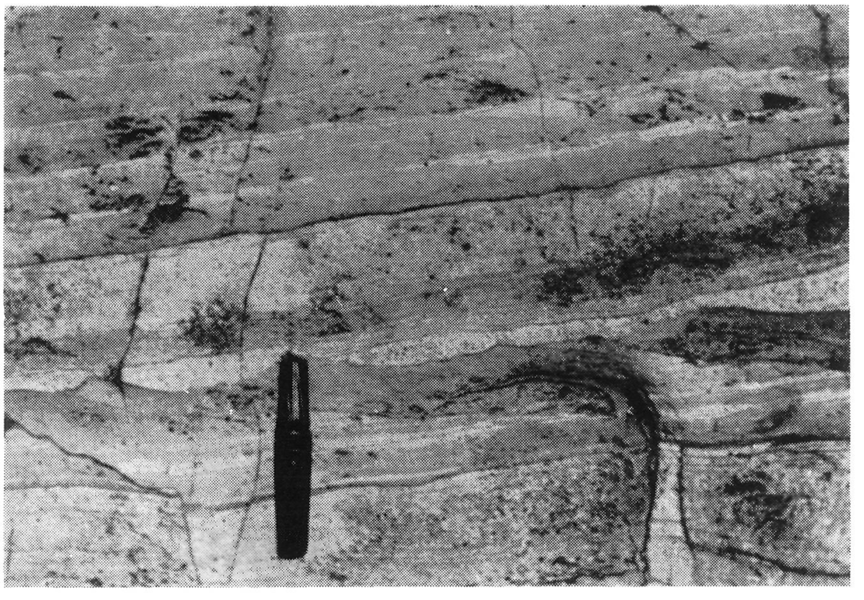


FIG. 3

*Ripple marks. Ribera de Serradilla*

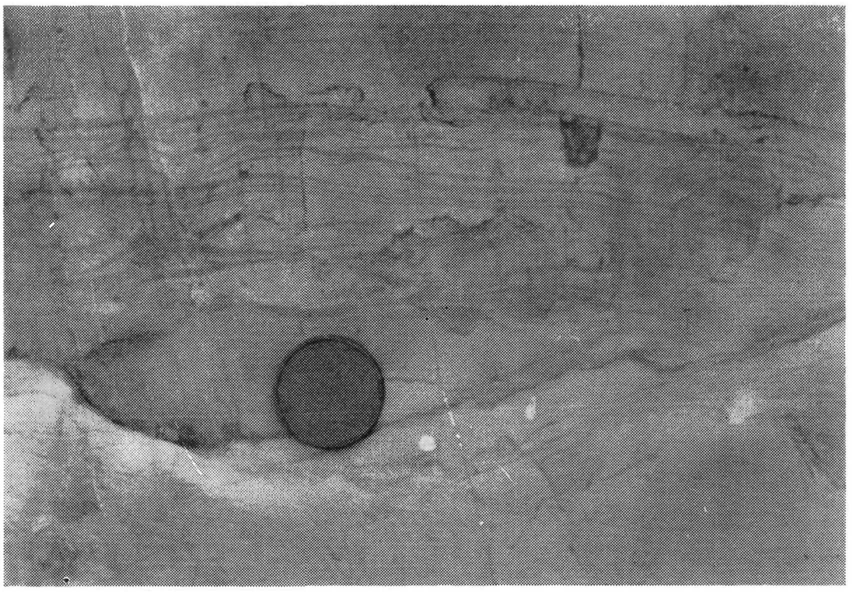


FIG. 4

*Laminación paralela y lechos con laminación ondulada en esquistos*

Estos esquistos, se alternan con grauvacas y areniscas líticas, que aparecen en bancos desde varios centímetros a más de un metro de potencia, en zonas donde existe mayor predominio de estas sobre los esquistos. Generalmente suelen ser de tonos grises claros y verdosos, aunque ocasionalmente son negras y de granulometría variable. Se observan estructuras sedimentarias como granoclasificación, laminaciones paralelas, flute cast y cantos aislados (Fig. 5). Entre ambos, esquistos y grauvacas, se intercalan en la zona centro y este del área, niveles de conglomerados polimícticos y de mixtitas, en el sentido empleado por SHERMERHORN (1966-75) (Sedimento que incluye clastos heterométricos desparramados en una matriz abundante de naturaleza pelítico-arenosa).

FIG. 5

*Flute cast. Ribera de Serradilla*

En general, se trata de varios niveles de potencia variable, con aspecto caótico muchas veces, asociados a slumpings y otras estructuras sedimentarias como estratificaciones cruzadas y granoclasificaciones (Figs. 6, 7 y 8). Presentan cantos de cuarzo, feldespato y fragmentos de roca de naturaleza y granulometría muy diversa, unos de procedencia exterior a la cuenca (de formas irregulares), que derivarían de estratos anteriormente depositados en ella y que han sido removilizados.

Sobre este tramo inferior, se encuentra una formación caracterizada por un predominio de esquistos carbonosos entre los que se intercalan niveles microconglomeráticos y de grauvacas muy oscuras.

Los esquistos son bandeados, de color azul oscuro y negro, presentando a veces cristales de pirita y las grauvacas son también muy oscuras y presentan gran cantidad de fragmentos de roca volcánica de naturaleza básica y estructuras sedimentarias como laminaciones paralelas y estratificaciones cruzadas.

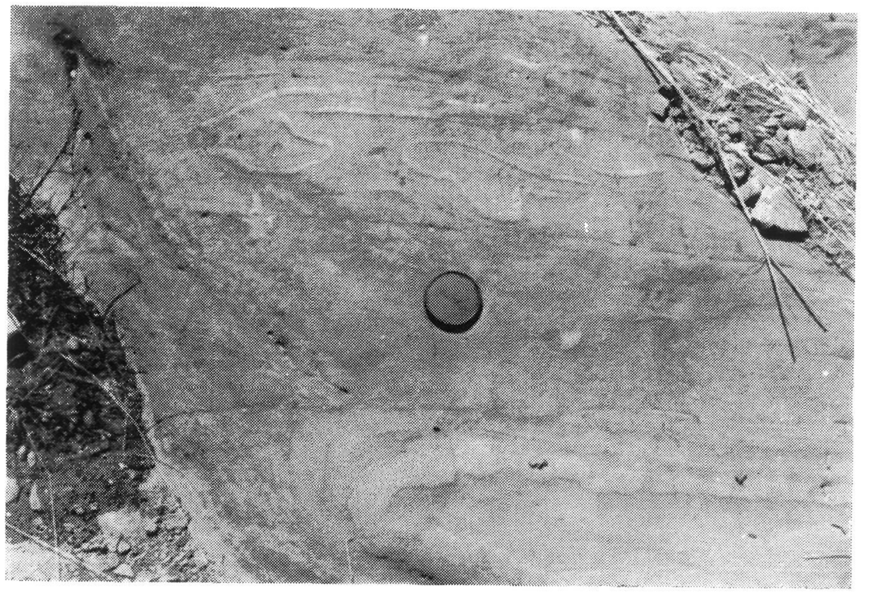


FIG. 6

*Slumpings asociados a los niveles de mixtitas y conglomerados. Ribera de Serradilla*

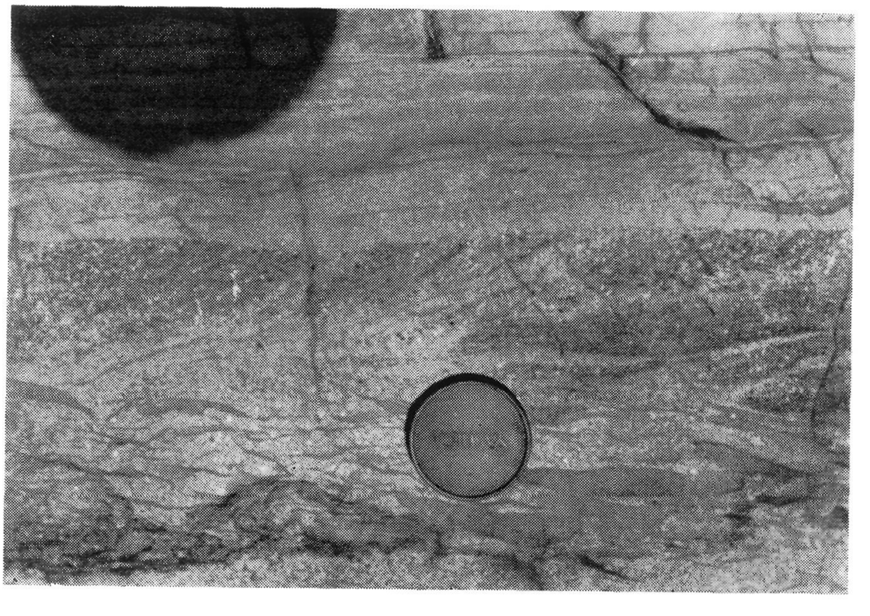


FIG. 7

*Mixtitas en la Ribera de Serradilla. Cantos procedentes del interior y del exterior de la cuenca. Estratificación cruzada. Notar el contacto neto de su límite superior*

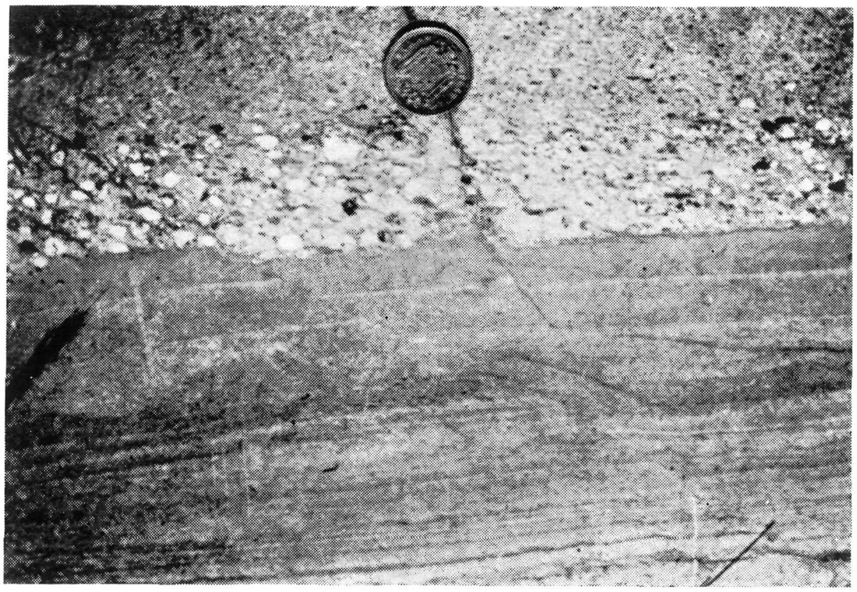


FIG. 8

*Laminación paralela y granoselección en los conglomerados. Ribera de Serradilla*

Sobre estos materiales van apareciendo únicamente en la zona más occidental (cerca de Pastores), niveles microconglomeráticos y de grauvacas carbonatadas que pasan gradualmente a un nivel de calizas impuras con dolomita, ankerita y bastante aporte detrítico y volcánico.

Estas calizas, aparecen en niveles perfectamente estratificados entre otros colapsados y brechificados, que pasan a conglomerados con cantos de cuarzo y caliza y conglomerados silíceos lateral y verticalmente.

Presentan estructuras sedimentarias como slumping y estratificación cruzada.

Este nivel calcáreo, no aparece hacia el este (Serradilla del Arroyo y Monsagro), donde se encuentra un tramo de esquistos arcillosos grises claros en alternancia con areniscas, directamente sobre el tramo con predominio de pizarras negras.

Encima, en esta zona, se sitúa una serie de potencia variable que constituye la base de la Cuarcita Ordovícica. Está integrada principalmente por limolitas, arenas arcillosas, areniscas y conglomerados. Presenta una coloración característica rojiza y diversas estructuras sedimentarias: laminaciones paralelas, estratificaciones cruzadas, ripple marks y pistas de *Scolithus* (Fig. 9).

Sobre ellos, se sitúa la Cuarcita Ordovícica en bancos masivos de varios metros de potencia que hacia arriba se hacen más tableadas y alternan con esquistos. Se trata de una cuarcita de grano fino a medio, muy compacta, de

FIG. 9

*Ripple marks - Serie Intermedia (Serie Púrpura). Carretera de Ciudad Rodrigo a Monsagro*

color blanco y a veces rojizo por su contenido en óxidos de hierro. Presenta diversas estructuras sedimentarias: laminaciones paralelas, estratificaciones cruzadas, ripple marks y pistas de *Cruziana* y *Vexillum.*

## PETROGRAFIA

### COMPLEJO ESQUISTO-GRAUVÁQUICO

*Rocas pelíticas.* Las rocas pelíticas que se encuentran en la serie son de tres tipos: esquistos sericíticos, cuarzo-sericíticos y carbonosos.

Los primeros (Fig. 10) son de grano fino, presentan un bandeado claro y oscuro marcado por la existencia de niveles más ricos en cuarzo o en sericita y opacos. Son característicos los cristales idiomórficos de rutilo un poco alterado a leucoxeno. Estos esquistos, se encuentran en el tramo más inferior de la serie, al igual que los cuarzo-sericíticos (Fig. 11), que suelen ser de grano más grueso y con cantos subangulosos de cuarzo fundamentalmente, presentando laminaciones marcadas por la abundancia de micas.

Los esquistos carbonosos caracterizan el tramo intermedio de la serie; son de grano fino, de color negro y con gran abundancia de materia orgánica y óxidos de hierro. A veces, presentan un bandeado marcado por la alternancia de láminas pelíticas y cuarcíticas, coincidiendo las primeras con el predominio de opacos, minerales arcillosos y sericita.

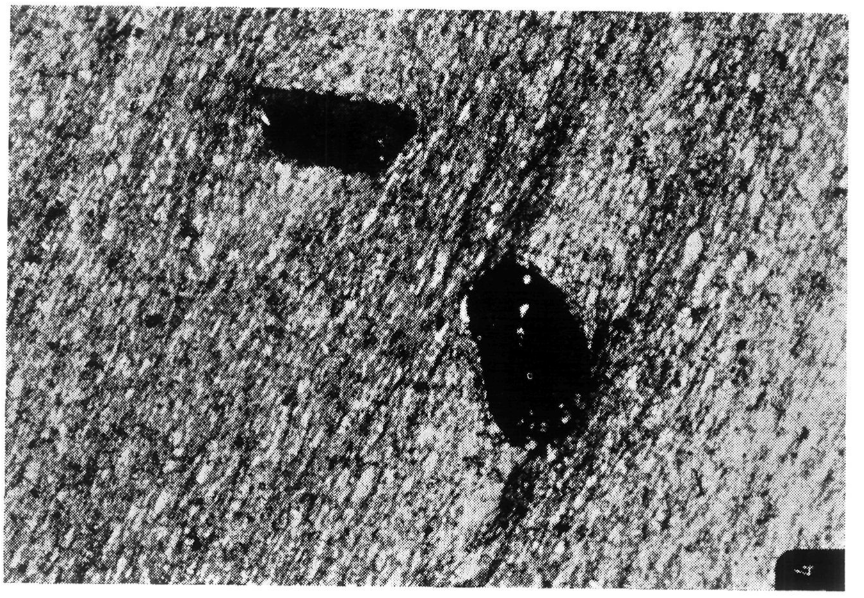


FIG. 10

*Esquisto sericítico. Rutilos sin $S_1$. LN - × 2,5. Carretera de Ciudad Rodrigo a Zamarra*

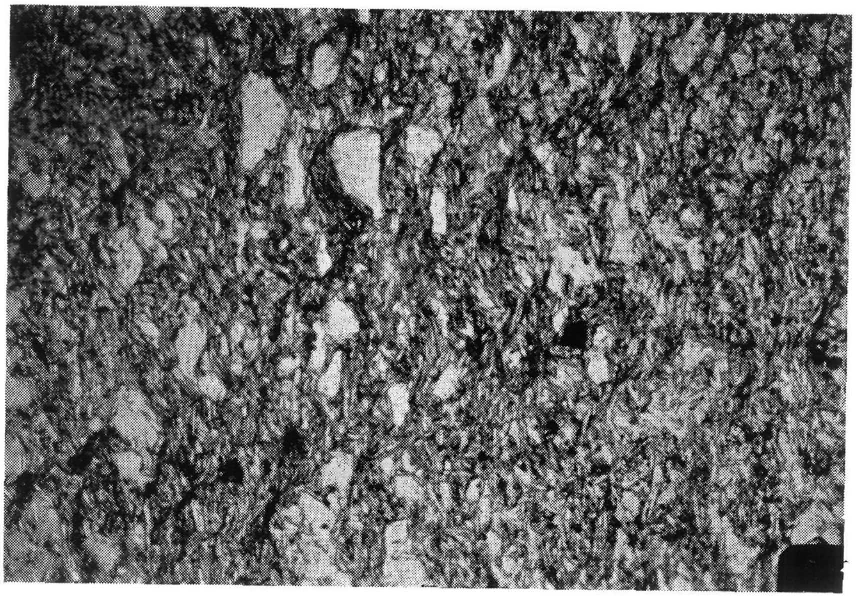


FIG. 11

*Esquisto cuarzo-sericítico. Crenulación débil, tardía y local. LN - × 10. Ribera de Serradilla*

*Grauvacas y areniscas.* Se trata de rocas de grano fino a medio generalmente, que presentan una textura clástica de cantos heterométricos, angulosos y subangulosos, siendo el cuarzo y los fragmentos de roca los minerales esenciales. La clasificación utilizada para este tipo de rocas, es la propuesta por PETTIJOHN-POTTER-SIEVER (1972). Según ella, pueden clasificarse como grauvacas y areniscas líticas, quartzwackes y areniscas con bastante proporción de micas.

En el tramo más inferior, este tipo de rocas suele ser de color gris o verdoso y raramente negro; su composición mineralógica basada en análisis modal es la siguiente (Fig. 12):

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Q ........... | 50,8 | 52,6 | 52 | 68 | 78,5 | 55 | 54,4 |
| Fd ........... | 2 | — | 2,5 | 0,2 | — | 2 | 3 |
| F. R. ......... | 14 | 15 | 2,4 | — | — | 6,4 | 4 |
| Matriz ...... | 17 | 11 | 9.3 | 30 | — | 7,6 | 23 |
| Micas ......... | 13 | 15,6 | 32,4 | — | 18 | 25,7 | 9 |
| Otros ......... | 3 | 5 | 1 | 1,4 | 3 | 3,3 | 6,7 |

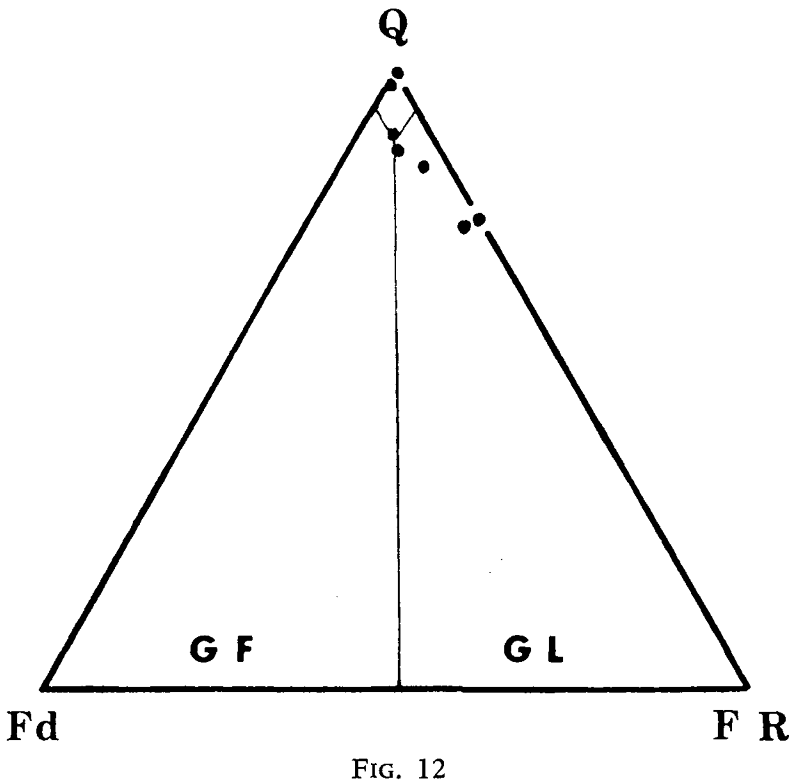



FIG. 12

*Clasificación de grauvacas según* PETTIJOHN - POTTER & SIEVER (1972). *Proyección en un plano medio con 15 % de matriz*

En el tramo medio de la serie, las grauvacas son de color negro, con cantos de cuarzo, fragmentos de roca y plagioclasas, envueltos en una matriz que se distingue mal de los propios cantos cuando la tectonización es más fuerte. Los fragmentos de roca más abundantes suelen ser volcánicos de tipo básico, en forma de vidrio unos y otros con textura fluidal semejantes a la matriz (Figs. 13 y 14). Un opaco muy abundante en algún tipo de

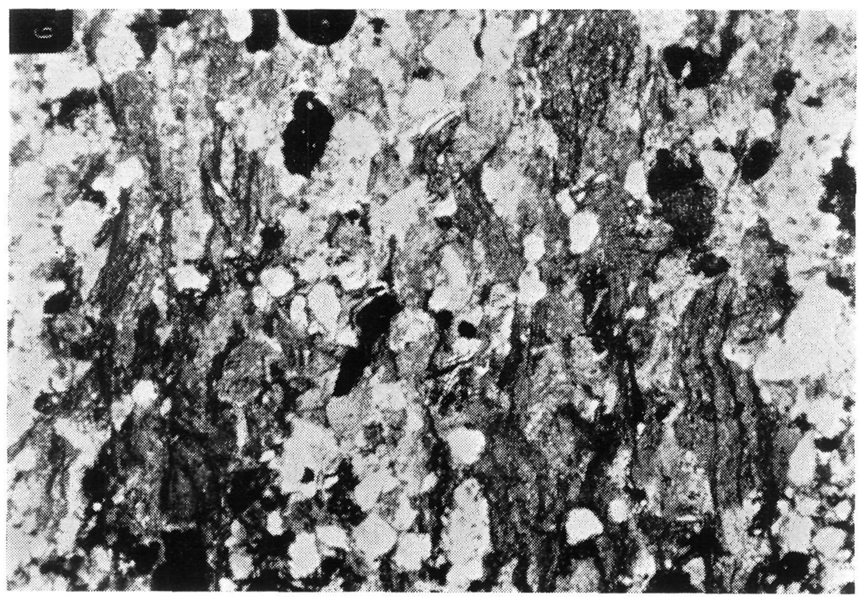


FIG. 13

*Grauvaca lítica. Bandeado definido por los fragmentos de roca efusiva básica con textura fluidal. W del Embalse del Río Agueda. LN - × 2,5*

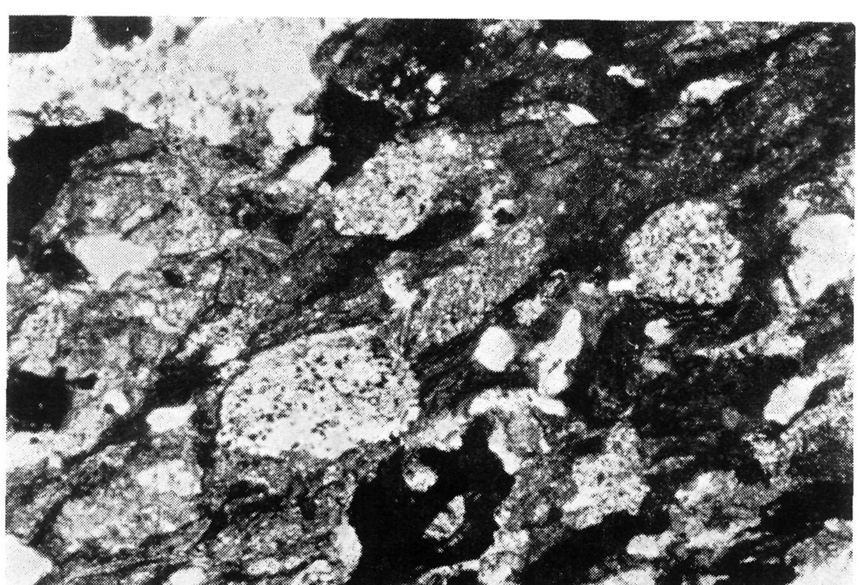


FIG. 14

*Detalle de la foto anterior. LP - × 2,5* grauvacas es la pirita, con la que se asocian minerales como clinozoisita, esfena y calcita. Estas rocas suelen ser bastante ricas en cuarzo y en ellas se encuentran agrupaciones fibroso-radiadas de tremolita/actinolita (Fig. 15) asociados a epidota, clinozoisita, esfena, calcita y pirita. Son similares a las metagrauvacas con minerales calco-magnesianos descritos por C. TORRE DE ASSUNÇAO (1969) para el complejo esquisto-grauváquico de Tras-os-Montes.

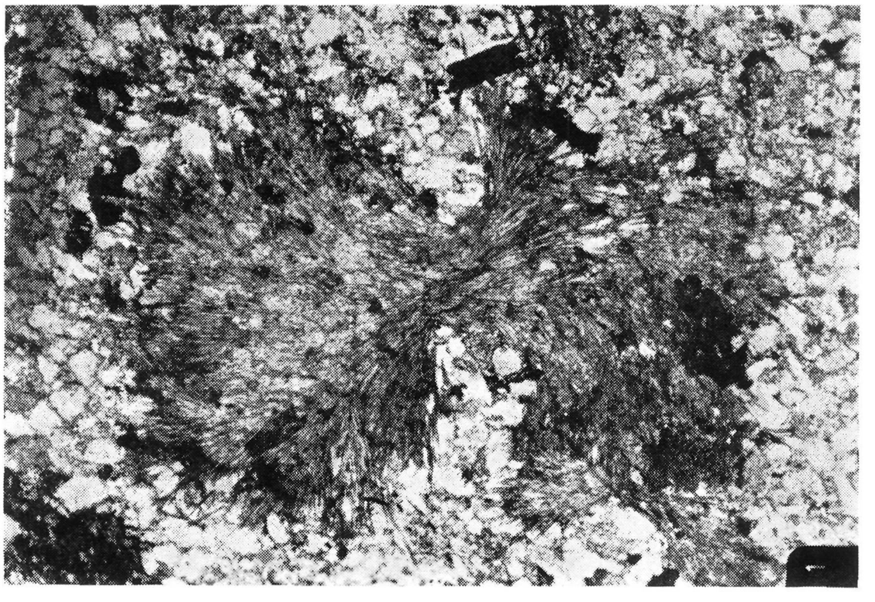


FIG. 15

*Fascículo anfibólico. Grauvaca lítica. Cabezal Viejo. LN - × 2,5*

Las grauvacas carbonatadas que aparecen en el nivel calcáreo de la serie, son muy semejantes a veces a las típicas de «Facies Pepper» (CAROZZI, 1960). Presentan gran cantidad de fragmentos de roca de naturaleza efusiva básica, en forma de vidrio volcánico y de otros fragmentos con textura fluidal, en los que existe algo de vidrio más un agregado muy fino de cuarzo, biotita y sericita.

La calcita, dolomita o ankerita que rodea los cantos, es esparítica muy recristalizada, presentándose como cemento, como un fragmento más y a veces rellenando huecos.

*Conglomerados.* Son rocas que presentan una textura detrítica constituida por cantos subredondeados de cuarzo y fragmentos de roca englobados en una matriz de naturaleza diversa.

Los existentes en el tramo inferior de la serie, son conglomerados polimícticos (Fig. 16) y mixtitas; se trata de tipos muy variados, desde los constituidos exclusivamente por rocas pelíticas, en una matriz también pelítica,

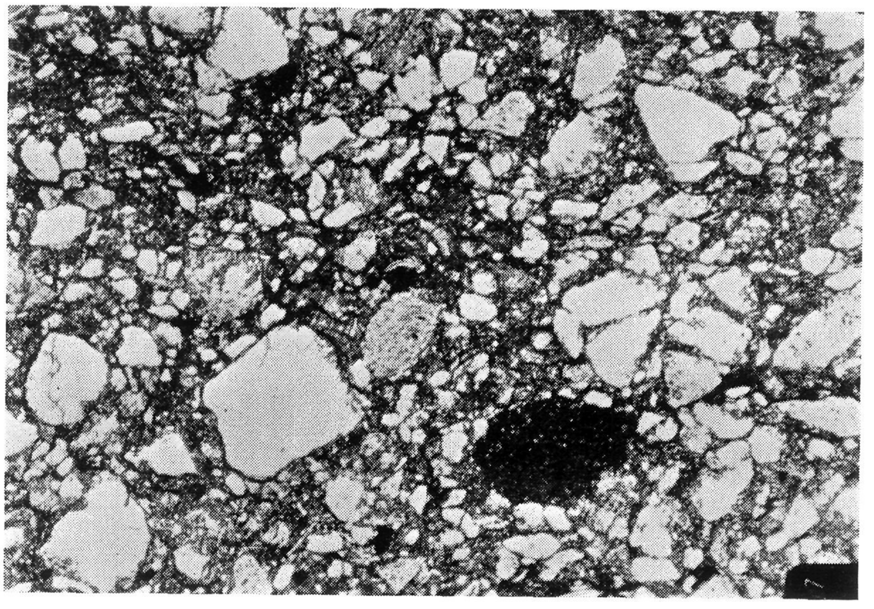


FIG. 16

*Conglomerado polimíctico. Ribera de Serradilla. LN - × 2,5*

hasta aquellos que presentan numerosos cantos de cuarzo y fragmentos de roca bastante isométricos, en una matriz pelítica o grauváquica que lateralmente va perdiendo los cantos hasta desaparecer éstos.

Existen también otros, que engloban cantos de grauvacas de gran tamaño (mayores de 15 cm. de diámetro, que serían verdaderos olistostromos) y en los que a su vez existen cantos pequeños (menores de 1 cm.), en una abundante matriz pelítica.

La presencia de feldespato potásico en algunos conglomerados es notable, presentándose en cantos y a veces en cristales idiomorfos de hasta 5 mm. de longitud, pudiéndose tratar de porfiroides.

Los conglomerados asociados al nivel calcáreo son polimícticos, formados por cantos heterométricos de cuarzo y fragmentos de roca cuarcítica, pelítica, efusiva básica y carbonatada, en una matriz cuarzo-pelítica y cemento carbonatado (Fig. 17). La forma de algunos fragmentos de roca es irregular y no parece detrítica, dando la sensación de haber fluido o de ser cantos blandos en el momento de su incorporación al sedimento.

En este tipo de conglomerados, la proporción de fragmentos de roca efusiva y de carbonatos varía mucho lateral y verticalmente pasando por todos los términos desde un conglomerado polimíctico con cantos de cuarzo, fragmentos de roca y cemento carbonatado, a un conglomerado silíceo constituido por cantos de cuarzo fragmentos de roca cuarcítica, con un cemento silíceo.

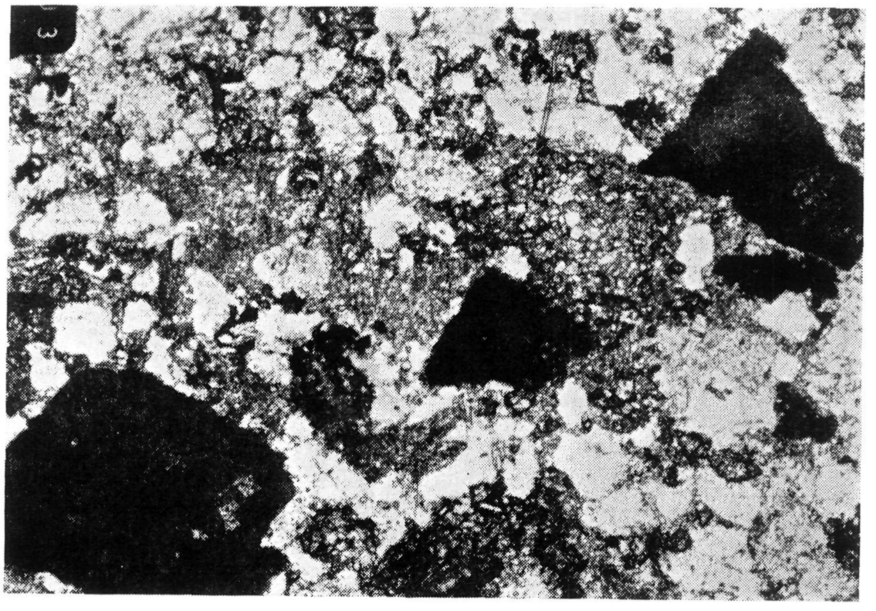


FIG. 17

*Conglomerado polimíctico carbonatado. Facies Pepper. Notar los fragmentos de vidrio volcánico de carácter básico. Cabezal Viejo. LN - × 2,5*

*Rocas carbonatadas.* Aparecen únicamente en la parte W del área estudiada y se trata de calizas arenosas bastante recristalizadas y dolomitizadas en parte, que presentan una textura cristalina esparítica generalmente y están constituidas por calcita, ankerita y dolomita que engloban cantos aislados de cuarzo, plagioclasas y fragmentos de roca. La proporción de fragmentos de vidrio volcánico con textura fluidal es importante en algunas muestras, encontrándose íntimamente mezclados con calcita, pudiendo tratarse de una caliza de tipo peperítico (Fig. 18).

Hay que destacar también, la presencia de unas formas ovaladas y en anillos concéntricos a veces, constituidas por un opaco muy fino y sin estructura interna visible debido a la intensa recristalización, que recuerdan posibles restos orgánicos, como: placas de equínidos, valgas de ostrácodos y secciones de serpúlidos (I. VALLADARES com. pers.) (Fig. 19).

## MATERIALES ORDOVÍCICOS

*Rocas arcillosas.* En este grupo se encuadran diversos tipos de rocas de grano fino, de tonos rosados y blancos grisáceos, que apenas presentan esquistosidad y aparecen en la Serie Intermedia de base de la cuarcita. Su clasificación según PETTIJOHN (1963), varía entre arcillas limosas y arenas arcillosas.

FIG. 18

*Caliza de tipo peperítico. Cabezal Viejo. LN - × 2,5*

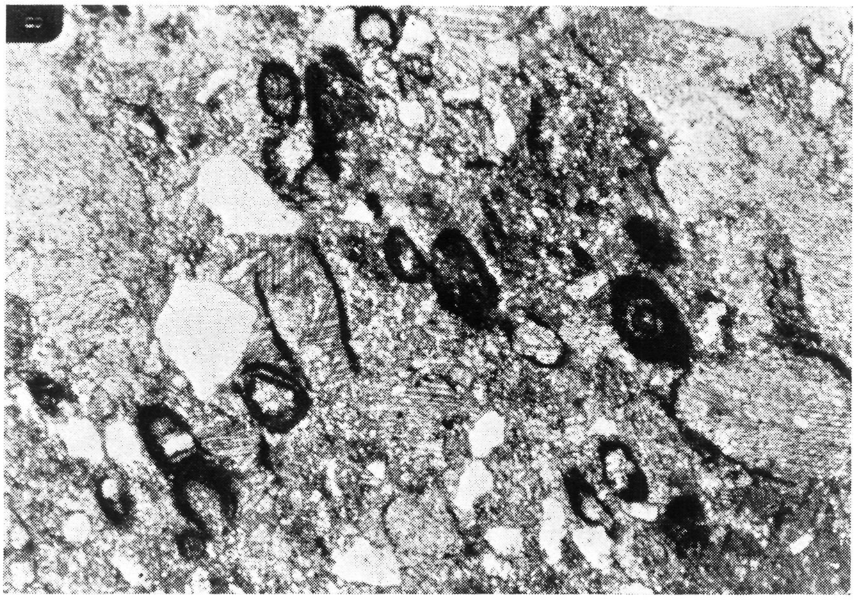


FIG. 19

*¿Caliza con estructuras orgánicas? Cabezal Viejo. LN - × 2,5*

*Areniscas.* Se trata de areniscas cloríticas y sercíticas que se presentan intercaladas con las rocas arcillosas en la Serie Intermedia. Están constituidas por cantos angulosos a subangulosos y heterométricos de cuarzo y fragmentos de roca cuarcítica en una matriz, poco abundante, cuarzo-sericítica.

*Conglomerados.* Aparecen en la Serie Intermedia en forma de lentejones de dimensiones muy variables y están constituidas por cantos de cuarzo y fragmentos de roca cuarcítica, subredondeados y heterométricos, en una matriz sericítico-cuarcítica (Fig. 20).

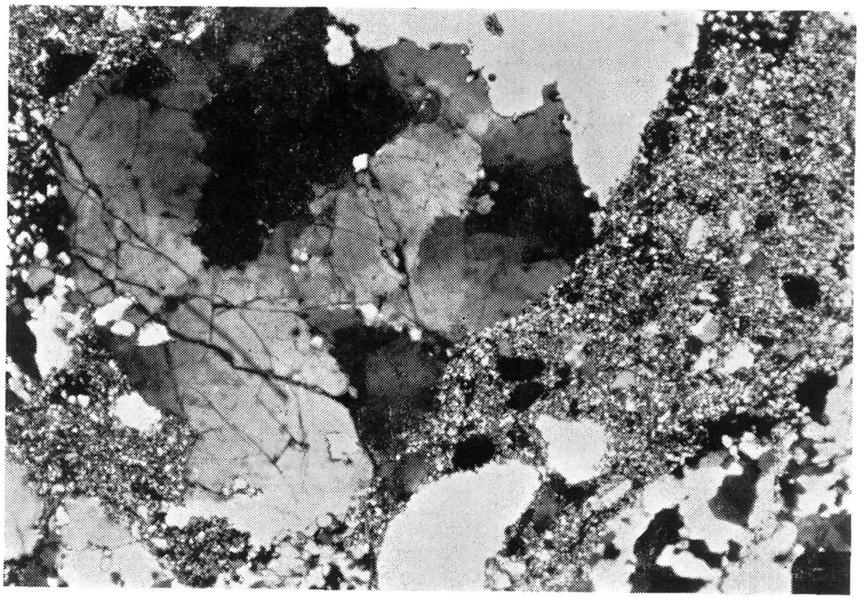


FIG. 20

*Conglomerado en la Serie Intermedia NW de Serradilla del Arroyo. LP - × 2,5*

*Cuarcita Armoricana.* Se trata de una roca bastante homogénea compuesta por granos de cuarzo fundamentalmente y con muy pocos minerales accesorios. Presenta a veces un cemento ferruginoso.

<table>
<tr><th colspan="3" rowspan="2">TRAMOS - LITOLOGIA</th><th colspan="2">ESTRUC. SEDIMENTARIAS</th></tr>
<tr><th>Inorgánicas</th><th>Orgánicas</th></tr>
<tr><td colspan="3"><u>Cuarcita</u>.<br>Bancos masivos de varios mts. de potencia que hacia arriba se hacen mas tableadas y alter-- nan con esquistos.</td><td>lam. paralela<br>estr. cruzada<br>ripple marks</td><td>cruzianas<br>scolithus<br>vexillum</td></tr>
<tr><td colspan="2" rowspan="3"><u>Serie intermedia</u>.<br>Pot. variable; coloración rojiza. Equivalente a la Serie Púrpura de otros autores.<br>Limolitas, arenas arcillosas, are niscas y conglomerados.</td><td>R. arcillosas</td><td>lam. paralela<br>estr. cruzada</td><td>---------</td></tr>
<tr><td>Areniscas</td><td>lam. paralela<br>estr. cruzada</td><td>scolithus</td></tr>
<tr><td>Conglomerados</td><td>-------------</td><td>---------</td></tr>
<tr><td rowspan="9">COMPLEJO ESQUISTO-GRAUVAQUICO</td><td rowspan="3"><u>Tramo superior calcáreo</u>.<br>Niveles microconglomeráticos y de grauvacas carbonatadas.<br>Transición a calizas impuras: niveles estratificados entre otros colapsados y brechificados, que pa san a conglomerados lateral y - verticalmente.</td><td>R. carbonatadas</td><td>lam. paralela<br>estr. cruzada<br>colapsobrechas</td><td>formas ovaladas que recuerdan restos orgánicos</td></tr>
<tr><td>Grauvacas</td><td>lam. paralela<br>granoselección</td><td>----------</td></tr>
<tr><td>Conglomerados</td><td>-------------</td><td>----------</td></tr>
<tr><td rowspan="2"><u>Tramo medio</u>.<br>Predominio de esquistos carbonosos con intercalaciones de niveles mi- croconglomeráticos y de grauvacas muy oscuras.</td><td>R. pelíticas</td><td>lam. paralela</td><td>----------</td></tr>
<tr><td>Grauvacas</td><td>lam. paralela<br>estr. cruzada</td><td>----------</td></tr>
<tr><td rowspan="4"><u>Tramo inferior</u>.<br>Alternancia de esquistos grises bandeados y grauvacas en sentido amplio entre las que se interca- lan en algunas zonas, niveles de conglomerados y mixtitas.</td><td>R. pelíticas - esquistos sericíticos</td><td rowspan="2">lam. paralela<br>estr. cruzada<br>ripple marks<br>wavy laminated bedding</td><td>----------</td></tr>
<tr><td>R. pelíticas - esquistos cuarzo-seri cíticos</td><td>----------</td></tr>
<tr><td>Grauvacas y areniscas</td><td>granoselección<br>lam. paralela<br>cantos aislados<br>flute cast</td><td>----------</td></tr>
<tr><td>Conglomerados y mixtitas</td><td>granoselección<br>estr. cruzada<br>slumpings</td><td>----------</td></tr>
</table>

M I N E R A L O G I A

| TEXTURA | Q | Fd | Plag. | F. R. | Carbonatos | Micas | Matriz | Cemento | Otros |
|---|---|---|---|---|---|---|---|---|---|
| granoblástica equigranular grano fino a medio | MA | -- | ---- | ME | ---- | ME moscov. | ME serct-clorit. | ME ferrug. | apatito circón turmalina opacos |
| granular muy fina | A | -- | ---- | ---- | ---- | MA serct mosc E clorit biotit | MA m. arcill | --- | A ox. Fe circón turmalina rutilo |
| granoblástica inequigran. o detrítica | A | -- | ---- | E cuarcítica | ---- | ME moscov. | E cuarzo-serct. | ME ferrug. | circón turmalina rutilo opacos |
| clástica inequigran. | MA | -- | ---- | A cuarcítica | ---- | ME moscov. | E cuarzo-serct. m.arcill. | --- | circón turmalina apatito opacos |
| cristalina esparítica | A-E | ME | E | A volcánica cuarzo-sericítica | MA calcita dolomita ankerita | ME moscov. clorita | ---- | --- | circón turmalina opacos |
| detrítica inequigran. | A | ME | ME (Ab) | MA volcánica cuarcítica pelítica carbonatos | calcita ankerita dolomita | ME moscov. clorita piotita | cuarzo-sericít. | carbo-natado a veces | circón opacos |
| clástica inequigran. | A MA | ME | ME | MA - E pelítica-efusiva | MA - E calcita dolomita ankerita | ME biotita moscov. clorita | cuarzo-pelítica | carbonatado o silíceo | circón turmalina opacos |
| finamente bandeada | E | -- | ME | ---- | ---- | A serct. moscov. E clorita biotita | ---- | --- | MA m.arcillos. opacos rutilo ox. Fe |
| clástica inequigran. granoblást. | A | ME | E | A efusiva | ME calcita | biotita E clorita ME moscov. | E cuarzo-sericít. | --- | A opacos zois./clin. actin./trem esfena turmalina circón |
| finamente bandeada | A-E | ME | E (Ab) | ---- | ---- | MA sericita clorita E moscov. | ---- | --- | m.arcillos. opacos rutilo |
| clástica inequigran. | MA | E | E (Ab) | ---- | ---- | A serici. clorita E moscov. | ---- | --- | turmalina circón esfena apatito |
| clástica inequigran. | MA | E | E (Ab) | A cuarcítica pelítica efusiva b. | ---- | A serici. cloria E biotita | sericít. clorítica | --- | turmalina circón opacos |
| clástica inequigran. | MA A | A-E | E | A volcánica pelítica cuarcítica | ME calcita | A clorita E moscov. | MA-A cuarzo-sericít.-clorítica | --- | turmalina epidota esfena circón, opac. |

MA.—muy abundante. A.—abundante. ME.—muy escaso.

## METAMORFISMO

El área estudiada ha sido afectada por un metamorfismo regional de Bajo grado (WINKLER, 1974), con las siguientes paragénesis:

— en rocas pelíticas: cuarzo-sericita-clorita-albita.
— en grauvacas: actinolita / tremolita-zoisita / clinozoisita-esfena-albita-cuarzo-calcita.
— en rocas carbonatadas: cuarzo-dolomita-calcita.

La actinolita/tremolita se presenta en agregados fibroso-radiados (Fig. 15), en grauvacas que probablemente tuviesen cantos derivados de rocas máficas y se encuentra asociada a clinozoisita/zoisita (WINKLER *op. cit.*). Según dicho autor, la aparición de clinozoisita/zoisita estable en rocas de composición apropiada, indica el comienzo de la Facies de los esquistos verdes o del metamorfismo de Bajo grado en el que es característica la asociación mineralógica: clorita + zoisita/clinozoisita + actinolita + cuarzo.

La formación de clinozoisita o zoisita, se efectuaría según NITSCH (1971), (in WINKLER *op. cit.*), por la reacción siguiente:

pumpellita + clorita + cuarzo = clinozoisita + actinolita + $H_2O$.

Teniendo lugar a $345^\circ \pm 20^\circ C$ y a una presión de vapor de $H_2O$ de $2{,}5 \pm 1{,}0$ Kb.

Para presiones más bajas (1 Kb. y $340^\circ \pm 20^\circ C$), deben producirse las siguientes reacciones que marcan el límite entre el metamorfismo de Muy bajo grado y el de Bajo grado (Facies de los esquistos verdes) (WINKLER, *op. cit.*).

pumpellita + cuarzo = prehnita + clinozoisita + clorita + $H_2O$.
prehnita + clorita + cuarzo = clinozoisita + actinolita + $H_2O$.

En la presente zona, se constata la existencia de tremolita/actinolita asociada a clinozoisita/zoisita, ambas estables en grauvacas con fragmentos de roca derivados de rocas máficas, con lo cual podría deducirse de los datos expuestos, que el área habría estado sometida a unas temperaturas y presiones por encima de los $345^\circ \pm 20^\circ C$ y $2{,}5 \pm 1{,}0$ Kb de presión de vapor de agua, datos apuntados por NITSCH, para la aparición de estos minerales, ya que únicamente se conoce la presencia de los productos finales de la reacción, pero no hay evidencia clara de la existencia de pumpellita o prehnita, a partir de las cuales se formasen.

Por otro lado, la ausencia de minerales de neoformación característicos en las calizas que están situadas estratigráficamente encima de dichas grauvacas, impiden precisar más sobre las condiciones existentes. Según WINKLER, las rocas calcáreas impuras (dolomítico-silíceas), no sufren modificaciones durante las condiciones de metamorfismo de Muy bajo grado; únicamente, en condiciones de Bajo grado, no bien definidas y generalmente no coincidentes con su inicio, comienzan a producirse algunas modificaciones. Según la curva de equilibrio de METZ (1970) y METZ & PUHAN (1970-71), (in WINKLER, 1974), puede deducirse que las condiciones a que estuvieron sometidas las rocas calcáreas fueron tales, que no se hizo posible la reacción de paso:

$$3 \text{ dolomita} + 4 \text{ cuarzo} + H_2O = \text{talco} + \text{calcita} + 3\ CO_2.$$

Ya que se observa la asociación: cuarzo-calcita-dolomita, no habiendo signos evidentes de la presencia de talco ni de otros minerales de neoformación.

La biotita, aparece únicamente en la zona W, en el embalse del río Agueda y en forma de cristales bastante pequeños sin orientar.

Otro mineral de neoformación presente en muchos esquistos es el rutilo, que aparece en cristales idiomorfos, un poco alterados a leucoxeno. De su posición con respecto a los cristales orientados de sericita, se deduce que es un mineral sinorogénico con la fase de deformación asociada a la esquistosidad de flujo existente. (A. SPRY, 1969) (Fig. 10).

## CONCLUSIONES SOBRE LA SERIE

Desde el punto de vista de la sedimentación, puede decirse en general, que en el área estudiada se inició con una serie rítmica bastante potente de grauvacas y pizarras, entre las que se intercalan niveles conglomeráticos con abundante matriz. Por las características que presentan, alternancia de esquistos y grauvacas entre los que se pueden reconocer algunos intervalos típicos de la secuencia de BOUMA y las estructuras sedimentarias existentes: estratificaciones cruzadas, laminaciones paralelas, granoselección, flute-cast, ripple-marks y slumping podría tratarse de una serie turbidítica que presentaría sus facies más distales hacia el W (mayor predominio de esquistos y grauvacas) y hacia el centro y E, sus facies más proximales (mayor predominio de niveles conglomeráticos y mixtitas).

Esta serie turbidítica, comprendería los tramos inferior y medio de las series descritas, culminando con un episodio fundamentalmente pelítico (pizarras negras).

Posteriormente y sin interrupción visible, se produjo una sedimentación carbonatada somera (de plataforma o umbral), a juzgar por el aporte detrítico que tiene, su asociación con conglomerados y las estructuras sedimentarias que presenta.

Esta zona, debió tener momentos de inestabilidad, y así lo indican los niveles de slumpings y colapsobrechas que se intercalan entre otros perfectamente estratificados; la presencia de un vulcanismo (existencia de vidrio volcánico y de fragmentos de roca volcánica en las calizas, conglomerados y grauvacas de la misma formación), explicarían la presencia de deslizamientos y colapsamientos en las capas, al provocar pequeñas oscilaciones en la pendiente del área.

Además, la existencia de caliza de tipo peperítico, sería el resultado de la intrusión subacuática de un magma básico a alta temperatura y muy fluido, en aguas someras y sedimentos sin consolidar o ligeramente consolidados (CAROZZY *op. cit.*). Esto, unido al aporte detrítico de cantos de cuarzo y materiales arcillosos fundamentalmente y a la existencia de conglomerados de cantos de cuarzo bastante redondeados y cemento silíceo ya en el techo de la formación, proporciona datos en favor de la deposición de las calizas en un medio somero.

Por otra parte, la posible presencia de organismos en las calizas que ha sido ya apuntada, abogaría igualmente en este sentido.

Sobre estos materiales (en la Serie de Monsagro-Serradilla del Arroyo, no se encuentran calizas), reposan sin discordancia visible en esta zona, los sedimentos pelítico-detríticos de tonos rosados y grises que caracterizan el comienzo de la transgresión Ordovícica. Encima de ellos, se sitúa la Cuarcita Armoricana.

## CORRELACIÓN CON OTRAS ÁREAS

La serie de Pastores parece equivalente a la descrita para el Bodón y Fuenteguinaldo (L. C. GARCÍA DE FIGUEROLA, 1970), en las que existen igualmente calizas reposando sobre una serie de pizarras negras, que a su vez descansan sobre otra serie de pizarras listadas y grauvacas. En algunos puntos, existen dos niveles discontinuos de calizas y en otros, estos están sustituidos por conglomerados.

Asimismo, existe gran semejanza entre esta serie y las descritas para el Azud de Villagonzalo-Alba de Tormes y Aldeatejada (A. DÍEZ BALDA y cols., in litt.). En esta última, se encuentran dos niveles conglomeráticos dolomíticos y dolomías y en la primera, uno solamente. Ambos, se hallan sobre un tramo de pizarras negras y por debajo se encuentran esquistos y grauvacas, que en su parte inferior tienen un conglomerado con feldespatos, que ha sido correlacionado con el llamado «Porfiroide de Monterrubio». (Serie de Morille; E. MARTÍNEZ GARCÍA y J. NICOLAU, 1973).

El origen de los niveles conglomeráticos dolomíticos ha sido interpretado en dicha zona, como el resultado de el «deslizamiento subacuático de capas dolomíticas colapsadas, en un flujo denso pelítico-arenoso que englobaría materiales de niveles inferiores». En el área estudiada no existen datos que permitan llegar a tales conclusiones.

Por otra parte, hay que destacar la semejanza de la Serie de Pastores con las Series de Tránsito Precámbrico-Cámbrico en el anticlinal de Valdelacasa (F. MORENO, 1974-75-76). En esta zona, aparece un nivel carbonatado discontinuo dentro de la serie, que es interpretado como formado en un medio de aguas someras, en una zona de umbral, a partir del que pudieron derivarse algunos episodios de colapsamiento hacia zonas más profundas; ya que al parecer, se encuentran verdaderos olistostromos calcáreos (Olistostromo del Membrillar), entre capas de naturaleza diferente.

Finalmente, es de destacar el gran parecido entre estas series y las descritas por SCHERMERHORN (1974-75), para el Precámbrico superior y que tienen gran desarrollo mundial. Se trata, en general de sucesiones pelítico-arenosas, entre las que se intercalan niveles de mixtitas, que a su vez están frecuentemente asociadas a sucesiones carbonatadas. Dicho autor, se inclina con respecto al origen de estas formaciones, por un control tectónico de la sedimentación en zonas de cadenas móviles o en plataformas inestables.

En cuanto a los materiales situados inmediatamente debajo de la Cuarcita Ordovícica, pueden correlacionarse perfectamente con las llamadas «Capas intermedias» o «Serie Púrpura», de los Montes de Toledo, Alta Extremadura, Alcudia y Despeñaperros, recientemente datados como Ordovícico inferior, por medio de Icnofósiles (F. MORENO y cols., 1976).

## TECTONICA

Las estructuras observadas en la zona se relacionan con dos fases principales de deformación hercínica, existiendo además otras deformaciones tardías y locales del tipo de Kink-bands y crenulación.

La primera fase de deformación se manifiesta dando pliegues de gran radio con dirección NW-SE, perfectamente visibles en la Cuarcita Ordovícica, siendo los responsables de las estructuras cartografiables. Se trata de pliegues de plano axial subvertical o ligeramente vergentes al NE, con ejes subhorizontales o buzando 30-40° (Sinclinal de Guadapero). Están asociados a una esquistosidad de plano axial, que es la regional y única existente, tanto en el Ordovícico como en el Complejo esquisto-grauváquico.

En el Complejo esquisto-grauváquico existen numerosos pliegues de primera fase decimétricos, métricos y decamétricos, con esquistosidad de plano axial asociada, que tiene una dirección predominante NW-SE, buzando hacia el SW unos 60-90°, aunque en algunas zonas la dirección es claramente N-S y NNE y en otras, el buzamiento de la esquistosidad es hacia el E.

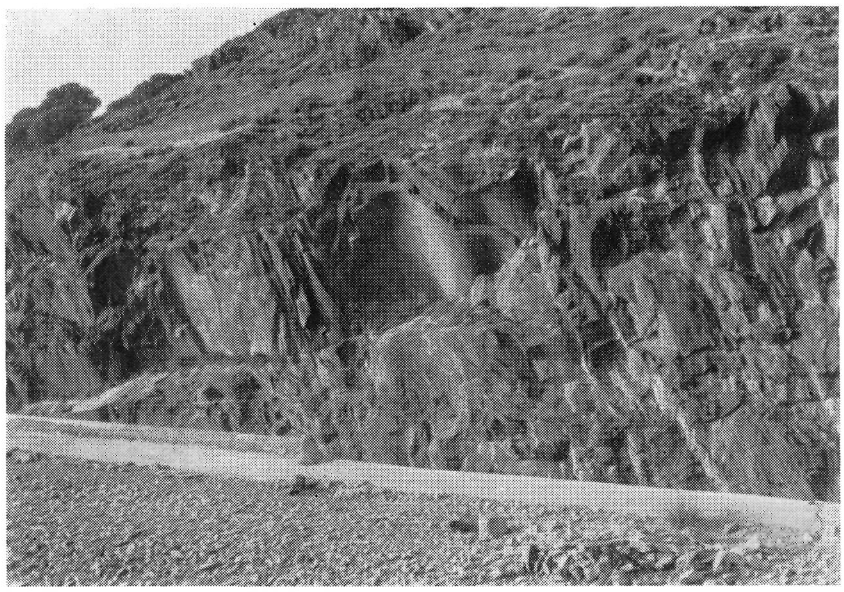


FIG. 21

*Pliegues de Fase I. Presa del Embalse del río Agueda*

FIG. 22

*Pliegue de Fase I. Ribera de Serradilla*

Los ejes de los pliegues, llevan una direccción general NW-SE y a veces N-S; su inclinación, varía desde subhorizontales (pliegues en las calizas de Pastores), hasta subverticales, buzando 60-80° (pliegues en la presa del Embalse del río Agueda) (Figs. 21 y 22).

La lineación de intersección entre la estratificación y la esquistosidad $L_1$, buza en la cuarcita uños 35-45°, mientras que en el Complejo esquisto-grauváquico varía desde subhorizontal hasta 80°, lo cual representa un dato a favor de la existencia de alguna fase de plegamiento anteordovícico, sin esquistosidad. (Varias veces citada en Portugal: C. TEIXEIRA, 1955; J. AVILA MARTINS, 1962; OEN-ING-SOEN, 1970).

Además, desdoblando en proyección estereográfica el efecto muy suave producido por la segunda fase de deformación en esta zona, puede apreciarse que las lineaciones $L_1$, tienen direcciones diferentes, lo cual sugiere que cuando actuó esta primera fase, las capas se encontraban de alguna forma ya inclinadas. Por otra parte, la evidencia de un plegamiento anteordovícico se ha confirmado al encontrar un pliegue de fase I con esquistosidad de plano axial asociada, que repliega a otro anterior en la presa del Embalse del río Agueda y en otro lugar, cerca de Zamarra, un pliegue anterior atravesado oblicuamente por la esquistosidad regional $S_1$.

Se desconoce por el momento la traza axial de estos pliegues; únicamente puede afirmarse que no existe esquistosidad asociada a estos pliegues y que deben tener tal geometría, que permitió en algunos lugares la deposición de los materiales superiores, sin apreciarse discordancia importante, como es el caso de Monsagro, mientras que en otros, la discordancia angular entre el Complejo esquisto-grauváquico y el Ordovícico es muy notable.

La segunda fase de deformación, da lugar a suaves flexiones de los pliegues y de la esquistosidad de fase I, según un plano axial cuya dirección es aproximadamente N 40°E. En el Ordovícico, se presenta con pliegues muy suaves, cuyos ejes bastante verticales, buzan en sentidos opuestos en los flancos de la gran sinforma y llegan a invertir los estratos en algún punto. Se trata de una interferencia de plegamientos del tipo 2 de RAMSAY (1967).

En el Complejo esquisto-grauváquico se aprecia esta segunda fase por el plegamiento de la $S_1$ (Fig. 23) y la existencia de algunos pliegues mesoscópicos, que doblan la esquistosidad regional. Además, esta fase debe de ser la responsable del cambio de dirección de los pliegues de fase I, así como de la verticalización de sus ejes.

Asociados quizás, a estos pliegues se encuentran una serie de fallas con componente vertical y de desgarre, de dirección NE-SW y otras, tal vez conjugadas con dirección NW-SE.

Finalmente, hay que citar otras estructuras más tardías y locales, como son la existencia de una crenulación muy débil, de dirección E-W (Fig. 12) y de unos Kink-bands subhorizontales o buzando ligeramente al S, producidos probablemente en fases distensivas.

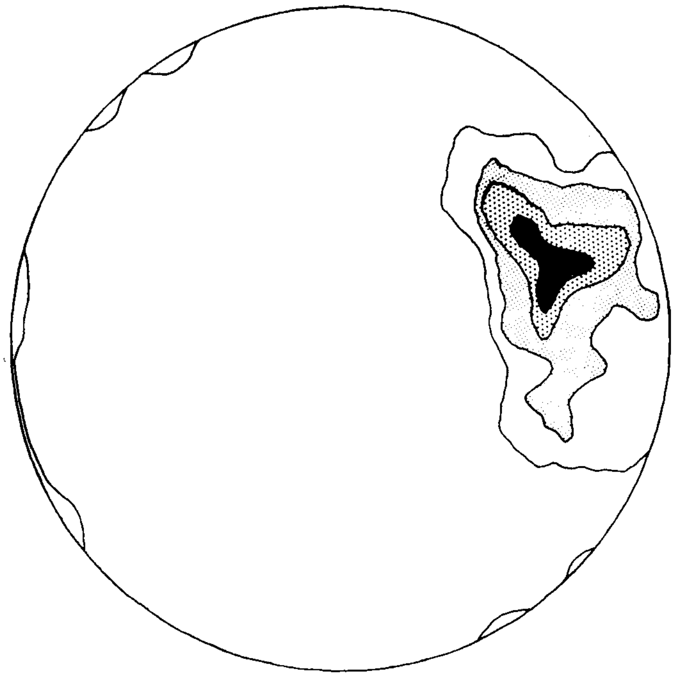


FIG. 23

*Polos de Esquistosidad $S_1$ en todo el área. Contornos: 3-7-10-13 % para el 1 % del área total*

RELACIÓN DEFORMACIÓN-METAMORFISMO

El metamorfismo regional de Bajo grado existente en el área, se manifiesta principalmente por la orientación de la sericita y clorita según los planos de esquistosidad $S_1$, existiendo además, neoformación de minerales como: rutilo, biotita, clorita, actinolita/tremolita, clinozoisita, y esfena.

Esta blastesis mineral, comienza con la fase I y está marcada por los rutilos, alcanzando su mayor desarrollo después de la fase I, ya que el resto de los minerales metamórficos no presentan orientación alguna.

La crenulación tardía y local de dirección E-W, desarrolla sobre los rutilos sombras de presión.

## CONCLUSIONES

Los materiales del Complejo esquisto-grauváquico están representados por una sucesión de tipo turbidítico, entre los que se intercalan niveles de conglomerados y mixtitas. Sobre ella, se sitúa localmente un tramo calcáreo poco potente y encima se encuentran, sin discordancia apreciable, los materiales correspondientes a la Serie Púrpura (arenas arcillosas, limolitas, areniscas y conglomerados) y la cuarcita Ordovícica.

El estudio tectónico, manifiesta la existencia de una fase de deformación hercínica, que afecta a los materiales del Complejo esquisto-grauváquico y a los Ordovícicos. Esta fase, se presenta con pliegues de plano axial subvertical de dirección NW-SE; está asociada a una esquistosidad de flujo y es la responsable de las estructuras cartografiables.

Una segunda fase de deformación de dirección NE-SW, provoca suaves flexiones en los pliegues y esquistosidad anteriores.

La zona, está afectada por un metamorfismo regional de Bajo grado.

## BIBLIOGRAFIA

AVILA MARTINS, J. (1962): *Contribuição para o conhecimento geologico da regiao do Caramulo.* Rev. Fac. Cien. Lisboa, 2.ª serie C, 9 (2); 123-228.

CAROZZI, A. V. (1960): *Microscopic Sedimentary Petrography.* John Wiley & sons, Inc. Publishers.

DÍEZ BALDA, M. A.; MARTÍNEZ CATALÁN, J. R.; GONZÁLEZ LODEIRO, F. e IGLESIAS PONCE DE LEÓN, M. (in litt): *La deformación en los materiales Paleozoicos y Precámbricos al S. de Salamanca.*

GARCÍA DE FIGUEROLA, L. C. (1970): *La existencia de pliegues en el Complejo esquisto-grauváquico de la provincia de Salamanca.* Act. Geol. Hisp., 5 (4); 105-108.

GARCÍA DE FIGUEROLA, L. C. y UGIDOS MEANA, J. M. (1971): *Rasgos geológicos de la región entre el sinclinal Sequeros-Ahigal de los Aceiteros y Cañaveral (provincias de Salamanca y Cáceres).* I Congr. Hisp. Luso-Amer. Geol. Econ.; 197-212.

MARTÍNEZ GARCÍA, E. y NICOLAU, J. (1973): *Los terrenos infraordovícicos de la antiforma de Martinamor (Salamanca).* B.G.M., 84 (6); 407-418.

MINGARRO MARTÍN, F.; MINGARRO MARTÍN, E. y LÓPEZ DE AZCONA, M. C. (1971): *Mapa geológico de España 1:50.000. Serradilla del Arroyo. Hoja núm. 526.* I.G.M.E.

MORENO, F. (1974): *Las formaciones infraordovícicas del anticlinal de Valdelacasa.* B.G.M., 85 (4); 396-400.

— (1975): *Olistostromos, Fangoconglomerados y Slump folds. Distribución de facies en las series de tránsito Precámbrico-Cámbrico en el anticlinal de Valdelacasa (provincias de Toledo, Cáceres y Ciudad Real).* Est. Geol., 31; 249-260.

— (in litt.): *Tectónica y sedimentación de las Series de Tránsito (Precámbrico terminal) entre el anticlinal de Valdelacasa y el Valle de Alcudia. Ausencia de Cámbrico.*

MORENO, F.; VEGAS, R. y MARCOS, A. (1976): *Sobre la edad de las series Ordovícicas y Cámbricas relacionadas con la discordancia Sárdica en el anticlinal de Valdelacasa (Montes de Toledo, España).* Brev. Geol. Ast., 20 (1); 8-16; Oviedo.

OEN-ING-SOEN (1970): *Granite intrusion folding and metamorphism in central northern Portugal.* B.G.M., 81 (2-3); 198-271.

PETTIJOHN, F. J. (1963): *Rocas Sedimentarias.* E.U.D.E.B.A.

PETTIJOHN, F. J.; POTTER, P. E. & SIEVER, R. (1972): *Sand and Sandstones.* Springer Verlag.

RAMSAY, J. G. (1967): *Folding and fracturing of rocks.* McGraw-Hill Book Co.

RÖLZ, P. (1972): *Beiträge zum Aufban des junpräkambrischen und altpaläzoischen Grundebirges in den Provincen Salamanca und Cáceres (Sierra de Tamames, Sierra de Francia und östliche Sierra de Gata). Spanien.* (Auszng), Tech. Univ. München.

RODRÍGUEZ ALONSO, M. D. (1976): *Estudio geológico de los materiales Ordovícicos de la zona SE. de Ciudad Rodrigo (Salamanca, España).* Tesis de Licenciatura. Facultad de Ciencias. Salamanca.

SCHMIDT THOME, P. (1950): *Basamento Paleozoico y cobertura moderna en la parte W de España Central (Provincias de Salamanca y Cáceres).* Publ. Extr. Geol. España, 5; 93-146.

SCHERMERHORN, L. J. G. (1966): *Terminology of mixed coarse-fine sediments.* Jour. Sed. Pet. Sept. 1966; 832-835.

— (1974): *Late Precambrian mixtites; Glacial and or non glacial?* Am. Jour. Sc., 274; 673-835.

— (1975): *Tectonic framework of Late Precambrian supposed glacials. Ice ages: Ancient and Modern.* Ed. by Wright, A. E. and Moseley, F.; 241-274.

SPRY, A. (1969): *Metamorphic Textures.* Pergamon Press.

TEIXEIRA, C. (1955): *O Complexo xisto-grauvaquico ante-ordoviciano. Notas sobre geologia de Portugal.* Lisboa.

TORRE DE ASSUNÇÃO, C. (1969): *Sur la petrografie du complexe des schistes et grauvackes ante-ordovicien. (Tras-os-Montes).* Com. Serv. Geol. Portugal. LII, Lisboa.

WINKLER, M. G. F. (1974): *Petrogenesis of metamorphic rocks.* Springer-Verlag.

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# ENSAYO SOBRE LA GENESIS DE LAS ROCAS GRANITICAS DEL MACIZO HESPERICO

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RESUMEN.—Con base en trabajos anteriores y en nuevos datos acerca de las rocas graníticas del Macizo Hespérico y de los cinturones metamórficos mejor conocidos en el mismo, los autores intentan establecer una hipótesis general para los diferentes procesos petrogenéticos. Tal hipótesis se construye atendiendo a los siguientes puntos:

a) Origen basicortical de las rocas graníticas calcoalcalinas.
b) Relación espacio-temporal entre los diferentes tipos de metamorfismos y series de rocas graníticas.
c) Características geoquímicas de estas series.
d) Procesos genéticos de granitos enraizados en dominios migmatíticos.
e) Presencia de cordierita en la mayor parte de las rocas graníticas del Macizo Hespérico.
f) Producción de series graníticas de origen anatéctico mesocortical en las que participa material procedente de las masas calcoalcalinas.
g) Procesos de contaminación y evolución de la serie granítica calcoalcalina.

Cuyo estudio y consideración contribuyen a establecer que las masas magmáticas calcoalcalinas que se intruyen son los focos térmicos causantes de los metamorfismos tipo "baja presión", así como de los fenómenos anatécticos asociados.

SUMMARY.—On basis in previous papers and in new data now available about granitic and metamorphic rocks of the Hesperian Massif the authors propose a general hypotesis on the different petrogenetic process. This hipotesis is based in the following points:

a) Deep crustal origin of the calc-alcaline granitic rocks.
b) Time-place relation among different types of metamorphism and granitic series.
c) Geochemical character of this series.
d) Genetic process of the autoctonous granites in migmatitic areas.
e) Cordierite presence in the greater part of the granitic masses.

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f) Development of granitic series of anatectic mesocrustal origin in which participate calc-alcaline magmatic components.

g) Contamination and evolution of the calc-alcaline granitic series.

The study and consideration on this aspects contributes to support that calc-alcaline magmatic bodies are the rising thermal focus responsible for low pressure types of metamorphism and related anatectic process.

## INTRODUCCION

La finalidad del presente ensayo es la propuesta de una base unificadora de diversos aspectos, ya conocidos, de los diferentes grupos de granitos del Macizo Hespérico y su relación con los niveles metamórficos en los que se encuentran emplazados.

Los autores son conscientes del carácter limitado de la hipótesis que proponen, habida cuenta el relativamente escaso número de datos que se conocen y la no coincidencia de los criterios con que se orientan los trabajos de los diferentes equipos o escuelas de investigación. Esto se traduce en que el valor de los datos obtenidos en el campo, laboratorio, etc., son relativizados a los citados criterios y en consecuencia su importancia queda señalada con diferente intensidad en función de los mismos.

La consecuencia inmediata de esta realidad es la carencia de una visión definida de cuál es la línea más adecuada a seguir en la investigación conjunta y por ello no se ha establecido qué datos son relevantes y cuáles no, en el intento de establecer una solución global, de carácter unitario, que defina una relación clara entre causas y efectos.

Esto determinó que en muchas ocasiones se hayan obtenido datos de índole diversa sin que su búsqueda estuviera ordenada inicialmente y de un modo directo a un fin, es decir, al intento de verificación o de falsación de una hipótesis. Naturalmente, esta etapa de recogida de datos es de todo punto necesaria, imprescindible, para a partir de un momento dado proceder en sentido inverso, es decir, de la hipótesis a la comprobación de la misma mediante la investigación de datos relevantes en relación con ella, tanto si son favorables como si se oponen a sus planteamientos.

Puesto que desde el punto de vista del avance científico el método deductivo se ha mostrado mucho más eficaz que el método inductivo y que el volumen de conocimintos actuales es suficiente como para iniciar la propuesta de un esquema general, se realiza tal intento con la esperanza de que sea válido no tanto como solución, sino como paso intermedio, necesario, hacia una respuesta más completa de la problemática de las rocas graníticas y asociadas, a medida que la contrastación con nuevos datos apoye o corrija tal esquema.

Si bien no parece necesario extenderse sobre distintos aspectos de petrogénesis de rocas graníticas y metamórficas, si puede ser oportuno a efectos de exposición posterior señalar qué aspectos son básicos y cuáles sus consecuencias lógicas, así como qué datos pueden contribuir a esta construcción de un modo eficaz. Tal es la finalidad del siguiente apartado.

## A.—PLANTEAMIENTO DE LA HIPOTESIS

### A.1.—DISCUSIÓN SOBRE LOS CONCEPTOS DE METAMORFISMO REGIONAL Y METAMORFISMO DE CONTACTO.

a) La semejanza de condiciones entre el metamorfismo regional de bajas presiones y el metamorfismo de contacto es ya suficientemente conocida como para insistir en ella de un modo exhaustivo.

La diferencia es cuantitativa por lo que se refiere a la profundidad (presión) a que se produce cada uno de los metamorfismos citados y también por lo que respecta a la extensión de las áreas afectadas.

Por otra parte el metamorfismo de contacto es adinámico y el regional por el contrario se desarrolla en relación con esfuerzos tangenciales, que producen esquistosidades definidas por el crecimiento de minerales metamórficos en relación con las mismas.

b) El metamorfismo regional de baja presión, como es en general el caso del metamorfismo hercínico en Europa (ZWART, 1967) provoca la aparición de series de facies cuya anchura total puede ser muy pequeña (de clorita a sillimanita, 1.500 mts.) respecto a la que presentan terrenos metamórficos afectados por condiciones de alta presión que pueden presentar *la misma asociación mineralógica en espesores de 3 Kmts. o más* (ZWART, *op. cit.*).

Esto sugiere que el metamorfismo regional considerado está próximo también, en cuanto a sus características espaciales, al metamorfismo de contacto y que como éste tiene un origen «puntual» debido a la presencia de un foco térmico concreto, si se comparan ambos con un metamorfismo de alta presión.

Es interesante exponer aquí la opinión de TURNER (1968), respecto al aspecto espacial de la causa del metamorfismo regional: «It is possible to locate the inmediate source in a thermal high or focus. Still completely unknown is the ultimate source of heat (presumibly in the mantle beneath) and the vehicle (perhaps water) of its upward transport to thermal highs as now identified at the surface». Más adelante (p. 380, ibid.): «In fact the distribution of isobars and isotherms... supports the concept of regional metamorphism induced by temperature gradient controlled by a vertical zone of excepcional heat flow, probably extending to the mantle itself».

Por otra parte y referido a las características mineralógicas del metamorfismo de contacto y regional de baja presión MIYASHIRO señala (1961, p. 292): «The contact metamorphism by sinkinematic intrusions produced a metamorphic facies series practically identical to the facies of the regional metamorphism». Asimismo, WINKLER (1967, p. 123) indica: «The mineral facies of the Abukuma type metamorphism may therefore be regarded as a connecting link between shallow contact metamorphism and regional dinamothermal metamorphism».

El metamorfismo regional de baja presión puede ser considerado, por tanto, como una perturbación local, si bien de gran magnitud debida a un foco térmico concreto cuyos efectos se sobreimponen a los efectos metamórficos de un gradiente normal o según expresión de HUANG (1962) a un metamorfismo geotérmico (Geothermal metamorphism) cuyo régimen térmico se supone estacionario.

c) Se señalan como valores máximos para el metamorfismo de contacto presiones de alrededor de 2.000 bars y temperaturas de 640 $\pm$ 20° (WINKLER, 1967) y 100° más para la subfacies ortopiroxeno, feldespato potásico, cordierita, lo cual significa que las rocas afectadas por estas condiciones se han formado por encima de la curva solidus que une los puntos mínimos de fusión, para composiciones graníticas, en condiciones de saturación en agua.

La opinión de TURNER (1968, p. 22): «... where bodies of granitic magma develop within, or are intruded into, deep-seated rocks where regional temperatures are several hundred degrees, contact and regional effects may be indistinguishable. It is for this reason that many of the classic accounts of contact metamorphism refer to aureoles that have formed at relatively shallow depths, with correspondingly low pressures, perhaps a few hundred to 2.000 bars», sugiere junto con lo anteriormente señalado, que la distinción entre ambos tipos de metamorfismos tiene un cierto componente de artificiosidad.

d) La extensión de una aureola de contacto depende de múltiples factores como son: tamaño y temperatura del cuerpo intrusivo, conductividad térmica, densidad, calor específico, etc., de la roca encajante y magma, temperatura inicial y contenido en agua de la roca encajante, etc. (v. TURNER, 1968). El tiempo durante el que permanecen unas determinadas condiciones térmicas es función directa de la anchura de la masa intrusiva (JAEGER, 1957, 1959; WINKLER, 1967, 1974), cuyos efectos pueden ser ampliados de modo importante por acción de los fluidos de la masa magmática transferidos a la roca encajante (HORI, 1964, in TURNER, *op. cit.*).

Por otra parte KHITAROV (1967) deduce a partir de diagramas de variación de volúmenes molares de fundidos albíticos hidratados que en el ascenso de un magma a niveles comprendidos entre 10 y 20 Kmts. de la superficie terrestre, la separación de la fracción volátil tiene lugar con el calentamiento del fundido y de los volátiles que se separan con lo cual: «Considerable local heating may occur at certain levels of the crust due to separation of the volatile components from the magmatic melt».

e) Muchos autores indican que el foco térmico que desarrolla los metamorfismos regionales con temperaturas elevadas es debido a fluidos o magmas que proceden de niveles infracorticales (ZWART, 1967; WINKLER, 1967; TURNER, 1968; BAYLEY, 1970; RAST, 1970; MIYASHIRO, 1967, 1971, 1972).

Admitidos los planteamientos de los puntos anteriores es más patente la semejanza entre el metamorfismo de contacto y el metamorfismo regional de baja presión, en el sentido de que la diferencia es puramente cuantitativa y no cualitativa. Pero demos un paso más.

Si en el metamorfismo de contacto se alcanzan condiciones como las citadas para una determinada masa intruida en un nivel concreto ¿Cuáles serán las condiciones y efectos en niveles inferiores donde la presión sea de 3 ó 4 Kbars? Son de considerar varios puntos:

- A esta profundidad el volumen de la masa magmática es con toda probabilidad mayor.
- La temperatura debe ser también superior que la presente en niveles más altos.
- La temperatura del encajante es más elevada por efecto del gradiente geotérmico normal y por otro lado parte del calor consumido en reacciones endotérmicas en niveles más altos no será utilizado en niveles inferiores pues algunas de las reacciones ya se habrán realizado como consecuencia de los efectos de dicho gradiente, significando esto que existirá, respecto a niveles superiores, un exceso de calor aprovechable en otras reacciones metamórficas.
- Puesto que la curva de fusión mínima de composiciones graníticas tiene pendiente negativa en condiciones de saturación en agua, en condiciones de más alta presión es más favorable la posibilidad de fusión de las rocas encajantes aún suponiendo temperaturas iguales a las desarrolladas en niveles más altos.

Si además se tiene en cuenta que una masa ígnea importante ascenderá únicamente a través de estructuras favorables del encajante, resulta que las isogradas sean o no contemporáneas del plegamiento coincidirán, a grandes rasgos, con la dirección de los ejes de las fases mayores.

Debe señalarse también la muy frecuente coincidencia entre cinturones metamórficos y plutonismo de rocas graníticas, hecho repetidamente puesto de manifiesto y a veces explicado atribuyendo al magma granítico el papel de foco térmico (v. TURNER, 1968, p. 378).

TURNER (*op. cit.*) señala la dificultad que supone el gran aporte térmico necesario que deberían realizar los granitos para producir tal metamorfismo. Sin embargo, en el caso del metamorfismo del área de Bosost donde ZWART (1962) admite un gradiente de 150ºC/Km. Turner propone que «... the granite would be the heat source, not the expression of heat concentration from shallow sources unknown» (TURNER, *op. cit.*, p. 255). La pregunta inmediata es ¿Por qué en otros casos no? y además ¿Qué ocurre, entonces, en niveles inferiores atravesados por ese granito-fuente térmica?

f) Indudablemente, cualquiera que sea la perturbación térmica en la corteza no es más que un reflejo o consecuencia de los fenómenos que tienen lugar en el manto superior. No queriendo entrar en este tipo de problemática, los autores del presente trabajo sitúan el punto inicial de los acontecimientos térmicos en la basicorteza y construyen la hipótesis que se propone desde los niveles corticales inferiores hasta niveles mesocorticales.

El metamorfismo regional como fenómeno asociado a acontecimientos orogénicos constituye una fuerte perturbación térmica capaz de producir asociaciones minerales que indican condiciones de temperatura elevadas (del orden de los 700ºC en dominios migmatíticos mesocorticales) y también magmas graníticos cuya génesis dentro de la corteza parece fuera de toda duda (WINKLER, 1974; RINGWOOD, 1975; MAALOE y WYLLIE, 1975; WYLLIE *et al.*, 1976), así como que tales masas graníticas son consecuencia del metamorfismo regional siempre que éste tenga lugar en presencia de agua, que puede encontrarse como «pore fluid» o formando parte de minerales hidratados (PIWINSKII y WYLLIE, 1968, 1970; BROWN y FYFE, 1970, 1972; FYFE, 1970, 1973; ROBERTSON y WYLLIE, 1971; WYLLIE, 1971).

Así mismo y de acuerdo con los autores citados, la mayor parte de la génesis y posterior historia de los granitos tiene lugar dentro de condiciones subsaturadas en agua. Dadas las temperaturas tan elevadas para producir un líquido granítico en estas condiciones (del orden de los 1.100ºC, WYLLIE, 1971) se acepta que el magma granítico no está totalmente líquido, sino que consiste en un «mush» integrado por una parte líquida y cristales residuales en suspensión, ya que tales temperaturas son excesivamente altas para los modelos térmicos admitidos (MAALOE y WYLLIE, 1975).

Por otra parte y según los datos experimentales de ROBERTSON y WYLLIE

(1971), Wyllie (1971), Maaloe y Wyllie (1975) y Wyllie *et al.* (1976), los fundidos graníticos comienzan a producirse a 705°C (a 2 Kb) si existe fase vapor en el sistema o a 875°C si el $H_2O$ presente no es suficiente para saturar el conjunto subsolidus y está contenido sólo en la biotita.

En el primer caso, el intervalo de temperaturas en el cual se obtiene un líquido saturado en agua es muy pequeño (v. gráficas de los autores citados), permaneciendo como sólido la mayor parte de los minerales en equilibrio con la fase líquida. Posterior aumento de temperatura hace al líquido subsaturado y el porcentaje del mismo producido como función de la temperatura es menor que para condiciones de vapor presente (Wyllie, 1971) y durante un amplio intervalo el líquido coexiste con cuarzo, feldespato alcalino, plagioclasas y minerales refractarios hasta que el incremento de temperatura es suficiente para disolver todo el cuarzo y el feldespato alcalino. La disolución total de la biotita tiene lugar hacia los 875°C. A 950°C el magma producido constaría de un 50 % de líquido con cristales suspendidos de plagioclasas y sanidina (Maaloe y Wyllie, 1975) para un contenido en $H_2O$ disuelta del 1,6 %.

En el caso de ausencia de vapor en el sistema el comienzo de la fusión tiene lugar a 875° (ibid.), tal como se ha señalado.

En consecuencia y admitidas las condiciones deficitarias en $H_2O$, en los fenómenos metamórfico-anatécticos, la producción de magmas graníticos en volumen significativo y capacidad ascensional importante exige temperaturas alrededor de los 900°C. Obviamente estas temperaturas únicamente son posibles en niveles inferiores de la corteza.

En cuanto a la posibilidad de formación de masas graníticas en niveles basicorticales en las condiciones señaladas, atendiendo a la composición de estos niveles, no parece que haya problema de acuerdo con Ringwood y Green (1966), Wyllie (1971), Presnall y Bateman (1973), y Ringwood (1975). Las condiciones mínimas en función de la composición de tales niveles son del orden de los 900°C y 9 Kb, según los diagramas de Green (1972) y Piwinskii (1975). No hay incompatibilidades, por tanto, en admitir el origen profundo de gran parte de los batolitos graníticos.

El mismo fenómeno térmico que ha producido estos magmas basicorticales habrá desarrollado hacia niveles superiores una serie de isotermas (que convencionalmente se denominarán isotermas iniciales) responsables del desarrollo de las isogradas del metamorfismo regional y dispuestas concéntricamente (no equidistantes) respecto al área de producción de dichos magmas.

El metamorfismo así producido será del tipo Barrowiense o próximo a él, ya que la zona de producción de los magmas citados corresponde a condiciones similares a las de la facies anfibolítica de dicho metamorfismo (debe señalarse que el metamorfismo tipo Barrow ha sido considerado como el «normal» durante mucho tiempo; v. Turner, 1968).

El régimen térmico de este metamorfismo no permite la producción de fenómenos anatécticos importantes en niveles mesocorticales (es decir, en condiciones de baja presión), por lo que es necesario admitir la presencia de algún foco en desplazamiento que desarrolle «domos térmicos» con subsiguiente generación de metamorfismos y anatexias de «altos gradientes», para explicar la presencia de granitos de anatexia mesocorticales. Atribuir al metamorfismo regional gradientes de este tipo (50°C/Km, 70°C/Km, etc.) implicaría temperaturas basicorticales de un orden muy superior a las admitidas en los modelos térmicos actuales.

Si los magmas basicorticales, sobrecalentados, se han producido en volumen suficiente, cabe atribuir a su ascenso el aporte térmico y de fluidos de tal forma que posibiliten la producción de nuevos fenómenos metamórfico-anatécticos en niveles más altos, prolongándose, así, el fenómeno iniciado en las zonas inferiores de la corteza. De ser así, los productos derivados de los magmas basicorticales deben de estar, necesariamente, asociados a los dominios metamórficos de baja presión.

## A.2.—Relación foco térmico-niveles corticales

a) El ascenso del foco térmico, admitido como material sobrecalentado, tiene lugar en el tiempo además de, evidentemente, en el espacio. Esto significa que el tipo de metamorfismo que desarrolle dependerá (admitiendo una temperatura prácticamente constante del foco) en gran medida de la presión, es decir, de la profundidad a que se encuentre en nivel afectado por el foco térmico. Los efectos de dicho metamorfismo, en cuanto a fenómenos petrogenéticos dependerán, entonces, del contenido en agua de dichos niveles y de su composición química y mineralógica.

Una misma causa, por tanto (foco térmico ascendente de un modo continuo), determina efectos que *en función del nivel de observación muestran, aparentemente, distinto significado.*

Se tendrán, así, distintas manifestaciones del mismo fenómeno metamórfico de acuerdo con el grado de proximidad a la superficie:

— Metamorfismo de contacto
— Metamorfismo regional de baja presión
— Metamorfismo regional intermedio de baja presión

en función no tanto de la temperatura como de la presión (nivel de llegada del foco), tiempo durante el que actúa el régimen térmico, volumen y anchura de los materiales magmáticos ascendentes y grado de proximidad (en horizontal, vertical o diagonal) a los mismos.

En el tiempo el metamorfismo más «joven» es, evidentemente, el de contacto. Pero en el tiempo se están produciendo acontecimientos dinámicos que marcan su impronta en forma de deformaciones que, si se postulan isócronas en vertical, servirán de criterio de relativización de la secuencia de las asociaciones mineralógicas. Según el nivel en que se observen éstas, serán pre, sin o pos fase de deformación (Fig. 1).

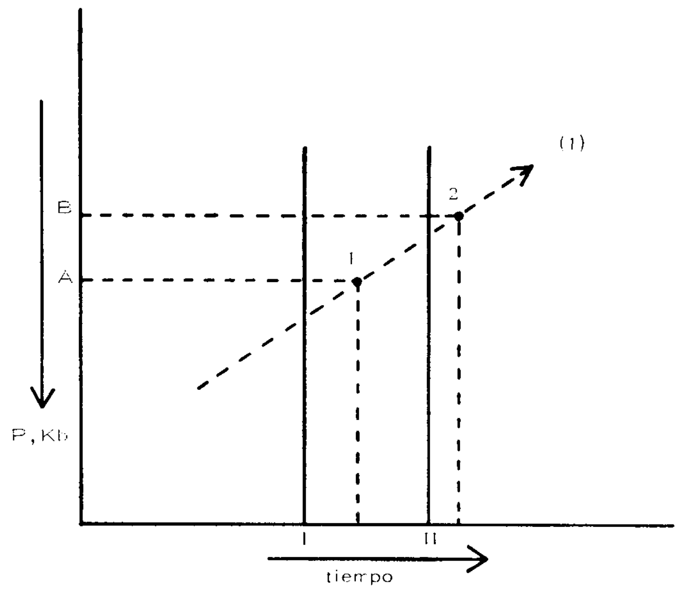


FIG. 1

*Trayectoria idealizada del desplazamiento de un foco térmico en la corteza terrestre (1). I y II momentos correspondientes a dos fases de deformación en un proceso orogénico, supuestas isócronas en vertical en una zona determinada. Los efectos térmicos causados por un foco ascendente observados en el punto 1 (nivel cortical de erosión A) son anteriores a la fase II de deformación. Pero si el metamorfismo es observado en el punto 2 (nivel de erosión B), las asociaciones son posteriores a la fase II, dado que el foco térmico no «llegó» a ese nivel hasta después de dicha fase.*

Cabe esperar, por tanto, que cuanto más alto sea el nivel considerado tanto más tardía será la mineralogía metamórfica respecto a la fase tomada como referencia. Consecuencia inmediata es también, que las asociaciones mineralógicas más profundas (de más alta presión) serán, necesariamente, más antiguas respecto a tal fase de deformación.

b) Desde que comienza un episodio orogénico-metamórfico hasta sus momentos finales transcurre un notable período de tiempo, suficiente como para que el ascenso continuado del orógeno determine modificaciones de la presión litostática de tal forma que las condiciones de presión, *para un mismo nivel original,* serán diferentes al comienzo del metamorfismo y en sus estadios tardíos, si se han originado a consecuencia del mismo domo térmico.

Por otra parte, variaciones en la presión pueden ser debidas también a la sobrepresión tectónica causada por los esfuerzos tangenciales, de tal manera que la mineralogía metamórfica desarrollada bajo estas condiciones puede ser interpretada como producida a profundidades más elevadas de las que en realidad ha tenido lugar, sin que esto sea así necesariamente.

La combinación de los aspectos señalados y teniendo en cuenta el posible ascenso continuo del material foco térmico condicionado por una menor presión litostática y por la existencia de estructuras favorables producidas durante los plegamientos iniciales, permite esperar un proceso continuo de formación de asociaciones mineralógicas de más baja presión cuanto más tardías sean respecto a una fase de deformación tomada como referencia. De acuerdo con las figuras 1 y 2, un mismo nivel puede presentar asociaciones que indican diferentes condiciones a lo largo del tiempo.

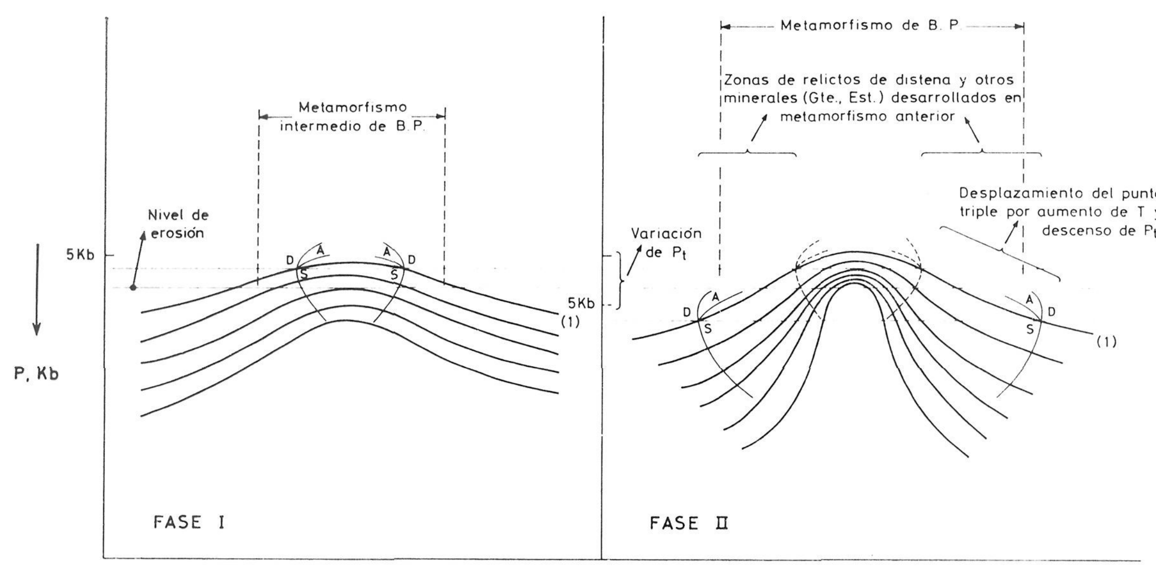


FIG. 2

*En un mismo nivel erosivo es posible encontrar un metamorfismo tipo Distena-Sillimanita o un metamorfismo tipo Andalucita-Sillimanita, en función del nivel a que haya llegado el foco térmico, sin necesidad de admitir saltos estructurales importantes. En el tiempo es más joven el segundo metamorfismo que puede solapar al primero. Igualmente puede darse un efecto de «telescoping» y un mineral como Sillimanita, p. ej., presentar un génesis muy larga en el tiempo (pre,sin y post fase II).*

*(1) Isoterma de referencia del punto triple.*
*Equilibrio And-Sill-Dist, según* RICHARDSON et al. (1969).
*Superficies isotermas e isogradas basadas en* TURNER (1968).

En un nivel determinado se dará, entonces, un fenómeno continuo de «telescoping» y/o solapamiento de asociaciones mineralógicas más o menos desarrollado, a consecuencia de que el material foco desplaza las isotermas iniciales. Es decir, que el resultado final será un conjunto metamórfico plurifacial y polifásico o en el límite un tipo único de metamorfismo de más baja presión que el inicial, por borrarse los efectos de éste en los estadios posteriores.

c) Un tercer aspecto a considerar es el de las consecuencias del planteamiento expuesto hasta el momento, por lo que se refiere a la producción de magmas anatécticos mesocorticales (condiciones de baja presión). Es decir, que se trata de considerar la posibilidad de que puedan desarrollarse magmas graníticos en niveles medios de la corteza a consecuencia del ascenso del magma-foco.

Evidentemente, mientras la composición químico-mineralógica del encajante atravesado sea similar a la de la roca original de la que procede dicho magma no se producirán fenómenos anatécticos.

En niveles en los que, atendiendo a la composición, sea posible la anatexia con formación de productos graníticos, ésta se producirá de un modo importante si la temperatura aportada por el foco es suficiente y si la cantidad de $H_2O$ que llega a estos niveles es también significativa.

Las temperaturas de las intrusiones graníticas pueden oscilar entre 700°C y 800°C (WINKLER, 1974) y de acuerdo con los datos de JAEGER (1957, 1959; in WINKLER, *op. cit.*; in TURNER, 1968), la temperatura en la zona de contacto es ligeramente superior al 60 % de la que presentan dichos magmas, añadida a la temperatura que presenta el encajante. Es decir, que oscilaría entre 460°C y 510°C (WINKLER, *op. cit.*) sumados a la temperatura de las rocas adyacentes. Esto significa que en zonas relativamente poco profundas es posible la producción de fenómenos anatécticos inducidos aun cuando la temperatura del encajante no sea superior a los 200°C. Condición para que tal anatexia tenga lugar es que el tiempo durante el cual se dan tales temperaturas sea suficiente como para que se realicen las reacciones necesarias y este tiempo es función de la anchura de la masa intruida (WINKLER, *op. cit.*: «In the case of intrusions several hundred to several thousand meters in thickness, the maximun temperature induced in the country rock will be maintained for very long periods of time. This means that reactions, which are posible, have sufficient time to proceed to completion, and equilibrium between adjacent minerals is established»).

Por otra parte, los datos cuantitativos establecidos por HORI (in TURNER, 1968) muestran que la cantidad de calor transferido a la roca encajante por los fluidos magmáticos es significativa y que la anchura de la aureola metamórfica puede, así, ser ampliada.

En consecuencia, si el volumen de magma-foco ascendente es importante, las condiciones térmicas que desarrolla sobre las rocas de los niveles en que se intruye pueden ser suficientes como para producir su fusión anatéctica.

Caben, entonces, varias posibilidades de acuerdo con los niveles en los que tenga lugar la solidificación del magma-foco y atendiendo a los aspectos señalados ya en los apartados anteriores.

1) Los materiales-foco térmico no llegan a intruirse en niveles mesocorticales de un modo masivo sino que permanecen en niveles próximos a los de su génesis.

En este caso, la disposición de las isotermas iniciales sufrirá poca variación en función del grado de ascenso de estas masas. En los dominios actualmente accesibles a la observación, los efectos de las isotermas iniciales no mostrarán variaciones o serán muy ligeras. El régimen térmico del metamorfismo será corto en el tiempo y las rocas ígneas graníticas serán escasas en estos dominios, con excepciones representadas por masas relativamente pequeñas derivadas de la masa-foco aprovechando estructuras concretas de alcance local. No habrá o serán muy raros los fenómenos anatécticos en zonas mesocorticales. Los granitos serán de composición similar a la del magma original basicortical y sobre todo, con mayor importancia cuantitativa, productos de la diferenciación de dicho magma. Es decir, granitos de características neumatolíticas e hidrotermales (leucogranitos en general).

2) Si la masa-foco continúa su ascenso hacia niveles mesocorticales, el desplazamiento de las isotermas será más rápido y acusado que en el caso anterior, la duración térmica del metamorfismo será mayor y las asociaciones mineralógicas presentarán variaciones hacia facies de más alta temperatura posteriores a las inicialmente presentes en el mismo nivel. Se producirá, por tanto un fenómeno de «telescoping» y cambios en las posiciones de las isogradas. En función de la composición de las rocas afectadas tendrán importancia los fenómenos anatécticos.

a) Si la masa-foco solidifica inmediatamente por debajo de estos niveles, el subsiguiente aporte de fluidos y elementos disueltos a las rocas afectadas térmicamente permitirá la ampliación del fenómeno anatéctico cuali y cuantitativamente, al modificarse la composición original de dichas rocas e introducir elementos que contribuyen al proceso de fusión.

Las rocas graníticas serán, así, más abundantes que en el caso anterior y representadas por las que se deriven de la anatexia en estos niveles más las que, con alcance local, procedan del magma original.

b) Si el material-foco continúa su ascenso y sobrepasa los niveles donde produjo la anatexia anterior podrá incorporar a su masa los fundidos anatécticos inducidos, de tal forma que se mezclará con los mismos, resultando una composición intermedia entre la original y la del producto anatéctico encajante. En el contexto anterior se tendrá, así, una nueva facies granítica o una nueva línea de evolución de rocas de este tipo.

En una misma zona, por lo tanto, pueden estar representados todos los tipos graníticos en mayor o menor proporción, dependiendo de la proximidad de la masa-foco y de su momento de cristalización y de aporte de fluidos.

El metamorfismo en el caso 1) será de más alta presión que en el caso 2a) y en éste de más alta presión que en el caso 2b). En estos dos últimos casos pueden permanecer restos mineralógicos de las condiciones iniciales, según se ha señalado en A.2 a y b.

En el caso 2b) las rocas ígneas estarán representadas mayoritariamente por las formadas a partir del material-foco y las procedentes de la cristalización de dicho material mezclado con los productos que induce.

En el caso 2a) donde los niveles de anatexia inducida no son sobrepasados masivamente por el magma-foco, predominarán las rocas formadas a consecuencia de los fenómenos anatécticos y estarán prácticamente ausentes los casos de mezcla de ambos productos.

Si el planteamiento es correcto y las anatexias son inducidas en el modo señalado, las rocas resultantes deberán presentar un quimismo que refleje en algún modo la participación de fluidos procedentes de otra masa ígnea, en el sentido de que los elementos más móviles pasarán a formar parte de los productos anatécticos inducidos.

Por otra parte y dadas las diferentes características de los procesos metamórficos (P, T, proximidad de la masa-foco, etc.) las anatexias desarrolladas bajo condiciones comprendidas entre los casos 1) y 2a) serán de diferente orden que anatexias similares a las producidas en casos próximos al 2b) o comprendidos entre el 2a) y el 2b), ya que en éstos se efectúan sobre rocas previamente afectadas térmicamente en las que habrá tenido lugar un cambio composicional debido a la posible migración de fluidos y elementos disueltos, como consecuencia de los primeros estadios metamórficos anteriores al desarrollo del «telescoping» y procesos asociados.

Esto deberá reflejarse en los granitos producidos en unos y otros casos, que presentarán diferencias cuali y cuantitativas ya que si el estadio inicial del metamorfismo permitió la anatexia, en los estadios finales, más térmicos, la composición química y mineralógica de las rocas afectadas ya no es la misma. Esta variación debe manifestarse en la composición química y mineralógica de las rocas metamórficas finales respecto a las iniciales, especialmente si las condiciones permiten los fenómenos anatécticos en ambos casos. Se deduce también que en caso de que se hayan producido granitos en los estadios iniciales pueden ser removilizados en los estadios posteriores si en esa zona el foco térmico ha ascendido lo suficiente.

En el tiempo y considerando el mismo nivel las rocas más «jóvenes» tanto metamórficas como graníticas serán las del caso 2b), las más antiguas serán las del caso 1) y ocuparan posiciones intermedias las del caso 2a), es decir, en paralelismo con la evolución temporal del metamorfismo.

### A.3.—Discusión en torno a la utilización del concepto de gradiente geotérmico en los dominios metamórficos de baja presión.

Con relativa frecuencia y a partir del dato de las condiciones metamórficas deducidas en una zona concreta, se establece la variación de la temperatura con la profundidad considerando el espacio comprendido entre la superficie (presión = O) y el dominio metamórfico definido por una o varias reacciones minerales.

Resultan, así, gradientes de 60°C/Km, 70°C/Km y superiores, cuyo establecimiento en la forma indicada comporta la admisión de una variación lineal de la temperatura con la profundidad en los cinturones metamórficos.

Tal utilización del concepto de gradiente geotérmico es a nuestro entender inexacta, en cuanto a soluciones del estudio del metamorfismo e induce a errores en la interpretación de las variaciones de presión y temperatura en los dominios metamórficos.

De acuerdo con los modelos térmicos de Turner (1968), en el caso de un régimen térmico de extensión lateral infinita, es decir, no debido a la existencia de un foco térmico concreto emplazado en unas coordenadas espaciales determinadas, las superficies isogradas serían horizontales al igual que las superficies isotermas. No siendo éstas equidistantes, el gradiente no sería exactamente una función lineal en un diagrama P-T. Este planteamiento sería válido, en todo caso, para un metamorfismo geotérmico.

Pero en un modelo térmico donde el calor es aportado por un foco concreto, de emplazamiento vertical en una zona determinada, las superficies isogradas no son horizontales y tampoco las superficies isotermas cuya distribución no es, en modo aún más acusado que en el caso anterior, equidistante. En consecuencia, la variación de la temperatura con la profundidad dista mucho de ser una función lineal en los dominios metamórficos de bajas presiones.

Lo que se señala con una función lineal del gradiente geotérmico que se deduce en un metamorfismo a partir de las asociaciones mineralógicas presentes es la distribución T/P en un estadio estacionario y también imprecisamente, pues tales asociaciones mineralógicas reflejan las máximas temperaturas alcanzadas antes de llegar a dicho estadio, las cuales son relativamente más altas que las existentes durante el mismo (WINKLER, 1967).

Durante el metamorfismo regional, por tanto, la relación T/P no es una función lineal, lo cual significa que no es exacta la extrapolación con que se presenta linealmente el gradiente geotérmico a partir de las asociaciones mineralógicas determinadas.

Admitir gradientes de 50-70°C/Km, deducidos en la forma señalada, es decir, como función lineal de T y P, supone:

a) O bien temperaturas superiores a los 1.500°C en la base de la corteza, que implicarían una fusión generalizada.

b) O bien que la función lineal que comporta tal admisión presenta un marcado punto de inflexión para hacerse casi asintótica con el eje de las presiones, a partir de un punto determinado.

c) Una tercera posibilidad sería la de un espesor muy reducido de la corteza, pero en el caso que aquí se considera, del Macizo Hespérico, los datos petrológicos en los actuales niveles de observación no permiten afirmar esta posibilidad.

El caso a) no es admisible. El caso b) supone una temperatura prácticamente constante desde niveles mesocorticales hasta los basicorticales (Fig. 3) y desde los primeros hacia niveles superiores una relación T/P muy pronunciada.

Desde el punto de vista de los autores del presente trabajo, tal modelo térmico puede ser explicado únicamente si (en la medida que las características de los metamorfismos de bajas presiones indican la presencia de «domos térmicos próximos») se admite que el metamorfismo es producido por el ascenso de masas magmáticas y/o fluidos sobrecalentados cuya intrusión en niveles mesocorticales provoca una modificación en la disposición de las isotermas iniciales.

El metamorfismo desarrollado no debe, así, ser considerado como resultado de un gradiente T/P sino de un gradiente T/D (D = distancia medida en dirección normal al foco térmico, es decir, normal a las superficies isogradas establecidas en el mapa). La presión a través de la aureola se supone constante (TURNER, 1968) y el gradiente T/D expresado por las isogradas establecidas será paralelo al eje de las temperaturas en un diagrama P/T (Fig. 3). El resultado final es un gradiente compuesto según terminología de TURNER (1968), o un gradiente en el tiempo además de en el espacio, según expresión de CHINNER (1966).

La relación T/P vendrá, entonces, expresada durante el metamorfismo y antes de llegar a un régimen estacionario, por una línea similar a las representadas por las curvas A' y A'' en la figura 3 y semejante también a las es-

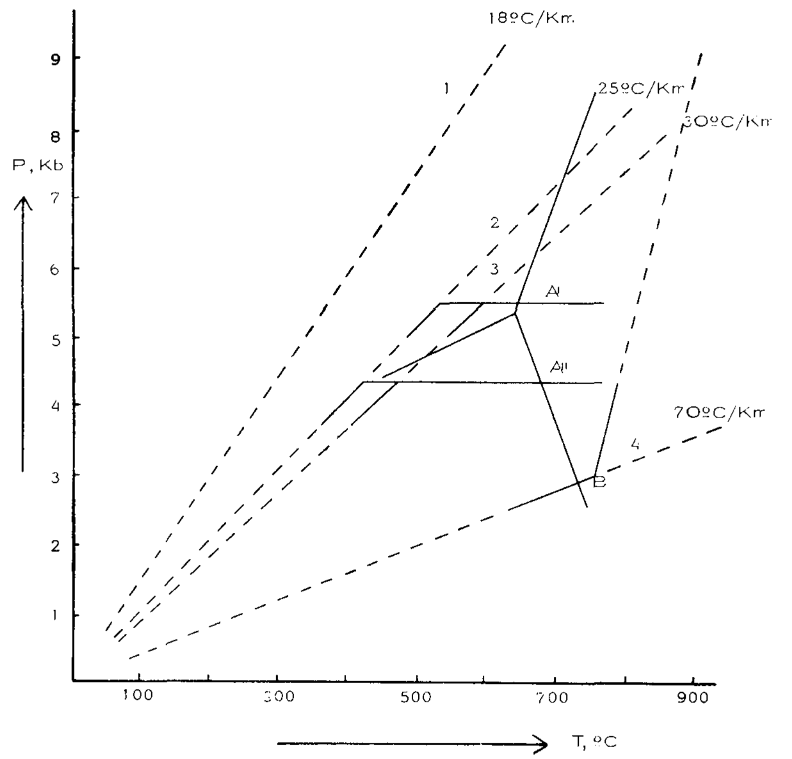


FIG. 3

*A' y A" curvas de distribución T/D (v. texto) durante el paroxismo metamórfico (régimen térmico no estacionario) para dos posiciones diferentes del foco térmico. 1, 2, 3 y 4 curvas para los gradientes señalados, en régimen térmico estacionario de extensión lateral infinita, supuestas equidistantes las isotermas. Gradientes «normales» de 25° C/Km, 30° C/Km sufren una modificación en el tiempo por efecto de intrusiones magmáticas de volumen importante. El régimen térmico resultante viene expresado por las citadas curvas A' y A". B, punto de inflexión (?) en «gradientes» elevados, admitidos como función lineal de T/P, para temperaturas basicorticales más realistas del orden de 900°C.*

*Punto triple de los polimorfos de $Al_2SiO_5$ según* RICHARDSON et al (1969).

tablecidas para el régimen de temperatura en un metamorfismo de contacto por TURNER (1968) y WINKLER (1967, 1974) a partir de los datos de JAEGER (1957, 1959).

De acuerdo con los razonamientos precedentes, puede apreciarse (Fig. 3) que la diferencia de presión entre un metamorfismo intermedio de baja presión y un metamorfismo de baja presión puede ser del orden de 1 Kb (es decir, valores del mismo orden que los admitidos como posiblemente debidos a sobrepresiones tectónicas), en ausencia de otros datos que permitan acotaciones más seguras en uno u otro tipo de metamorfismo. Incluso a la misma presión pueden presentarse los tres polimorfos alumínicos (aparte del caso del punto triple), en un mismo acontecimiento metamórfico, distribuidos de acuerdo con su distancia al foco (Fig. 2). Para una misma presión la distena será el mineral más alejado del foco térmico y será afectado por un «telescoping» si el foco se desplaza. Su inestabilidad en las nuevas condiciones da paso a la formación de sillimanita y andalucita que serán más tardías respecto a la distena residual (v. fig. 2).

Aceptar los aspectos señalados implica aceptar que los metamorfismos regionales en regímenes térmicos con alta relación T/P son causados por masas o focos concretos, fuente del calor aportado. Es decir, considerar tales metamorfismos como megametamorfismos de contacto. La diferencia respecto a un metamorfismo de contacto, en el sentido en que habitualmente se emplea esta expresión, es únicamente cuantitativa, tal como se ha señalado en el apartado A.1, y los distintos efectos función de los niveles en que se observe el fenómeno metamórfico.

## A.4.—Resumen y postulados

Consecuentemente con lo hasta aquí expuesto cualquiera que sea el material transportador del calor, su ascenso condicionará posibles fenómenos de fusión a su paso, variables en extensión y volumen, de tal forma que los nuevos productos anatécticos podrán iniciar su ascenso conjuntamente con el material inductor de la anatexia, que queda, así, contaminado respecto a su composición original.

Esta posibilidad puede darse de un modo continuo o desarrollarse en determinados niveles en función de variables como: contenido en fluidos del encajante, temperatura inicial del mismo, relación composición-curva solidus, etc., aparte de las propias del cuerpo inductor ascendente: anchura del mismo, volumen, temperatura, estado de cristalización, contenido en agua, etc.

Igualmente y en función de las mismas variables pueden producirse fenómenos anatécticos a partir de los cuales se desarrollan magmas con un comportamiento independiente una vez producidos.

Si todo el planteamiento expuesto hasta el momento es correcto y admitiendo un proceso único orogenia-metamorfismo, deberán obtenerse los siguientes resultados:

— La presencia de rocas graníticas «tempranas» estará asociada a metamorfismos de más alta presión y más «jóvenes» que los metamorfismos asociados a las rocas graníticas «tardías».

— La cantidad de granitos será mayor en el segundo caso que en el primero, y se darán series graníticas originadas por contaminación con material encajante.

Todos los aspectos expuestos pueden sintetizarse en la aceptación de los siguientes postulados:

I) El foco térmico que desarrolla temperaturas elevadas en un cinturón metamórfico está representado por un gran volumen de materiales magmáticos que ascienden a través de la corteza, durante un episodio orogénico completo.

II) Por debajo del frente superior de esquistosidad las fases de deformación, más o menos intensas, son *isócronas en vertical,* para cada área geográfica.

III) En el caso concreto del Macizo Hespérico y teniendo en cuenta que las rocas de origen ígneo más abundantes están representadas por grandes volúmenes de granitos calcoalcalinos y asociados, de origen profundo, se parte de la base de que los magmas que dieron lugar a estos tipos graníticos han sido el foco térmico ascendente que ha condicionado la mayor parte de los fenómenos plutonometamórficos.

Un último aspecto a considerar es que el criterio de situación temporal relativo a una fase de plegamiento debe de ser tomado con precaución, ya que no tiene por qué ser isócrona en todas las zonas geográficas donde se ha producido (tal es el caso de la II fase de deformación en el Macizo Hespérico; v. BARD y FABRIES, 1970; CORRETGÉ, 1971). Así, un granito considerado como «older» por estar afectado por la fase II puede resultar, en cronología absoluta, de la misma edad que otro granito de distinta localidad geográfica señalado como «younger» por no estar afectado por dicha fase y esto ser debido a que en el segundo caso es más antigua que en el primero.

Por otra parte y tal como se deduce de la figura 1, el que un granito esté afectado por una deformación depende del nivel en que se observe su emplazamiento.

En cualquier caso, además, el carácter «older» o «younger» no puede ser un criterio definitivo a tener en cuenta en un planteamiento de génesis global, en el sentido de separar de acuerdo con él líneas genéticas. Las razones son en parte las antes aducidas y por otra el hecho de que un mismo proceso genético en la medida que tiene lugar en el tiempo puede producir a lo largo de estadios sucesivos efectos propios de cada caso, en apariencia no relacionados entre sí.

## B.—ASPECTOS CONOCIDOS EN EL MACIZO HESPERICO

Se expondrán a continuación diversos aspectos de las características de las rocas graníticas y metamórficas del Macizo Hespérico, en diversas zonas geográficas, a fin de mostrar una serie de puntos comunes que son o pueden ser importantes en el análisis global.

La relativización temporal de los acontecimientos metamórficos y de intrusiones graníticas se hace por referencia a dos fases de deformación hercínicas (fase I y fase II de BARD *et al.*, 1971) si bien se ha citado en varias ocasiones la existencia de otra fase situada entre estas dos y también una fase anterior de posible edad prehercínica (para una revisión del problema véase: ALDAYA *et al.*, 1973).

Con independencia de la existencia de metamorfismos y fases de deformación prehercínicos, así como de la presencia de otras fases hercínicas de importancia menor, se utilizarán la fase I y II de los autores citados por razones prácticas, ya que siendo las más desarrolladas permiten un mejor análisis global en la secuencia de acontecimientos petrológicos. Evidentemente, la importancia relativa de las fases puede variar de unos puntos a otros y en consecuencia la deformación tomada por fase II en algunas áreas puede ser en realidad otra fase post-I distinta, pero en el caso de que sea así, la importancia a efectos de relativización temporal es mínima, dada la edad intracorbonífera de estas fases menores. En cualquier caso, además, no se trata de hacer una equivalencia cronológica exacta entre fenómenos de distintas áreas (pretensión imposible, por otra parte, dado el carácter migratorio de las fases. BARD y FABRIES, 1970; CORRETGÉ, 1971), sino de comparar la secuencia temporal de acontecimientos entre unas áreas y otras, con independencia de cuál sea el momento inicial absoluto de los mismos.

## B.1.—NO PENINSULAR, N Y CENTRO DE PORTUGAL

B.1.1.—En el NO Peninsular se han puesto de relieve características que pueden ser relevantes en la interpretación que se propone:

a) El metamorfismo hercínico oscila entre tipos intermedios de baja presión a tipos de baja presión (DEN TEX y FLOOR, 1971; BARD *et al.*, 1971; CAPDEVILA *et al.*, 1973) siendo de destacar que en zonas centrales y orientales donde las isogradas están plegadas por las fase II (CAPDEVILA, 1968, 1969; MEEBERKE *et al.*, 1973) el metamorfismo es de más alta presión que en la zona occidental; y en ésta: «From generally undeformed habit of the minerals it follow that hercynian metamorphism outlasted deformation» (FLOOR, 1966).

De un modo general puede señalarse, de acuerdo con CAPDEVILA *et al.* *(op. cit.)* que el tipo de metamorfismo es variable y: «Intermédiaire de basse pression à disthène ou à andalusite en Galice orientale, il devient de plus en plus basse pression vers le secteur occidental de Galice». Por otra parte el metamorfismo es también más joven por relación a la fase II hacia el sector occidental, es decir, que parece existir una relación entre la edad del metamorfismo y sus condiciones P-T en el sentido de que condiciones más bajas de presión van asociadas a momentos más tardíos.

b) Respecto a los granitos, predominan los de origen mesocortical (Capdevila y Floor, 1970; Capdevila *et al.*, 1973) emplazados o desarrollados en general subcontemporáneamente con la fase II, si bien se encuentran casos de sin fase I a ligeramente tardíos respecto a la fase II.

Los más abundantes son los leucogranitos, de composición muy constante (cuarzo, albita, microlina, moscovita, biotita y muy raramente silicatos alumínicos), acompañados de fuerte actividad neumatolítica e hidrotermal. Su posición en el tiempo se extiende desde sin fase I hasta post fase II, siendo los más abundantes los post-fase I y pre-fase II. Dado que el paroxismo metamórfico es post fase I y pre fase II, al menos parte de estos granitos pueden representar fluidos alóctonos procedentes de zonas inferiores en las que cristalizan magmas graníticos de origen profundo. Apoya esta idea el hecho de que a veces son fracamente alóctonos y «Ces leucogranites recoupent souvent les granodiorites d'anatexie et les isogrades profonds» y el que se encuentren presentes «no seulement pendant le paroxisme métamorphique mais pendant tout le temps que dure ce métamorphisme» (ibid.).

Otro grupo es el constituido por las granodioritas de anatexia en macizos concordantes autóctonos o subautóctonos, contemporáneos del paroxismo metamórfico. Su composición mineralógica y posición respecto a las rocas migmatíticas es similar a la que presentan en las Sierras centrales (Capdevila *et al.*, *op. cit.*) y su origen por anatexia parece claro. Igualmente, se encuentran relacionados con granitos de dos micas cuya posición respecto a la fase II oscila de pre a post dicha fase (Capdevila y Floor, 1970).

Un tercer grupo de granitoides considerados como de origen mesocortical (Capdevila *et al. op. cit.*) es el representado por granitos en macizos circunscritos de carácter alóctono. Son poco abundantes y presentan frecuentes silicatos alumínicos (cordierita, sillimanita, andalucita, granate). Son ligeramente tardíos respecto a la fase II y sus características los hacen comparables a los granitos calcoalcalinos cordieríticos de zonas centrales españolas, si bien en Galicia son mucho menos frecuentes (Capdevila y Floor, *op. cit.*). Más adelante se volverá a hacer referencia a este problema.

Por lo que respecta los granitos de serie calcoalcalina precoz son de destacar varios aspectos significativos, según Capdevila *et al. (op. cit.)*:

— «La plupart de ces granodiorites précoces cicatrisent des grands accidents cassants post phase I, situés dans la charnière de la virgation, ou apparaissent au coeur d'anticlinaux de la deuxième phase de déformation».

— «Les relations avec le métamorphisme régional sont d'un type analogue à celles des leucogranites: les granodiorites precoces sont à peu près contemporaines du metamorphisme regional».

— «Les granodiorites precoces, mises en place dans les gneiss pelitiques du facies amphibolite profond, sont plus alumineuses et plus muscovitiques que celles qui atteignent des niveaux plus superficiels. Ces diferences chimico-mineralogiques en fonction du niveau final d'intrusion, correspondent sans doute a une capacité d'assimilation d'encaissant plus grande des magmas granodioritiques, lorsqu'ils se mettent en place dans des formations soumises a un metamorphisme mesozonal intense. Les granodiorites precoces mises en place dans ces conditions et par consequent riches en muscovite, presentent alors des analogies de facies avec les leucogranites» [1].

— «...est importante de noter, que leur mise en place est contemporaine du metamorphisme regional et qu'elle est quasi exclusivement limitée aux zones fortement metamorphiques».

En cuanto a los granitos calcoalcalinos tardíos, de origen profundo, las características son de todo punto similares tanto en el NO como en otros dominios hespéricos y también similares a los granitos calcoalcalinos precoces (CAPDEVILA *et al.*, *op. cit.*).

Atendiendo a la mineralogía de los granitos anatécticos enraizados y rocas asociadas, así como de los granitos de la serie calcoalcalina tardía, conviene destacar dos aspectos:

1) Que las rocas migmatíticas y granitos heterogéneos de anatexia asociados no tienen o es muy rara la cordierita (v.: FERRAGNE, 1966 a, 1966 b, 1968; ANTONIOZ y FERRAGNE, 1967; ZUUREN, 1969; HILGEN, 1971; E. MARTÍNEZ y CORRETGÉ, 1970; E. MARTÍNEZ, 1973; GONZÁLEZ-LODEIRO *et al.*, 1974 a, b, c, d; FERNÁNDEZ POMPA y BOQUERA, 1974; FERNÁNDEZ TOMÁS y PILES, 1974; CHAMÓN y FERNÁNDEZ TOMÁS, 1974; CHAMÓN y FERNÁNDEZ POMPA, 1974), que alcanza importancia sólo en algunos puntos concretos (FLOOR, 1966; WOENSDREGT, 1966), siendo relativamente más frecuente el granate. Esta escasez de la cordierita es con toda probabilidad causada por condiciones de presión más elevadas en el metamorfismo del NO, que en las zonas peninsulares centro-occidentales y centro-meridionales, donde la cordierita es un mineral muy frecuente en rocas de tipo migmatítico y granitos asociados, si bien la composición química de las rocas originales es otro factor a tener en cuenta, dado el control químico condicionante de la aparición de cordierita y/o granate (v. CURRIE, 1971; DALLMEYER, 1972).

[1] Esta relación parece similar, cualitativamente al menos, al paralelismo de la serie calcoalcalina tardía con la serie calcoalcalina contaminada, con cordierita y moscovita (v. UGIDOS y BEA, 1976).

b) Que los granitos calcoalcalinos «younger» en las áreas del NO no presentan facies con prismas cordieríticos con la importancia que se presentan en otras zonas peninsulares (CAPDEVILA y FLOOR, 1970), pero si existen facies de transición a granitos de dos micas con andalucita y más raramente sillimanita (GONZÁLEZ-LODEIRO *et al.,* 1974 b, c, d) que pueden indicar un fenómeno de asimilación similar al que presentan los primeros.

B.1.2.—*Zonas de Sanabria y Arribes del Duero*

En la zona de Sanabria (provincias de León, Orense y Zamora) estudiadas por E. MARTÍNEZ y CORRETGÉ (1970) y E. MARTÍNEZ (1973), el metamorfismo hercínico es de tipo «presión intermedia» y se desarrolla en torno a la fase I hercínica (fase II en la región citada, ibid.) con migmatización tardía respecto a esta fase. En cuanto a los granitos, los de edad hercínica son netamente calcoalcalinos y su emplazamiento tuvo lugar desde la fase I hercínica hasta estadios posteriores a la fase II (IV en esta región, ibid.).

Por lo que se refiere a la zona de los Arribes del Duero (provincias de Zamora y Salamanca), estudiada por F. MARTÍNEZ (1974), el metamorfismo se inicia bajo condiciones de más alta presión que las finales, teniendo lugar fenómenos anatécticos cuantitativamente poco importantes durante los primeros estadios. Posteriormente a la primera etapa metamórfica y con anterioridad a la fase II (III en esta zona) se intruyen granitos calcoalcalinos (granitos monzoníticos y granodioritas) en cuyas aureolas térmicas se desestabilizan las paragénesis metamórficas iniciales, sufriendo un reajuste las isogradas y variando las condiciones metamórficas hacia asociaciones de más baja presión (ibid.). Es en estos momentos cuando los fenómenos anatécticos alcanzan su máximo desarrollo y se produce la principal masa de granitos alcalinos, debido en parte a que el sistema se abre para el $H_2O$ (ibid.). Estos granitos se intruyen en relación con la fase II, por lo que el autor los considera, en conjunto, como sincinemáticos.

Posteriormente tiene lugar la intrusión de granitos de afinidades calcoalcalinas y tendencia alcalina, que se consideran como de carácter mixto de acuerdo con la nomenclatura de CAPDEVILA *et al.* (1973), admitiendo que pueden representar un magma calcoalcalino contaminado en niveles superiores de la corteza.

Es importante señalar en relación con estos granitos que presentan cantidades variables de moscovita, a veces con sillimanita asociada, careciendo de prismas cordieríticos que por otra parte tampoco se encuentran en el neosome las migmatitas, ni en los granitos anatécticos.

Finalmente se produce la intrusión de pórfidos graníticos, según fracturas de dirección NE-SO, comparables a las rocas graníticas de la serie calcoalcalina «younger» (ibid.). Esta serie se encuentra, por tanto, muy poco representada.

B.1.3.—*N de Portugal*

En el N de Portugal, el metamorfismo es anterior-subcontemporáneo de la fase II, de acuerdo con los trabajos de WESTERWELD (1956), SCHERMERHORN (1956), OEN (1970), PORTUGAL (1965, 1967), y de baja presión, en general. Las asociaciones minerales muestran gran similitud con el metamorfismo de Galicia oriental, presentando ocasionales asociaciones con distena hercínica (BARD, *et al.*, 1971). Las áreas metamórficas estudiadas por TORRE DE ASSUNÇAO (1962) en los dominios norocidentales portugueses revelan asociaciones mineralógicas (con cordierita abundante en rocas migmatíticas y granitos asociados) que definen un metamorfismo, en relación con la fase II, de más baja presión que los metamorfismos citados por los autores anteriores.

Por otra parte ATHERTON *et al.* (1974) señalan en el cinturón metamórfico de Oporto-Viseu varios puntos de interés en relación con la secuencia de aparición de minerales índice y desarrollo del metamorfismo. Según estos autores la andalucita raramente se presenta con estaurolita, a la cual posdata. Estaurolita y andalucita son anteriores a «coarse or recristallized sillimanite». «For the time relations could well be similar to those at Cavernais where early staurolite plus kyanite is followed in the same metamorphism by andalusite and finally by sillimanite». Los autores opinan que no se trata de dos episodios metamórficos superpuestos (metamorfismo tipo Barrow + metamorfismo tipo Abukuma), sino de un único metamorfismo cuyas condiciones se han modificado en el tiempo.

Los granitos tardíos del N de Portugal se han considerado como representados por granitos calcoalcalinos mayoritariamente, y en menor proporción por granitos alcalinos, es decir, al contrario de lo que ocurre en Galicia (FLOOR *et al.*, 1970). Sin embargo, exceptuando los granitos calcoalcalinos pertenecientes al grupo IV de FLOOR *et al. (op. cit.)* los demás grupos graníticos presentan caracteres intermedios alcalinos-calcoalcalinos y son alóctonos (grupos II y III, ibid.).

En cualquier caso, la comparación del N de Portugal con la región gallega ha permitido establecer, de acuerdo con la interpretación de FLOOR *et al. (op. cit.)*, los siguientes puntos:

a) «Que des granites alcalins antérieurs à la fin des plissements régionales et des granites calcoalcalins post-tectoniques sont communs dans les deux régions comparées».

b) «Qu'en Galice, on trouve deux types importantes de massifs granitiques que jusqu'a présent l'on n'a pas décrits en grand quantitié au Portugal»:

— Des granites alcalins (à albite, oligoclase acide, riches en muscovite, leucocrates) essentialement post-tectoniques».

— Des granites calcoalcalins (à oligoclase, riches en biotite, assez sombres) déformés par la tectonique régionale.

c) «Qu'au N de Portugal, on trouve une variété plus grande de types de granites calcoalcalins post-tectoniques, mais une variété moins grande de types texturaux del granites alcalins que précèdent le fin des plissements régionaux».

La diferencia entre Galicia y N de Portugal puede explicarse si se admite (como se ha señalado en B.1.1,b) que los leucogranitos representan, al menos en parte, fluidos derivados de los magmas calcoalcalinos que cristalizan en niveles inferiores. En el N de Portugal estos magmas son más tardíos, se encuentran emplazados en niveles más altos y se contaminan con productos anatécticos produciendo los tipos graníticos correspondientes a los grupos II y III de FLOOR *et al.* (1970), de caracteres intermedios alcalinos-calcoalcalinos. Esta posibilidad necesita, evidentemente, comprobación geoquímica.

### B.1.4.—*Centro de Portugal*

En áreas centrales portuguesas se ha puesto de relieve la presencia de granitos calcoalcalinos biotíticos con prismas de cordierita (Serra da Estrela: observaciones realizadas durante la II reunión de Geólogos del SO del Macizo Hespérico, 1972). Asimismo, TORRE DE ASSUNÇAO (1962) señala en algunos granitos calcoalcalinos del área Miño-Duero, la presencia de cordieritas. ROCHA DO MACEDO (1974), en la región de Braga, indica también cordieritas formando parte de la mineralogía en el mismo tipo de granitos. Igualmente TEIXEIRA (1959) en Vilar Fermoso y PALACIOS (1974) en el «complexo xisto-granito-migmatitico» de la Serra do Geres.

Es de destacar en estas zonas, entonces, la presencia de prismas cordieríticos asociados a granitos calcoalcalinos «younger».

## B.2.—ÁREAS CENTRO-MERIDIONALES Y MERIDIONALES

Se conocen en estos dominios aspectos parciales de complejos metamórficos y graníticos que muestran datos relevantes coincidentes con los de otras áreas.

Las zonas metamórficas conocidas son:

— Cinturón Badajoz-Córdoba

— Cinturón Aracena-Lora del Río

— Complejo metamórfico de Evora-Beja.

B.2.1.—El cinturón metamórfico de Badajoz-Córdoba, aún insuficientemente conocido, ha sido considerado como formado bajo condiciones metamórficas características de presión intermedia (BARD *et al.*, 1971 a y b). MUÑOZ y VEGAS (1974) señalan también este tipo de metamorfismo y discuten la posibilidad de su edad antehercínica inclinándose por una solución hercínica con desarrollo de granate, distena y sillimanita sincrónicas con la foliación $F_1$ posteriormente plegada. Igualmente descartan la existencia de un polimetamorfismo.

Nuevos datos obtenidos por CHACÓN (1974) y CHACÓN *et al.* (1974) muestran la complejidad del cinturón metamórfico Badajoz-Córdoba al oeste de Valencia de las Torres, señalando que hay dos dominios metamórficos diferentes. Uno del mismo tipo que el señalado por los autores anteriores y otro de menos presión (sin distena y con andalucita-sillimanita), en el que se dan materiales anatexíticos y masas granitoides postmetamórficas.

No están claras por el momento las relaciones mineral-fase de deformación ni los equilibrios paragenéticos por lo que es difícil establecer la secuencia del desarrollo de las asociaciones metamórficas. En cualquier caso, este cinturón metamórfico carece de manifestaciones graníticas importantes (BARD, 1971), presenta ortoneises y es probablemente plurifacial (ibid.).

B.2.2.—Mejor conocidas son las áreas metamórficas de Aracena (FABRIES, 1963) y Lora del Río (BARD, 1969), donde el metamorfismo es típicamente de baja presión alcanzando su paroxismo en estadios intermedios entre las fases I y II prolongándose en Lora del Río hasta la fase II (BARD y FABRIES, 1970). La presencia de rocas graníticas es aquí mucho más importante que en el cinturón metamórfico Badajoz-Córdoba y son frecuentes los fenómenos anatécticos (BARD, 1970; BARD y FABRIES, 1970).

Si bien las condiciones globales de los metamorfismos en Aracena y Lora del Río son de todo punto semejantes, algunos aspectos son de gran interés:

— En Lora del Río, la migmatización en la que se producen abundantes facies cordieríticas, es posterior a una etapa metamórfica que asociada a las fases principales de deformación origina neises biotítico-sillimaníticos, sobreponiéndose a éstos la mineralogía cordierítica en rocas de tipo diatexítico, isótropas, en las cuales micropliegues y textura neisica tienen carácter residual. Una feldespatización posterior granitiza y homogeneiza a estas rocas (FABRIES, 1963).

Aparentemente, por tanto, se dan dos estadios metamórficos de temperatura elevada, sin que esto descarte la posibilidad de su carácter progresivo.

— En Aracena, por el contrario (BARD, 1969), no tiene lugar más que un único estadio de temperatura elevada de sin a post fase I bastante amplio en el tiempo, sucediéndose varias asociaciones mineralógicas que finalizan con la blastesis de feldespato potásico y sillimanita prismática (BARD y FABRIES, 1970).

B.2.3.—En la región de Evora-Beja, se da un tipo de metamorfismo similar al indicado en Aracena-Lora del Río (CARBALHOSA, 1971; CAPDEVILA *et al.*, 1973) en estadios situados entre las fases I y II y los granitos de dos micas están deformados por la fase II y son muy análogos a los granitos de dos micas del NO peninsular.

Los granitos calcoalcalinos pre fase II, si bien están representados, son excepcionales y predominan los posteriores a esta fase. De acuerdo con CAPDEVILA *et al.* (1973) en la región de Evora-Beja los tipos graníticos, aparte de los netamente calcoalcalinos, son los siguientes: granitos de anatexia aparentemente autóctonos, raros leucogranitos en macizos alóctonos y sobre todo granitos porfiroides de dos micas y cordierita en macizos alóctonos netamente discordantes.

Los granitos tempranos se encuentran formando pequeños macizos alargados paralelamente con la dirección de las estructuras mayores, afectados por la fase II y son contemporáneos con el metamorfismo regional. Los granitos tardíos alcanzan también extensiones muy pequeñas, disponiéndose según alineaciones de los ejes de antiformas tardías y en parte también con una distribución más irregular en dominios metamórficos de facies anfibolíticas, en extensiones relativamente pequeñas (CAPDEVILA *et al.*, 1973).

La observación conjunta de la región Lora del Río-Aracena-Evora, permite señalar los siguientes aspectos más destacables:

a) El metamorfismo es de baja presión con formación de migmatitas de tipo nebulítico ricas en cordierita, llegando a formarse incluso rocas de afinidad charnockítica. En todos los casos las asociaciones mineralógicas finales están precedidas por asociaciones integradas por: fibrolita-granate-biotita-plagioclasas-cuarzo (Lora del Río), plagioclasas-biotita-granate-cuarzo (Aracena), finalizando los procesos de desarrollo de los minerales con una granitización metasomática de feldespato potásico (Macizo de las Camachas, zona de Lora del Río) o blastesis de feldespato potásico (Aracena) (FABRIES, 1963; BARD y FABRIES, 1970).

b) Predominio de los granitos calcoalcalinos «younger» sobre los tempranos, presentando aquéllos, prismas cordieríticos (CARBALHOSA, 1970).

c) Es importante señalar que el metamorfismo tiene una historia diferente en el tiempo (respecto a las fases de deformación) de unas regiones a otras, siendo más joven en Lora del Río que en los otros dominios, a pesar de la continuidad estructural y de la proximidad espacial, sugiriendo esto una diferente posición espacio-temporal del foco térmico en Lora del Río que en las otras dos áreas. En Lora *el metamorfismo es más tardío, los granitos alcalinos también y están ausentes los granitos calcoalcalinos tempranos.*

### B.3.—ZONAS CENTRALES ESPAÑOLAS

El metamorfismo en las áreas centrales peninsulares es conocido desde hace relativamente poco tiempo de un modo preciso y los datos obtenidos han permitido establecer, de un modo generalizado, los aspectos más importantes, que se resumen a continuación.

#### B.3.1.—*Areas del Guadarrama*

Considerado en su conjunto el metamorfismo es plurifacial (BARD *et al.*, 1970, 1971 a y b) y polifásico (FUSTER *et al.*, 1974) y sus condiciones de presión y temperatura varían de estadios pre fase II a post fase II. Las condiciones iniciales indican un metamorfismo de presión intermedia o intermedio de baja presión (BARD *et al., op. cit.*; FUSTER y GARCÍA CACHO, 1971; GARCÍA CACHO, 1973; PEINADO, 1973; FUSTER *et al., op. cit.*; LÓPEZ RUIZ *et al.*, 1975) mientras que las finales (de sin a post fase II) son netamente de baja presión con desarrollo de andalucita, cordierita y sillimanita. De acuerdo con los autores citados, algunos de los minerales correspondientes a los primeros momentos metamórficos permanecen como relictos en dominios donde predominan las últimas asociaciones, de baja presión.

La variación de las condiciones metamórficas ha sido establecida no sólo de acuerdo con las relaciones fase de deformación-crecimiento mineral, sino también, en ocasiones, atendiendo a la zonación química de minerales como el granate (LÓPEZ RUIZ *et al.*, 1975) que revela un cambio en las condiciones metamórficas, en concordancia con el primer tipo de datos. Según LÓPEZ RUIZ *et al. (op. cit.)*: «... teniendo en cuenta los diferentes tipos de zonado que presentan los granates de la Sierra de Guadarrama, estos se generaron en una primera etapa metamórfica, caracterizada por un gradiente geotérmico intermedio. Posteriormente tuvo lugar un descenso importante de la presión y un aumento de la temperatura y bajo estas condiciones los granates (y otras fases minerales originadas durante la primera etapa, como por ejemplo, estaurolita y distena) sufren un proceso de reabsorción, el cual queda evidenciado por el enriquecimiento en Mn en el borde del cristal, o cuando el proceso ha sido intenso, por la existencia de zonado inverso al mismo tiempo que, según lo ya expuesto, se desarrollan, especialmente en los sectores central y occidental, las nuevas paragénesis actualmente predominantes. Ahora bien, puesto que únicamente los granates de las zonas del cloritoide y estaurolita del sector oriental presentan zonado normal, esta segunda etapa de metamorfismo ha afectado a todo el conjunto metamórfico de la Sierra del Guadarrama, a excepción de los niveles epi-mesozonales del sector oriental».

Es importante señalar, en relación con esto último, que en el sector oriental del Guadarrama, *a diferencia de los sectores central y occidental, no se presentan los granitos calcoalcalinos tardíos,* lo cual sugiere que las etapas metamórficas tardías, de baja presión, predominantes en dominios centro-occidentales del Guadarrama, son producidas por la intrusión de grandes masas de magma calcoalcalino, dada la coincidencia espacio-temporal.

Por lo que se refiere a las rocas graníticas, son en general, tarditectónicas con relación a las fases mayores (BARD *et al.,* 1970; CAPDEVILA *et al.,* 1973; PEINADO, 1973) si bien se ha señalado la presencia de algunas facies graníticas con foliación marcada, cuyo origen se atribuye al carácter sincinemático de las intrusiones con la fase II (APARICIO *et al.,* 1975).

Desde un punto de vista químico los granitos son mayoritariamente calcoalcalinos según datos de diversos autores (IBARROLA y FUSTER, 1950, 1953; FUSTER, 1951; GARCÍA DE FIGUEROLA, 1959; NICOLLI, 1966; APARICIO *et al.,* 1975) si bien en algunos casos se señalan también pequeños plutones de granitos de dos micas o moscovíticos, de contenidos en CaO inferiores al 1 %.

Petrográficamente y con excepción de masas graníticas locales, el conjunto está constituido por rocas graníticas de tipo granodiorítico o adamellítico, en general porfiroides y a veces con silicatos alumínicos, predominantemente cordierita prismática (BARD *et al.,* 1970; CAPDEVILA *et al.,* 1973; PEINADO, 1973; APARICIO *et al.,* 1975; GONZÁLEZ-LODEIRO, com. personal, 1976; UGIDOS y PEÓN, observaciones personales en la Sierra de Gredos).

En menor proporción se presentan leucogranitos con nódulos cordieríticos (APARICIO *et al.,* 1975) de todo punto similares a los descritos por GARCÍA DE FIGUEROLA y MARÍN BENAVENTE (1959), UGIDOS (1973 a) y BABÍN (1974, 1975) en otras áreas del Macizo Hespérico (zonas de Béjar-Barco de Avila-Piedrahíta).

B.3.2.—*Complejo metamórfico de Plasencia-Béjar-Barco de Avila-Piedrahita. (Provincias de Salamanca, Cáceres y Avila).*

En las áreas de Plasencia-Béjar, el metamorfismo es netamente de baja presión y de acuerdo con las relaciones minerales-fases de deformación, predominantemente post-fase II (UGIDOS, 1974 a). No obstante, hay datos que permiten admitir que el desarrollo del metamorfismo ha alcanzado condiciones térmicas elevadas antes de la citada fase (como es la presencia abundante de sillimanita y restos de rocas migmatíticas pre-fase II), si bien no ha sido posible el hallazgo de minerales índice que pudieran hacer pensar en condiciones metamórficas de presión intermedia o similares. El intenso fenómeno de «telescoping» que ha tenido lugar tardíamente (UGIDOS, 1973 b; 1974 b) causado por la intrusión de grandes volúmenes de magmas calcoalcalinos debió de borrar posibles isogradas anteriores, permaneciendo finalmente como estables las asociaciones de baja presión.

En algunas zonas como al S de Salamanca se ha señalado la presencia de asociaciones mineralógicas con almandino y estaurolita post fase I y pre fase II (PELLITERO *et al.*, 1976) que indican probablemente condiciones de presión más elevada que en el caso anterior. Es de destacar que en relación con este dominio metamórfico se encuentran granitos leucocráticos, no porfídicos, de tamaño de grano medio a fino, que presentan granate y turmalina como minerales accesorios y se encuentran tectonizados por fases de deformación hercínicas (PELLITERO *et al.*, *op. cit.*).

También, al NO de Barco de Avila (GARCÍA DE FIGUEROLA y FRANCO, 1975), se ha señalado la presencia de restos de estaurolita desestabilizada a andalucita y biotita, que podrían representar momentos metamórficos iniciales de más alta presión que los tardíos.

Igualmente, en el área Barco de Avila-Piedrahíta, el metamorfismo es de baja presión (asociaciones de sillimanita, cordierita y feldespato potásico. BABÍN, 1974, 1975) y tardío respecto a las principales fases de deformación, si bien ha sido posible determinar asociaciones residuales de más alta presión integradas por estaurolita, granate, distena, sillimanita y feldespato potásico en relación con la primera fase de plegamiento (BABÍN, *ops. cits.*).

Las rocas graníticas predominantes en todo el conjunto considerado se corresponden con la serie calcoalcalina tardía y son abundantes las facies cordieríticas en transición con el encajante migmatítico-diatexítico (UGIDOS, 1973 b, 1974 a). Les siguen en importancia cuantitativa granitos de dos micas de diversos tipos, parcialmente enraizados con rocas de tipo diatexítico, resultantes en parte de los fenómenos metamórficos finales y de un importante desarrollo de procesos metasomáticos inducidos por los magmas calcoalcalinos (UGIDOS, 1973 b, 1974 c y d). Un último tipo de rocas graníticas son las representadas por los granitos aplíticos de nódulos (UGIDOS, 1973 a; BABÍN, 1974, 1975) equivalentes a los granitos aplíticos mosqueados de GARCÍA DE FIGUEROLA y MARÍN BENAVENTE (1959). Todas las rocas graníticas conocidas hasta el momento son tardías respecto a las principales fases de deformación al igual que las producidas en momentos de máxima intensidad metamórfica. El granito de Martinamor (Pellitero *et al.,* 1976) constituye una excepción.

En otras zonas al O y NO de Piedrahíta se han señalado rocas graníticas deformadas (García de Figuerola y Franco, 1975), consistentes por una parte en neises moscovítico-biotíticos en relación con rocas de tipo micacítico y migmatítico y por otra por neises derivados de rocas graníticas calcoalcalinas. Los primeros parecen estar en relación con el metamorfismo regional pre fase II. Los segundos son considerados como equivalentes a las granodioritas «precoces» de otros puntos del Macizo (García de Figuerola y Franco, *op. cit.*) y su relación con los procesos de deformación no ha sido resuelta (ibid.).

B.3.3.—*Macizo de Toledo*

Ha sido estudiado fundamentalmente por Aparicio (1971) y la comparación de las rocas graníticas de esta región así como de las características del metamorfismo ha sido ya realizada con la zona de Béjar-Plasencia (Ugidos y Bea, 1976). El tipo de metamorfismo es de baja presión con desarrollo de fenómenos anatécticos y de intrusión granítica tardíos respecto a las principales fases de deformación. Los granitos de anatexia guardan relaciones espaciales y petrográficas similares a las señaladas en Béjar y los granitos biotíticos son calcoalcalinos de acuerdo con los datos químicos de Nicolli (1966; contenidos de CaO entre 1,5 y 2,5 %) y tienen cordierita de forma prácticamente constante en sus facies marginales (Aparicio, *op. cit.*).

B.3.4.—*Zonas graníticas con metamorfismo de bajo grado: granitos alóctonos emplazados en niveles epizonales.*

Los principales granitos y plutones graníticos que se encuentran emplazados en niveles de bajo grado metamórfico, en áreas centro meridionales son los siguientes: batolito de Cabeza Araya, batolitos de Jalama y Cadalso-Casilla de Flores, granitos de Albalá, Montánchez y Trujillo, granito de Fontanosas, batolito de los Pedroches y granito de Albuquerque. Su análisis comparativo ha sido ya realizado por Ugidos y Bea (1976) a partir de los datos de Corretgé (1971), García de Figuerola (1954, 1966, 1972), Monteiro (1973), Saavedra y Pellitero (1973), Leutwein *et al* (1970), Bea (1975) habiéndose puesto de manifiesto que en todos ellos es factor común la presencia muy abundante de prismas cordieríticos y en menor proporción andalucita y a veces sillimanita, así como la tendencia alcalina de estos granitos que conservan, por otra parte, características afines a los granitos calcoalcalinos.

Nuevos datos debidos a SAAVEDRA *et al* (1974) muestran una vez más el carácter zonado de los granitos con cordierita, presentándose este mineral fundamentalmente en facies externas de los granitos, más alcalinas, mientras que en las facies más internas, más calcoalcalinas, es más raro o ausente. Este hecho se ha puesto de manifiesto en el extremo oriental del batolito de los Pedroches (SAAVEDRA *et al., op. cit.*).

Evidentemente, en estos casos al igual que en otros ya señalados el que se observen o no las facies centrales calcoalcalinas no cordieríticas depende de la forma y estructura de cada batolito así como del nivel de erosión.

El batolito de Albuquerque, muestra también una gran abundancia de prismas cordieríticos en la mayor parte de sus facies, variando de ser biotítico a presentar, además, cantidades variables de moscovita (GUMIEL *et al.,* 1976). Marginalmente presenta facies moscovíticas y aplíticas (ibid.).

Dado que todos estos batolitos graníticos son epizonales no resulta posible establecer su relación directa con los niveles metamórficos pero en cualquier caso es importante señalar su carácter «younger», su afinidad calcoalcalina y tendencia alcalina y especialmente su contenido en cordierita.

## C.—CONCLUSIONES: CLASIFICACION CON BASE GENETICA DE LAS ROCAS GRANITICAS DEL MACIZO HESPERICO

El análisis global del conjunto de fenómenos metamórficos y de génesis de rocas graníticas permite establecer los siguientes hechos, algunos de los cuales han sido ya puestos de manifiesto:

1. El metamorfismo hercínico es plurifacial y presenta asociaciones mineralógicas que oscilan de tipos intermedios o intermedios de baja presión a tipos de baja presión.

2. En los dominios donde, más o menos próximos, están representados los dos tipos de metamorfismos se dan las siguientes circunstancias:

a) El metamorfismo es tanto más joven cuanto menores son sus condiciones de presión.

b) En las áreas donde se presenta el metamorfismo intermedio o intermedio de baja presión se presentan, a veces, granodioritas tempranas afectadas por la fase II de deformación.

c) En las zonas donde se encuentra metamorfismo intermedio o intermedio de baja presión faltan o son muy poco extensas o carecen de control estructural regional las granodioritas tardías (batolitos circunscritos).

d) Los granitos de anatexia (leucogranitos) asociados a este proceso metamórfico son, en general, pre o sin fase II y autóctonos o parautóctonos.

e) En aquellas áreas donde los metamorfismos están muy próximos o el de baja presión solapa al intermedio de baja presión, son abundantes los granitos calcoalcalinos tardíos y frecuentes también los granitos de anatexia, enraizados, posteriores a los granitos de anatexia relacionados con el metamorfismo intermedio de baja presión. Ambos tipos graníticos, de origen anatéctico, presentan diferencias petrográficas y químicas. En el primer caso son granitos leucocráticos, de plagioclasa albítica, predominantemente moscovíticos y con raros silicatos alumínicos en su mineralogía. En el segundo las plagioclasas son más básicas, es mayor el contenido en biotita, frecuentes los silicatos alumínicos y no presentan manifestaciones importantes de fenómenos hidrotermales o neumatolíticos, frecuentes en el caso anterior.

3. En los dominios donde se presentan masivamente los granitos calcoalcalinos «younger» el metamorfismo es de baja presión y oscila de sin a post fase II, faltando las granodioritas precoces.

4. Si el metamorfismo de baja presión es interfase, se encuentran también granodioritas tempranas y granitos de anatexia de pre a sin fase II.

5. Donde el metamorfismo es post fase II predominan los granitos calcoalcalinos tardíos, no hay granitos calcoalcalinos precoces y tampoco metamorfismos intermedios de baja presión, encontrándose, en todo caso, algún mineral aislado de paragénesis correspondientes a este metamorfismo.

6. En áreas en que el metamorfismo de baja presión llega a desarrollar facies migmatítico-nebulíticas, los granitos calcoalcalinos presentan también transición gradual con estas facies y son marginalmente ricos en prismas de cordierita similares a los encontrados en las mismatitas y de todo punto diferentes a las cordieritas poiquiloblásticas típicas del metamorfismo de contacto.

7. Los granitos del Macizo Hespérico son mayoritariamente calcoalcalinos o de afinidad calcoalcalina cuando menos, presentando, en general, cordierita como componente mineralógico más o menos abundante. En consecuencia, y si realmente las cordieritas son xenocristales, con todo lo que esto implica (v. UGIDOS, 1974 a, 1976 y UGIDOS, BEA, 1976), entonces parece claro que el fenómeno anatéctico inducido por los magmas calcoalcalinos es un fenómeno generalizado. Por tanto es muy probable que estos magmas constituyan el foco térmico responsable de los metamorfismos de baja presión y próximos. Desde esta perspectiva tales granitos son la causa y no el efecto de dichos metamorfismos.

La aparente excepción del NO peninsular, donde son raros los granitos calcoalcalinos con cordierita, puede explicarse teniendo en cuenta:

a) Que las rocas migmatíticas de tipo diatexítico tampoco presentan cordierita en dichas zonas o muy raramente (v. apartados B.1.1 y B.1.3).

b) Que los granitos calcoalcalinos de estas zonas muestran evidencias de contaminación ya que presentan facies de dos micas con silicatos alumínicos.

c) En algún caso se ha señalado la existencia de cordierita en granitos de afinidad calcoalcalina (granito de Ponferrada, O. SUÁREZ, 1970).

8. En cualquier caso, las rocas graníticas calcoalcalinas, tempranas o tardías, aparecen en zonas de máxima intensidad metamórfica:

— NO peninsular, referido a granodioritas precoces: «Cependant il est important de noter, pour la suite, que leur mise en place est contemporaine du métamorphisme régional et qu'elle est quasi exclusivement limitée aux zonas fortement métamorphiques» (CAPDEVILA *et al.*, 1973).

— NO peninsular, referido a granodioritas tardías: «... la tres grande majorité de ces granodiorites et adamellites tardives apparaît là où le métamorphisme régional a été le plus important» (ibid.).

— En general: «...les lieux de production des granitoïdes hybrides sont situés sur les mêmes verticales que les sources thermiques du métamorphisme régional...», «...les granodiorites tardives apparaissant préférentiellment dans la zone où le métamorphisme a été de plus basse pression» (ibid.).

9. En muchas de las zonas donde se ha producido una migmatización cordierítica, los autores señalan también un fenómeno metasomático afectando a estas rocas (FABRIES, 1963; TORRE DE ASSUNÇAO, 1962; UGIDOS, 1973 b, 1974 c).

10. El paralelismo entre los datos conocidos y los aspectos considerados en el apartado A, es suficientemente acusado como para que la hipótesis propuesta pueda ser considerada como válida, al menos para el grado de conocimientos actuales. En cualquier caso, las relaciones espacio-temporales señaladas entre metamorfismos y rocas graníticas son datos que ninguna hipótesis puede obviar.

Los aspectos considerados hasta el momento tienen carácter general, es decir, válidos para la mayor parte de las zonas consideradas. Otros datos de carácter más restringido apoyan también (o son compatibles) con el planteamiento global de las relaciones causa-efecto entre los granitos y metamorfismos. Así mismo, algunas diferencias entre unos dominios y otros pueden explicarse en función de tal planteamiento.

En un trabajo anterior, de alcance más limitado, UGIDOS y BEA (1976) señalan las posibles líneas genéticas de los granitos del Macizo Hespérico para áreas centro-peninsulares, con base en datos químicos (BEA, 1975) y en modelos petrogenéticos establecidos anteriormente (UGIDOS, 1973 b, 1974 a y c; BEA, 1975, 1976).

Los autores admiten la existencia de las siguientes líneas petrogenéticas:

— Serie calcoalcalina, de origen profundo, tal como ha sido admitida en trabajos anteriores (CAPDEVILA *et al.*, 1973) de acuerdo con las relaciones bajas de $^{87}Sr/^{86}Sr$ (PRIEM, 1970) y relaciones de elementos menores como Ba, Sr, Rb y otros (BEA, 1975, 1976).

— Serie calcoalcalina contaminada, representado por granitos biotíticos, a veces con moscovita, de afinidad calcoalcalina y con prismas cordieríticos cuyo origen exterior al granito revela un acusado proceso de contaminación. Estos granitos son, en muchos casos, petrográficamente similares a los anteriores (exceptuando la presencia de aluminosilicatos) pero químicamente tienden hacia términos de la serie alcalina de origen mesocortical (CORRETGÉ, 1971; UGIDOS, 1973 b, 1974 a; BEA, 1975).

— Serie alcalina inducida, anatexitas y diatexitas, granitos mixtos. De acuerdo con la interpretación de UGIDOS y BEA (1976), en estas series quedan agrupados tanto los granitos que no pertenecen a las dos series anteriores debido a que en su génesis participa mayoritariamente material mesocortical (anatexitas y diatexitas), como los granitos en los que la participación de material meso y basicortical es cuantitativamente similar (granitos mixtos).

A partir de nuevos datos (BEA, 1976; BEA y UGIDOS, 1976) y de consideraciones sobre los ya conocidos, se puede realizar una interpretación más precisa sobre la génesis de estos tipos graníticos si bien y en tanto no se disponga de datos de otras regiones tiene validez sólo para la zona centro-peninsular. No obstante y en la medida en que este modelo local encaja en el planteamiento general cabe pensar, en principio, que sea válido también para otras regiones con las que presenta aspectos coincidentes.

En la serie alcalina desarrollada básicamente a partir de materiales mesocorticales en estadios metamórficos de alto grado pueden considerarse (en las zonas de los Arribes del Duero y Plasencia-Barco de Avila) dos líneas de génesis diferentes aunque en ambos casos los autores admiten la intervención de fluidos o componentes derivados de las masas magmáticas calcoalcalinas sobre los productos metamórfico-anatécticos.

Una primera línea genética se desarrolla durante etapas ligadas a las condiciones de metamorfismo inicial, intermedio o intermedio de baja presión. Los granitos de anatexia producidos en estas condiciones se caracterizan por presentar dos micas, albita, son leucocráticos y de pre a sin-cinemáticos con la fase II (F. MARTÍNEZ, 1974; zona de los Arribes del Duero) y tienen carácter autóctono o subautóctono.

Datos químicos (BEA, 1975; BEA y UGIDOS, 1976) revelan que estos granitos presentan el mismo tipo de «anomalías» de elementos menores, que los granitos calcoalcalinos «younger» y tanto más acusadas cuanto mayor es el grado de desenraizamiento de los primeros. Por esta razón se admite que fluidos provinientes del magma calcoalcalino situado en niveles inferiores han intervenido en el proceso anatéctico. La existencia de dicho magma viene apoyada por el hecho de que posteriormente a la formación de los granitos alcalinos se intruyen diques de pórfidos graníticos calcoalcalinos equiparables a los granitos calcoalcalinos «younger» (F. MARTÍNEZ, *op. cit.*).

De acuerdo con las características de estos granitos y con el contexto metamórfico al que están asociados, así como su posición respecto a la fase II, son equiparables a los leucogranitos del NO. Si estos últimos han sido originados con aporte de fluidos derivados del magma calcoalcalino no puede afirmarse, por el momento, por falta de datos. No obstante las coincidencias con los granitos de la zona de los Arribes del Duero son muy acusadas y cabe la propuesta de esta línea genética como hipótesis inicial de trabajo.

Otra línea es la representada por los granitos de origen anatéctico del área de Plasencia-Barco de Avila, donde la secuencia de acontecimientos es más compleja que en el caso anterior. Deben señalarse los siguientes puntos:

a) Los granitos de Plasencia están parcialmente enraizados con los granitos heterogéneos de anatexia producidos en una etapa metamórfica tardía, de baja presión, en la que se desarrolla un importante proceso mestasomático sobre rocas de tipo migmatítico-nebulítico con cordierita muy abundante (UGIDOS, 1973 b, 1974 c).

b) Dichas rocas migmatíticas son resultado, a su vez, de un fenómeno de «telescoping» y superposición de condiciones metamórficas (UGIDOS, 1974 b) que sobrepasan en el tiempo a la fase II, sobre rocas ya metamorfizadas en facies anfibolítica (presencia de sillimanita pre fase II), es decir, que la migmatización final se ha realizado sobre rocas en las que tuvo lugar antes un proceso metamórfico de alto grado. Cabe pensar, por tanto, que al desarrollarse el proceso migmatítico final tenga lugar afectando a rocas en las cuales se ha producido en alguna medida un estadio de eliminación de fluidos y elementos disueltos de tal manera que estas rocas se encuentran deshidratadas y desgranitizadas al producirse dicha etapa final, en la que resultan migmatitas de tipo grano-cuarzodiorítico muy cordieríticas. La aparición de la cordierita, en un proceso similar al de kinzigitización, ha sido posible en parte por la ausencia de fluidos potásicos y exceso de alúmina, constituyendo un residuo cristalino en el proceso anatéctico (UGIDOS, 1976).

c) Posteriormente al estadio anatéctico en el que se producen las citadas migmatitas cordieríticas tiene lugar un intenso fenómeno metasomático que favorece la continuación de fusiones anatécticas, cuantitativamente más importantes, a consecuencia de las cuales se desarrolla el magma a partir del que se forma el granito de Plasencia (UGIDOS, 1974 c, d).

De acuerdo con estos resultados, tanto en el caso de los Arribes del Duero como en el caso de Plasencia han intervenido fluidos derivados de las masas magmáticas calcoalcalinas situadas en niveles inferiores.

La diferencia en cuanto a productos resultantes en uno y otro caso es debida a que en el primero el aporte de dichos fluidos tiene lugar sobre rocas que no han sido previamente migmatizadas, es decir, que coincide la anatexia con el aumento de las condiciones de $P_{H_2O}$ y no hay fenómenos anatécticos posteriores.

En el caso de Plasencia, por el contrario, los procesos metamórficos finales se desarrollan sobre rocas que han sido afectadas, en estadios pre fase II, por condiciones metamórficas intensas con producción de migmatitas y posibles leucogranitos. Todo el complejo resultante es sometido posteriormente (post fase II) a condiciones térmicas elevadas, que producen la migmatización cordierítica indicada, bajo contenidos deficitarios de $H_2O$. Posteriormente, el metasomatismo señalado favorece el desarrollo de nuevos productos anatécticos y nuevos tipos graníticos.

Los fenómenos anatécticos no son, por tanto, equivalentes en una zona y otra, reflejándose esto tanto en las características petrográficas de ambos conjuntos, como en las químicas (BEA y UGIDOS *in litt.*; UGIDOS y BEA *in litt.*).

Al igual que los leucogranitos de los Arribes del Duero son equiparables a los leucogranitos del NO, los granitos de dos micas de Plasencia tienen también equivalentes en otras zonas del Macizo Hespérico: petrográfica y químicamente son similares a los granitos de los grupos II y III de FLOOR *et al.* (1970) y OEN (1970), de las áreas del N de Portugal coincidiendo también en su carácter alóctono y posición respecto a la fase II.

El problema que surge en estas zonas es que al estar dichos granitos emplazados en niveles no anatécticos es difícil establecer si se han formado de acuerdo con la segunda línea genética, que se admite para los de Plasencia, o bien si proceden de la evolución de los granitos calcoalcalinos contaminados. No hay datos, por el momento, para establecer la separación y cada caso necesita ser considerado en forma independiente. Por esta razón se mantiene la denominación de granitos mixtos para los representados por estos tipos.

De acuerdo con el planteamiento de la segunda línea genética alcalina, pueden presentarse fenómenos de removilización de granitos originados durante la primera en zonas donde el magma calcoalcalino haya ascendido a niveles más altos y se haya producido la migmatización asociada al metamorfismo tardío. Por el momento los autores no tienen datos acerca de si se ha dado este fenómeno en alguna zona.

Las dos líneas genéticas alcalinas constituyen, si se comprueban para otras zonas, dos datos importantes en apoyo de la hipótesis general.

## BIBLIOGRAFIA


ALDAYA, F.; ARRIBAS, A.; GONZÁLEZ-LODEIRO, F.; IGLESIAS, M.; MARTÍNEZ-CATALÁN, J. R. y MARTÍNEZ-GARCÍA, E. (1973): *Presencia de una nueva fase de deformación probablemente prehercínica en el noroeste y centro de la Península Ibérica.* Stvd. Geol., 6, 29-48.

ANTHONIOZ, P. M. y FERRAGNE, A. (1967): *Sur la presence d'orthogneiss en Galice moyenne (Nord-Ouest de l'Espagne).* C. R. Acad. Sc. París, 265, 848-851.

APARICIO, A. (1971): *Estudio geológico del Macizo cristalino de Toledo.* Est. Geol., 27, 369-414.

APARICIO, A.; BARRERA, J. L.; CARABALLO, J. M.; PEINADO, M. y TINAO, J. M. (1975): *Los materiales graníticos hercínicos del Sistema Central español.* Mem. Inst. Geol. Min. Esp., 88.

ATHERTON, M. P.; ATKIN, B. P. y NAGGAR, M. H. (1974): *Kyanite in the Hercynian metamorphic rocks of the Oporto-Viseu belt. North Portugal.* Geol, en Mijn., 53 (4), 189-192.

BABIN, R. B. (1974): *Materiales metamórficos y plutónicos presentes en la región de Piedrahita-Barco de Avila-Béjar.* Stvd. Geol., 7, 41-61.

— (1975): *Estudio estructural de los afloramientos metamórficos de la región de Piedrahita-Barco de Avila-Béjar (Sierra de Gredos).* Tesis doctoral. Univ. Madrid.

BARD, J. P. (1969): *Le métamorphisme régional progressif de la Sierra d'Aracena (Andalusie occidentale).* Tesis doctoral. Univ. Montpellier.

— (1971): *Sur l'alternance des zones métamorphiques et granitiques dans le segment hercynien sud-ibérique; comparaison de la variabilité des caractères géotectoniques de ces zones avec les orogènes "orthotectoniques".* Bol. Geol. Min. Esp., 82 (3/4), 324-345.

BARD, J. P. y FABRIES, J. (1970): *Apercu pétrographique et structural sur les granitoïdes de la Sierra Morena accidentale (Espagne).* Bol. Geol. Min. Esp., 81-82-83, 226-241.

BARD, J. P.; CAPDEVILA, R. y MATTE, Ph. (1970): *Les grands traits stratigraphiques, tectoniques, métamorphiques et plutoniques des Sierras de Gredos et de Guadarrama (Espagne centrale).* C. R. Acad. Sc. París, 270, 2630-2633.

— (1971 a): *Sobre el tipo de metamorfismo regional progresivo hercínico en el Guadarrama oriental (Sistema Central español).* Act. Geol. Hisp., 6 (2), 46-48.

— (1971 b): *La structure de la Chaine Hercynienne de la Meseta Ibérique: comparaison avec les segments voisins.* Pub. Inst. Franc. Petrol., 22.

BAILEY, D. K. (1970): *Volatile flux, heat focusing and the generation of magma.* In: "*Mechanism of igneous intrusion*". Liverpool. G. Newall y N. Rast, Ed., 177-186.

BEA, F. (1975): *Caracterización geoquímica y esquema petrogenético de los granitoides hercínicos del área Salamanca-Cáceres.* Tesis doctoral. Univ. Salamanca.

— (1976): *Anomalías geoquímicas de los granitoides calcoalcalinos hercínicos del área Salamanca-Cáceres-Zamora. Implicaciones petrogenéticas.* Stvd. Geol., 11, 25-73.

BEA, F. y UGIDOS, J. M. (1976): *Anatexia inducida: petrogénesis de los granitos hespéricos de tendencia alcalina. Parte I: Leucogranitos del área O de Zamora y Salamanca.* Stvd. Geol., 11, 9-24.

— (in litt.): *Anatexia inducida: petrogénesis de los granitos hespéricos de tendencia alcalina. Parte III: El granito de Plasencia.*

BROWN, G. C. y FYFE, W. S. (1970): *The production of granitic melts during ultrametamorphism.* Contr. Min. Petr., 28, 310-318.

— (1972): *The transition from metamorphism to melting status of the granulite eclogite facies,* 24th. Intern. Geol. Cong., 2, 27-35.

CAPDEVILA, R. (1968): *Les types de metamorphisme "intermédiaires de basse pression" dans le segment hercynien de Galice Nord Orientale (Espagne).* C. R. Acad. Sc. París, 266, 1924-1927.

— (1969): *Le métamorphisme régional progressif et les granites dans le segment hercynien de Galice Nord Orientale (NW de l'Espagne). Tesis doctoral.* Univ. Montpellier.

CAPDEVILA, R. y FLOOR, P. (1970): *Les differents tupes de granites hercyniens et leur distribution dans le nord ouest de l'Espagne.* Bol. Geol. Min., 81 (2/3), 215-225.

CAPDEVILA, R.; CORRETGÉ, L. G. y FLOOR, P. (1973): *Les granitoïdes varisques de la Meseta Ibérique.* Bull. Soc. Geol. France, 15, 209-228.

CARVALHOSA, A. B. (1970): *Roches granitiques de l'Alentejo (Portugal).* Bol. Geol. Min., 81 (2/3), 211-214.

— (1971): *Estudo geologico-petrografico da regiao de Viana do Alentejo-Alvito.* Bol. Soc. Geol. Portugal, 18, 7-56.

CORRETGÉ, L. G. (1971): *Estudio petrológico del batolito de Cabeza de Araya (Cáceres).* Tesis doctoral. Univ. Salamanca.

CURRIE, K. L. (1971): *The reaction 3 Cordierite = 2 Garnet + 4 Sillimanite + Quartz, as a Geological Thermometer in the Opinicon Lake Region, Ontario.* Contr. Min. Petr. 33, 215-226.

CHACÓN, J. (1974): *Metamorfismo dinámico en la banda Badajoz-Córdoba: Los gneises milonitas de Higuera de Llerena (provincia de Badajoz).* Bol. Geol. Min., 85 (6), 700-712.

CHACÓN, J.; DELGADO-QUESADA, M. y GARROTE, A. (1974): *Sobre la existencia de dos diferentes dominios de metamorfismo regional en la banda Elvas-Badajoz-Córdoba (Macizo Hespérico Meridional).* Bol. Geol. Min., 85 (6), 713-717.

CHAMÓN, C. y FERNÁNDEZ TOMÁS, J. (1974): *Memoria explicativa de la Hoja Geológica n.º 264 (Ginzo de Limia), escala 1:50.000.* Inst. Geol. Min. España.

CHAMÓN, C. y FERNÁNDEZ POMPA, F. (1974): *Memoria explicativa de la Hoja Geológica n.º 225 (Ribadavia), escala 1:50.000.* Inst. Geol. Min. España.

CHINNER, G. A. (1966): *The distribution of temperature and pressure during Dalradian metamorphism.* Geol. Soc. London Quart. J., 486, 159-186.

DALLMEYER, R. D. (1972): *Compositional controls on cordierite bearing assemblages in high-grade regional metamorphism.* Int. Geol. Cong. Montreal, 2, 52-63.

DEN TEX, E. y FLOOR, P. (1971): *A synopsis of the geology of Western Galicia.* In: *Histoire structural du golfe de Gascogne,* París. Ed. Technip.

FABRIES, J. (1963): *Les formations cristallines et métamorphiques du Nord Est de la province de Séville (Espagne).* Tesis doctoral. Univ. Nancy.

FERNÁNDEZ POMPA, F. y BOQUERA, J. (1974): *Memoria explicativa de la Hoja Geológica n.º 302 (Baltar), escala 1:50.000.* Inst. Geol. Min. España.

FERNÁNDEZ TOMÁS, J. y PILES MATEO, E. (1974): *Memoria explicativa de la Hoja Geológica n.º 301 (Lovios), escala 1:50.000.* Inst. Geol. Min. España.

FERRAGNE, A. (1966 a): *Sur les conditions du métamorphisme et de la migmatisation de la série de Celanova (Province d'Orense, Espagne).* C. R. Acad. Sc. París, 263, 480-482.

— (1966 b): *Aperçu sur les formations granitiques de la province d'Orense.* Act. Soc. Lin. Bordeaux, 103, 3-7.

— (1968): *Sur léxistence d'un socle précambrien dans la région de Viana del Bollo (Galice Méridionale,Nord-Ouest de l'Espagne).* C. R. Acad. Sc. París, 266, 2376-2379.

FLOOR, P. (1966): *Petrology of an aegirine-riebeckite gneiss-bearing part of the Hesperian Massif: The Galiñeiro and surrounding areas, Vigo, Spain.* Tesis doctoral. Univ. Leiden.

FLOOR, P.; KISCH, H. J. y OEN ING SOEN (1970): *Essai de corrélation de quelques granites hercyniennes de la Galice et du Nord de Portugal.* Bol. Geol. Min., 81 (2/3), 242-244.

FUSTER, J. M. (1951): *Rocas de España Central. Granitos y lamprófidos del puerto de Navacerrada (Segovia).* III. Estud. Geol., 14, 431-442.

FUSTER, J. M .y GARCÍA CACHO, L. (1970): *Sobre el metamorfismo regional progresivo en el Guadarrama oriental (Sistema Central Español).* Estud. Geol., 26, 327-329.

— (1971): *Discusión sobre el metamorfismo regional del Guadarrama Oriental (Sistema Central Español).* Acta Geol. Hisp., 5, 123-130.

FUSTER, J. M.; APARICIO, A.; CASQUET, C.; GARCÍA CACHO, L.; MORA, A. y PEINADO, M. (1974): *Interacciones entre los metamorfismos plurifaciales y polifásicos del Sistema Central Español.* Bol. Geol. Min. España, 85, 83-88.

FYFE, W. S. (1970): *Some thoughts on granitic magmas.* In: "*Mechanism of Igneous Intrusion*". Liverpool. Newall and Rast Edit., 201-216.

— (1973): *The generation of batholiths. Tectonophysics,* 17, 273-283.

GARCÍA CACHO, L. (1973): *Evolución temporal del metamorfismo y procesos de blastesis sucesiva en el sector oriental del Sistema Central Español.* Tesis doctoral. Univ. Madrid.

GARCÍA DE FIGUEROLA, L. C. (1954): *Contacto entre el granito y facies de los esquistos verdes en Perosín (Peñaparda, Salamanca).* Not. y Com. Inst. Geol. Min., 33, 2-31.

— (1959): *Los granitos del Centro-Oeste de España.* 21 st. Inter. Geol. Congr., 14, 131-137.

— (1966): *Datos petrológicos de la Sierra de Gata.* Rev. Fac. Cienc. Oviedo, 7, 53-79.

— (1972): *Memoria explicativa de la Hoja Geológica n.º 573 (Gata), escala 1:50.000.* Inst. Geol. Min. España.

GARCÍA DE FIGUEROLA, L. C. y MARÍN BENAVENTE, C. (1959): *Tres granitos diferentes al E de Béjar.* Estud. Geol., 15, 181-187.

García de Figuerola, L. C. y Franco, M. P. (1975): *Las formaciones infraordovicias y el borde de las granodioritas al Este de Guijuelo (Salamanca).* Estud. Geol., 31, 487-500.

González-Lodeiro, F.; Martínez, J. R. e Iglesias, M. (1974 a): *Memoria explicativa de la Hoja Geológica n.º 155 (Chantada), escala 1:50.000.* Inst. Geol. Min. España.

— (1974 b): *Memoria explicativa de la Hoja Geológica n.º 188 (Nogueira de Ramuin), escala 1:50.000.* Inst. Geol. Min. España.

— (1974 c): *Memoria explicativa de la Hoja Geológica n.º 154 (Lalin), escala 1:50.000.* Inst. Geol. Min. España.

— (1974 d): *Memoria explicativa de la Hoja Geológica n.º 187 (Orense), escala 1:50.000.* Inst. Geol. Min. España.

Green, T. H. (1972): *Crystallyzation of calc-alcaline andesite under controlled high-pressure hydrous conditions.* Contr. Min. Petr., 34, 150-167.

Gumiel, P.; Arribas, A. y Saavedra, J. (1975): *Geología y metalogenia del yacimiento de estibina-scheelita de "San Antonio". Albuquerque (Badajoz).* Stv. Geol., 10, 61-96.

Hilgen, J. D. (1971): *The Lalin unit: a new structural element in the Hercynian orogen of Galicia (NW Spain).* Koninkl. Neder. Akad. Wetensch., 74 (4), 1-10.

Huang, W. T. (1962): *Petrology.* New York. McGraw-Hill Inc., 480 pp.

Ibarrola, E. y Fuster, J. M. (1950): *Granitos de España Central. I. Zarzalejo (Madrid).* Estud. Geol., 11, 173-189.

Jaeger, J. C. (1957): *The temperature in the neighborhood of a intrusive sheet.* Am. J. Sc., 255, 306-318.

— (1959): *Temperature outside a cooling intrusive sheet.* Am. J. Sc., 257, 44-54.

Khitarov, N. I. (1967): *Properties of the Deep-Seated zone of the Earth's Crust according to certain experimental data.* In: *"Chemistry of the Earth Crust"*, 2. Jerusalem. Vinogradov, A. P., Ed.

Leutwein, F.; Saupé, F.; Sonet, F. y Couyx, E. (1970): *Première mesure géocronologique en Sierra Morena. La granodiorite de Fontanosas (Province de Ciudad Real, Espagne).* Geol. en Mijnbouw, 49, 297-304.

López Ruiz, J.; Aparicio, A. y García Cacho, L. (1975): *El metamorfismo de la Sierra de Guadarrama. Sistema Central Español.* Mem. Inst. Geol. Min. España, 86.

Maaloe, S. y Wyllie, P. J. (1975): *Water content of a granite magma deduced from the sequence of crystallization determined experimentally with water-undersaturated conditions.* Contr. Min. Petr., 52, 175-191.

Martínez, E. (1973): *Deformación y metamorfismo en la zona de Sanabria (NW de España).* Stvd. Geol., 5, 7-106.

Martínez, E. y Corretgé, L. G. (1970): *Nota sobre la serie metamórfica de Porto Villavieja (provincias de Zamora y Orense).* Stvd. Geol., 1, 47-58.

Martínez, F. (1974): *Estudio del área metamórfica y granítica de los Arribes del Duero (provincias de Salamanca y Zamora).* Tesis doctoral. Univ. Salamanca.

Meerbeke, G. L. E. van; Hilgen, J. D. y Floor, P. (1973): *Preliminary results of the investigation of the Central Galician schist area (prov. of Orense and Pontevedra, NW Spain).* Leidse Geol. Meded., 49, 33-37.

Miyashiro, A. (1961): *Evolution of metamorphic belts.* J. Petr., 2, 277-311.

— (1967): *Orogeny, regional metamorphism, and magmatism in the Japanese Islands.* Medd. Dan. Geol. Foren., 17, 390-446.

— (1971): *Pressure and temperature conditions and tectonic significance of regional and ocean-floor metamorphism.* Tectonophysics, 13 (1/4), 141-159.

— (1972): *Paired and unpaired metamorphic belts.* Tectonophysics, 17 (3), 241-254.

MONTEIRO, H. (1973): *Caracteres metalogenéticos de los yacimientos intragraníticos españoles de uranio.* Tesis doctoral. Univ. Salamanca.

MUÑOZ, M. y VEGAS, R. (1974): *Paraneises y ortoneises de la banda metamórfica Badajoz-Córdoba.* Bol. Geol. Min. España, 85, 450-463.

NICOLLI, H. B. (1966): *Estudio de la geoquímica del uranio en rocas graníticas españolas.* Tesis doctoral. Univ. Salamanca.

OEN ING SOEN (1970): *Granite intrusion, folding and metamorphism in Central Northern Portugal.* Bol. Geol. Min. España, 81 (2/3), 271-298.

PALACIOS, T. (1974): *Contribução para o conhecimento petrográfico dos granitos da Serra do Geres.* Bol. Geol. Min. España, 85, 582-594.

PEINADO, M. (1970): *Evolución metamórfica en el macizo El Escorial-Villa del Prado (Sistema Central Español).* Tesis doctoral. Univ. Madrid.

PELLITERO, E.; MARTÍNEZ, J.; ARRIBAS, A. y SAAVEDRA, A. (1976): *Geología de áreas mineralizadas en la antiforma de Vecinos-Martinamor (Salamanca. España).* Tecniterrae, 10, 20-27.

PIWINSKII, A. J. (1975): *Experimental studies of granitoid rocks near the San Andreas fault zone in the Coast Range and Mojave desert, California.* Tectonophysics, 35, 217-231.

PIWINSKII, A. J. y WYLLIE, P. J. (1968): *Experimental studies of igneous rock series: a zoned pluton in the Wallowa Batholith, Oregon.* J. Geol., 76, 205-234.

— (1970): *Experimental studies of igneous series: "Felsic body suite" from the Needle Point pluton Wallowa batholith, Oregon.* J. Geol., 78, 52-76.

PORTUGAL, M. R. (1965): *Geologia e petrologia da região de Rebordelo Vinhais.* Tesis doctoral. Univ. Coimbra.

— (1967): *Comentario sobre o metamorphismo no complexo de Vinhais (NE Portugal).* Memorias e Noticias, 63, 3-18. Coimbra.

PRESNALL, D. C. y BATEMAN, P. C. (1973): *Fusion relations in the System $NaAlSi_3O_8$-$CaAl_2Si_2O_8$ - $KAlSi_3O_8$ - $SiO_2$ - $H_2O$ and generation of granitic magmas in the Sierra Nevada Batholith.* Bull. Geol. Soc. Am., 84, 3181-3202.

PRIEM, H. N. D.; BOELRIJK, N. A. I. M.; VERSCHURE, R. H. y HEBEDA, E. M. (1970): *Dating events of acid plutonism through the Paleozoic of the Western Iberian Peninsula.* Eclog. Geo. Helvet., 63, 255-274.

RAST, N. (1970): *The initiation, ascent and emplacement of magmas.* In: "*Mechanism of Igneous Intrusion*". Liverpool. Newall y Rast, Ed., 339-360.

RICHARDSON, S. W.; GILBERT, M. C. y BELL, P. M. (1969): *Experimental determination of Kyanite-Andalousite and Andalousite-Sillimanite equilibria: the alumine silicate triple point.* Am. J. Sc., 267, 259-272.

RINGWOOD, A. E. (1975): *Composition and petrology of the Earth's Mantle.* New York. McGraw-Hill, Inc., 618 pp.

RINGWOOD, A. E. y GREEN, D. H. (1966): *Petrological nature of the stable continental crust.* In: "*The Earth beneath the Continents*". Washington. Steinhart, J. S., Smith, T. J., Ed. Geophys. Monograph, 10.

ROBERTSON, J. K. y WYLLIE, P. J. (1971): *Rock water systems with special reference to the water-deficient region.* Am. J. Sc., 266, 513-541.

ROCHA DO MACEDO, J. (1974): *Contribução para o conhecimento petroquímico das rochas graníticas da Area de Braga.* Bol. Geol. Min. España, 85 (6), 725-738.

SAAVEDRA, J. y PELLITERO, E. (1973): *Estudio geoquímico de rocas ígneas del norte de la provincia de Cáceres.* Stvd. Geol., 6, 49-63.

SAAVEDRA, J.; GARCÍA SÁNCHEZ, A.; BERZAS, J. J.; HERRERO, J. y RODRÍGUEZ, S. (1974): *Caracterización geoquímica de los granitos de Montánchez (Cáceres) y el extremo oriental del batolito de los Pedroches (Córdoba).* Bol. R. Soc. Española Hist. Nat. (Geol.), 72 (1/4), 173-190.

SCHERMERHORN, L. J. G. (1956): *Igneous, metamorphic and ore geology of the Castro Daire-São Pedro do Sul-Sátao region (Northern Portugal).* Com. Serv. Geol. Portugal, 37, 5-617.

SUÁREZ, O. (1970): *Estudio petrológico de los afloramientos plutónicos de la zona occidental Astur-Leonesa (NW de España).* Tesis doctoral. Univ. Salamanca.

TEIXEIRA, C. (1959): *Noticia explicativa da folha 18-B (Almeida), escala 1:50.000.* Serv. Geol. Portugal.

TORRE DE ASSUNÇÃO, C. F. (1962): *Fenómenos metasomáticos em granitos do Norte de Portugal.* Est. cientif. ofrecidos em homenagem ao Prof. Doutor J. Carrington da Costa, 225-242.

TURNER, F. J. (1968): *Metamorphic petrology.* New York. McGraw-Hill, Inc., 403 pp.

UGIDOS, J. M. (1973 a): *Los granitos aplíticos de nódulos en el área Béjar-Barco de Avila (Salamanca-Avila).* Stvd. Geol., 6, 85-93.

— (1973 b): *Estudio petrológico del área Béjar-Plasencia.* Tesis doctoral. Univ. Salamanca.

— (1974 a): *Los granitos biotíticos ± cordierita de Béjar y áreas adyacentes.* Bol. Geol. Min. España, 85, 66-74.

— (1974 b): *Características del metamorfismo en el área Béjar-Plasencia.* Bol. Geol. Min. España, 85 (6), 73-81.

— (1974 c): *Metasomatismo y granitización en el complejo metamórfico de Béjar-Barco de Avila-Plasencia. Petrogénesis de los granitos de tendencia alcalina.* Stvd. Geol., 8, 27-46.

— (1974 d): *Granitos de dos micas y moscovíticos en la región de Barco de Avila-plasencia y áreas adyacentes.* Stvd. Geol., 7, 63-86.

— (1976): *Significado petrológico de cordierita, sillimanita y andalucita en migmatitas y granitos de Plasencia-Béjar y áreas adyacentes (Salamanca-Cáceres).* Stvd. Geol., 10, 31-43.

UGIDOS, J. M. y BEA, F. (1976): *Análisis comparativo de los granitos del área Béjar-Plasencia con otros granitos "younger" centro peninsulares: precisiones sobre la serie mixta.* Stvd. Geol., 10, 45-59.

— (in litt.): *Anatexia inducida: petrogénesis de los granitos hespéricos de tendencia alcalina. Parte II: Petrología y geoquímica de los mobilizados cordieríticos.*

WESTERWELD, J. (1956): *Roches éruptives, gîtes métallifères et métamorphisme entre Mangualde et le Douro dans le nord du Portugal.* Geol. en Mijnbouw, 18, 94-105.

WINKLER, H. G. F. (1967): *Petrogenesis of metamorphic rocks.* Second Ed. New York. Springer-Verlag, 237 pp.

— (1974): *Petrogenesis of metamorphic rocks.* Third. Ed. New York. Springer-Verlag, 320 pp.

WOENDSDREGT, C. F. (1966): *Informe preliminar sobre los estudios de la petrografía del extremo occidental de Galicia.* Leids. Geol. Meded., 36, 261-178.

WYLLIE, P. J. (1971): *The Dynamic Earth.* New York. John Wiley and Sons Ed., 416 pp.

WYLLIE, P. J.; WUU-LIANG HUANG; STERN, C. R. y MAALOE, S. (1976): *Granitic magmas: possible and impossible sources, water contents and crystallization sequences*. Can. J. Earth. Sc., 13, 8, 1007-1019.

ZUUREN, A. VAN (1969): *Structural petrology of an area near Santiago de Compostela (NW Spain)*. Leids. Geol. Meded., 45, 1-71.

ZWART, H. J. (1962): *On the determination of polymetamorphic mineral associations and its application to the Bosost area (Central Pyrenees)*. Geol. Rundschau, 52, 38-65.

— (1967): *The duality of orogenic belts*. Geol. en Mijnbouw, 46, 283-309.

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# PROGRAMA FORTRAN PARA LA OBTENCION DE PARAMETROS GEOQUIMICOS A PARTIR DE ANALISIS QUIMICOS DE ROCAS

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En los últimos años, el empleo de métodos instrumentales en el análisis de los elementos mayores de las rocas ígneas y metamórficas, ha tenido como consecuencia la necesidad de automatizar al máximo los procedimientos de cálculos petroquímicos, labor lenta y tediosa cuando se disponen de grandes series de análisis.

Afortunadamente, la utilización de ordenadores nos permiten obtener con comodidad todo tipo de datos.

Con este fin hemos realizado un programa FORTRAN, utilizando siempre sentencias procesables en cualquier tipo de ordenador con la excepción de algunas especificaciones características del lenguaje FORTRAN V, por lo tanto, aunque el programa haya sido escrito para su utilización en el sistema UNIVAC 1108 puede ser adaptado muy fácilmente a otros sistemas de procesamiento.

El programa USLPET realizado, es únicamente paramétrico y tiene la particularidad de procesar indiscriminadamente todos los cálculos, dejando a criterio del petrólogo la conveniencia o inconveniencia de utilizar algunos de los datos del OUTPUT para cada análisis o grupo de análisis en concreto.

Los parámetros se obtienen, unas veces, a partir de los óxidos y otras, a partir de las proporciones moleculares y atómicas, cuya obtención está ultimada en el programa USLPET.

1. Parámetros de V. GOTTINI (1969): De aplicación en series volcánicas. Estos parámetros intentan diferenciar los magmas de quimismo cortical, de los magmas procedentes del manto superior. Los parámetros de Gottini obtenidos a partir del programa son:

$$\mathrm{LOGT} = \log \frac{Al_2O_3 - Na_2O}{TiO_2}$$

$$\mathrm{LOGR} = \log \frac{(K_2O + Na_2O)^2}{SiO_2 - 43}$$ (logaritmo del parámetro $\sigma$ de RITTMAN 1957)

2. Parámetro X de LARSEN (1938).

$$X = \frac{SiO_2}{3} + K_2O - FeO - MgO - CaO$$

Este parámetro de gran poder dispersivo nos permite comprobar las variaciones en el quimismo de series poco diferenciadas, utilizando el valor X como abcisa y como ordenadas el porcentaje de cada uno de los óxidos.

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3. Parámetros de NIGGLI (BURRI, 1964), ampliamente utilizados para comparar con comodidad el quimismo de las rocas tanto ígneas como metamórficas.

4. Número de cuarzo %: Se obtienen a partir de los parámetros de Niggli y es una expresión de saturación de la roca con respecto al $SiO_2$. En el programa viene expresado como QZ:

$QZ > O$, existencia de $SiO_2$ como óxido (cuarzo).

$QZ = O$, paragénesis sin cuarzo pero con fases ricas en sílice (piroxenos, feldespatos).

$QZ < O$, presencia de silicatos pobre en sílice (melilitas, olivino, feldespatoides).

5. Características cifradas de ZAVARITZKY (1950): de gran utilidad en el estudio de series volcánicas y subvolcánicas. En el programa los parámetros se expresan de la forma habitual: A, B, C y C (—).

6. Parámetros de H. DE LA ROCHE (1964) aplicables a granitoides: Estos parámetros son hoy los más altamente dispersivos y por lo tanto puramente adecuados para el estudio de series poco evolucionadas tal como acontece en la mayoría de los batolitos graníticos.

En el programa USLPET, hemos utilizado los variables ROGAL, ROGMAF y ROGSIL, equivalentes a los siguientes valores de H. de la Roche.

$$\begin{aligned} \text{ROGAL} &= (K + Ca) - Na \\ \text{ROGMAF} &= Fe + Mg + Ti \\ \text{ROGSIL} &= Si/3 - (Na + K + 2Ca/3) \end{aligned}$$

7. Control de contenido en cuarzo en los granitos: utilizando los sistemas de H. DE LA ROCHE (1964). Estos parámetros nos sirven para comprobar si existe una buena correspondencia entre el contenido modal medio y el análisis químico. Se trata de un cálculo normativo simple.

$$\text{CUAR} = \text{\% en peso de cuarzo} = \frac{Si/3 - (K + Na + 2Ca/3)}{5.55}$$

8. Control de contenido en biotita en los granitos: El cálculo es sumamente útil en los granitos biotíticos o en los de dos micas.

$$\text{BIOT} = \text{\% en peso de biotita} = \frac{Fe + Mg + Ti}{5.55}$$

9. Parámetros (Al/3 — Na) y (Al/3 — K) de H. DE LA ROCHE (1968): Estos parámetros permiten la separación de los dominios volcánicos y sedimentarios y sirven como guía de estudio de formación plutónica y metamórfica. En el programa vienen expresados por la variable ALSOD y ALPOT.

$$\text{ALSOD} = \frac{Al}{3} - Na$$

$$\text{ALPOT} = \frac{Al}{3} - K$$

10. Parámetros de KARAYEVA (1969). Utilizado especialmente en la Geoquímica de granitoides mineralizados (granitos a granodioritas) los parámetros que denominamos AR y AB, sirven para describir la alcalinidad de la roca y el grado de albitización.

$$AR = (Na + K) - Ca$$
$$AB = (Na - Ca) / K$$

11. Parámetros de DE LA ROCHE & LETERRIER (1973), en rocas volcánicas: Este procedimiento basado en una transposición del tetraedro de Tilley permite diferenciar muy claramente todas las series volcánicas, merced al gran poder dispersivo de los parámetros y a la proyección del plano crítico de subsaturación (Cpx — Pl — Ol). En USLPET los denominamos

$$ROVAB = 4Si - 11(Na + K) - 2(Fe + Ti)$$
$$ROVOR = 6Ca + 2Mg + Al$$

12. Parámetros de OPLETAL (1971), son modificación de los de KOLER-RAAZ (1951). Proporcionan un tipo de cálculo normativo. Los análisis se procesan de forma diferente según pertenezcan a diferentes tipos de rocas:

Grupo I: $AlK + 2(Ca + Ba + Sr) > Al > AlK$
Grupo II: $AlK + 2(Ca + Ba + Sr) > Al < AlK$
Grupo III: $AlK + 2(Ca + Ba + Sr) > Al$

Los pasos concretos que se efectúan en cada caso pueden consultarse en la obra de OPLETAL o en el listado del programa. Los parámetros que se obtienen, nueve en total, se proyectan en dos triángulos, pudiendo unirse los valores de dos a dos por medio de un vector. La información que proporcionan los parámetros de OPLETAL es la siguiente:

*a*) Relación de los grupos de componentes (> qz, f, fm) que representan respectivamente al cuarzo libre, feldespatos y componentes máficos. En nuestro programa:

$$QZ = \pm qz$$
$$F1 = F$$
$$FM2 = fm$$

*b*) Relación porcentual de los componentes K — Na — Ca, ligados a enlaces feldespáticos expresados en el programa con los variables:

$$SOD = Na$$
$$CAL = Ca$$
$$POT = K$$

*c*) Basicidad teórica de la plagioclasa: BASPG.

*d*) Relación porcentual de los componentes ligados a componente máfico:

Grupo I: $Fe - Mg - Ca_1$
Grupo II: $Fe - Mg - Na_1$
Grupo III: $Fe - Mg - Al$

Expresados en el programa por las variables FER, MAG, CAL, ALUM y SODIO.

Los datos de entrada se han programado en formato (4A1, 10F6.2). Los caracteres A1 corresponden a la etiqueta de referencia del análisis, que nos permitirá por medio de cuatro caracteres numéricos, alfabéticos o alfanuméricos, identificar con facilidad el análisis.

Los óxidos utilizados en este programa son 10, reservándonos seis espacios para cada análisis, incluyendo el punto decimal y dos decimales. El orden de entrada es $SiO_2$, $TiO_2$, $Al_2O_3$, $Fe_2O_3$, FeO, MgO, CaO, $Na_2O$, $K_2O$, $P_2O_5$.

Los datos de salida, incluyen como encabezamiento, la etiqueta del análisis, los valores de los óxidos utilizados como datos de entrada y a continuación todos los parámetros procesados por el ordenador, con sus etiquetas de identificación correspondientes.

Para mayor comodidad del lector incluimos el OUTPUT de un análisis a continuación del listado del programa.

## BIBLIOGRAFIA


BURRI, C. (1964): *Petrochemical calculations based on equivalents (Methods of Paul Niggli).* Israel Program Sci. Transl.; Jerusalem.

GOTTINI, V. (1969): *Nuovo metodo di calcolo petrochimico per distinguere i magmi anatettici crostali da quelli provenienti dal mantello superiore.* Boll. d. sed. Accad. Gioenia Sci. Nat.; [IV] 9 (9); 609-618; Catania.

KARAYEVA, Z. G. (1969): *Geochemistry of Mineralized granitoids.* Dok. Akad. Nauk. SSSR; 179; 164-167.

KÖHLER, A. & RAAZ, F. (1951): *Uber eine neue Berechnung und graphische Darstellung von Gesteinsanalysen.* N. Jb. Mineral., Mh.; 247-263; Sttugart.

LARSEN, E. S. (1938): *Some new varation diagrams for groups of igneous rocks.* J. Geol.; 46 (3); 505-520.

OPLETAL, M. (1971): *A modified calculation and new graphical representation of the rock analyses.* Acta Univ. Carolinae Geol. Hejtman Voe.; 1/2; 109-122.

RITTMANN, A. (1957): *On the serial character of Igneous Rock. Egypt.* Journ. Geol.; 1; 23-48; Cairo.

LA ROCHE, H. DE (1964): *Sur l'expression graphique des relations entre la composition chimique et la composition minéralogique quantitative des roches cristallines. Présentation d'un diagramme destiné à l'étude chimico-minéralogique des massifs granitiques ou granodioritiques. Application aux Vosges cristallines.* Sci. de la Terre; 9; 293-337; Nancy.

— (1968): *Comportement géochimique différentiel de Na, K et Al dans les formations volcaniques et sédimentaires: un guide pour l'étude des formations métamorphiques et plutoniques.* C. R. Acad. Sci.; 267 (D); 39-42; Paris.

LA ROCHE, H. DE et LETERRIER, J. (1973): *Transposition du tétraèdre minéralogique de Yoder et Tilley dans un diagramme chimique de classification des roches basaltiques.* C. R. Acad. Sc.; 276 (D); 3115-3118; Paris.

ZAVARITZKY, A. N. (1950): *Introduction to the Petrochemistry of the Igneous Rocks (in Russian), Moscow,* in GORSHKOV, G. S.: "*Volcanism and the upper mantle. Investigation in the Kurile Island Arc*". Plenum Press, New York, 1970.


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```
C     DEPARTAMENTO DE PETROLOGIA UNIVERSIDAD DE SALAMANCA
C     PROGRAM. L.G.CORRETGE UNIVERSIDAD DE SALAMANCA
C     PROGRAMA USLPET,CALCULOS PETROQUIMICOS
      REAL LOGT,LOGR,K,MG,MAG,NQZ
      DIMENSION  Z(10),A(10),B(10),N(4)
    1 READ(5,70,END=160) N,Z
C     PARAMETROS DE V.GOTTINI
      IF((Z(3)-Z(8)).LT.0..OR.Z(2).LE.0.)GO TO 5
      IF((Z(1)-43.).LE.0.)GO TO 5
      LOGT=ALOG10((Z(3)-Z(8))/Z(2))
      LOGR=ALOG10((Z(9)+Z(8))**2./(Z(1)-43.))
C     DIAGRAMA  DE LARSEN,VALOR DE LA ABCISA X
    5 X= Z(1)/3.+Z(9)-Z(5)-Z(6)-Z(7)
C     CALCULO DE NUMEROS MOLECULARES EQUIVALENTES
      A(1)=Z(1)*1000./60.06
      A(2)=Z(2)*1000./79.90
      A(3)=Z(3)*1000./101.94
      A(4)=Z(4)*1000./159.68
      A(5)=Z(5)*1000./71.84
      A(6)=Z(6)*1000./40.32
      A(7)=Z(7)*1000./56.08
      A(8)=Z(8)*1000./61.99
      A(9)=Z(9)*1000./94.19
      A(10)=Z(10)*1000./141.96
C     CALCULO DE PARAMETROS DE NIGGLI
      AFE = A(4)*2.+A(5)+A(6)
      AK  = A(8)+ A(9)
      SUM= A(3)+ AFE+A(7)+AK
      SI  = A(1)* 100./SUM
      AL  = A(3)* 100./SUM
      FM  = AFE  * 100./SUM
      ALK= AK   * 100./SUM
      C   = A(7)* 100./SUM
      K=A(9)/(A(8)+A(9))
      TI  = A(2)* 100./SUM
      MG  = A(5)/AFE
      P=A(10)*100./SUM
      W   = 2.* A(4)/(2.*A(4)+A(5))
C     NUMERO DE CUARZO
      IF(ALK-AL)11,12,12
   11 NQZ = SI-(100. +4.*ALK)
      GO TO 20
   12 NQZ = SI-(100. +3.*AL+ALK)
C     NUMEROS ATOMICOS EQUIVALENTES
   20 B(1)= A(1)
      B(2)= A(2)
      B(3)= A(3)*2.
      B(4)= A(4)*2.
      B(5)= A(5)
      B(6)= A(6)
      B(7)= A(7)
      B(8)= A(8)*2.
      B(9)= A(9)*2.
      B(10)=A(10)*2.
C     CARACTERISTICAS CIFRADAS DE ZAVARITZKY
      IF((A(7)+A(8)+A(9)).GE.A(3).AND.A(3).GE.(A(8)+A(9)))GO TO 24
      IF( A(3).LT.(A(8)+A(9))) GO TO 26
      IF( A(3).GT.(A(7)+A(8)+A(9))) GO TO 28
   24 AZ1 = 2.* ALK
      CZ1 = AL-ALK
      BZ1 = FM+C-CZ1
      SZ1 = SI
      SZA = AZ1+CZ1+BZ1+SZ1
      AZ  = AZ1* 100./SZA
```

```
      CZ   = CZ1* 100./SZA
      BZ   = BZ1* 100./SZA
      SZ   = SZ1* 100./SZA
      GO TO  29
   26 AZ1 = 2.*AL
      CZ1N= 2.*(ALK-AL)
      BZ1 = FM+C-2.*(ALK-AL)
      SZ1 = SI
      SZA = AZ1+CZ1N+BZ1+SZ1
      AZ   = AZ1 *100./SZA
      CZN = CZ1N*100./SZA
      BZ   = BZ1 *100./SZA
      SZ   = SZ1 *100./SZA
      GO TO  29
   28 AZ1   = 2.*ALK
      CZ1   = C
      BZ1   = FM +2.*(AL-ALK)-2.*C
      SZ1   = SI
      SZA   = AZ1+CZ1+BZ1+SZ1
      AZ    = AZ1*100./SZA
      CZ    = CZ1*100./SZA
      BZ    = BZ1*100./SZA
      SZ    = SZ1*100./SZA
   29 CONTINUE
C     CALCULO DE PARAMETROS DE H.DE LA ROCHE EN ROCAS GRANITICAS
      ROGAL =(B(9)+ B(7))-B(8)
      ROGMAF= B(4)+B(5)+B(6)+B(2)
      ROGSIL= B(1)/3.-(B(8)+B(9)+2.*B(7)/3.)
C     CONTROL DE CONTENIDO EN CUARZO
      CUAR= ROGSIL/5.55
C     CONTROL DE CONTENIDO EN BIOTITA
      BIOT= ROGMAF/5.55
C     DIAGRAMA DE H.DE LA ROCHE AL/3-NA,AL/3-K
      ALSOD= B(3)/3.-B(8)
      ALPOT= B(3)/3.-B(9)
C     PARAMETROS DE KARAYEVA
C     ALCALINIDAD DE LA ROCA=AR
      AR= B(8)+B(9)-B(7)
C     GRADO DE ALBITIZACION=AB
      AB= (B(8)-B(7))/B(9)
C     CALCULO DE PARAMETROS DE LA ROCHE EN ROCAS VOLCANICAS
      ROVAB = 4.*B(1)-11.*(B(8)+B(9))-2.*(B(4)+B(5)+B(2))
      ROVOR = 6.*B(7)+2.*B(6)+B(3)
C     PARAMETROS DE OPLETAL (KOHLER-RAAZ MODIFICADOS)
      C1= B(7)-5.*B(10)/3.
      ALKAL   = B(8)+ B(9)
      FM1 = B(2)+B(4)+B(5)+B(6)
      IF((ALKAL   + 2.* B(7))-B(3)) 30,40,40
   30 X3 =B(3)-(ALKAL   +2.*C1)
      SILIF = 3.* ALKAL    + 2.*C1 +FM1
      QZ   = (B(1)- SILIF)- X3/6.
      F=B(8)+C1+(B(9)-X3/3.)
      FM2 = FM1 +X3 +X3/6.
      SUMK= QZ + F + FM2
      QZ = 100* QZ/SUMK
      F1 = 100 * F/SUMK
      FM2= 100 * FM2/SUMK
C     ALCALIS Y  ALCALINOTERREOS
      SOD = 100.*B(8)/(B(8)+C1+B(9)-X3/3.)
      CAL = 100.*C1/(B(8)+C1+B(9)-X3/3.)
      POT = 100.*(B(9)-X3/3.)/(B(8)+C1+B(9)-X3/3.)
C     BASICIDAD HIPOTETICA DE LA PLAGIOCLASA
      BASPG = (CAL*100.)/(CAL+SOD)
C     DISTRIBUCION DE LOS CATIONES FEMICOS Y ALUMINIO
```

```
      TOTAL = B(4)+ B(5) +B(6) + X3
      FER  = 100.*(B(4)+B(5))/TOTAL
      MAG  = 100.*B(6)/TOTAL
      ALUM = 100.*X3/TOTAL
      GO TO 800
   40 IF( B(3)-ALKAL  ) 50,60,60
   50 X2 = ALKAL   -B(3)
      F  = (B(8)-X2) + B(9)
      FM2= FM1 +C1 + X2
      SILIF =  3*F + FM2
      QZ = B(1)- SILIF
      SUMK = QZ +F + FM2
      QZ = 100.* QZ/ SUMK
      F1 = 100.* F/ SUMK
      FM2= 100.* FM2/SUMK
C     PORCENTAJE DE ALCALIS
      SOD = (B(8)-X2)* 100./(B(8)-X2+ B(9))
      POT =  B(9)*100./(B(8)-X2+B(9))
C     FERROMAGNESIANOS Y SODIO LIGADO  A  ACMITA
      TOTAL = B(4)+ B(5) +B(6) + X2
      FER = 100.* (B(4)+ B(5))/TOTAL
      MAG = 100.*B(6)/TOTAL
      SODIO= 100.*X2/TOTAL
      GO TO 800
   60 X1 =(ALKAL    + 2.* C1)- B(3)
      C2 =C1 - X1/2.
      FM2= FM1 +X1/2.
      SILIF = 3.* ALKAL   +2.*C2+FM2
      QZ = B(1)-SILIF
      F= B(9) +B(8)+ C2
      SUMK = QZ + F + FM2
      QZ = 100.* QZ /SUMK
      F1 = 100.* F/SUMK
      FM2= 100.* FM2/SUMK
C     ALCALIS Y ALCALINOTERREOS  EN  PLAGIOCLASAS
      POT = 100.* B(9)/F
      SOD = 100.* B(8)/F
      CAL = 100.* C2/F
C     BASICIDAD HIPOTETICA  DE LA PLAGIOCLASA
      BASPG=(CAL*100.)/(CAL+SOD)
      FER = B(4)+ B(5)
      MAG = B(6)
      CAL= X1/2.
C     DISTRIBUCION PORCENTUAL DE LOS CAT. FEMICOS EN LOS MIN. OSCUROS
      SUMFE = FER + MAG + CALC
      FER = 100.* FER/ SUMFE
      MAG = 100.* MAG/ SUMFE
      CALC= 100.* CALC/SUMFE
  800 WRITE (6,10) N,Z
      WRITE(6,80)LOGT,LOGR
      WRITE(6,85)X
      WRITE(6,90) SI,AL,FM,ALK,C,K,TI,MG,P,W,NQZ
      WRITE (6,95) AZ,CZ,CZN,BZ,SZ
      WRITE(6,100) ROGAL ,ROGMAF, ROGSIL
      WRITE(6,105)CUAR,BIOT,ALSOD,ALPOT
      WRITE(6,107)AR,AB
      WRITE(6,110) ROVAB ,ROVOR
      WRITE(6,120) QZ,F1,FM2
      WRITE(6,130) SOD,CAL,POT
      WRITE(6,140) BASPG
      WRITE(6,150) FER,MAG,ALUM,SODIO,CALC
   70 FORMAT (4A1,10(F6.2))
   10 FORMAT(1H1,4HNUM.,4A1,/1H0,16HANALISIS QUIMICO/1H0,3HSI=,F6.2,2X,
     13HTI=,F6.2,2X,3HAL=,F6.2,2X,4HFE3=,F6.2,2X,4HFE2=,F6.2,2X,3HMG=
```

```
     2,F6.2,2X,3HCA=,F6.2,2X,3HNA=,F6.2,2X,2HK=,F6.2,2X,2HP=,F6.2)
  80 FORMAT(1H0,21HPARAMETROS DE GOTTINI/1H0,5HLOGT=,F6.2,2X,5HLOGR=
     1,F6.2)
  85 FORMAT(1H0,44HPARAMETRO DE LARSEN X=SIO2/3+K2O-FEO-MGO-CAO/1H0,
     12HX=,F7.2)
  90 FORMAT(1H0,20HPARAMETROS DE NIGGLI/1H0,3HSI=,F7.2,2X,3HAL=,F7.2,
     12X,3HFM=,F7.2,2X,4HALK=,F7.2,2X,2HC=,F7.2,2X,2HK=,F7.2,2X,3HTI=
     2,F7.2,2X,3HMG=,F7.2,2X,2HP=,F7.2,2X,2HW=,F7.2/4HNQZ=,F7.2)
  95 FORMAT(1H0,38HCARACTERISTICAS CIFRADAS DE ZAVARITZKY/1H0,
     22HA=,F6.2,2X,2HC=,F6.2,2X,5HC(-)=,F6.2,2X,2HB=,F6.2,
     32X,2HS=,F6.2)
 100 FORMAT(1H0,34HPARAMETROS DE LA ROCHE EN GRANITOS/1H0,6HROGAL=
     1,F9.2,2X,7HROGMAF=,F9.2,2X,7HROGSIL=,F9.2)
 105 FORMAT(1H0,30HCONTROL DE CONTENIDO EN CUARZO/1H0,5HCUAR=
     1,F7.2/1H0,31HCONTROL DE CONTENIDO EN BIOTITA/1H0,5HBIOT=
     2,F7.2//1H0,40HDIAGRAMA DE H DE LA ROCHE AL/3-NA,AL/3-K/1H0,
     36HALSOD=,F9.2,2X,6HALPOT=,F9.2)
 107 FORMAT(1H0,22HPARAMETROS DE KARAYEVA/1H0,3HAR=,F7.2,2X,3HAB=
     1,F5.2)
 110 FORMAT(1H0,36HPARAMETROS DE LA ROCHE EN VOLCANICAS/1H0,6HROVAB=
     1,F9.2,2X,6HROVOR=,F9.2)
 120 FORMAT(1H0,33HPARAMETROS DE OPLETAL(KOLER-RAAZ)//1H0,3HQZ=,F7.2,
     12X,3HF1=,F7.2,2X,4HFM2=,F7.2)
 130 FORMAT(1H0,4HSOD=,F7.2,2X,4HCAL=,F7.2,2X,4HPOT=,F7.2)
 140 FORMAT(1H0,35HBASICIDAD TEORICA DE LA PLAGIOCLASA/1H0,6HBASPG=
     1,F7.2)
 150 FORMAT(1H0,4HFER=,F7.2,2X,4HMAG=,F7.2,2X,5HALUM=,F7.2,2X,6HSODIO=
     1,F7.2,2X,5HCAL=,F7.2)
      GO TO 1
 160 STOP
      END
```

```
NUM.F538

ANALISIS QUIMICO

SI= 73.50  TI=   .16  AL= 13.07  FE3=   .77  FE2=  1.65  MG=  1.12  CA=   .75  NA=  2.74  K=  4.86  P=   .06
PARAMETROS DE GOTTINI
LOGT=  1.81  LOGP=   .28
PARAMETRO DE LARSEN X=SIO2/3+K2O-FEO-MGO-CAO
X=  25.84
PARAMETROS DE NIGGLI
SI= 410.97  AL=  43.06  FM=  20.28  ALK=  32.17  C=   4.49  K=    .54  TI=    .67  MG=    .46  P=    .14  W=    .30
QZ= 182.29

CARACTERISTICAS CIFRADAS DE ZAVARITZKY

A= 12.55  C=   .88  C(-)=   .00  B=  6.45  S= 80.13
PARAMETROS DE LA ROCHE EN GRANITOS
ROGAL=    28.17  ROGMAF=    62.39  ROGSIL=   207.41
CONTROL DE CONTENIDO EN CUARZO
CUAR=  37.37
CONTROL DE CONTENIDO EN BIOTITA
BIOT=  11.24

DIAGRAMA DE H DE LA ROCHE AL/3-NA,AL/3-K
ALSOD=    -2.93  ALPOT=   -17.72
PARAMETROS DE KARAYEVA
AR= 178.22  AB=  .73
PARAMETROS DE LA ROCHE EN VOLCANICAS
ROVAB=  2718.31  ROVOR=   392.22
PARAMETROS DE OPLETAL(KOLER-RAAZ)


QZ=  64.94  FI=  22.19  FM2=  12.86
SOD=  46.54  CAL=   6.30  POT=  47.16

BASICIDAD TEORICA DE LA PLAGIOCLASA
BASPG=  11.92
FER=  32.20  MAG=  27.42  ALUM=  40.38  SODIO=    .00  CAL=,    .00
```

INTERNATIONAL GEOLOGICAL CORRELATION PROGRAMME

# STVDIA GEOLOGICA

(SPECIAL ISSUE)

# Mineralization Associated With Acid Magmatism

UNIVERSIDAD DE SALAMANCA

1978

# MEETING OF THE WORKING GROUP OF THE PROJECT «MINERALIZATION ASSOCIATED WITH ACID MAGMATISM»

Salamanca (Spain), 26-30 April 1976

## SCHEDULE

MONDAY 26

| | | |
|---|---|---|
| 9:30 | 12:00 | Mawam Business Meeting |
| 12:00 | 14:00 | Lunch |
| 14:00 | 17:00 | Business Meeting (Cont.) |
| | Evening free | |

TUESDAY 27

| | | |
|---|---|---|
| 9:30 | 12:00 | Scientific Sessions |
| 12:00 | 14:00 | Lunch |
| 14:00 | 18:00 | Scientific Sessions (Cont.) |
| | Evening free | |

WEDNESDAY 28 FIELD TRIP «A»

| | | |
|---|---|---|
| 8:00 | | Departure |
| 9:00 | 11:30 | Barruecopardo Mine (W) |
| 11:30 | 12:00 | Trip to Aldeadávila |
| 12:00 | 13:00 | Aldeadávila dam |
| 13:00 | 13:30 | Trip to Villarino |
| 13:30 | 15:00 | Lunch |
| 15:00 | 16:30 | Villarino Hydroelectric Power Plant |
| 16:30 | 17:00 | Trip to Almendra |
| 17:00 | 17:30 | Almendra dam |
| 17:30 | 18:30 | Return to Salamanca |

THURSDAY 29

| | | |
|---|---|---|
| 10:00 | | Departure |
| 11:00 | 15:00 | Special program (Rodasviejas) |
| 15:00 | | Return to Salamanca |
| 16:30 | 19:30 | Seight-Seeing tour (Old town, Cathedrals, University) |
| 20:00 | 21:00 | Reception Given by the President of the Provincial Deputation (Palacio de la Salina) |

| | | |
|---|---|---|
| FRIDAY 30 | | FIELD TRIP «B» |
| 10:00 | | Departure |
| 10:30 | 12:30 | Golpejas Mine (Sn, Nb, Ta) |
| 12:30 | 13:30 | Lunch |
| 13:30 | | Departure |
| 14:00 | 16:00 | Cubito Mine (Sn) |
| 16:00 | 17:00 | Trip to Morille |
| 17:00 | 18:30 | Morille Mine (W) |
| 18:30 | | Return to Salamanca |
| 19:00 | 20:00 | Mawam W. G. Final Meeting |
| 21:00 | 23:00 | Farewell Dinner Offered by the Department of Geology and Mineralogy. |

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(25) VIDAL, Alfredo. Ibergesa. Juan Ramón Jiménez, 22. Madrid-16.

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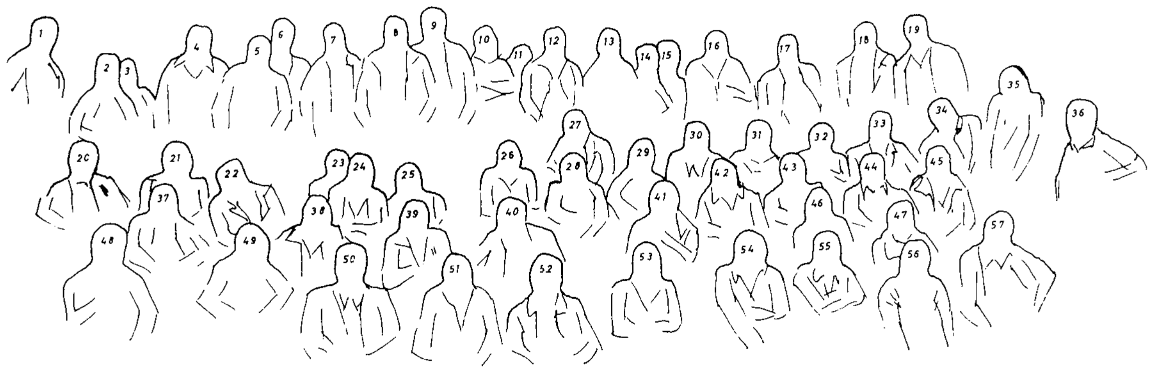
(1) SAAVEDRA, Julio

*Members of the Working Group and participants at the MAWAM meeting after IBERDUERO'S lunch, Villarino (28-4-76)*



## SCIENTIFIC MEETING

The second meeting of the IGCP project «Mineralization Associated With Acid Magmatism» was held 26-30 April, 1976, at the University of Salamanca, Spain. It consisted of a business meeting (April 26), a scientific session (April 27), and two field-trips (April 28-30).

*Business meeting*

It was attended by 10 national representatives of the countries participating in the MAWAM project and devoted to the agenda of the project, future plans of activity, and membership policy. The following members were presents:

Prof. Arribas, Antonio. Spain
Dr. Bowden, Peter. Great Britain
Dr. Burnol, Lucien. France
Prof. Dr. Evrard, Pierre. Belgium
Dr. Haapala, Ilmari. Finland
Dr. Olade, M. A. Nigeria
Dr. Oosteroom, M. C. The Netherlands
Prof. Dr. Pauly, Hans. Denmark
Dr. Stemprok, Miroslav. Czechoslovakia
Prof. Thadeu, Décio. Portugal

*Scientific session*

The scientific meeting of the Working Group was held at the Department of Geology and Mineralogy. It was attended by the national representatives of the MAWAM WG and was joined by numerous Spanish mining geologists and students invited to the meeting.

The meeting was held in two half-day sessions. The morning session was chaired by Professor Antonio Arribas with the following programme:

M. Stemprok: Classification criteria of tin and related deposits /convenor's report/.

G. Tischendorf /delivered by P. Bowden/: Criteria of distinguishing normal granites from metallogenetically speciallized ones.

Each report was followed by discussions.

The afternoon session was chaired by Professor P. Evrard with the following lectures:

M. Oosteroom: Ways of treatment of geochemical data in granite investigation related to tin-tungsten mineralization.

P. Bowden: Geochemical aspects of the evolution and mineralization of the Nigerian Mesozoic anorogenic granites.

A. Arribas and J. Saavedra: Introduction to the field trips in the Salamanca area.

The convenor's report of M. STEMPROK summarized the present state of criteria which have been applied to the classification of tin and related deposits associated with acid magmatic rocks. At first M. Stemprok gave the review of earlier views on the classification of deposits based on physicochemical parameters, ore formations, wall rock alteration etc., which gave in total eleven parameters so far employed.

The second part of M. Stemprok's report delt with the latest views on classification delivered for his convenor's report by different geologists. It was the latest information on the types of deposits described from Korea and India by Soo Jin Kim from the College of Natural Sciences of Seul and by N. K. Mukerjee, Banaras Hindu University, Varanasi. The most complete proposal of tin deposits classification was the one by late Professor N. Varlamoff, delivered in printed form. His classification is based on the spatital distribution of mineralisations, i.e., the depth of the formation of deposits as well as the paragenesis of minerals. V. K. Denisenko based his classification of tungsten deposits on ore formations which have been grouped into plutonic, plutono-volcanic and sedimentary-metamorphic ones. Another suggestion of classification was given by D. V. Rundkvist and V. K. Denisenko who, by using the method of cluster and factor analysis, suggested in total 7 types of Sn-W deposits and distinguished the main associations of elements in them. The proposal by R. Taylor from Australia considers as the main criteria of classification the factors of geological environment and distinguishes five groups of tin deposits. This classification is oposed by C. L. Sainsbury from the U.S.A. who rejects the possibility to classify the deposits on the basis of the geographic provinces and proposes the form of the deposits and its genetic history as the main classification criteria.

M. Stemprok presented his own suggestion for classification of Sn-W deposits based on the distinction of individual mineralisation stages which were active in the formation of ore deposits. In total, he differed 8 stages of mineralisation, manifested themselves as a special type of wall rock alterations, which can be variously combined within a single deposit: pegmatitization (skarnization in calcacerous rocks), feldspatization, quartz vein formation and silicification, greisenization, tourmalinization, chloritization, sericitization, argillitization.

The review showed a vast disagreement in the application of classification criteria by various geologists. The criteria based on physico-chemical aspects are less widely used recently. Many of the present classifications stress the genetic and mineralogical or geochemical aspects.

In discussion, Prof. Evrard pointed out that the identical position of skarnization and pegmatitization in the first phases of the processes of ore deposition is justified; also thermodynamic data indicate that skarnization occurs at high temperature and low pressures while pegmatitization is characterized by high temperature and high pressure.

G. Tischendorf, in his convenor's report, presented geologic-tectonical, geochemical and petrological criteria which might be used as a guide for the recognition of metallogenetically specialized granites. He gave 15 features by which the metallogenetically specialized granites can be distinguished. They include also the petrochemical data, which show that, in their averages, the specialized granites, when compared with the normal ones, are characterised by higher contents of $K_2O$ and $SiO_2$ and by lower contents of $TiO_2$, $Fe_2O_3$, MgO and CaO. Further the metallogenetically specialised granites show and increase in the content of specific rare elements (regional specialization). Proposed average values for some trace elements are as follows:

| | | | | |
|---|---|---|---|---|
| fluorine | 3700 | ± | 1500 | ppm |
| rubidium | 580 | ± | 200 | ppm |
| lithium | 400 | ± | 200 | ppm |
| tin | 30 | ± | 20 | ppm |
| beryllium | 13 | ± | 6 | ppm |
| tungsten | 7 | ± | 3 | ppm |
| molybdenum | 3.5 | ± | 2 | ppm |

In the discussion, the importance of water in the interpretation of silicate analyses was stressed, and the problem of the difference between late-magmatic and postmagmatic processes was extensively discussed.

M. Oosteroom gave in his review a broad account of the application of X-ray fluorescence analysis in the problem of ore-bearing granites. The results of the semiquantitative analyses of samples mainly from Galicia in Spain and some other provinces were treated by the methods of mathematical statistics. The trace elements showing a positive correlation with tin are *Rb, Cs, Li, Nb,* Be, B, Ga, Pb and negative correlation *Sr, Ba, Ti, Sc,* Y, V, Zr. It was stated that some correlations are strongly decreasing or increasing during the granitic differentiation, indicating thus the geochemical evolution of a granite belt. The use of factor score operation was found useful in the geochemical classification of granitoids in the Hercynian belt.

In the discussion the main problem raised was the number of samples needed as representative of a particular granite body.

P. Bowden gave an introduction to the planned meeting in Nigeria, discussing the aspects of the evolution and mineralization of the Nigerian Mesozoic granites. The anorogenic Mesozoic ring complexes of northern Nigeria evolved through the early development of trachyte-peralkaline silicic volcanics, mirrored at subvolcanic levels by syenite and related paralkaline granites. As the magmatic cycle progressed, the granitoid liquids became less alkalin and allowed the associated peraluminous biotite granites to dominate and end the magmatic cycle. In the peralkaline granites there was one period of mineralization essentially related to recrystallization and the introduction of albite. High agpaitic coefficient maintained miscibility of the albite-rich ore fluids between silicate and aqueous phases to low temperatures, so that mineralizing components continually accumulated together and prevente widespread precipitation of ore minerals. If, however, the high agpaitic coefficient could not be maintained, silicate and aqueous fluids would have separated, what resulted in substantial ore formation. This process appears to have occurred in the peraluminous biotite granites. Data on $Sr^{87}/Sr^{86}$ isotopic ratios suggest that there have been three contributions to the granite material: from the mantle, lower crust and sialic upper crust.

Prof. Arribas gave a summary of the geological features of West central Spain, especially the characteristic of granitoids, including their late and postmagmatic alterations and tin and tungsten mineralization. These lectures gave an excellent introduction to the field trips following the session and summarized the new data on the geology and geochemistry of ore-bearing granitoids with which tin and tungsten deposits are spatially associated.

## *Field-trips*

*Excursion A* was on Wednesday, April 28, 1976, heading look from Salamanca to the Barruecopardo scheelite mine and the Aldeadávila dam. The geological explanation was presented by Prof. Arribas.

The Barruecopardo tungsten deposit is mined by a large open pit. It is confined to two-mica granite (muscovite $>$ biotite), intersected by a swar of steep subparallel quartz veins striking N-S and with an average width of 5-15 cm. The vein filling consists besides quartz of scheelite, arsenopyrite, probably löllingite, small amounts of wolframite (ferberite) and pyrite. There is no wall-rock greisenization, but the granite has been affected altered by extensive microclinization and chloritization. Chlorite is present in the vein filling too, mainly in association with arsenopyrite. The genesis of the scheelite mineralization is explained by the microclinization which was responsible for the leaching out of tungsten originally dispersed in the granites. The discussion following the explanation concerned the problem of microclinization in relation to the genesis of the deposit and the question of late magmatic or post magmatic muscovitization of the granites.

The participants of the excursion were provided by a tasty dinner by the Iberduero Company which hosted the excursion in the afternoon and showed the important dam system of the Duero and Tormes rivers. The hydroelectric plant is cut in the two-mica granite showing little signs of secondary alteration.

*Excursion B* was on Friday, April 30, 1976, going to the Golpejas tin mine, located 18 km W of Salamanca, which is a strongly kaolinized albite granite with Nb-Ta-rich cassiterite disseminations. Then the excursion visited a tin placer quarry at Cubito, and afterwards two scheelite deposits of both the skarn and vein types at Morille, 20 km S of Salamanca. The deposit at Morille occurs in an area of Paleozoic metamorphic schists containing carbonate layers following the foliation. The skarn bodies with scheelite impregnations consist mainly of grossular, pyroxene, vesuviane, zoisite, plagioclase and actinolite. The skarn bodies are characterized by actinolization of the surrounding biotite schists and are clearly earlier than quartz veins which contain scheelite and cassiterite at the intersection with the skarn bodies. The owner of the mine offered the excursion participants with a field lunch.

## *Social programme*

In addition to the business and scientific sessions and field trips the participants of the meeting were entertained at many enjoyable social events.

Of special interest was the visit to the Rodasviejas farm where the geologists enjoyed the first steps in bull fighting, followed by a lunch at the farm. A nice look into the ancient history of Salamanca was given to the participants by Prof. Caamaño, Head of the Department of Art Histroy of the University. A reception for the particpants of the MAWAM meeting was given by the president of the Provincial Deputation of Salamanca on April 29, and on the last evening the farewell dinner was offered by the Department of Geology and Mineralogy of the University of Salamanca.

Both the meetings and excursions were carried out efficiently, reflecting great care and effort, given to the meeting by Prof. Arribas and his coworkers. All the particpants enjoyed the cordial hospitality of the Spanish colleagues which created a pleasant atmosphere for fruitful discussions and exchange of opinions.

M. Stemprok

# CRITERIOS PARA LA CLASIFICACION DE LOS YACIMIENTOS DE Sn, W y Mo

M. STEMPROK

(RESUMEN)

Se hace en este trabajo un amplio y crítico repaso histórico a las diferentes clasificaciones de los yacimientos de estos tres elementos, especialmente las de Fuchs, de Launay, Posepny, Groddeck, Phillips, von Cotta, Lindgren, Niggli, Tatarinov y Magakian, Zakharov, Abdullaev, Volfson, Karasik, Smirnov, Sainsbury, Varlamoff, Denisenko y Kruschov. A lo largo de este siglo y parte del pasado los criterios empleados para las diferentes clasificaciones se basaban en la utilización de distintas variables, las cuales son agrupadas por el autor de la siguiente forma.

- variables....
  - medibles directamente......
    - — posición geológica con respecto a un campo intrusivo.
    - — composición mineralógica del yacimiento.
  - medibles indirectamente...
    - — profundidad del yacimiento.
    - — T de los fluidos mineralizadores.
    - — P, composición, y estado de dichos fluidos.

En general, se concede la mayor importancia a dos de las variables medibles indirectamente: la temperatura y el estado de las soluciones mineralizadoras.

Por lo que se refiere a T, los resultados obtenidos en numerosas mediciones demuestran la existencia de un amplio rango de variación para muchos yacimientos. En opinión del autor, pequeñas variaciones de la temperatura de deposición —por ejemplo, entre 200 y 300°C— son insuficientes para explicar la gran diferenciación que presentan numerosos yacimientos. Igualmente, el criterio basado en el estado de las soluciones mineralizadoras es muy discutible, ya que el límite hipotético entre los estados hidrotermal y pneumatolítico no justifica de forma razonable la consiguiente inclusión de muchos yacimientos en uno de aquellos dos grupos; hecho confirmado por el gran número de mineralizaciones que se pueden incluir tanto entre los hidrotermales como entre los pneumatolíticos.

Dada la importancia de la composición mineralógica, la cual se utiliza prácticamente en todas las clasificaciones, la posición de un yacimiento se puede definir por los resultados del proceso mineralizador —es decir, la paragénesis—, y por los procesos genéticos. Por ello, una clasificación razonable se podría hacer, de acuerdo con el autor, teniendo en cuenta, en primer lugar, el origen de la mineralización, y estableciendo después distintos grupos atendiendo a criterios geológicos que fueran fácilmente medibles. Entre estos, el mejor sería considerar la posición relativa de un yacimiento con respecto a la intrusión con la que dicho yacimiento está relacionado. El siguiente paso exigiría definir claramente los diferentes factores —temperatura, alteración de las rocas encajantes, etc.— que permitan hacer subdivisiones, pero estableciendo una terminología precisa que explique claramente el significado de los términos utilizados.

# CRITERIOS PARA DISTINGUIR LOS GRANITOS NORMALES DE LOS METALOGENICAMENTE FERTILES

G. TISCHENDORF

(RESUMEN)

El análisis metalogénico de los distritos estanníferos demuestra que los granitoides de estos últimos se caracterizan por criterios geológicos, tectónicos, geoquímicos y petrográficos bien definidos. Se puede pues asumir que entre los complejos graníticos intrusivos y los yacimientos asociados de Sn, Li, Rb, Cs, Be, Nb, Ta, W, Mo y F existe una relación no sólo espacial sino también genética.

De acuerdo con estos hechos, se trata de definir las peculiaridades de los granitos especializados que podrían ser utilizadas como criterio para la búsqueda de nuevos distritos mineros.

Los granitoides metalogénicamente fértiles se caracterizan por las siguientes particularidades:

— están confinados a los estadios medios y finales de una orogenia.

— tienen un pronunciado carácter siálico, probablemente poligenético.

— son intrusivos.

— están relacionados con las fases postcinemáticas e hipoabisales de los complejos intrusivos.

— están confinados a las partes apicales de los batolitos.

— tienen un alto contenido en algunos elementos principales —$SiO_2$ y $K_2O$— y bajo en otros —$TiO_2$, $Fe_2O_3$, MgO y CaO— en relación con los granitos normales.

— están enriquecidos en ciertos elementos trazas, tales como B, Nb, Ta, Cs, U, Th y T.R., y empobrecidos en otros, tales como Ni, Cr, Co, U, Sr y Ba, en comparación con los que existen en los granitos normales.

— presentan una distribución regional asimétrica (log normal) de los elementos traza, caracterizada por el aumento de los elementos granitófilos en las zonas de borde del plutón.

— muestran un fuerte incremento de los elementos granitófilos en las fases más jóvenes de los complejos intrusivos.

— hay una dispersión relativamente alta de los elementos que participan en la especialización.

— la composición mineral media permite clasificar petrográficamente a los granitoides especializados como: granitos alaskíticos, leucogranitos, granitos aplíticos, granitos de dos micas (sienogranitos y granitos de feldespato alcalino en el sentido de Streckeisen).

— muestran una asociación frecuente de casiterita, topacio, fluorita y turmalina, así como columbo-tantalita y berilo, como minerales accesorios.

— se caracterizan por la aparición de cuarzo precoz y biotita.

— son evidentes en ellos los procesos tardimagmáticos de microclinización, moscovitización y albitización autometasomática.

— son frecuentes los procesos postmagmáticos de greisenización.

Con respecto a los granitos normales, los granitos especializados muestran considerables desviaciones en el contenido de algunos elementos traza (Sn, Li, Be, Rb, F); cierta variación en la proporción de los elementos menores (Ca, Mg, Ti); y sólo muy pequeñas desviaciones de los elementos mayores (Si, Al, Fe, Na, K). El bajo contenido en F de las rocas magmáticas ácidas e intermedias (adamellitas) de las regiones estanníferas puede explicarse por los procesos de diferenciación avanzada que han conducido a la acumulación de ciertos elementos en las fases graníticas más especializadas.

En cualquier caso, los granitos metalogénicamente fértiles se han emplazado en niveles relativamente altos de la corteza y en un ambiente muy rico en volátiles.

# CLASIFICACION DE LAS MINERALIZACIONES RELACIONADAS CON EL MAGMATISMO ACIDO

D. V. RUNDKVIST, USSR

(RESUMEN)

En primer lugar se presenta en este trabajo una clasificación de los yacimientos de estaño de la URSS basada en los caracteres geológicos y mineralógicos. Así se establecen siete tipos principales:

1. Pegmatitas con casiterita; de poca importancia en la URSS.
2. Skarns con casiterita; no muy ampliamente representados.
3. Cuarzo-casiterita, de tipo greisen.
4. Turmalina-clorita-casiterita.
5. Casiterita-estannita-sulfuros, con cobre y otros subtipos polimetálicos.
6. Formaciones con casiterita xilofórmica desarrolladas en los cinturones volcánicos orogénicos más recientes.
7. En estos últimos años, un nuevo grupo de yacimientos de sulfuros (piríticos) con estaño ha sido establecido.

Entre todos estos tipos, los 3, 4 y 5 son los de mayor importancia económica en la URSS.

Se acompaña, además, una tabla en la que se recogen las características morfológicas, los elementos asociados, y los tipos de alteraciones hidrotermales en cada uno de los siete tipos de yacimientos. En opinión del autor, el principal fallo de esta clasificación radica en los límites tan precisos que se han establecido para definir los diferentes tipos, ya que en la naturaleza existen numerosos yacimientos que poseen características intermedias y que por ello quedan fuera de esta clasificación.

Por ello, el autor propone una clasificación de los yacimientos relacionados con granitoides teniendo en cuenta la composición y las características estructurales de dichas rocas. En primer lugar, se establecen 2 *clases* principales: una, de yacimientos relacionados con la rama evolutiva Gabro-Granito-Leucogranito, y otra, con la del Granito-Alaskita-Granito Alcalino. En la primera clase se establecen 3 *familias,* las cuales corresponden a los tres tramos de esa misma serie evolutiva, que son: yacimientos relacionados con gabro-dioritas, con grano-dioritas-plagiogranitos, y con granitos-leucogranitos. Dentro de cada familia se establecen varios *tipos* —en total 11, para esta primera clase— de acuerdo con las características morfológicas y la composición de los yacimientos. En la segunda clase, y siguiendo el mismo sistema, se establecen otras 4 familias, a las que corresponden 9 tipos.

# SUGERENCIAS PARA LA CLASIFICACION DE LOS YACIMIENTOS DE ESTAÑO, WOLFRAMIO Y MOLIBDENO ASOCIADOS A ROCAS PLUTONICAS

Miroslav Stemprok

(Resumen)

La clasificación que propone el autor se basa en el hecho real de que los yacimientos son el resultado de varias etapas mineralizadoras, las cuales representan la llegada de soluciones que están generalmente separadas en el tiempo por movimientos tectónicos.

La clasificación se basa en los mismos principios genéticos o «formacionales» de Levitskii (1947) y Radkevich (1968) para los yacimientos de Sn; de Denisenko (1975), para los de W; y de Kruschov (1961), para los de Mo. La diferencia principal es que aquí se admite una composición relativamente simple para los productos que acompañan a cada una de las etapas mineralizadoras importantes, y que consisten, por ejemplo, en solo cuarzo, greisen, o pegmatitas cuarzo-feldespáticas.

Por otra parte, casi todos los yacimientos que el autor considera en este trabajo se han formado en varias etapas mineralizadoras superpuestas, ya que en la naturaleza es raro encontrar yacimientos que correspondan a una sola fase, y que ésta aparezca claramente definida. Es decir, que las mineralizaciones de interés económico pueden estar asociadas a algunas fases determinadas de la secuencia mineralizadora, pero pueden haberse sobreimpuesto a los productos de las fases estériles o estar diluidas en las etapas posteriores no mineralizadas. En cualquier caso, los períodos principales de mineralización persisten a escala global, por lo que pueden ser identificados fácilmente en yacimientos de forma y edad geológica muy variadas.

Los dos primeros estados de transformación de las rocas encajantes son diferentes según los materiales geológicos sobre los que actuaron. Así, por ejemplo, en rocas de naturaleza sílico-aluminosa, las últimas fases están representadas generalmente por pegmatitas, pegmatitas de reemplazamiento, o feldespatitas, mientras que en las rocas carbonatadas se pueden formar distintos tipos de skarn cálcico o magnésico.

Las diferentes etapas de transformación que intervienen en la formación

de los yacimientos de estaño, wolframio o molibdeno tienen lugar, por lo general, en el orden siguiente:

1. *Pegmatización.* Se caracteriza por el desarrollo de la asociación cuarzo, feldespato y mica.

1a) Skarnización (Fase silicatada). En rocas carbonatadas; esta fase se caracteriza por el desarrollo de piroxenos, granates y vesubiana. Esta asociación constituye una buena base para el desarrollo posterior de las fases mineralizadas.

1b) Skarnización (Fase oxidada). Se caracteriza esta fase por el desarrollo de la magnetita de los skarns.

2. *Feldespatización.* Desarrollo de asociaciones minerales por reemplazamiento de pegmatitas (metasomatismo sódico o lítico), o albitización de las rocas ígneas. Las mineralizaciones metálicas pueden estar relacionadas con esta fase.

3. *Cuarzo y silicificación.* Formación de filones de cuarzo y silicificación de la roca encajante.

4. *Greisenización.* Caracterizada por la formación de silicatos de aluminio (topacio, micas) con redeposición de cuarzo. La mineralización metálica está relacionada con los períodos finales de greisenización.

5. *Turmalinización.* Formación de turmalina en los filones y rocas encajantes. A veces va acompañada por la deposición de la mena metálica.

6. *Cloritización.* Esta es la fase principal para la formación de sulfuros, concretamente los de arsénico, hierro y zinc.

7. *Sericitización.* Durante esta fase de alteración, la mineralización va acompañada por la deposición de sulfuros sencillos de plomo, cobre y zinc.

8. *Arcillización.* Se caracteriza por la formación de sulfuros y sulfosales complejos, con caolinización y formación de carbonatos en las rocas encajantes.

Las principales fases de la mineralización ocurren a lo largo de estas ocho etapas de transformación, pero en la mayoría de los yacimientos sólo se desarrollan durante dos o tres de ellas.

El número de las posibles combinaciones —siempre que el orden de los períodos de transformación sea invariable— se puede representar mediante las siguientes fórmulas matemáticas.

Una sola fase: 8C1 = 8.

Dos fases: 8C2/28 = 28.

Tres fases: 8C3/56 = 56.

Hay pues un total de 2 posibles combinaciones de las 8 fases de transformación en grupos de una, dos o tres. Como generalmente sólo se combinan dos o tres fases, y una o dos pueden estar ausentes, las combinaciones se reducen a 53 posibles, de las cuales, solo de 10 a 20 ocurren en la naturaleza.

Los yacimientos plutónicos de estaño, wolframio o molibdeno se pueden representar entonces, gráficamente, por un octógono que, al unir el centro con los vértices, queda dividido en triángulos, cuadrángulos, o figuras más complejas, cuyos bordes caracterizan las más importantes etapas de transformación de un yacimiento.

De acuerdo con estas normas, la terminología de cada yacimiento es una función de los minerales metálicos presentes en el mismo y las más importantes fases de mineralización que han contribuido a su formación.

# CLASIFICACION DE LAS PROVINCIAS METALOGENICAS DE ESTAÑO

R. G. TAYLOR

(RESUMEN)

En este trabajo se propone una nueva clasificación de las provincias metalogénicas estanníferas basada en parámetros relacionados con la situación geológica de los yacimientos.

Aunque ya el autor había establecido una clasificación que tenía en cuenta los trabajos de ITSIKSON sobre esta misma base, ahora, mediante la síntesis de datos correspondientes a más de 50 provincias estanníferas, propone un modelo de clasificación más exacto. De todas formas, advierte el autor que esta clasificación se debe tomar como provisional, y que estará sujeta a modificaciones cuando se tengan más datos, ya que aún hay provincias poco conocidas y que se adaptan mal al modelo propuesto.

Los ambientes en los que se encuentran significantes concentraciones primarias de estaño se agrupan de la siguiente forma:

TIPO 1.—*Cinturones orogénicos*

Aquí, los yacimientos de Sn están asociados a granitoides que muestran una estrecha relación espacial y temporal con los períodos orogénicos. Se pueden hacer los siguientes grupos:

a) Yacimientos asociados a rocas efusivas o piroclásticas. Las intrusiones con ellas relacionadas tiene escaso interés económico. Ejemplo: Méjico.

b) Yacimientos relacionados con complejos intrusivos de carácter subvolcánico y que están asociados a efusiones volcánicas aéreas. Se presentan como pequeños stocks, chimeneas, e intrusiones de forma muy irregular, asociados con diques, haces, brechas y sills. Predominan las texturas porfídicas. La composición de las rocas intrusivas varía de pórfidos graníticos a cuarzo-dioritas. Las vulcanitas asociadas con ellos son generalmente riolitas y andesitas. Su importancia económica varía con la provincia.

Ejemplos: Bolivia (zona meridional), Japón, Maly Kinghan (URSS).

c) Yacimientos asociados con complejos intrusivos de carácter mixto, es decir, que varían entre un ambiente volcánico profundo o uno plutónico

de poca profundidad. Las rocas efusivas están generalmente ausentes pero pueden existir en algunos casos. Las rocas ígneas asociadas pueden variar de pequeños stocks a complejos intrusivos de gran tamaño. En los niveles más altos aparecen guirnaldas de pequeñas rocas intrusivas asociadas a fracturas regionales que reflejan estructuras batolíticas más profundas. Se encuentran aquí los granitos geoquímicamente especializados que forman los términos extremos de una serie de diferenciación granodiorita-granito. Los filones y haces de diques son normalmente abundantes, aunque están distribuidos irregularmente. Las aplitas y pegmatitas son, por el contrario, poco frecuentes.

Las rocas más abundantes son los granitos y granodioritas, con algunas monzonitas y dioritas. Las texturas plutónicas prevalecen sobre las porfídicas.

La importancia económica varía según la provincia.

Ejemplos: Herberton (Australia), Transbaikal (URSS) y New Brunswick (Canadá).

d) Concentraciones de estaño asociadas con complejos intrusivos de carácter plutónico. Ausencia de rocas efusivas. Pocos diques y filones.

Las rocas predominantes son granitos y granodioritas, con algunas alaskitas, leucogranitos y otros granitos geoquímicamente especializados. Predominan las texturas plutónicas, y son comunes las pegmatitas y aplitas. Su importancia económica es muy variable. Ejemplo: Bolivia (Zona Septentrional). Erzgerbirge, Macizo Central Francés, Sodoeste Asiático, y Noreste de Tasmania.

TIPO 2.—*Granitos anorogénicos*

Los yacimientos están asociados a granitoides emplazados en zonas de fuerte fracturación, es decir, en áreas cratónicas sin relación con las orogenias. Rocas intrusivas circulares u ovaladas, y complejos anulares. Pocas rocas volcánicas.

Las rocas asociadas son granitos, microgranitos y riolitas. Las texturas pueden ser plutónicas y porfídicas. Su valor económico es escaso en los yacimientos primarios, pero muy importante en los secundarios. Ejemplos: Nigeria, Brasil y Africa del SW.

TIPO 3.—*Pegmatitas precámbricas*

Yacimientos asociados con las pegmatitas de los escudos metamórficos antiguos. La asociación con los granitos puede estar bien definida o ser, por el contrario, incierta.

La forma de las rocas intrusivas asociadas es muy variable. Predominan las texturas plutónicas y neísicas. La composición de las rocas ígneas es generalmente granítica, con algunas alaskitas. Son frecuentes las aplitas, las pegmatitas y los granófidos. Su importancia económica es escasa. Ejemplos: Africa Central, escudo brasileño, y Sur de Rodesia.

TIPO 4.—*Rapakivis precámbricos*

Los yacimientos están asociados con granitos tipo rapakivi de zonas cratónicas antiguas. Este tipo puede ser considerado como un subtipo del 3. Las rocas ígneas son stocks formados por granitoides polifásicos con texturas graníticas o porfídicas. Las rocas intrusivas de la última fase están geoquímicamente especializadas en estaño. Su importancia es muy reducida. Ejemplo: Ladoga-Karelia (URSS).

TIPO 5.—*Bushveld*

Los yacimientos se encuentran únicamente en el Complejo de Bushveld, donde están asociados a los términos graníticos de las intrusiones bandeadas, básicas, de las zonas cratónicas antiguas.

Las rocas ígneas asociadas son granitos tabulares, estratiformes, asociados a rocas volcánicas y piroclásticas félsicas, que fueron intruidas por stocks graníticos y que yacen sobre gabros y noritas. Su importancia económica es muy pequeña, especialmente en los yacimientos secundarios.

# ASPECTOS GEOQUIMICOS DE LA EVOLUCION Y MINERALIZACION DE LOS GRANITOS ANOROGENICOS MESOZOICOS DE NIGERIA

PETER BOWDEN

(RESUMEN)

Los complejos anulares anorogénicos, mesozoicos, del norte de Nigeria, están compuestos por rocas graníticas de ascendencia sienítica. Los estudios de campo y los datos geoquímicos sugieren que los granitos peralcalinos y peralumínicos se desarrollaron consecutivamente, lo que implica que cada uno de ellos tiene tendencias propias que dieron lugar a diferentes fluidos mineralizadores residuales. Los granitos con mineralizaciones de Nb-U y Zn-Sn tienen una relación isotópica $^{87}Sr/^{86}Sr$ inicialmente alta (0.752), mientras que los otros granitos relacionados con ellas, y las sienitas muestran valores intermedios (0.706-0.709) o bajos (0.704-0.706), respectivamente.

Los datos geoquímicos sugieren, pues, que tanto el manto como la corteza inferior y la superior siálica han contribuido para producir los granitos jóvenes de Nigeria y sus mineralizaciones.

# MINERALIZACIONES ASOCIADAS CON LOS COMPLEJOS ANULARES MESOZOICOS DE NIGERIA

JUDITH A. KINNAIRD

(RESUMEN)

Los granitos anorogénicos jóvenes del Norte de Nigeria han evolucionado según dos tendencias petrográficas independientes, y cada una lleva asociada una mineralización diferente. Los de tendencia peralcalina muestran preferentemente una fase mineral dispersa, mientras que los granitos biotíticos tienen una fase inicial dispersa, en la que la columbita puede ser importante, y otra posterior, rica en sulfuros y casiterita, correspondiente a una etapa filoniana tardía. En esta fase, el zinc es un elemento más abundante que el estaño, mientras que el wolframio juega un papel menos importante que el que le atribuyeron los primeros autores. También se ha observado la presencia de abundantes minerales metálicos accesorios asociados a la fase mineralizadora en la que se depositaron la casiterita y la columbita.

# TIPOS DE ROCAS ESTANNIFERAS EN COREA

Soo Jin Kim

(Resumen)

Los yacimientos de estaño de Corea se encuentran en la región centro-oriental de Corea del Sur, asociados a una estructura anticlinal de edad precámbrica.

Las rocas pertenecientes a esta estructura han sufrido un fuerte metamorfismo. En la parte norte del anticlinorio aparecen formaciones del Peleozoico y Mesozoico, mientras que al sur del mismo solo hay rocas del Mesozoico. Dentro de este área se han emplazado intrusiones graníticas de diferentes edades.

De acuerdo con su génesis, los yacimientos de Corea se pueden agrupar en los siguientes tipos:

A) Diseminaciones magmáticas

*Albititas y cuarzo-albititas.* Consisten en cuerpos tabulares, raramente diques, que aparecen en el contacto de los gneises graníticos y los esquistos. La potencia de la zona mineralizada varía entre 0.3 y 15 metros. Normalmente hay greisen. Las rocas están formadas sólo por albita o por albita con cuarzo sericita, y casiterita diseminada.

*Greisen.* Se desarrolla en el contacto de las albititas y los esquistos. El greisen está formado por sericita y cuarzo, con cantidades variables de casiterita, lepidolita, berilo, scheelita y fluorita.

B) Formaciones pegmatíticas

1. *Pegmatitas y aplitas* que cortan o son paralelas a las rocas encajantes. Su potencia varía entre 0.3 y 18 metros, y la longitud de 10 a 600 metros. Estas rocas están formadas por cristales muy grandes de cuarzo, microclina y moscovita, a los que acompañan en menor proporción casiterita, turmalina y scheelita. Las pegmatitas están muy desarrolladas en el área de Sandong.

C) Formaciones hidrotermales

Filones y chimeneas con sulfuros.

Stvdia Geologica, XIV, 1978 (119-143)

# CLASSIFICATION CRITERIA OF TIN, TUNGSTEN AND MOLYBDENUM DEPOSITS (convenor's report)

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## INTRODUCTION

One of the aims of the IGCP project «Metallization associated with acid magmatism» is to establish an internationally agreed classification of tin, tungsten, molybdenum and related deposits. This review is intended not only to discuss the diverse classifications at present in use but also to clarify the different genetic interpretations which widely exist. These interpretations differ in the weight each gives to certain criteria on the basis of which tin, tungsten and molybdenum deposits are divided and subdivided.

This review was prepared on the basis of available literature as well as from contributions received by the convenor from C.L. Sainsbury, R. Taylor and K. Denisenko and D. V. Rundkvist, members of the international working group «Mineralization associated with acid magmatism».

## HISTORICAL BACKGROUND

Scientific classifications of ore deposits have existed since the middle of the last century, and have played an essential role in the presentation of the main principles of the current theories on the genesis of ore deposits. Tin deposits were among those that strongly influenced the development of these classifications, as they were actively mined in the nineteenth century and are characterized by a specific geological position in relation to igneous rocks. Tungsten and molybdenum deposits were not classified until this century but the same principles were used as those applied to tin deposits.

The earliest classifications of ore deposits can be traced to the early textbooks on economic geology which were published during the latter half of the 19th century. Among the first classifications are those by v. Cotta (1859), v. Groddeck (1879), Phillips (1884), Pošepný (1893), Fuchs and

DE LAUNAY (1893). The most significant step in the development of modern principles in economic geology was the presentation of the ideas by POŠEPNÝ (1893) followed by the discussion in 1901 in POŠEPNÝ'S volume (NOBLE 1955).

This trend in the application of predominantly genetic ideas of classification was followed in Europe in many economic geology textbooks, e.g. those written by STELZNER, BERGEAT (1904-06), BECK (1903), BEYSCHLAG, KRUSCH and VOGT (1914), DE LAUNAY (1913). In the U.S.A. LINDGREN (1907) played a prominent role in the development of present classifications. He later elaborated his early work and presented it as a textbook in 1933. This book is still in use.

European schools of economic geology were strongly influenced by the ideas of NIGGLI (1929) which were later elaborated by SCHNEIDERHÖHN (1941). A full discussion of the classification criteria of magmatic deposits was given by NIGGLI (1941).

In the U.S.S.R. a genetic method of classification of ore deposits was outlined in the textbook by OBRUCHEV (1928). The classification criteria presented by NIGGLI (1941) were critized by SMIRNOV (1947). In the post-war period several new classifications were proposed by TATARINOV and MAGAKYAN (1949), ZAKHAROV (1953), ABDULLAEV (1954), VOL'FSON (1953), KARASIK (1963) which discussed in general the classifications of the magmatogenic deposits.

A general discussion on the problem of the state of the classification of ore deposits was written in the anniversary volume of Economic Geology by NOBLE (1955). The particular aspect of tin deposits was treated in the volume «Geology of Tin» edited by SMIRNOV (1947), where general problems in the classification of tin deposits were discussed by LEVITSKII (1947a), the classification of tin-bearing pegmatitic formations by STREL'KIN (1947), of cassiterite-quartz formations by LEVITSKII (1947 b), and of cassiterite sulphide formations by RADKEVICH (1947). This is the most complete treatment in the classification of tin deposits ever published. A classification of lode tin deposits was reviewed by SAINSBURY and HAMILTON (1967), who distinguished pegmatite, contact-metamorphic deposits, pneumatolytic-hydrothermal deposits, subvolcanic or tin-silver deposits, fumarole deposits and disseminated deposits.

A recent classification of tin deposits was published by VARLAMOFF (1975) who summarized his great practical experience of tin deposit exploration, mainly on the African continent. The classification of tungsten deposits was prepared by DENISENKO (1975) and that of molybdenum deposits by KHRUSHCHOV (1961).

TABLE I

*Classification criteria used by various authors*

| AUTHOR | FIRST DIVISION | SECOND DIVISION | THIRD DIVISION |
|---|---|---|---|
| Fuchs, de Launay (1893) | chem. element | geol. position | |
| Pošepný (1902) | geol. position (geol. environment and tectonics) | geol. position (igneous rocks) | |
| Stelzner, Bergeat (1904-1906) | geol. position | state of the solution | ore associations |
| Lindgren (1933) | temperature (depth region) | ore types | |
| Schneiderhöhn (1941) | state of the solution | geol. position (intrusive of subvolcanic) | ore formations |
| Levitskii (1947) | ore formations | | |
| Sainsbury, Hamilton (1947) | geol. position | state of the solution | |
| Tatarinov, Magakyan (1949) | geol. position (depth of the formation) | temperature | ore associations and ore formations |
| Abdullaev (1954) | geol. position (type of the contamination of intrusive and position to intrusive body) | state of the solution (pegmatites or hydrothermal) | ore formations |
| Vol'fson (1926) | geol. position (development of magmatism) | wall-rock alteration | ore formations |
| Karasik (1963) | state of the solution (pegmatite, contact, hydrothermal) | geochem. association | ore formations |
| Radkevich (1968) | ore formations | | |
| Denisenko (1975) | geol. position (igneous rocks) | ore formations | |
| Štemprok (1976) | geol. position (igneous rocks) | mineralization processes | rock environment |
| Taylor (1976) | geol. position (major geol. units) | geol. position (igneous rocks) | |

## CLASSIFICATION CRITERIA

The classification of ore deposits has always been problematical. The form of the deposit and the purpose for which the deposit was economically exported were important criteria in the earliest classifications. These are essentially artificial aspects which can be related only in a broad sense to genesis.

Within the later genetic classification a set of variables can be defined, measurable directly or indirectly. Those parameters which are directly measurable include relative geological position of an intrusive body and mineralogical composition of the deposit. Parameter which are indirectly measurable include the depth of the deposit, the temperature of the ore-bearing fluid, its composition, pressure and state (table I).

NIGGLI (1941) used the following criteria 1) The source of ore-bearing solutions. 2) The location of the ore deposit relative to a) the surface, b) the source of ore-bearing solutions and c) the wall rocks. 3) The temperature of the primary process in the formation of the ores. 4) The temperature range of the main stage of the ore formation.

SMIRNOV (1947) in his criticism of the criteria used in NIGGLI'S classification suggested the following revision: 1) character of the physico-chemical system giving rise to ores, 2) ore formations, 3) depth of the origin of ore deposits, 4) temperature of the main stage of ore deposition. NOBLE (1955) defined four variables for the classification of ore deposits among which are the composition of ore-bearing fluids, temperature and pressure of the system and the composition of intruded rocks. However, the main parameter defined by NOBLE (1955) is the composition of the ore-bearing fluid, the variation of which is reflected in the changing ore association of deposits.

A. D. MUTCH (1956) suggested that a more effective system of classification should give greater stress to 1) the relative position of the ore minerals in the standard paragenesis; and 2) the observed association of the various metals to particular igneous rocks and the intimacy of this association. He concluded that a more effective system of classification of ore deposits in general and those of magmatic affiliations in particular should be based on all recognizable geological variations as far as possible, free of any terminological or artificial theoretical divisions.

## VARIABLES USED IN CLASSIFICATIONS

The form a mineral body or of a deposit was employed as a parameter in the earliest classifications. It is directly measurable, fairly objective and is of practical value for the exploration and mining of an ore deposit.

It was used by Agricola, then in the modern era by v. WALLENSTEIN (1824) (quoted by BECK 1903) and used as a main classification parameter by v. COTTA (1859). VON COTTA distinguished regularly formed deposits (ore sills and veins) and irregularly formed deposits (impregnations and stockwerks). In the classification suggested by BATEMAN (1950) relatively recently, the form of ore bodies was again applied as a main variable.

Tin, tungsten and molybdenum deposits are usually not found as true infillings of the vein fissures but in many types as metasomatic bodies whose form is considerably variable. If the differing shape of a deposit is used as a parameter the categories proposed by SAINSBURY (1976) may be used. He distinguishes: 1. a) greisens, b) veins, c) skarns, d) disseminated cassiterite in granitic rocks, e) stock-works in the case of a tin deposit. Sainsbury further suggests genetic criteria for the division of additional groups: 2. Tin-bearing massive sulphide ore bodies. 3. Pegmatites of large size not contained within a «mother» intrusive. 4. Tin-bearing rhyolites and rhyolite domes (extrusives). 5. Sedimentary or metamorphic rocks containing tin as an original detrital constituent of potential ore grade. 6. Lode deposits of base metals in which tin occurs merely as a minor constituent or a mineralogical curiosity.

## METAL

A classification of the deposits according to the metal for which they are mined was used by DE LAUNAY (1913) and recently by PETRASCHECK (1961). The classification of PETRASCHECK (1961) was based on that devised by SCHNEIDERHÖHN and incorporating modifications suggested by CLAR, and MAUCHER. This parameter of the principal metal has a certain genetic significance, since many metals of the same chemical properties occur together also in mineral deposits. However, it cannot be regarded as a genetic criterion and should be placed among the artifical variables.

## DEPTH OF THE ORIGIN

The depth factor in the formation of the deposit has been considered as a variable in classifications in terms both of the real vertical extension from the surface and of the probable temperature and pressure gradients in a particular depth zone.

In fact NOBLE (1955) has called the classification proposed by LINDGREN as the «depth-zone classification» even though it is based mainly on the temperature variable.

SCHNEIDERHÖHN (1941) gives the following division of deposits relative to the depth of the formation: abyssal, 6 to 10 km from the surface; hypoabyssal, 2-6 km; subvolcanic, less than 2 km; volcanic, on the surface.

A similar division was presented by NIGGLI (1941) who according to the place of the origin of a deposit toward the surface differentiated:

$\alpha$ areal-subareal or subcrustal (on the surface)
$\beta$ subaquatic (marine or lake)
$\mu$ epicrustal (near the surface)
$\delta$ hypoabyssal
$\epsilon$ abyssal

SMIRNOV (1974) considers the depth of formation of a deposit to be of primary importance, and this may be a valid concept in current classifications since the depth of formation of the deposits probably corresponds to pressure during ore deposition.

TATARINOV and MAGAKYAN (1949) based their classification on the depth of formation of the deposits:

a) shallow depths (hundreds meters to 1 km)
b) intermediate depths (from 1 to 3 km)
c) considerable depths (more than 3 km)

The depth factor introduced by TATARINOV and MAGAKYAN was criticized by VOL'FSON (1953) who doubted the validity of depth as a parameter for classification.

VARLAMOFF (1975) based his classification both on the depth of the intrusion and on the depth of related deposits. He divided the deposits into: abyssal, 8000 to 7000 m; lower mesoabyssal, 6000-5000 m; upper mesoabyssal, 4000-3000 m; hypoabyssal, 2000 m; subvolcanic, 1000 m; and surface deposits, formed from 500 to 0 m under the surface. As the second main parameter he used the mineral content of the deposits.

## GEOLOGICAL DEVELOPMENT

Many criteria do not take into account total geological development. They consider the evolution of a particular geological enviroment. VOL'FSON (1953) classified 3 groups of ore deposits associated with granitoids:

1. hydrothermal deposits formed at an earlier stage in the development of a magmatic chamber.
2. deposits formed at a late stage of the origin of a magmatic chamber.
3. deposits formed in the late stage of the origin of a magmatic chamber, found in regions where granitoid outcrops are absent.

ITSIKSON (1967) separated the deposits according to their position and development in the mobile zones. She distinguished between mobile zone regions in the middle and late stages and regions of tectonic and magmatic reactivation. Within the deposits in the mobile zones, late stage hypoabyssal intrusions of complex composition are associated with deposits of quartz-silicate and cassiterite-quartz formations (see definitions later). Batholitic intrusions of acid and ultra-acid granitic composition are typical of the middle stages in develonpment of these zones, and contain associated cassiterite-quartz deposits, tin-bearing skarns, and tin-bearing pegmatites.

Regions of tectonic and magmatic reactivation produce small, near-surface intrusions associated with acid or intermediate effusives which are responsible for the origin of the deposits of sub-volcanic group. Subaereal effusions and extrusions of rhyolites give rise to the volcanic group of deposits.

Korolev and Shekhtman also distinguish between ore fields in the mobile zones and those found on platforms (quoted by Karasik 1963).

The criterion of geological development within a particular province is applied by Taylor (1977-this volume) who differentiated:

1) tin deposits associated with granitoids which show a close spatial and temporal relationship with a major period of orogeny (Fold belt type). Granitoid emplacement is predominantly post major folding.
2) Tin deposits associated with granitoids emplaced via major zones of fracturing in cratonic shield areas (Anorogenic).
3) Tin deposits associated with pegmatites in ancient metamorphic cratogenic terrains (Precambrian pegmatitic).
4) Tin deposits associated with rapakivi granites in ancient metamorphic cratonic areas (Precambrian rapakivi).
5) Tin deposits associated with granitoid members of layered mafic intrusives in ancient metamorphic cratonic terrains (Bushweld).

## Relationship towards intrusive rocks

The common association between tin, tungsten and molybdenum deposits and acid igneous bodies led to the introduction of igneous body proximity as a criterion in many classifications. Pošepný (1902) differentiated between: ore veins in stratified rocks, ore veins in the neighborhood of eruptive masses and ore veins wholly within large eruptive formations.

Schneiderhöhn (1941) made a distinction between the deposits related to plutonic and subvolcanic intrusives and also the exhalation group of deposits. Plutonic intrusions are responsible for the origin of the hypoabyssal series of deposits while subvolcanic intrusives form a subvolcanic series of deposits. In the same line of reasoning Niggli (1941) distinguished the following group of deposits, according to the origin of ore-bearing solutions: I volcanic, II subvolcanic, III plutonic, IV deep plutonic.

However, in his classification the deposits are also defined, according to their position relative to the parental magmatic body, into a) telemagmatic, b) cryptomagmatic, c) apomagmatic, d) perimagmatic, e) intramagmatic. Intramagmatic deposits are largely contained by intrusive rocks belonging to the identical interval of ore formation. Perimagmatic deposits are near the contact of various bodies in an intrusive igneous complex belonging to the same period of magmatic activity. Apomagmatic deposits do not possess an obvious relationship to intrusive rocks in the form of dykes or to contact metamorphism belonging to a corresponding period of magmatic activity. Crypto and telemagmatic deposits have a hypothetical relationship to large masses which are at depth and are not manifested on the present surface.

The separation of the deposits on the basis of the character of the composition of associated intrusive rocks was made by ABDULLAEV (1954). He defines two types of postmagmatic deposits associated with acid intrusives:

1) Postmagmatic deposits associated with intrusives of intermediate depths which show sign of carbonate-iron-magnesia and rarely carbonate-alumosilicate assimilation (granitoids of elevated basicity). This series is represented by skarn ore deposits which are regionally accompanied by hydrothermal sulphide deposits with base metal sulphides, siderite, hematite, etc.

2) Postmagmatic deposits associated either with intrusives with alumosilicate assimilation or with deeper-seated weakly contaminated intrusives (granites, alaskites, etc.). In contrast with the former, this series is represented by pegmatites and various hydrothermal deposits, consisting of quartz-cassiterite and carbonate-cassiterite deposits. This genetic series was formed by the participation of silica, water, fluorine and some mineralizers.

The individual categories are given in tables II and III.

The division of hydrothermal deposits according to their relationship with intrusive rocks is a variable also employed in the classification suggested by ABDULLAEY (1954) who differentiated deposits of the intrusive zone, near-intrusive zone, over intrusive zone and deposits in a remote zone.

The relative position of deposits and igneous bodies is an important parameter which may be used in the category of measurable parameters. However, the relationship of many deposits to adjacent igneous bodies is disputable and the measure of the direct and indirect relationships of certain

TABLE II

*Classification of postmagmatic deposits associated mainly with acid intrusives (deep-seated, weakly contamined or with a weak alumosilicate contamination)*
(after Kh. M. ABDULLAEV, 1954)

| GENETIC CLASSES AND TYPES | MAIN ORE FORMATIONS |
|---|---|
| I. Pegmatitic deposits........... | formations of pegmatites according to A. E. Fersman |
| II. Hydrothermal deposits: | |
| a) intrusive zone ........... | 1) quartz-greisen-wolframite<br>2) quartz-greisen-wolframite-cassiterite<br>3) quartz-greisen-cassiterite<br>4) quartz-greisen-molybdenite |
| b) near-intrusive zone ...... | 5) quartz-molybdenite<br>6) quartz-chalcopyrite-molybdenite<br>7) quartz-arsenopyrite (?) |
| c) over-intrusive zone ...... | 8) carbonate-cassiterite (?)<br>9) bismuth (?) |
| d) with no intrusive zone. | ore formations not clear owing to the difficulty in establishing a genetical association with certain intrusives |

groups of deposits to the igneous activity belongs to not fully clarified questions.

TAYLOR (1976) utilises the position of an ore deposit relative to igneous rock bodies as a criterion to subdivide the deposits of the fold belt type. He distinguished a) tin concentrations associated predominantly with extrusives and pyroclastics, b) tin concentrations associated with intrusive complexes of subvolcanic nature occurring in association with terrestrial extrusives, c) tin concentrations associated with intrusive complexes of mixed character, i.e. representing a deep subvolcanic to high plutonic environment, d) tin concentrations associated with intrusive complexes of plutonic character.

TABLE III

*Classification of postmagmatic deposits of the genetic series associated with intrusives of elevated basicity (less deep-seated with signs of carbonate, iron-magnesium and mixed contamination)* (after ABDULLAEV, 1954)

| GENETIC CLASSES AND TYPES | MAIN ORE FORMATIONS |
|---|---|
| I. Skarn deposits | 1) Skarn magnetite<br>2) Skarn magnetite-scheelite (very rare)<br>3) Skarn scheelite<br>4) Skarn scheelite-sulphide |
| II. Hydrothermal deposits: | |
| a) near-intrusive zones | 1) Quartz-cassiterite-sulphide<br>2) Quartz-arsenopyrite (?)<br>3) Quartz-scheelite-gold-bearing |
| b) over intrusion zone | 4) Quartz-sphalerite-galena-cassiterite<br>5) Quartz-chalcopyrite-sphalerite<br>6) Quartz-fluorite-sphalerite-galena<br>7) Siderite<br>8) Quartz-gold-bearing |
| c) remote zone | 9) Quartz-barite-calcite-galena in limestones (?)<br>10) Galena-silver (?)<br>11) Fluorite and fluorite-barite |

## ORE FORMATIONS

The term «vein formation» was first used by WERNER (1791) who divided all known veins into groups of ore formations which he characterized according to a particular association (Gesellschaft) of ore and gangue species. FREIESLEBEN (1843) defined vein formations as those belonging to veins of various «fossils» which occur everywhere together, mainly under the same conditions and thus may be considered to be of the same type of formation.

Tin veins are not typical of the Freiberg district and thus were not considered in the classifications of vein formations suggested by WERNER and VON HERDER. However, FREIESLEBEN in his study on the formation of the Erzgebirge (Krušné hory) defined 15 tin formations and one copper-tin formation (quoted by von WEISSENBACH 1847).

The regularities not only in the mineral association but also in the sequence of the mineral formation were stated by VON COTTA (1854) who wrote:

«Das Zusammenvorkommen wie die Aufeinanderfolge der Mineralien in Gängen und Drusen sind nicht zufällig sondern in gewissen Grade gesetzmässig».

«Man kann daher Mineralverbindungs —und Reihenformeln (Combinations— und Successionsformeln) construiren, und dabei von den speziellen Fällen ausgehend durch ihre Verbindung nach und nach zu immer allgemeineren Resultaten gelangen.

Bei der Betrachtung solchen sich oft wiederholender Combinationen und Reihen von Mineralien drängt sich nothwending die Frage nach ihre Ursachen auf. Die Ursachen scheinen nun zwar mehr chemischer als geologischer Natur zu sein.»

Beck (1903) separates formations (Formationen A) with mainly oxidic ores including «veins of tin-ore» from formations with mainly sulphidic ores (B).

Schneiderhöhn (1941) uses the term formation not only with respect to the mineralogical association of the ores but also with regard to the probable state of the ore-bearing solution. He distinguishes pneumatolytical formations in the narrow sense and within this formation he defines a series of deposits and veins, e.g., ore-free pneumatolytical quartz veins, pneumatolytical tin deposits, pneumatolytical wolframite deposits, pneumatolytical molybdenum deposits, tourmaline gold quartz veins, tourmaline chalcopyrite veins, tourmaline bismuth veins, tourmaline quartz veins with other ores.

According to Smirnov (quoted by Vol'fson 1962) ore formations are identical associations of minerals formed in similar geological enviroment independent of the age of mineralization.

The classification of Zakharov (1953) was based on the concept of mineral formations, and Magakyan (1950) defined a total of 42 families of ores (semeistvo) which are further subdivided into 35 types.

For tin deposits the most elaborate and widely used classification in the U.S.S.R. is that introduced by Levitskii (1947) who suggested the division of endogenous tin deposits into three main formations which are subdivided into ore types and further into subtypes.

This division is as follows:

Formation of tin-bearing pegmatites

1) Type quartz-microcline
    a) subtype muscovite-albite
    b) subtype topaz-muscovite-albite

Quartz-cassiterite formation

1) Type tin-bearing greisens
2) Type topaz-quartz

3) Type feldspar-quartz
4) Type quartz

Cassiterite-sulphide formation

1) Type tin-bearing skarns
   a) subtype magnetite
   b) subtype sulphidic
2) Type tourmaline-sulphidic
3) Type chlorite-sulphidic
4) Type galena-sphalerite

A detailed description of tin-bearing pegmatites was given by STREL'KIN (1947) who regards them as crystallization products of residual solutions in the range 800 to 400°C. Tin-bearing pegmatites are associated with apical parts or with elevations of granite intrusions. STREL'KIN defines a quartz-microcline type which is divided into 1a) albite-muscovite subtype, 1b) albite-topaz-muscovite (fluorine) subtype and secondly a quartz-microcline-spodumene type which is divided into a 2a albite-tourmaline (boron) subtype and 2b) albite-muscovite subtype. According to STREL'KIN the most significant processes which accompany the origin of tin-bearing pegmatites are albitization and greisenization. Albitization may be traced out in the form of clevelandite or as masses of «sacharoidal» albite.

The cassiterite-quartz formations are closely associated with granitic intrusions and can be further subdivided into definite types: greisens, which are separated by LEVITSKII (1947b) into intrusive greisens and replacement ones, i.e., quartz-topaz deposits which occur as veins and stockwerks and are typically infilled by quartz, topaz, muscovite, zinnwaldite, fluorite, occasionally with beryl and tourmaline, whilst the quartz-feldspar subtype can occur both as veins and stockwerks. Potash feldspar belongs to an earlier phase of crystallization in the veins and it is replaced by muscovite, chlorite, fluorite and low temperature varieties of tourmaline. Most of the deposits of this type are of the vein form.

Quartz-cassiterite type deposits are mostly associated with large massifs of relatively deep-seated granites, generally they form veins which may be extensive both along the strike and at depth. These deposits are characterized by a close genetic association with the granites of acid and ultraacid character. A detailed discussion of the deposits of cassiterite-sulphide formation was given by RADKEVICH (1947). She believes such deposits are associated with young folded areas and may be related to intrusives of elevated basicity including granodiorites and even quartz diorites.

Mineralogically, the deposits of this formation may range from tin-bearing skarns to tourmaline-sulphide and chlorite-sulphide deposits with sulphides of iron, and to deposits bearing galena and sphalerite.

Skarn deposits were formed by the action of emanations from a granitic magma on limestones and are composed of various kinds of silicates and alumosilicates. In their genesis the following stages of mineralization may be differentiated: marmorization, skarnization, followed by the formation of magnetite and sulphides. The skarn deposits can be well divided into magnetite and sulphide subtypes.

The tourmaline-sulphide deposits are represented mostly by veins and mineralized crushed zones in granites, and in sand-clayey rocks of the exocontact. The most typical minerals of these deposits are quartz, tourmaline and cassiterite which may be accompanied by large amounts of chlorite and sulphides.

The chlorite-sulphide deposits are characterized by iron-rich chlorite, iron sulphides and cassiterite. The deposits can be metasomatic veins, mineralized crushed zones and fissure infilling veins.

In the galena-sphalerite deposits the typical minerals, galena and sphalerite, may occur in two different subtypes of deposits either in limestones or as near-surface deposits. In the latter subtype various kinds of sulphostannates are characteristic thus making this subtype akin to the Bolivian type of tin deposits.

These classifications were later changed and the cassiterite-sulphide formation was split into cassiterite-silicate, cassiterite-sulphide and skarn formations (RADKEVICH 1968). The cassiterite-silicate formation includes those tin deposits which contain chlorite and tourmaline as the main gangue minerals. A similar classification of tin deposits was also employed by MATERIKOV (1964) who gives the following main features of these formations:

1) Tin-bearing pegmatite formations are typical of areas of earlier metallogeny and occur chiefly in shields. The bodies are irregular in form and may occurs as lenses or stocks.
2) Deposits of cassiterite-quartz formation characteristic of younger metallogenic provinces, mainly of Hercynian or Cimmerian age. Cassiterite-quartz deposits are associated with amall intrusive cupolas of acid composition.
3) Deposits of cassiterite-silicate and cassiterite-sulphide formation may be united into a cassiterite-silicate-sulphide formation. This latter varies in its relationship toward igneous intrusives and sometimes may be considered to be paragenetic (i.e. not directly derived from a nearby intrusive rock).

4) Tin deposits of the skarn formation are defined in a similar way as by earlier authors. These deposits are of a little economic significance.

KRYLOVA (1972) adopted a similar classification which proved to be useful for the purposes of exploration. She defined the following four groups of endogenous tin deposits:

Group 1: formation of tin-bearing granites
pegmatite formation
cassiterite-quartz formation

Group 2: deposits of cassiterite sulphide formation in skarns and limestone. There are both magnetite and sulphide types in tin-bearing skarns.

Group 3: deposits of cassiterite-sulphide formation which may be divided into tourmaline-chlorite and sphalerite-galena types (with sulphostannates).

Group 4: This group contains the deposits associated with rhyolites where tin ores appear as wood-tin.

MO-CHU-SUN (1957) proposed a classification of tungsten deposits based on the distinguishing of mineral systems. These systems are further subdivided into types of deposits. The pegmatite ore systems consist only of quartz-microcline whilst the wolframite-quartz system may be composed of a) greisen), b) feldspar-quartz, c) quartz, or d) stibnite quartz typs of deposits. The scheelite-quartz system however comprises, a) skarns, b) barite-quartz, and c) stibnite-native gold-quartz ore types.

The classification of tungsten deposits on the basis of formations was given by DENISENKO (1975) who defined plutonic, plutonic-volcanic and sedimentary metamorphic groups of formations according to the relationship to igneous rocks.

The plutonic formations consist of: A) skarn, scheelite-garnet-pyroxene, B) tourmaline-chlorite-gold-scheelite, C) greisen, wolframite-quartz formations.

The deposits of skarn-scheelite-garnet-pyroxene are localized in carbonate strata near the endocontact of intrusions generally of elevated basicity and their morphology is controlled by the shape of intrusive bodies. The deposits of the B formation are either within the granitoids or in the overlying rocks. They form veins which are closely associated with dykes of gabbro-diabases, diorites, porphyrites, granodiorite-porphyrites, etc.

The greisen, wolframite-quartz formation is associated with apical portions of the massifs of alaskite granites. Their vertical extent does not usually exceed 350 to 450 m.

The plutonic-volcanic group of formations includes the deposits which do not generally show a close relationship to intrusive magmatism. The deposits may have signs of a near-surface origin.

The plutonic-volcanic formation comprises:

D) The gumbeite scheelite-quartz-feldspar formation: which is regarded by some as a variety of greisen deposits. However, the author thinks that it is justified to separate this group from the preceeding one.

E) The deposits of the berezite-hübnerite-sulphide-quartz formation are characterized by fluorine minerals and sulphosalts of Cu, Ag and Pb.

F) The argillite ferberite-stibnite-chalcedony formation is associated with Mesozoic and Cenozoic acid magmatism.

Finally the sedimentary-metamorphic group contains: G) skarnoid scheelite-sulphide-quartz formation, H) tungsten-psilomelane and I) tungsten-halogenic formations.

Denisenko thinks that some deposits are composed of several of these formations. The interval between the appearence of these associations might have lasted several milion years. Thus a mineral formation should be taken as the classification unit.

In accordance with Rundkvist, Denisenko writes about isomorphic series of formations in which deposits of a particular formation pass through transition types into deposits of another one.

| Formation or hydrothermally altered rocks | Series of ore formations | | | |
|---|---|---|---|---|
| | Sn - W | Mo - W | Au - W | Sb - W |
| A Skarn .......................... | + | + | | |
| B Tourmaline - chlorite ...... | | | + | |
| C Greisen ....................... | + | + | | |
| D Berezite ....................... | + | | | |
| E Argillite ...................... | | | | + |

KHRUSHCHOV (1961) presented a most elaborate classification of molybdenum deposits. His principle division is also based on formation. He divides them as follows:

1) Molybdenite,
2) Quartz-molybdenite,
3) Molybdenite-scheelite in skarns,
4) Quartz-wolframite-greisen with molybdenite,
5) Quartz-molybdenite-sericite,

6) Quartz-molybdenite-chalcopyrite-sericite,
7) Pyritic with molybdenite,
8) Uranium-molybdenite.

A detailed description of the deposits of uranium-molybdenum was given by VLASOV et al. (1966). These deposits are formed at the end of magmatic activity and typical there is a paragenetic association of pitchblende with colloform molybdenite-jordisite. The deposits form veinlet-impregnations, stockwerk and fissure veins.

### GEOCHEMICAL ASSOCIATION

A more sophisticated classification has been elaborated using the combination of chemical elements as a classification criterion. In this sense KARASIK (1963) subdivided the classes of his classification into types of hydrothermal ore fields where the association Sn, W, Mo, Bi, Be, Ta, Nb, Pb, Zn, Cu, Ag, Au, As, Sb, S, Te, Se, B (Co, Ni) is characteristic of the molybdenum-tungsten-tin ore field type.

### AFFINITY OF THE ELEMENTS

The concept of the chemical affinity between the elements was reflected in the early genetic classifications presented by the authors of the first half of the last century. DAUBREÉ (1841) noted that all known tin deposits are characterized by increased amounts of fluorine. Tin fluoride, which is volatile and can be transported from the depths was regarded as a stable compound at all temperatures. The same was probably true, in Daubreé's opinion, of tungsten and molybdenum. Boron was also known to form thermally stable compounds which are also volatile. Daubreé thought that these vapours were generated at considerable depths and that they ascended towards the surface through fissures, depositing their load of metalliferous matter partly as veins in the fissures (CROOK 1933) and partly as impregnations in the surrounding rocks.

The idea of the extraction of tin and associated metals was later mainly extended by VOGT (1894) who characterized cassiterite veins as fluorine and boron extraction of Si, Sn, K, Li, Be, W, U, V, Ta, F, B in contrast with the association of apatite veins in which the extraction derived from gabbros was governed by the action of chlorine.

These opinions led to genetic concepts of the special nature of the gaseous character of ore-bearing solutions which gave rise to tin ore and associated deposits. BEYSCHLAG, KRUSCH and VOGT (1914) in their textbook characterized the origin of tin deposits as an extraction of certain elements such as tin, tungsten, etc. from acid magmas by fluorine. They called this process «pneumatolysis» and understood it to be the sum of mineralization processes in which gases and vapours played an essential part.

## State of the solutions

The employment of the physico-chemical state of ore-bearing solutions as a variable was one of the most significant steps in the introduction of modern parameters in the present classifications.

These ideas gradually arose from the concept of chemical affinity of elements but was altered to the present concept mainly due to the study of systems containing volatile and non-volatile constituents as given by Niggli (1920). Niggli supposed a gradual accumulation of volatile contituents by the progressive crystallization of silicates in magma and its continuous migration to the wall rocks or fissures.

He wrote: «Wird nun durch die äussere Erstarung zeitweise die Innenpartien von der Aussenwelt abgeschlossen, so reichen sich darin die leichtflüchtigen Bestandteile stärker an, und ein an gewissen Bestandteilen konzertrierten Nachschub kann nach einer Ruhezeit erfolgen. Das wäre eine typisch nachpneumatolytische Erscheinung. Die Pneumatolyse zeigt ausgesprochener sauren Character. Vogt spricht von einem aciden Extract. Es ist wahrscheinlich dass die Anreicherung an $H_2O$, und zwar freien $H_2O$, im Magma die Hauptveranlassung dazu ist. So destillierte eine an leichtflüchtigen Fluoriden und Chloriden reiche, gasförmige Phase in die Kontaktionrisse der bereits erstarrten Granite über.»

An idea that has been popular in Europe is that tin, and associated ores, was deposited from a gaseous state or from a supercritical water solution whilst the mainly sulphidic assemblages were deposited from hydrothermal liquid solutions. This idea has been put forward in many books and papers on economic geology (Schneiderhöhn 1941, Schröcke 1954, Petrascheck 1961, Tanatar 1959 and many others).

However, the concept of differentiation between the gaseous and liquid state of the ore-bearing fluid was criticized by Lindgren (1928) and has never been accepted as a classification criterion by North American geologists. Smirnov (1947) also refused to accept the term «pneumatolytical» since he believed that distinguishing a pneumatolytical phase is not appropriate. He felt that «it is better to combine pneumatolytical and hydrothermal deposits into a single hydrothermal group calling them simply a group of postmagmatic depth formations (in contrast to exhalation ones)».

The fact that the terms «hydrothermal and pneumatolytical are not of a single sense is expressed also by SCHNEIDERHÖHN and BORCHERT (1956) who state from the general discussion: «Ferner müssen wir daran denken, dass die Begriffe hydrothermal pneumatolytisch usw. ja doppelsinning sind. Einderseits sind es Temperaturbegriffe und anderseits sind sie mit geologischen Zustandbedingingen verknüpft, d.h. mit gewissen Phasen innerhalb des Festwerdens und der Nachgeschichte eines Eruptivmagmas (Schneiderhöhn)».

A discussion on the inclusion of a pneumatolytical phase in the classification of postmagmatic processes was also held at a symposium in Prague where both the opinions for and against its application were delivered in several lectures (INGERSON 1963, ŠTEMPROK 1963, OVCHINNIKOV 1963, ŠTEMPROK, VANEČEK 1963).

## TEMPERATURE OF DEPOSITION

Temperature as the most important variable in the classification of ore deposits was introduced by LINDGREN (1907 and 1933) who distinguished hydrothermal deposits in the following groups:

a) those formed by ascending waters which were further subdivided into:

1) epithermal deposits with the temperature interval 50-200°C, and medium pressures,
2) mesothermal deposits - temperature 200-300°C, and high pressures,
3) hypothermal deposits - temperature 300-500°C and very high pressures,

b) those formed by magmatic emanations which were further subdivided into:

1) pyrometasomatic - temperature 500-800°C and very high pressures,
2) sublimates - temperature 100-600°C and the pressure from low to medium.

Lindgren in his textbook of economic geology places tin deposits among the hypothermal veins where he defines classes of deposits as tin veins, wolframite veins and molybdenite veins.

SCHNEIDERHÖHN (1941) further subdivided Lindgren's hypothermal deposits into «katathermal 370-300°C and pneumatolytical 500-370°C».

FERSMAN (1955) distinguishes within the ore-bearing process an epimagmatic stage, pneumatolytical, hydrothermal, and supergene stages.

He further classifies these stages according to the temperature interval, between 800-600°C as epimagmatic, 600-400°C as pneumatolytical and 400-100°C as hydrothermal. He used the term «geophases» ranging from A in epimagmatic to L in supergenes processes. The pneumatolytic stage 600-400°C is with geophases B, E, F, and the hydrothermal stage 400-200°C with geophases H, I and K.

Similarly TATARINOV and MAGAKYAN (1949) divide the processes of ore deposition into:

a) high-temperature processes - more than 300°C
(mainly 350-500°C)

b) medium-temperature processes from 200 to 300°C

c) low temperature - less than 200°C

NIGGLI (1941), in contrast to Lindgren and Schneiderhöhn, introduced as classification parameters:

1) high-temperature-deposits (formed from the temperatures characteristic of the origin of igneous rocks) to 350°C

2) medium-temperature from 350 to 200°C

3) low-temperature from 200°C and lower.

SMIRNOV (1947) accepts the characteristics of Niggli's temperature range as more realistic than that in the terminology of hypo-meso and epithermal.

He writes: «Full consent may be expressed with similar terminology (Niggli's suggestion - ed.note) as the expressions hypo-meso- and epithermal, according to their original sense, should include at the same time both the data on depths as well as on the temperature of the formation of a particular deposits».

This is also in accordance with the original concept of Lindgren where the introduction of the temperature intervals was classified as the depth classification.

## WALL ROCK ALTERATIONS

The character of the wall rock alteration is not generally used as a classification variable even if it is clear that it shows the composition of the mineralizing fluid perhaps better than the association of minerals.

VOL'FSON (1953, 1962) distinguished seven main types of wall rocks alterations at the contact of ore veins which could be used as a basis for the division of hydrothermal ore deposits. These alterations make it possible to define the most characteristic types of ore deposits as follows: skarns, greisens, berezites, silicified rocks, chloritized and sericitized rocks, as well as the rocks subjected to carbonatization and propylitization.

TABLE IV

*Types of hydrothermal deposits in relation to the composition of hydrothermally altered wall rocks* (VOL'FSON 1953, 1962)

| TYPE | CHARACTERISTICS |
|---|---|
| I | Deposits accompanied by the greisenization of wall rocks |
| II | Deposits in skarns |
| III | Deposits accompanied by the berezitization of the enclosing rocks in pure state or with a superimposed chloritization |
| IV | Deposits accompanied by the silicification of enclosing rocks |
| V | Deposits accompanied by the sericitization and chloritization of enclosing rocks |
| VI | Deposits accompanied by dolomitization or ankeritization of carbonate or weakly sericitized and silicified of silicate enclosing rocks |
| VII | Deposits accompanied by the propyllization of enclosing rocks |

Berezitization was active in granitoids, acid effusives and in tuffs and also in arkoses, sandstones, conglomerates and similar rocks. It is characterized by the replacement of feldspars by sericite and quartz and of the dark minerals by pyrite and partly by chlorite.

D. I. GORZHEVSKII (1962) also arrived at the conclusion that the classification of endogenous deposits should be based on geological and mineralogical principles rather than on the physico-chemical ones. He proposed a classification based on formations which are characterized as mineralogical associations developed in a particular geological environment. He also considers as a parameter the character of the enclosing rocks and wall-rock alterations associated with these formations. A secondary feature is the morphology of ore bodies.

The table proposed by Gorzhevskii uses two main parameters a) wall-rock alterations and b) wall-rock characteristics. Within the category of the wall-rock alteration he distinguishes I) skarnization, II) greisenization, III) chloritization (Fe-Mg metasomatism), IV) sericitization (K-metasomatism), V) dolomitization and silicification, VI) kaolinization and alunitization, VII) propyllitization, VIII) deposits without a significant wall-rock alteration. The main wall rock types are grouped into sandy-shale deposits, volcanic hypoabyssal rocks of acid composition, volcanic rocks of basic and intermediate composition, granitoids, carbonate rocks. Within these «coordinates» Gorzhevskii defined a total of 23 ore formations.

### Discontinuous mineralization

The fact that the ore deposits are not formed by a continuous flow of solution but by discrete inflows of solutions was discussed by many authors mainly in the post-war period. Noble (1955) stressed that the incorporation of the mineral association as a main parameter is in agreement with the concept of mineralization stages which reflect the changing character of the ore-bearing fluid in time. Thus, the mineral association reflects the chemical composition of the fluids in a particular mineralization stage from which this association was formed.

The separate mineralization processes are considered as the main parameters in the classification proposed by the author of this review (Štemprok 1963, 1976) whose detailed description is presented also in this volume. The concept (Štemprok 1976) differs from the formational classification in that it assumes a relativelly simple composition of mineralization stages. Practically all the deposits of the type considered are composed of the products of many of these mineralization stages while pure types are almost absent. Important mineralizations stages are pegmatitization, (skarnization), feldspatization, quartz formation, greisenization, tourmalinization, chloritization, sericitization, argillization. The superrimposition of the stages in a deposit can be represented diagramatically.

## DISCUSSION

The comparison of various criteria used by the authors of classifications throughout the whole history of modern science shows a considerable diversity of opinion. In contrast to other natural sciences the classifications did not utilise a uniform nomenclature for the main chategories used in these divisions and alternated arbitrarily between «groups», «formations», «types», «subtypes», and «classes».

The main problem is the introduction of «measurable» and «nonmeasurable» variables which were evaluated with a different emphasis by various authors.

The most important role was attributed to two indirectly measurable parameters i.e. temperature and the state of the solution. Many attempts have been made to measure the temperature of the origin of the principal minerals but results show that a wide range of temperatures exist in the formation of many deposits. Small variations in temperature deposition, e.g. between 200 and 300°C, are in the author's opinion insufficient to explain immense differentiation of deposit types. Temperature must have played a secondary role in the origin of hydrothermal differentiation. Also the criterion relating to the state of the solution is very disputable. The hypothetical boundary between the «pneumatolytical» and «hydrothermal» states of solution cannot give a reasonable justification for the division of mineral deposit groups. This fact is also confirmed by a large number of transitional types between the «pneumatolytical» and «hydrothermal» ore types which are by no means accidental. The depth factor is also within the category of indirectly measurable parameters. The assessment of the depth of origin of deposits gives such a variety of estimates that their direct application by different investigators may lead to many contraversial conclusions.

The only directly measurable parameter which has been retained in practically all the classifications since the beginning of the scientific period is the mineral content of a deposit. The authors characterized it variously as an ore-formation, ore-assemblage or paragenesis meaning essentially the same, i.e. ore types have a world-wide persistency and occur irrespective of the age of minerallization. BEYSCHLAG, KRUSCH and VOGT (1914) stated «the importance of the contents of a deposit is the function of their genesis». This is also the main conclusion of Noble's paper (NOBLE 1955) in which he stressed the primary importance of this variable. The definition of ore formation may be based both on the result of a mineralization processes (assemblages) as well as on the definition of processes by which they originated. These processes may also be defined in terms of wall-rock alterations.

Thus a reasonable classification should be in the convenor opinion based on the formational principle with the grouping of the formations according to geological criteria. The application of the criterion of the position relative to intrusive igneous rocks seems to give a best «measurable» geological criterion. In the next step it seems to be desirable to agree on the definition of such categories, giving them a precise terminology and also an exact meaning of acceptable terms.

The classification of deposits should go forward among such branches of science where the terminology and grouping is internationally agreed and used. It is definitely one of the aims of the International Geological Correlation Programme to contribute to these efforts.

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## REFERENCES


ABDULLAEV, Kh. M. (1954): *Genetic association of ore mineralization with granitoid intrusions (in Russian).* Gos. nauchno tekht. izdat. Moskva.

BATEMAN, A. M. (1950): *Economic mineral deposits,* 2 ed. New York.

BECK, R. (1903): *Lehre von den Erzlagerstätten.* Verlag Gebrüder Borntraeger. Berlin.

BEYSCHLAG, F.; KRUSCH, P. & VOGT, J. H. L. (1914): *Die Lagerstätten der Nutzbaren Mineralien und Gesteine.* I Band. Stuttgart.

v. COTTA, B. (1854): *Ueber die Bildungsreihen der Mineralien in Gängen und Drusen.* Cotta Gangstudien, 2 Bd., Freiger.

— (1859): *Die Lehre von den Erzlagerstätten,* 2 Bd., Freiberg.

CROOK, Th. (1933): *History of the theory of ore deposits.* London.

DAUBRÉE, A. (1841): *Ueber die Zinnerz-Lagerstätten* (nach Dufréno's Kommisions Bericht an die Pariser Akademie, Abt. 14, Inst. 1841, IX, 365-6). Ref. N. Jhb. 1842, 609-10.

DENISENKO, V. K. (1975): *Classification of tungsten deposits for the purpose of their prognosis.* Zap. Vses. min. obshch. 104, vyp. 5, 526-538 (in Russian).

FERSMAN, A. E. (1931): *Pegmatites (in Russian).* Moskva.

— (1931): *Selected works.* Vol. 3. Izd. Akad. Nauk SSSR (in Russian).

FREIESLEBEN, J. C. (1843): *Die Sächsischen Erzgänge in einer vorläufsgen Aufstellung ihrer Formationen.* Freiberg.

FUCHS, E. & DE LAUNAY, L. (1893): *Traité de gites minéraux et métalliféres.* Paris.

GORZHEVSKII, D. I. (1962): *On the question of classification of hydrothermal deposits (in Russian).* Mineralog. sbornik, No. 16, 291-301. Lvov.

v. GRODDECK, A. (1879): *Die Lehre von den Lagerstätten der Erze.* Leipzig.

INGERSON, E. (1963): *The concept of a separable pneumatolytic stage in post-magmatic ore formation.* Symposium Problems of postmagmatic ore deposition, vol. I, 463-471.

ITSIKSON, M. I. (1967): *Geological and geochemical types of tin-bearing formations in the active belts and regions of tectonic and magmatic activization (in Russian).* Sov. geol., No. 11, 92-103.

KARASIK, M. A. (1963): *Postmagmatic ore fields and their classification (in Russian).* Izd. Akad. Nauk SSSR, Kiev.

KHRUSHCHOV, N. A. (1961): *Molybdenum, the evaluation of deposit in the search and exploration (in Russian).* Vyp. 19, Gosgeoltechizdat, Moskva.

KRYLOVA, V. V. (1972): *The classification of tin-bearing deposits for the exploration purposes (in Russian).* Geol. i razvedka, No. 3, 70-75.

DE LAUNAY, L. (1913): *Traité de métallogenie. Gites minéraux et métallifères.* Paris et Liège.

LEVITSKII, O. D. (1974 a): *Genetic classification of tin-bearing deposits.* Geology of tin, Trudy inst. geol. nauk, vyp. 82, ser. rudnykh mestorozhdenii, No. 8. Izd. Akad. Nauk SSSR, Moskva-Leningrad (in Russian).

— (1974 b): *Deposits of the cassiterite-quartz formation (in Russian).* Geology of tin. Tr. inst. geol. nauk, vyp. 82, 113-147.

LINDGREN, W. (1907): *The relation of ore-deposition to physical conditions.* Econ. Geol., 2, 105-127.

— (1928): *Some remarks on reviews and criticism.* Econ. Geol., 24, 650-653.

— (1933): *Mineral deposits.* 4 th ed. New York.

MAGAK'YAN, I. G. (1950): *Main industrial families and ore types (in Russian).* Zap. vses. min. obshch., 2 ser., vol. 79, No. 4.

— (1955): *Ore deposits (in Russian)* Gosgeoltechizdat. Moskva.

MATERIKOV, M. P. (1964): *Geological conditions of the appearence of the specialized tin-bearing intrusions (in Russian).* Metallogenic speciaiization of magmatic complexes. Nedra, Moskva.

MO CHU-SUN (1957): *A preliminary classification of tungsten industrial types.* Acta geol. sinica, 37, 181-189.

MUTCH, Q. D. (1956): *A critical evaluation of the classification of ore deposits of magmatic affiliation.* Econ. Geol., 51, 122.

NIGGLI, P. (1920): *Die leichtflüchtigen Bestandteile im Magma.* Leipzig.

— (1929): *Ore deposits of magmatic origin.* London.

— (1941): *Die Systematik der magmatischen Erzlagerstätten.* Schw. Min. Petr. Mitt., 21, 161-172.

NOBLE, J. (1955): *The classification of ore deposits.* Econ. Geol. Fiftieth Anniversary Volume, Pt. 1, 155-169.

OBRUCHEV, V. A. (1928): *Ore deposits (in Russian).* Part I, Izd. Gorn. Akad., Moskva.

OVCHINNIKOV, L. N. (1963): *On the participation of gases in postmagmatic ore deposition and the distinguishing of a pneumatolytical phase (in Russian).* Symposium Problems of postmagmatic ore deposition, vol. 2, 482-498.

PETRASCHECK, W. E. (1961): *Lagerstättenlehre.* Springer-Verlag, Wien.

PHILLIPS, J. A. (1884): *Treatise on ore deposits.* London.

POŠEPNÝ, F. (1893): *The genesis of ore deposits.* An, Inst. Min. Engrs. Trans., 23, 197-369.

— (1902): *The genesis of ore deposits.* Pošepný volume.

RADKEVICH, E. A. (1947): *Deposits of cassiterite-sulphide formation (in Russian).* Geology of tin. Tr. inst. geol. nauk, vyp. 82, 149-180.

— (1968): *Tin-bearing formations and their practical significance (in Russian).* Sov. geol., 1, 14-24.

RUNDKVIST, D. V. & DENISENKO, V. K. (1976): *Information on the works done in the U.S.S.R. in 1975 on the topic of the* MAWAM *program "Classification of ore deposits.* Manuscript, Salamanca.

SAINSBURY, C. L. & HAMILTON, J. C. (1967): *Geology of lode tin deposits.* Techincal conference on tin of the International Tin Council. London.

SAINSBURY, C. L. (1976): Personal communication.

SCHNEIDERHÖHN, H. & BORCHERT, H. (1956): *Zonale Gliederung der Lagerstätten.* Neues Jb. Mineral. Mh., 6/7, 136-161.

SCHRÖCKE, H. (1954): *Zur Paragenese erzgebirgischer Zinnerzlagerstätten.* N. Jb. Mineral. Abh. 87, 33-109.

SMIRNOV, S. S. (1947): *A review of the paper by P. Niggli "System of magmatogenous ore deposits" (in Russian).* Izv. Akad. Nauk SSSR, ser. geol., No. 1 - in Izbr. trudy AN SSSR 1955.

STELZNER, A. W. & BERGEAT, A. (1904-06): *Die Erzlagerstätten.* Leipzig.

STRELKIN, M. F. (1947): *Formation of tin-bearing pegmatites (in Russian).* Geology of tin. Tr. inst. geol. anuk, vyp. 82, 93-114.

ŠTEMPROK, M. (1963): *Genetic features of the deposits of tin, tungsten and molybdenum formation.* Symposium Problems of postmagmatic ore deposition, vol. 2, 472-481.

ŠTEMPROK, M. & VANĚČEK, M. (1963): *Review of opinions on the question "reasons for or against the distinguishing of a pneumatolytical phase in the classification of* *postmagmatic processes" (in Russian).* Symposium Problems of postmagmatic ore deposition, vol. 2, 499-508.

ŠTEMPROK, M. (1976): *Suggestions for the classification of tin, tungsten and molybdenum deposits of the plutonic type.* Lecture at the MAWAM meeting, Salamanca, April.

TANATAR, I. I. (1959): *Principles in the study of ore deposits (in Russian).* Izd. gos. univ. Kharkov.

TATARINOV, P. M. & MAGAK'YAN, I. G. (1949): *Suggestion for the classiGcation of postmagmatic deposits (in Russian).* Zap. vses. mineral, obshch., 2 ser., 78.

TAYLOR, R. (1976): Personal communication.

VARLAMOFF, N. (1975): *Classification des gisements d'etain.* Mem. Acad. royale des Sciences d'Antre. Mèr., Classe des Sciences Naturelles et Médicales, N. S., XIX-5, Bruxelles.

VLASOV, B. P.; VOLOVIKOVA, I. M.; GLADYSHEV, G. D.; KAZHDAN, A. B.; LAVEROV, N. P.; MEL'NIKOV, I. V. & TANANAEVA, G. A. (1966): *Geology of the deposits of the uranium-molybdenum ore formation (in Russian).* Atomizdat, Moskva.

VOGT, J. H. L. (1894): *Ueber die durch pneumatolytische Processe an Granit-gebundenen Mineral Neubildungen.* Z. prakt. Geol., 2, 458-465.

— (1895): *Beiträge zur genetischen Classification der durch magmatische Differentiation processe und durch Pneumatolyse entstandenen Erzvorkommen.* Z. prakt. Geol., 145-156.

— (1902): *Problems in the geology of ore deposits.* In POŠEPNÝ: *"The genesis of ore deposits"*, 636-680.

VOL'FSON, F. I. (1953): *Problems in the study of hydrothermal deposits (in Russian).* Izd. AN SSSR, Moskva.

— (1962): *Problems in the study of hydrothermal deposits (in Russian).* Gos. nauchnotekh. izd. Moskva.

v. WEISSENBACH, C. G. A. (1847): *Ueber Gangformationen vorzugsweise Sachsens in Cotta: Gangstudien.* Heft 1, J. G. Engelhardt, Freiberg.

WERNER, G. (1791): *Neue Theorie von der Entstehung der Gänge.* Freiberg.

ZAKHAROV, E. E. (1953): *On the problem of classification of deposits of raw materials (in Russian).* Izv. AN SSSR, ser. geol., No. 5 (per Vol'fson).

STVDIA GEOLOGICA, XIV, 1978 (145-148)

# CRITERIA FOR DISTINGUISHING NORMAL GRANITES FROM METALLOGENETICALLY SPECIALIZED ONES

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The metallogenetic analysis of tin-bearing ore districts shows that granitoid rocks occurring within these districts as contrasted with other granitoides, are characterized by distinctive geological, tectonic, geochemical and petrographic criteria.

Usually these granites are named as «tin granites», «tin-specialized granites», «specialized granites» or «metallogenetically specialized granites» respectively. It may be assumed that between the concerning granitoidic intrusive complex and the associated rare-metal deposits (with Sn, Li, Rb, Cs, Be, Nb, Ta, W, Mo, F) exists not only a spatial but also a genetic relation.

There are possibly a number of geological, tectonic, geochemical and petrographical pecularities of the metallogenetically specialized granitoides which may be used as criteria for their recognition. Application of these criteria aims to the recognition of promising districts in relation to the existence of rare-metal deposits.

1. The metallogenetically specialized granites or granitoid intrusive complexes are distinguished by:

a) their confinement to the middle to late stages of an orogeny;

b) a pronounced sialic magmatism presumably of palingenetic origin;

c) a true intrusive character;

d) their affiliation to postkinematic polyphase intrusive complexes at a hypabyssal intrusion level;

e) their confinement to the apical stage of batholiths and their relatively strongly undulating morphology (stocks, ridges);

f) the specific contents of some main elements which deviate from those in normal granites:

| | | | |
|---|---|---|---|
| $SiO_2$ | 73,38 | ± | 1,39 |
| $TiO_2$ | 0,16 | ± | 0,10 |
| $Al_2O_3$ | 13,97 | ± | 1,07 |

| | | | |
|---|---|---|---|
| $Fe_2O_3$ | 0,80 | ± | 0,47 |
| FeO | 1,10 | ± | 0,47 |
| MnO | 0,045 | ± | 0,040 |
| MgO | 0,47 | ± | 0,56 |
| CaO | 0,75 | ± | 0,41 |
| $Na_2O$ | 3,20 | ± | 0,61 |
| $K_2O$ | 4,69 | ± | 0,68 |

Comparcd to normal granites, the specialized granites are characterized by higher contents of $SiO_2$ and $K_2O$ and by lower contents of $TiO_2$, $Fe_2O_3$, MgO and CaO. Significant differences between both granite types occur with decreasing certainty in CaO, $TiO_2$ and MgO.

g) An increase of the contents of specific rare elements in comparison to normal granites (regional specialization). Proposed averages for some trace elements are:

| | | | | |
|---|---|---|---|---|
| fluorine | 3700 | ± | 1500 | ppm |
| rubidium | 580 | ± | 200 | ppm |
| lithium | 400 | ± | 200 | ppm |
| tin | 30 | ± | 20 | ppm |
| beryllium | 13 | ± | 6 | ppm |
| tungsten | 7 | ± | 3 | ppm |
| molybdenum | 3,5 | ± | 2 | ppm |

Compared to the granite averages, in the specialized granites further granitophile elements (B, Nb, Ta, Cs, U, Th, RE) are also enriched, whereas granitophobe elements (Ni, Cr, Co, V, Sr, Ba) are impoverished;

h) An assymetrical (log normal) regional distribution of the rare elements, characterized by a strong increase in the amount of granitophile elements from the core of the pluton towards the outer margin (zonal specialization);

i) A strong increase of granitophile elements from the older to the younger intrusive phases in the specialized intrusive complexes (temporal specialization);

j) A relatively high dispersion of the elements which participate in the specialization;

k) A certain mineralogical composition, which leads to their classification, according to petrographical criteria, as alaskite granites, leucogranites, aplite granites, two mica granites (syenogranites and alkalifeldspar granites in the sense of STRECKEISEN).

The proposed average mineral composition (in vol-%) is:

| | |
|---|---|
| quartz | 35 ± 3 |
| alkali feldspar | 33 ± 6 |
| plagioclase | 25 ± 3 |
| dark mica | 3 ± 1 |
| light mica | 3 ± 1 |
| accessories | 1 |

As carriers and concentrators of rare elements, all rock forming minerals must be considered, especially the accessories. Dark micas, for instance, play a particular role as carriers as well as concentrators:

l) by a special association of accessories of which cassiterite, topaz, fluorite, tourmaline as well as columbite-tantalite and beryl are the most important;

m) by a paragenetic sequence of crystalization for the rock-forming minerals which deviates from that in normal granites. Quartz appears as early crystallization product and dark mica as a late one. This is probably caused by the high contents of volatiles, particularly fluorine, in the melt;

n) by autometasomatic late-magmatic processes leading to microclinization, muscovitization and albitization. These processes represent the first stage of the formation of apogranites (in the sense of BEUS);

o) by post-magmatic metasomatism (greisenization) with the formation of rare element deposits.

2. The specialized granites or granitoid intrusive complexes can be distinguished by the sum of their characteristics mentioned above. Considering the chemical elements, one can state that the specialized granites show considerable deviatins from normal granites in their rare element content (Sn, Li, Be, Rb, F), but variations with regard to the minor elements (Ca, Mg, Ti), and only very slight insignificant deviations in the major elements (Si, Al, Fe, Na, K). It cannot be expected that with only of *one* characteristic or a *few* characteristics a granite can be predicted as being ore bearing. The detection of specialized granites, moreover, only states something about the ore-generating capability of the corresponding specialized melt but nothing about the real existence of ore deposits. For the formation of ore deposits further prerequisites (presence of ore-supplying and ore-concentrating structures) must be given.

3. It is possible to distinguish intermediate to acid magmatic rocks (adamellites) occurring in tin-bearing regions as precursors of specialized grani-

tes. Like the specialized granites they also may form intrusive complexes. Their geotectonic position and geological setting is the same as the specialized complexes. In some properties (contents of the elements, petrographical composition, association of the accessories) these precursours are entirely similar to normal granites. In other properties (increased contents of granitophile rare elements, like Sn, Li, Rb, Be) they are similar to the specialized granites. They have typically *low* fluorine content. The pre-enrichment of the granitophile rare elements is considered as an indication of heredity and as a precondition of the still greater accumulation in the subsequently fractionated specialized granites. Of great importance for the formation of specialized granites is a magmatic trend following the formation of the precursors which allows a high enrichment of the volatiles, especially of fluorine, to develop.

4. The use of the existence of specialization in granitoid rocks as the basis for the detections of ore deposits is, according to present knowledge, applicable only where there exists a rather close, direct relationship between ore accumulation and spatially related intrusive complexes. This is obviously valid for Sn, Li, Rb, Be, Nb, Ta. In the case of W and Mo it is probable, but for Cu, Pb and Zn, according to our present knowledge, improbable.

5. The cause of a geochemical-petrographical specialization is considered to be related to a certain pre-enrichment of the corresponding element in the magma and to specific conditions of its formation. Such specialized granites are intruded at a relatively high level in the earth's crust, and by the abundance of volatiles, especially fluorine. Special conditions of formation delay the accumulation of rare elements if processes of crystallization dispersion prevail, and stimulate them if processes of emanation concentration predominate. High contents of fluorine seem not only to stimulate the anomalous crystallization sequence and to stimulate the autometasomatic processes, but also seem to be a fundamental prerequisite for the migration of tin and other trace elements. It can be said that for the formation of tin deposits high contents of fluorine are even more important than high contents of tin.

6. Presumably differing geotectonical preconditions control the formation of specialized granitoids (normal, agpaitic, plumasitic). Furthermore, on a planetary scale since regional (continental) and temporal (evolutionary) peculiarities appear, it might be expected, that, in spite of similar development in principle, the specialized granitoids are rather variable. This must be taken into consideration in the evaluation of the ore-generating capability of granitoid magmas or rocks respectively.

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# CLASSIFICATIONS OF MINERALIZATIONS RELATED TO ACID INTRUSIVE MAGMATISM

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In my report I shall try to give the review of ideas of the Soviet geologists on classification of the tin-ore deposits and deposits of related metals.

Allow me to discuss the following questions:

I. Formational classification of tin deposits.
II. Faults in classifications and suggestions for their improvement.
III. Classification of deposits related to granitoids.
IV. Interrelation of various types of deposits according to the characteristics of their zoning.
V. Conclusion.

## I. FORMATIONAL CLASSIFICATION OF TIN DEPOSITS

Due to the works of S. S. Smirnov, E. A. Radkevich, O. D. Levitskii, M. I. Materikov, M. I. Itsikson, V. Matveenko, S. F. Lugov and others carried out in the Soviet Union during the fourties and seventies, large tin-ore provinces and regions were revealed. They include Chukotka, Yakutia, Sikhote-Alin, Middle Asia Transbaikalia, Hingan and others (fig. 1).

To a large extent it is a result of the use of formational classification of deposits allowing to reveal constant regional and local criteria of forecasting the occurrences of each formation.

The following main types of deposits (table I) are distinguished:

1. Cassiterite pegmatite having subordinate importance in the Soviet Union.
2. Cassiterite-skarn, not widespread.
3. Cassiterite-quartz, greisen-like.
4. Cassiterite-tourmaline-chloritic.

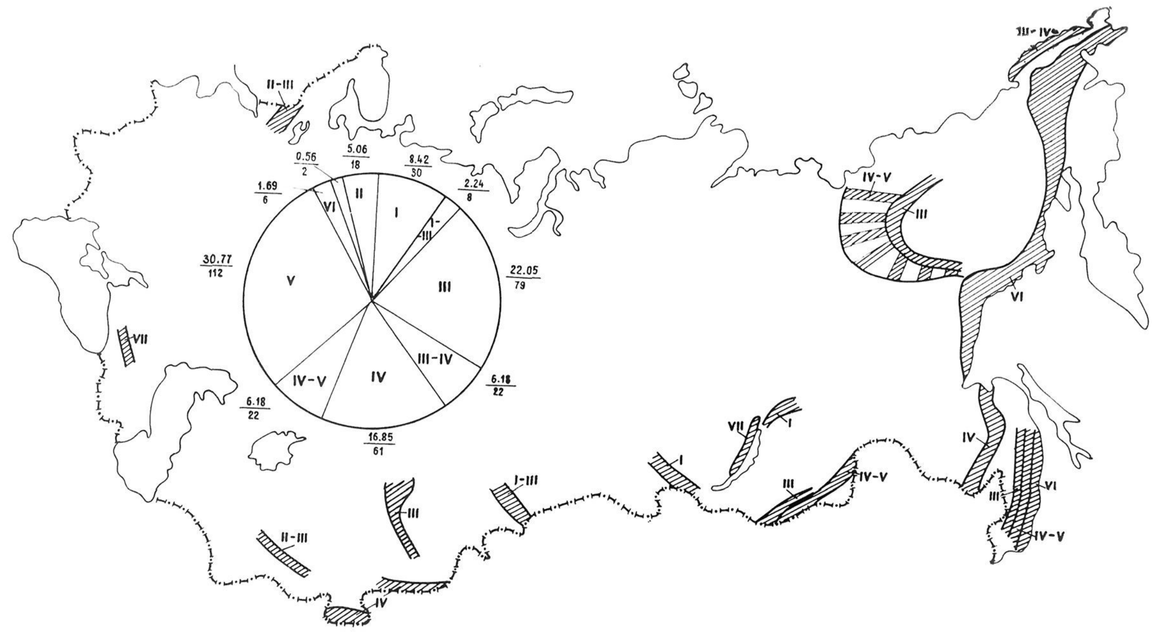


FIG. 1

*Scheme of the distribution of zones with tin-ore mineralization in the USSR territory. The diagram shows the quantity distribution of individual types (Table 1)*

5. Cassiterite-stannite-sulfides with copper and polymetallic subtypes. The last three formations (3, 4, 5) are of the greatest economic importance and give about 95 percent of the tin reserves of the USSR.
6. Cassiterite formation with woody-tin developed within young orogenic volcanic belts, is only of mineralogical interest.
7. During the last years a special group of sulfide (pyriteferous) deposits with tin was established (BARSUKOV, 1973). In the nearest future the importance of these deposits may be increased.

The diagram constructed on the bases of the data on 360 deposits of the USSR summarized by S. N. Iznairskii gives the picture of the distribution of the mentioned types of deposits.

In Table I. characteristic features of the main formations, in particular the associated ore elements, are summarized and typical hydrotermal alterations of rocks are given.

## II. FAULTS IN CLASSIFICATIONS AND SUGGESTIONS FOR THEIR IMPROVEMENT

Firstly, the main fault of classification presented consists in accurate delimitation of established types. In reality numerous transitional varieties oc-

TABLE I

*Formation types of tin deposits of the USSR*

(according to S. S. SMIRNOV, E. A. RADKEVICH, V. T. MATVEENKO, M. I. ITSIKSON, S. F. LUGOV, M. P. MATERIKOV et al.)

| Denomination | Characteristic morphological types | Associated elements (elements-admixtures in cassiterite) | Hydrothermal alteration of rocks (leading non-metallic paragenesis) |
|---|---|---|---|
| Cassiterite-pegmatite (I) | Veins | Li, Rb, Cs, Ta, Nb, Be, W, Mo, TR, Y, V (Ta, Nb) | Greisenization<br>Albitization<br>Microclinization<br>Amazonitization |
| Cassiterite-quartz, greisen (III) | Veins, stockworks, mineralized domes, zones | rarely-Be, W, Mo, rare metal Bi, As (Ta, Nb) | Greisenization<br>Albitization<br>K-feldspatization<br>Muscovitization |
| Cassiterite-skarn (II) | Sheet bodies, bodies of irregular form | Cu, Zn, Pb, Fe, Bi, rare metal | Scarnization<br>Amphibolization<br>Greisenization<br>Fluoritization<br>Flogopitization |
| Cassiterite-chlorite-tourmaline (IV) | Mineralized zones of stockwork type, rarely-veins in apical parts of intrusions | W, rarely Mo, Pb, Zn, Cu, Bi, Ag, Au, Co, Ni (In) | Tourmalinization<br>Silicitization<br>Sericitization<br>Chloritization |
| Cassiterite-(stannite) sulphide (V) | Veins, bodies, stockworks, domes | Pb, Zn, Cu, Ag, Bi, Au, Sb, Co, Cd, Ni (In) | Chloritization<br>Sericitization<br>Silicification<br>Carbonatization<br>Pyrrhotitization |
| Cassiterite-pyrite (VII) | Banded bodies, lenses, representing zones of stockwork metasomatic changes breccia | Fe, As, Cu, Zn, Pb, Bi | Chloritization<br>Silicification<br>Sericitization<br>Tourmalinization<br>Axinitization<br>Actinolitization<br>Diopsidization |
| Cassiterite-rhyolite (VI) (woody tin) | Dissemination in rhyolites, pockets | Fe, sometimes F, (In) | Propylitization<br>Sericitization<br>Silicification<br>Argillization |

cur in nature. In this case it is always difficult to attribute deposits to one or another type. Besides it was found that, as a rule, large and unique ore fields and deposits are the result of coincidence of various types of mineralizations.

Therefore it seems to me that one of the tasks of the MAWAM project is the working out of a new type of classification showing the main trends and transitions between formations.

Secondly, usually in existing classifications, data on zonation changes of mineralization along vertical direction and also types of associated mineralization are not used enough.

Therefore in the MAWAM project it would be expedient to work out a classification not of proper tin deposits but allied deposits and evolution series of deposits connected with granitoids including W, Mo, As, Bi, Fe, Au, Cu, Pb, Ln.

Here is the material on these two questions presented for a preliminary discussion.

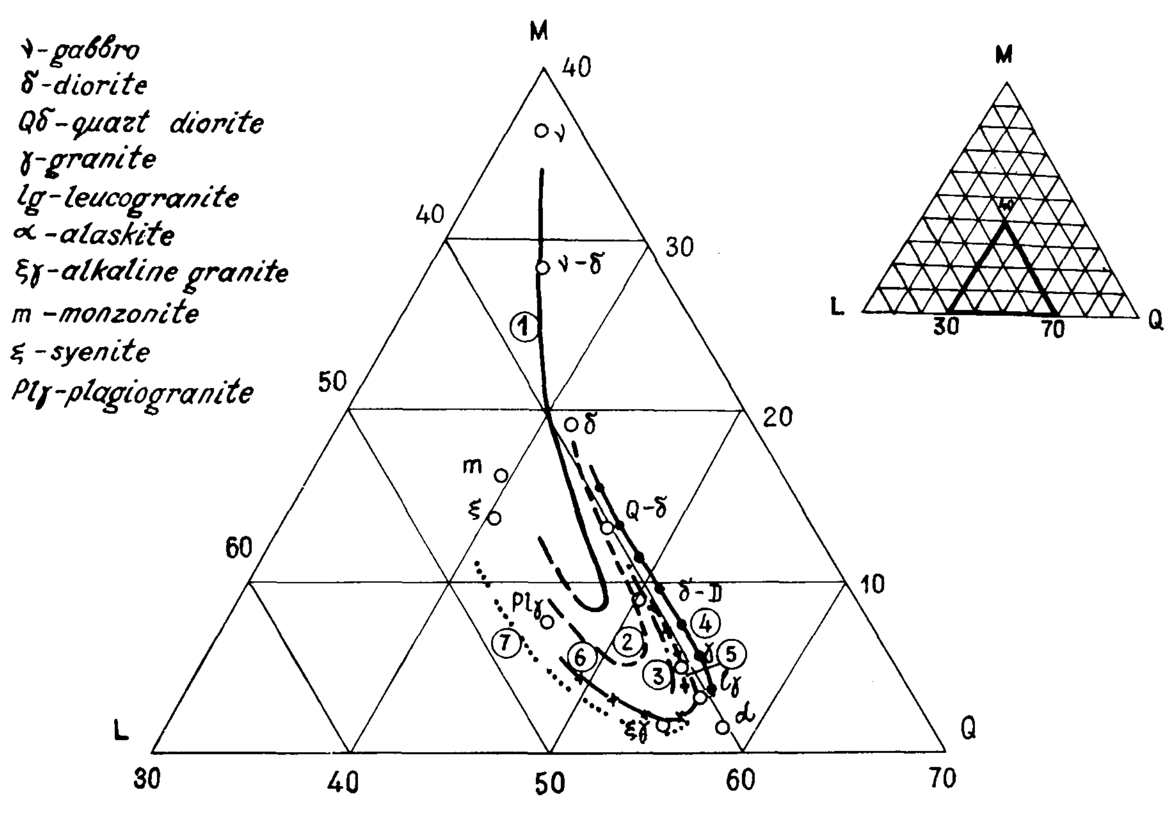


FIG. 2

*Lines of the composition of various granitoid formations in Niggli's triangle*

TABLE II

## Main formations of granitoids and mineralization related to them.

| Class | Magmatic formation | Typical evolutionary series, range of evolution | Zonal series of mineralization | Types of deposits | Family | Class |
|---|---|---|---|---|---|---|
| I<br>gabbro - leucogranite | ① gabbro-diorite | $\nu - \delta - Q\delta - \xi\delta - \mu - \gamma\delta$ | Fe — Cu<br>(W) — Mo — Cu Au — Zn Pb — Ag Au | Fe<br>Fe Cu (Mo) skarns<br>Cu Mo propylites<br>Au Cu | ① | I |
| | ② granodiorite - plagiogranite | $\delta - Q\delta - \gamma\delta - Pl\gamma - \gamma$ | Mo(Au)<br>W(Au) — Au (FeAs) — Au Zn Pb — (Sb Au) | Au W beresites<br>Au As gumbeites<br>Au Mo | ② | |
| | ③ granite - leucogranite | $\gamma\delta - \gamma - l\gamma$ | Mo<br>W — Mo Be W — W Bi — (Cu Zn Pb) — (Au) | Mo gumbeites<br>Mo W, W beresites<br>Mo W Bi greisens skarns | ③ | |
| II<br>granite-alaskite - alkaline-granite | ④ leucogranite with dike basic rock | $\pi - \delta - \gamma\delta - \gamma - l\gamma$ | Sn — (W Bi) — Sn (FeAs) — Sn Zn Pb — Sb Hg<br>Sn Cu | Sn (Fe) tourmaline-chlorite<br>Sn Cu „sulphide"<br>Sn Pb Zn | ④ | II |
| | ⑤ granite - alaskite | $\gamma\delta - \gamma - l\gamma - \alpha$ | Sn Be — W Sn — W Bi As | Sn<br>Sn W skarns<br>Sn W Be Bi greisens pegmatites | ⑤ | |
| | ⑥ granite - alkaline-granite | $\gamma - l\gamma - \xi\gamma$ | Li Sn Be — Sn — Sn W Bi As — (Zn Pb)<br>Nb Ta — Sn Be W | Sn Be Nb Ta greisens<br>Li Rb Cs Nb Ta feldspatholites pegmatites | ⑥ | |
| | ⑦ alkaline-granite | $l\gamma - \xi\gamma$ | Zr (Hf) — Nb+Ta — (TR) / (Th) — (Li Be) — (Be W) — (W Bi) | Tb Ta Zr Hf TR feldspatholites<br>Th Y Zr Hf Nb Ta pegmatites | ⑦ | |

## III. CLASSIFICATION OF DEPOSITS RELATED TO GRANITOIDS

According to the composition and structural features, seven major granitoid formations accompanied by different types of mineralization have been conventionally distinguished.

For establishing the formations, data by E. Kuznetsov, E. Shatalov, E. Izokh and Yu. Marin, recently published, have been used. The names of the formations were given according to the most characteristic rocks. Figure 2 shows the compositions of the distinguished formations in Niggli's triangle in the form of zones. The figure shows a single «evolutionary branch» with a rock change from gabbro through gabbro-diorites and diorites to granodiorites, granites, leucogranites and alaskites.

This general homodrome direction of the evolution is complicated by the increase of alkalinity and the appearance of monzonites, syenito-diorites, alkaline granites, syenites and plagiogranites, as well as of numerous dykes alternating in composition from aplites and pegmatites to lamprophyres and porphyrites.

Evolutionary series of rocks characteristic of the distinguished formations and the main types of deposits related to them are outlined in table II.

In figure 3 an attempt is made to show these relations in terms of the K/Na ratio in rock series being taken into consideration.

The general configuration of the «field» of the granitoid development is of asymmetrical shape (fig. 3), as Na alkalinity is more characteristic for more basic differentiates of granitoids, and K alcalinity for the more acid.

As it was noted before by Yu. Bilibin, E. Kuznetsov and E. Izokh et al, Fe, Fe-Cu, Cu-Mo deposits are skarn ones, Cu-Mo deposits are porphyry ones, and Au-Mo deposits are related to the series of high Na alkalinity. Cassiterite-sulphide, tourmaline-chlorite and cassiterite-quartz deposits are relted to K differentiates, and Mo-W deposits to normal calc-alkalic granites.

As figure 3 shows, each granitoid formation acts as if it supplements the former in its evolutionary development. The variety of the ways in the evolution and the role of the regressive antidrome trend in the final part of the process increases successively.

The formation structure changes regularly, the role of minor intrusions and dykes increases.

Two main lines in a single «branch» are distinguished relatively clearly. A great relationship of formations 1-2-3 from one side, and 4-5-6-7 from the other is revealed. Mineralizations related to them differ essentially. In the

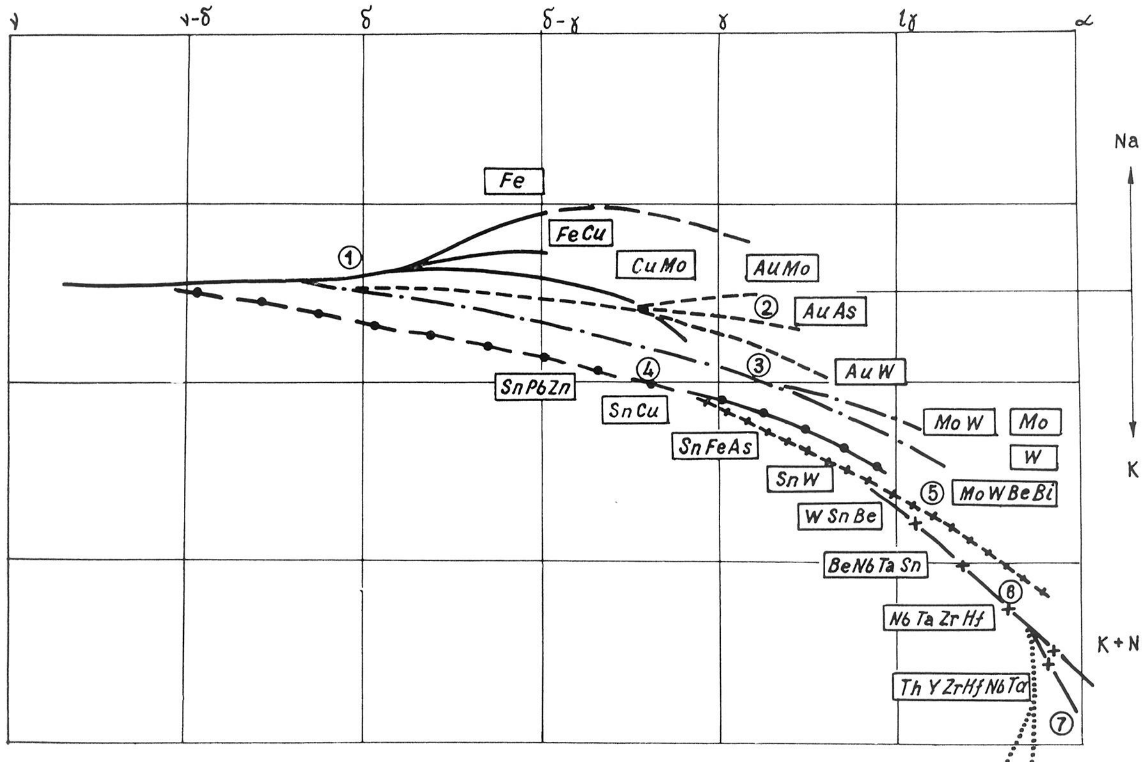


FIG. 3

*Relation of different types of mineralization with granitoids of different formation belonging and differing in K/Na ratio*

first case it is: (Fe-Cu)Mo-W-Au-Bi-Be, in the second - it is a rare-metal mineralization proper: W, Sn, Be, Li, Nb, Ta, TR.

Thus, according to a number of granitoid formations and the display of the evolutionary series of magmatism, 2 classes and 7 families of ore deposits might be distinguished, in the composition of which about 20 major formation types are outlined (table II). Five of them correspond to the types of tin-ore deposits mentioned above: pegmatite, skarn, quartz-cassiterite, silicae-cassiterite, and sulphide-cassiterite.

It should be noted that the outlined types of mineralization might be found associated with other magmatic formations. However, in those cases, they are, as a rule, small, and they are not of economic importance. Thus, in the classification of the deposits, if magmatism is being taken into account, it is a peculiar criterion of the evaluation of probable scales of mineralization.

When considering the interrelations of magmatic and ore formations with the acount of the data by K. Konstantinov, V. Denisenko, V. Zagruzina, and others from the USSR territory, there is established:

1. The duration of the development of ore mineralization in the series of a single family is commeasurable wit the duration of the development of magmatism and covers intervals of dozens of millions of years.

2. The conformity in the direction and variety of the composition of rocks in the evolutionary series with the direction of alteration and variety of the composition of associated mineralization is displayed clearly.

When summarizing data in greisen deposits, two main different ways of the development (for mean depths) might be outlined for acid granitoid magmatism of orogenic stages.

1) In relatively closed systems, with the formation of granites among rocks of low permeability, for instance, under a cover of shales; and

2) In relatively open systems, with abundant fissures both in the roof of the granites and in the zone as a whole.

In the first case, alkalinity increases regularly; rocks of subalkaline leucogranite, and in a number of cases of even alkaline-granite formations, are formed. Stock- and dome- shaped granites with pseudostratified structures and the development of complex Sn, W, Mo, Be, Al, Th, Li mineralization are characteristic.

In the second case, the transition is characteristic to the rocks of high basicity variegated in composition, dykes of granite-porphyries, felsites, granodiorite-porphyries, andesite porphyries, plagioporphyrites to late basalt dykes. The greatest remoteness of basic dykes and the location of acid dykes directly over granites are characteristic. Lode and stockwork Sn, W, Mo deposits are typical for this case.

Each of the distinguished series of formations has its petrochemical features and might be correlated with the geochemical types of granitoids by L. V. Tauson (1974).

As a whole, the more basic rocks exist in the evolutionary series, the greater is the role of sulphide parageneses in the ores. The less is the range of the rock alteration in the series, the more homogeneous are the ores in composition. The more are the alkaline acid granitoids present, the more widely are developed the rare-metal and rare-earth mineralizations.

## IV. INTERRELATION OF VARIOUS TYPES OF DEPOSITS ACCORDING TO THE COMMUNITY OF THEIR ZONING

The right side of Table II shows the most characteristic zonal series drawn on the basis of the generalization of the data of about 200 ore fields and deposits (Rundkvist, Nezhenskii, 1975). The succession of the arrangement of ore elements shows alteration of mineralization when moving off from granitoids of various formations.

TABLE III

*Classification of deposits related to acid intrusive magmatism*

I. CLASS OF DEPOSITS WITH THE GABBRO-GRANITE-LEUCOGRANITE EVOLUTIONARY BRANCH

*1. Family of deposits related to the gabbro-diorite formation.*

1. Skarn iron-ore deposits with complicated complex ore (deposits Magnetic-mountain, Visokaymountain, etc.).
2. Skarn iron-copper-ore deposits and copper-molybdenum ones (Sayak, Karata deposits, Turyen mines).
3. Copper porphyry and copper-molybdenum deposits (Kalmakir, Kadzaran, etc.).
4. Propylite sulphide copper-gold ore deposits.

*2. Family of deposits related to the granodiorite-plagiogranite formation.*

5. Quartz-lode gold-bearing deposits with scheelite (Berezovskoe, etc.).
6. Quartz-vein gold-arsenic deposits (Kochkarskoe, etc.).
7. Quartz-vein gold-molybdenum deposits (Darasunskoe, Shakhtaminskoye, etc.).

*3. Family of deposits related to the granite-leucogranite formation.*

8. Molybdenum-bearing quartz stockworks (Umalta, Zharikei).
9. Molybdenum-tungsten (scheelite) skarn deposits (Tyrnyauz, Vostok II, etc.).
10. Molybdenum-tungsten (scheelite) stockworks among schists volcanites enclosing granites (V. Kairakty, Urzarsay).
11. Quartz-vein, greisen, wolframite deposits with molybdenum bismuth, sometimes with other rare metals (Akchatau, Karaoba).

II. CLASS OF DEPOSITS RELATED TO THE GRANITE-ALASKITE-ALKALINE-GRANITE EVOLUTIONARY BRANCH

*4. Family of deposits related to the leucogranite-diorite-porphyrite formation.*

12. Tin-sulphide (cassiterite-stannite-sulphide deposits (Khrustalnoe, Khapckeranginskoe, etc.).
13. Tin-iron-silicate or cassiterite-tourmaline-chlorite deposits (Deputatskoye, Valkumeyskoe, etc.).

*5. Families of deposits related to the granite-alaskite formation.*

14. Tin-bearing and tin-rare-metal greisens and quartz-vein deposits (Iultinskoe, Ononskoe, etc.).
15. Tin-bearing and tin-rare-metal skarns (Potyarant).
16. Tin-bearing and tin-rare-metal pegmatites (noncommercial small deposits).

*6. Family of deposits related to the granite-alkaline-granite formation.*

17. Complex rare-metal "apogranites"-feldspatholites (deposits of Transbaikalia, Kazakhstan).
18. Rare-metal pegmatites (deposits of Transbaikalia, Kazakhstan).

*7. Family of deposits related to the alkaline-granite formation.*

19. Rare-metal-rare-earth "apogranites"-feldspatholites (deposits of Eastern Siberia).
20. Rare-metal-rare-earth pegmatites (deposits of Eastern Siberia).

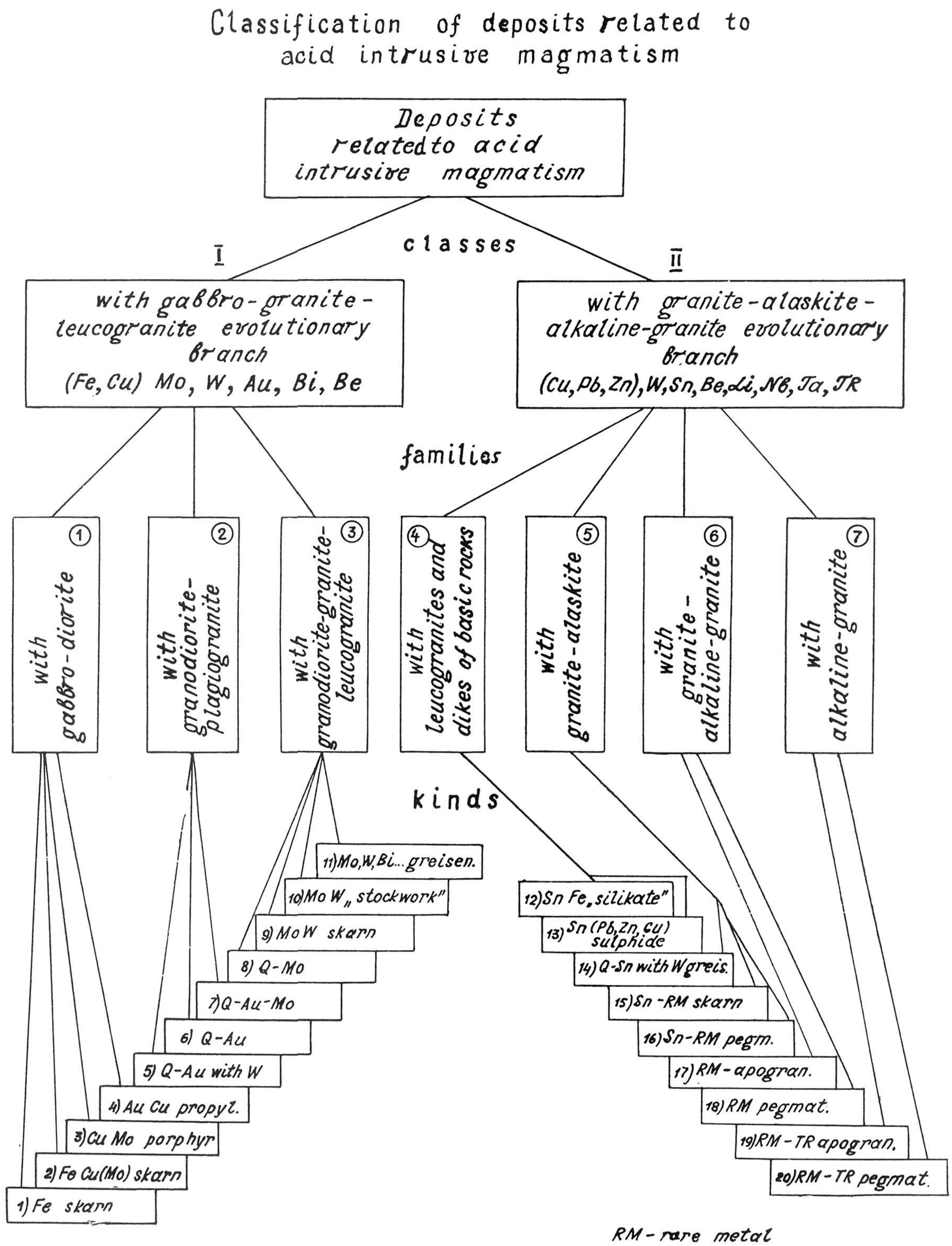


FIG. 4

*Classification of deposits related to acid magmatism*

Elements of one series characterize the alteration of zones within deposits. At the same time these series reflect the location of the deposits themselves within ore fields.

The form of zones, as it has been established by the works of B. Flerov, L. Indolev, Ya. Yakovlev and O. Ivanov, depends for the author and others not only on the morphology of the intrusion roof but on the location of intrusions with respect to the paleosurface of the ore formation period and the surface of the geoid.

As a result of the combined influence of these factors as well as of erosion level, a direct zoning, a reverse one, or a cover ore zoning (direct-reverse) is fixed (fig. 4).

Within the outlined families of ore deposits a general series of zoning is, as a rule, preserved (Table III). Varieties are outlined within the families, for instance, for tin-ore deposits with Cu and Pb-Zn mineralization.

It is interesting to note that the manifestation of Au-Ag mineralization is more characteristic of the first class (W, Mo, Cu), in external zones, and Sb-Hg, in the second.

The outlined zonal series enable to show mutual transitions between different types of deposits as well as to reflect their varieties according to the features of the composition of ore mineralization.

Thus a general scheme of the classification of deposits related to acid intrusive magmatism might be presented in the following way (fig. 4, Table III).

## CONCLUSION

1. Among different versions of classifications of deposits, an evolutionary classification taking into account the similarity in composition and structure (zoning) of deposits of various types, mutual transitions existing between types, should be considered.
2. The evolutionary series of rocks successively displaying in time and regularly arranged with respect to each other in space are one of the basic elements of such a classification.
3. The preliminary systematization of data on zoning and series of magmatism enables to subdivide deposits related to acid intrusive magmatism into 2 classes, 7 families, about 20 basic kinds. The most regular mutual transitions between kinds and different degrees of their relationships have been outlined.
4. The consideration of magmatic and ore formations from the point of view of their evolutionary development enables to work out the criteria

for their prospecting and evoluation of deposits as a function of a directed alteration of features, regularities of their distribution in the evolutionary series.

5. Besides evident practical significance of such a classification using the most informational signs - the relationship of magmatism to mineralization and zoning, it is of great scientific importance.

Firstly, the possibilities of the creation of natural taxonomy of deposits in geology analogous to the biological one should be tested. As is known, Berr's principle is widely used in the biological taxonomy that each earlier formation in the time of the development is of greater classification significance (N. SEVERTSEV, 1955).

In the essence, when subdividing deposits into classes, families and kinds, we used an analogous proposition.

Secondly, the further working out of classification questions in the outlined direction may lead to new important generalizations in the theory of zoning of endogenous ore deposits. As a result of the data correlation, a system of the regular distribution of maximum concentration of ore elements near granitoids should be elaborated (Spurr's and Emmons's universal zoning).

It seems that the questions of the evolution of magmatism and mineralization, and near-intrusive zoning should be the subject of a more detailed study at the next MAWAM symposia.

Stvdia Geologica, XIV, 1978 (161-169)

# A SUGGESTION FOR THE CLASSIFICATION OF TIN, TUNGSTEN AND MOLYBDENUM DEPOSITS ASSOCIATED WITH PLUTONIC ROCKS

Miroslav Štemprok
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## INTRODUCTION

Ore deposits are large accumulations of certain elements in specific mineral associations. These associations may provide a suitable parameter for classifying tin, tungsten and molybdenum deposits associated with plutonic rocks.

The proposed classification is based on the observation that ore deposits are formed as products of distinct stages of mineralization. These sequences may represent independent inflows of solutions usually separated in time by intra-stage tectonic movements. The stage inflow may be composed of several sequential infiltration periods.

This proposal utilises the same principles of «formational» classification as that devised by Levitskii (1947) and Radkevich (1968) for tin deposits, Denisenko (1975) for tungsten deposits and Khrushchov (1961) for molybdenum deposits. However, it differs in that it assumes a relatively simple composition of the products of each stage of mineralization, e.g. pure quartz, greisen or quartz-feldspar pegmatite assemblages. Virtually all the deposits considered here are composed of several overlapping stages of mineralization. Clearly defined and separate stages are rarely found in nature.

Economic mineralization is only associated with some of the stages of this classification but may be superimposed on the products of earlier barren stages of may be «diluted» by later ore-free stages. The main mineralization stages have a world-wide persistency and can easily be identified in deposits of any form and any geological age.

The first two sequences of the alteration stages differ depending on the geological environment in which they were active. For example in aluminosilicate rocks the early stages are commonly developed as pegmatites, replacement pegmatites or feldspathites, whereas in carbonate rocks various types of calcium or magnesium skarns are formed.

The sequence of stages involved in the formation of tin, tungsten or molybdenum deposits are as follows:

| | |
|---|---|
| 1. Pegmatitization: | This is characterized by the development of quartz, feldspar and mica assembiages. It is the first phase in the formation of pegmatites. |
| 1a. Skarnization: (silicate stage) | In carbonate rocks this stage is characterized by the development of pyroxene, garnet or vesuvian. This stage constitutes a basis for the introduction of later mineral assemblages. |
| 1b. Skarnization: (oxide stage) | In silicate skarns this stage is characterized by the development of magnetite. |
| 2. Feldspathization: | Results in the development of replacement complexes in pegmatites (sodium or lithium metasomatism) or albitization in igneous rocks. Ore mineralization may be related to this stage. |
| 3. Quartz formation and silicification: | Quartz fissure fillings form veins whilst wall rocks are subjected to silicification. |
| 4. Greisenization: | This stage is characterized by the origin of aluminosilicates (topaz, micas) with re-deposition of quartz. Ore mineralisation is related to the final periods of greisenisation. |
| 5. Tourmalinization: | A simple mineralization stage characterized by the origin of tourmaline in veins and wall rocks, in places accompanied by ore mineralization. |
| 6. Chloritization: | This is the main sulphide-bearing stage during which As, Fe and Zn sulphides are deposited. |
| 7. Sericitization: | Widespread mineralization accompanies the deposition of simple sulphides of Cu, Pb and Zn, during this stage. |
| 8. Argillization: | This stage is characterized by the origin of complex sulphides and sulphosalts with wall rock kaolinization or carbonate formation. |

*Relationships between pegmatites and quartz veins*

The suggested classification is based on the observation that pegmatites and quartz ore veins are genetically different bodies (ŠTEMPROK 1965). Pegmatites do not pass transitionally into ore veins within a single mineralization stage. Thus, soon after their formation, the pegmatites may be affected by the later stages of feldspatization (albitization or potashfeldspar metasomatism) or greisenization.

*Relationship between skarns and greisens*

According to SOKOLOV and KOMAROV (1968) in those areas where skarns and greisens were formed during a single stage of magmatism, greisen mineralization followed the formation of the typical skarns (i.e. typical silicate skarn with magnetite). Greisen development subsequent to skarn formation differs for magnesian and calcareous skarns.

*Tin, tungsten and molybdenum deposits*

The sequence of stages involved in the formation of tungsten deposits is almost identical to those for tin deposits. Tin and tungsten ores therefore, may co-exist in many types of deposits. However, tungsten shows a possible association with gold in the tourmaline and chlorite stages of ore deposition whilst molibdenum is rarely associated with these stages.

*Graphical representation*

The main mineralization stages occur in a definite eightfold sequence but in most deposits only 2 or 3 stages are developed. The number of possible combinations —if the order of the stages is invariable from 1 to 8— can be expressed by a simple mathematical formula:

$$\begin{aligned} &\text{single stage:} && 8C1 = 8 \\ &\text{two stages:} && 8C2 = 28 \\ &\text{three stages:} && 8C3 = 56 \end{aligned}$$

In total there are 92 possible combinations of the 8 stages in groups of 1, 2 or 3. However, this number can be considerably reduced when it is considered that only 2 or 3 sequential stages are generally combined, and that 1 or 2 subsequent sequential stages may be absent. This results in about 53 possible combinations of which about 10 - 20 combinations of the stages commonly occur in nature.

Plutonic Sn, W and Mo ore deposits can be graphically represented by an octagon whose edges represent the eightfold stages in the development of mineralization. The bisectrix of each angle is drawn to the centre of the octagon to give a series of triangles, quadrangles or more complex figures whose edges characterise the most important mineralization stages present in a deposit.

Figure 1 shows the various sequential stages for the development of tin deposits. Figure 2 presents the similar sequences for tungsten deposits. Bi and Be may be associated with the greisen assemblages, gold is a typical accompanying element of many tourmaline-chlorite types. Unlike tin and tungsten deposits molybdenum deposits (fig. 3) rarely show a complete development of all stages. In the classification suggested by KHRUSHCHOV (1961) the chlorite or tourmaline stages of mineralization are of no economic importance.

The application this classification to the physicochemical phases of late magmatic and post magmatic processes is shown in fig. 4. Each phase covers several stages of mineralization. For example the term «pneumatolysis» does not characterize the mineral content of a deposit but only indicates its position within the sequence of mineralization stages.

The proposed classification can be compared to that for tin deposits by RADKEVICH (1968) who distinguished pegmatite, skarn, quartz-cassiterite, cassiterite-silicate-sulphide and cassiterite-sulphide stages of formation. These formations can result from the combination of two or three simple mineralization stages (fig. 5).

The graphical representation of some tin deposits in the Central European metallogenic province of Czechoslovakia is presented in fig. 6, and the shaded areas of the octagons show the main mineralization stages which gave rise to a particular deposit.

### *Terminology of the deposits*

The names of deposits may be derived from the most important ore minerals (cassiterite, wolframite, scheelite, etc.) and from the main mineralization stages active in the formation of a deposit. Thus the cassiterite quartz veins with wall-rock greisenization may be termed as cassiterite quartz-greisen deposits, those with wolframite and quartz vein infilling and wall-rock chloritization as wolframite quartz-chloritic deposits. Examples are given in table I.

ACKNOWLEDGEMENT.—I thank Dr. PETER BOWDEN of the University of St. Andrews who commented the first version of the manuscript and offered many suggestions which helped to improve the text.

TABLE I

*The names of some typical tin, tungsten and molybdenum deposits of plutonic geol. position*

| Tin, tungsten or molybdenum deposits — Stages | Symboles | Name of the deposit (cassiterite, scheelite, wolframite, molybdenite) |
|---|---|---|
| quartz-greisenization | 3-4 | quartz-greisen deposit |
| quartz-sericitization | 3-7 | quartz-sericitic |
| quartz-greisenization sericitización | 3-4-7 | quartz-greisen-sericitic |
| tourmalinization-chloritization | 5-6 | tourmaline-chloritic |
| skarnization silicate oxide stage | 1 a, b | silicate-oxidic skarn |
| pegmatitization-feldspatization (albitization) | 1-2 | pegmatite-albititic |
| quartz-tourmalinization cloritization | 3-5-6 | quartz-tourmaline-chloritic |
| cloritization-sericitization | 6-7 | chlorite-sericitic deposit |

## REFERENCES


DENISENKO, V. K. (1975): *Classification of tungsten deposits for the purposes of their prognosis.* Zap. Vses. min. obshch., 104, vyp. 5, 526-538 (in Russian).

KHRUSHCHOV, N. A. (1961): *Molybdenum. The evaluation of deposit in the search and exploration.* Vyp. 19. Gosgeoltechizdat, Moskva (in Russian).

KRYLOVA, V. V. (1972): *The classification of tin-bearing deposits for the exploration purposes.* Geol. i razvedka, No. 3, 70-75 (in Russian).

LEVITSKII, O. D. (1947): *Genetic classification of tin-bearing deposits.* Geology of tin, Trudy inst. geol. nauk, vyp. 82, ser. rudnykh mestorozhdenii, No. 8. Izd. AN SSSR, Moskva-Leningrad (in Russian).

MATERIKOV, M. P. (1964): *Geological conditions in the appearence of the specialized tin-bearing intrusions. Metallogenic specialization of magmatic complexes.* Nedra, Moskva (in Russian).

RADKEVICH, E. A. (1968): *Tin-bearing formations and their practical significance.* Sov. geol., 1, 14-24 (in Russian).

SOKOLOV, G. A. & KOMAROV, D. V. (1968): *On the relationship between metalliferous greisens and skarns.* Rep. 23rd IGC, section 7, 305-312.

ŠTEMPROK, M. (1965): *On the transition of pegmatites into tin, tungsten and molybdenum-bearing veins.* Sbor. geol. věd, ser. LG, 7-38.

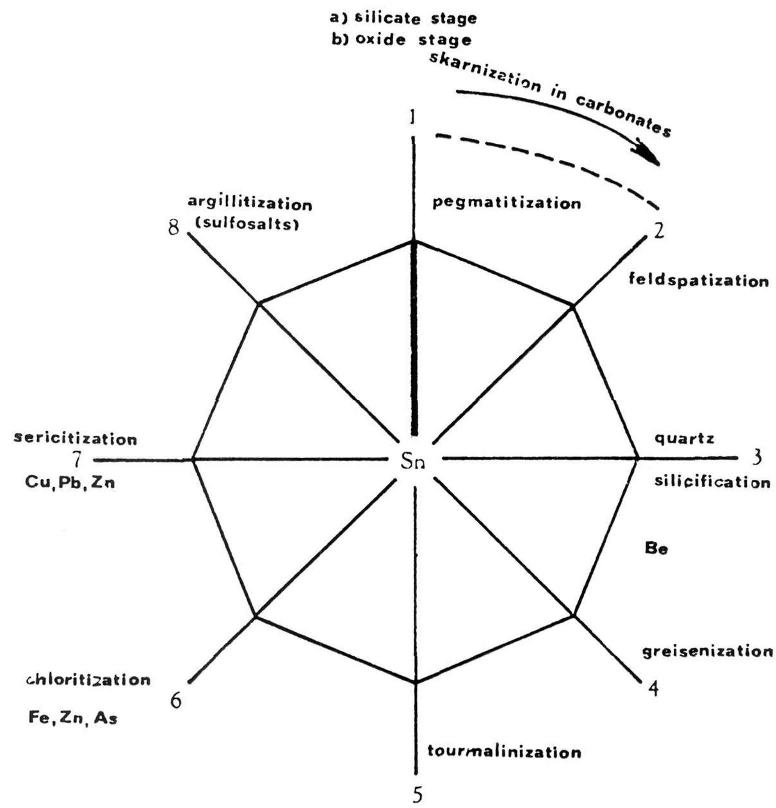


FIG. 1

*Sequential stages for the development of endogenous tin deposits*

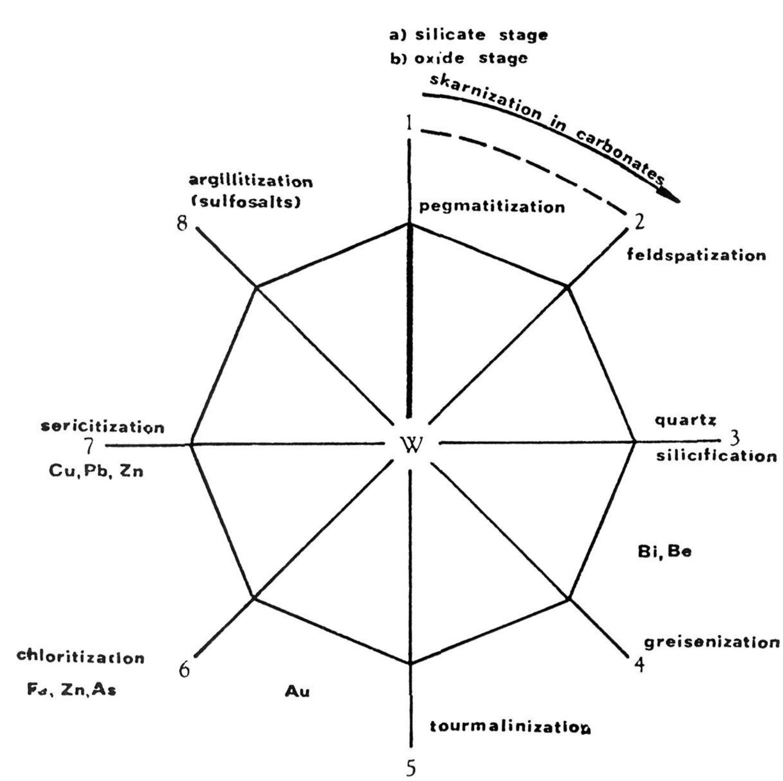


FIG. 2

*Sequential stages for the development of endogenous tungsten deposits*

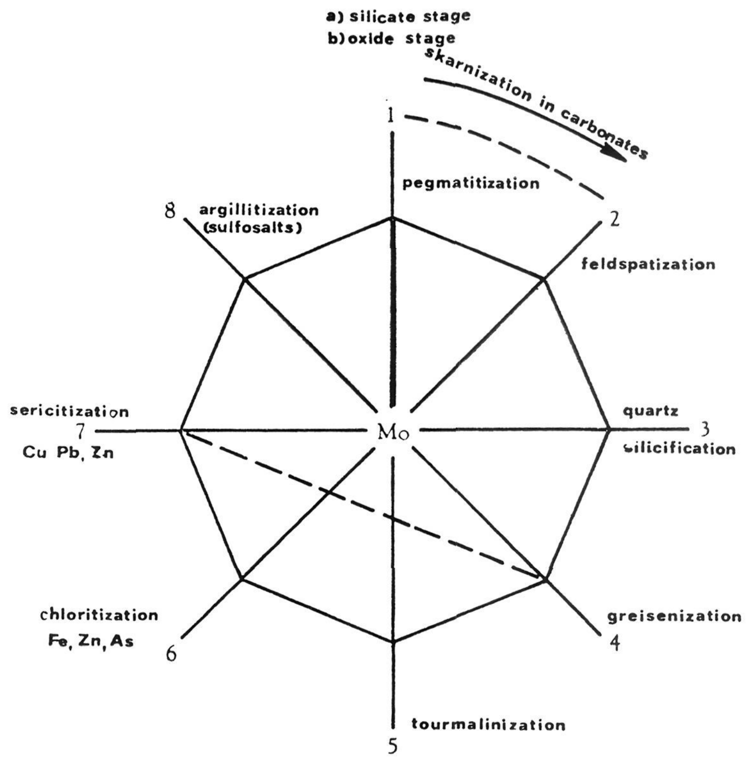


FIG. 3

*Sequential stages for the development of endogenous molybdenum deposits. The chlorite and tourmaline stages are of little economic importance*

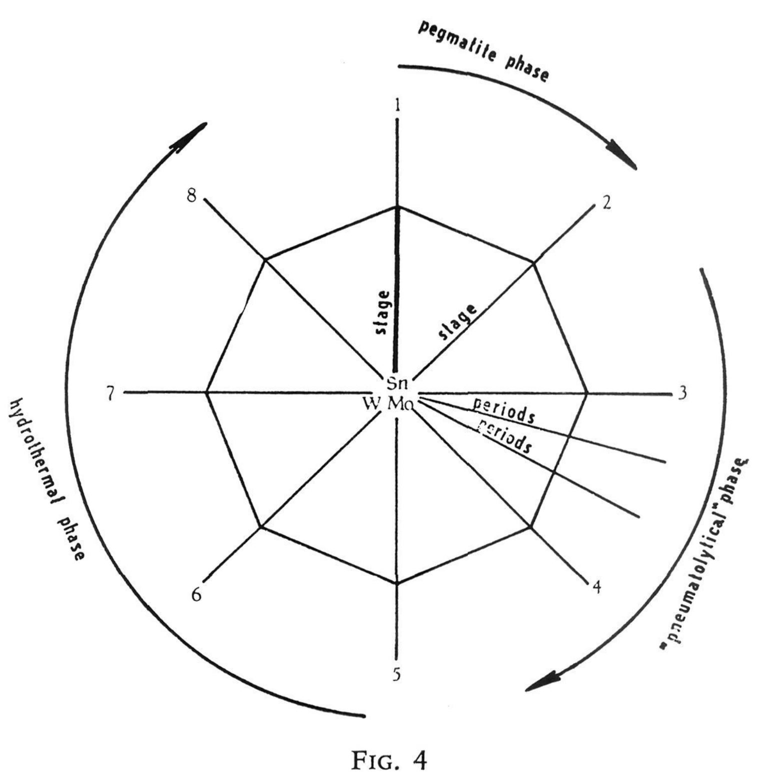


FIG. 4

*Comparison of the proposed classification with the physico-chemical phases of late magmatic and postmagmatic processes*

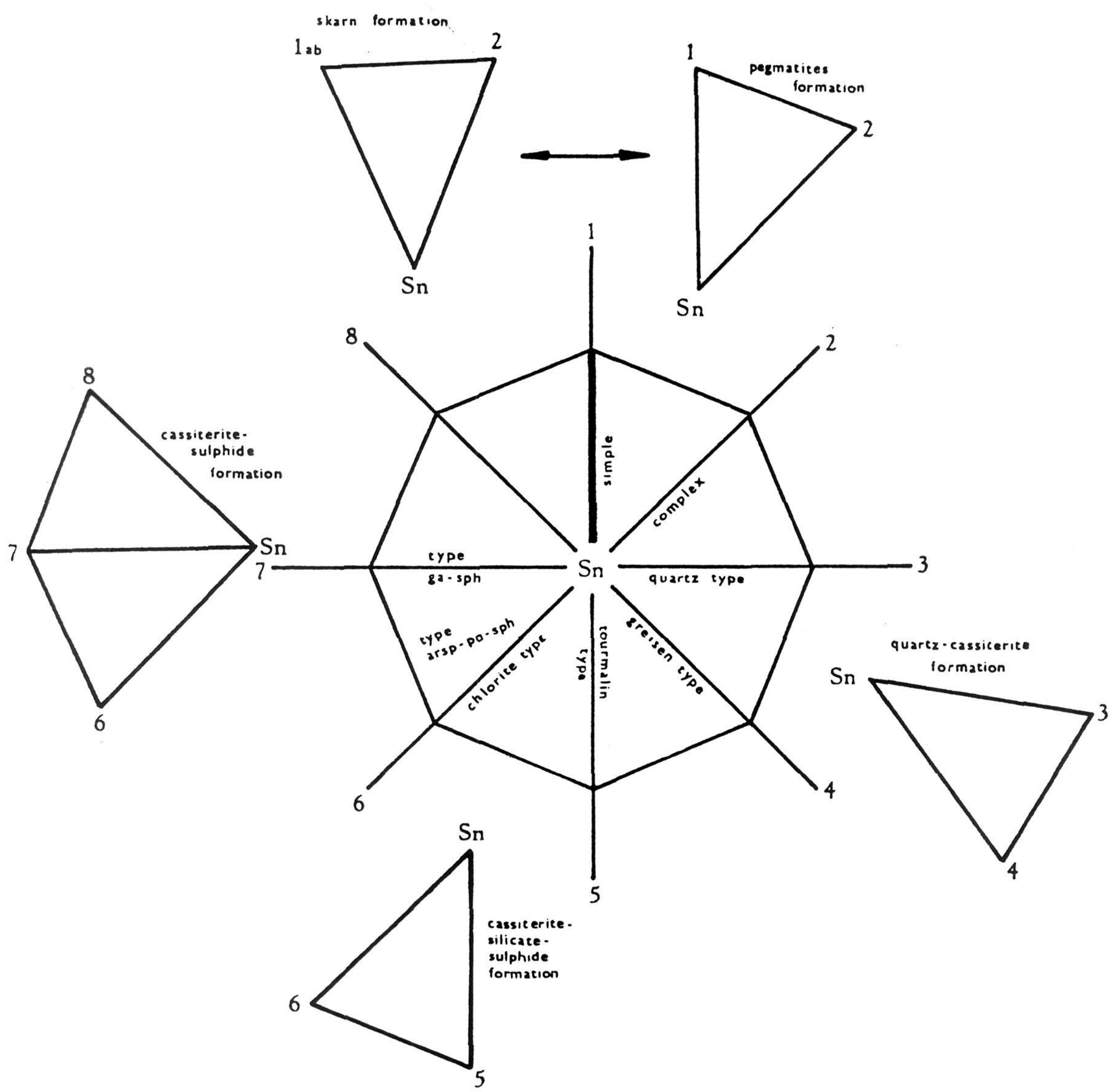


FIG. 5

*Comparison of the proposed classification with the formational classification devised by Radkevich (1968)*

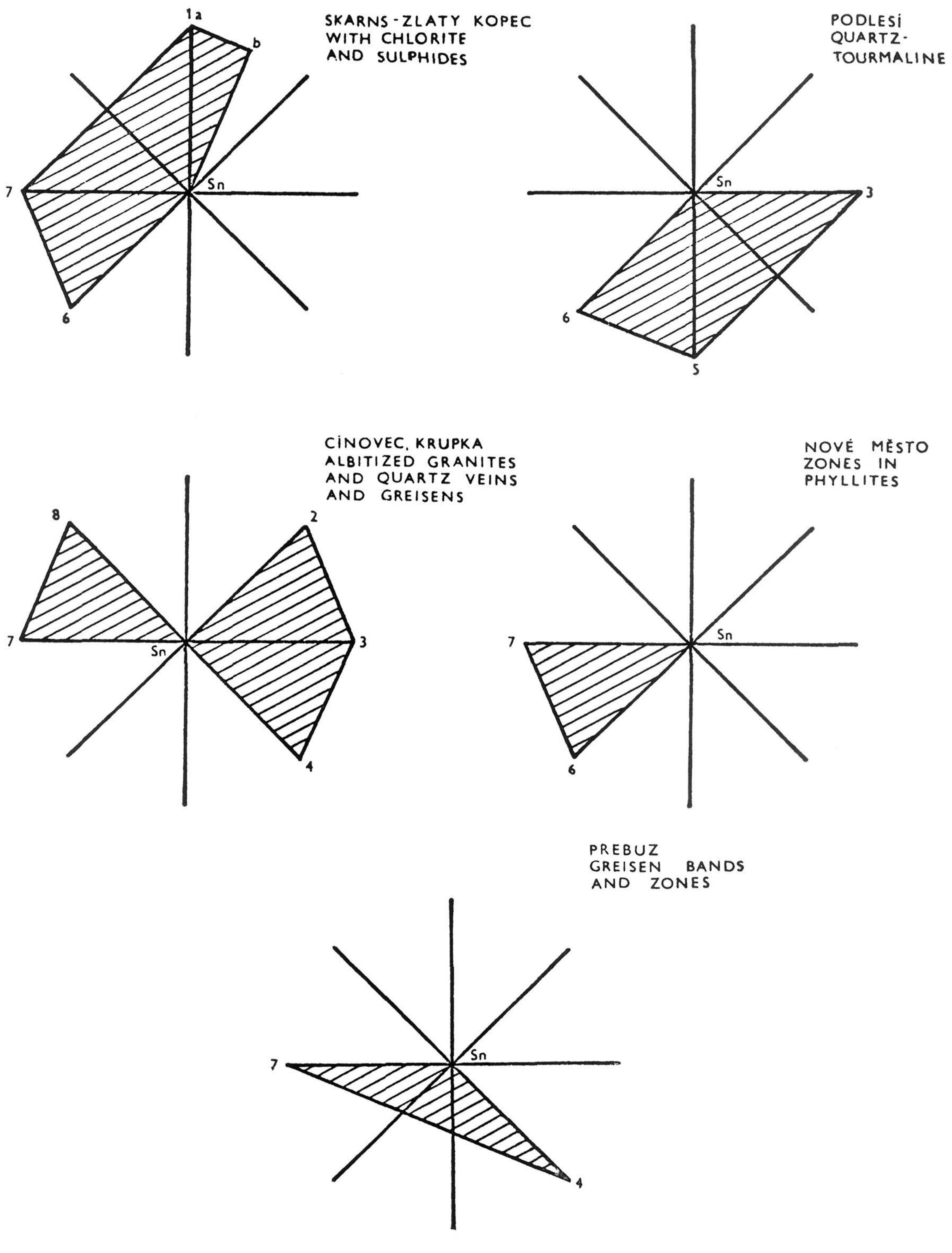


FIG. 6

*Example of the application of the proposed classification to some deposits of the Central European metallogenic province of Czechoslovakia*

a) *Skarn deposit Zlatý Kopec with silicate and oxidic skarn, superimposed chloritic and sericitic mineralization with sulphides.*
b) *Podlesí-quartz veins or tourmaline bands with weak chloritization.*
c) *Cínovec, Krupka-albitites, quartz veins with wall-rock greisenization.*
d) *Nové Město-chloritization zones with cassiterite impregnation accompanied by sericitization.*
e) *Přebuz-greisen zones without quartz accompanied by sericitization. Tourmalinization and chloritization is lacking.*

STVDIA GEOLOGICA, XIV, 1978 (171-181)

# A CLASSIFICATION OF TIN PROVINCES *

R. G. TAYLOR**

## INTRODUCTION

The problem of classifiying ore deposits has exercised the minds of several generations of geologists, and although the state of the art is far form perfection, considerable advances have occurred during the last decade. The underlying premise of the exercise is that correct groupings of related deposits will ultimately give valuable indications regarding genesis. Increasing attention has recently been given to the need to incorporate environmental factors into the classification, as well as the details of the actual deposit.

Early concepts from the U.S.S.R. stressed classification based primarily upon mineralogical characteristics, i.e. tin bearing pegmatites, quartz cassiterite, quartz sulphide, etc. This however proved unworkable and more recently ITSIKSON (1960) has approached the problem from an environmental viewpoint, relating tin deposits to different types of batholithic regions produced at different stages in the development of fold belts, this style of approach seems to offer a sound basis for further development. A simplified version of the Itsikson approach is given by ŠTEMPROK (1969), reproduced here as Table I.

The Itsikson approach was adopted by TAYLOR (1974) who similarly stressed that detailed analysis of provinces might provide a basis for classification and genetic interpretation of tin deposits.

In recent years the author has been collecting and synthesizing data concerning the 40-50 known tin provinces, with a view to classification. Whilst it is inappropriate to detail the characteristics of individual provinces here, it does seem that most provinces can be accommodated within a modified version of the Itsikson approach. Many provinces have not been well investigated or documented and in this sense the classification presented below is regarded as provisional and subject to modification as more data becomes available. Some of the environments are illustrated by Figs. 1-4.

* Paper presented verbally to a scientific meeting of MAWAM at the International Geological Congress, Sydney, 1976.

** Associate Professor (Economic Geology). James Cook University of North Queensland.

TABLE I

*Classification of tin-bearing formation modified according to* M. I. ITSIKSON (From ŠTEMPROK, 1969)

| | | |
|---|---|---|
| *Regions of tectonic and magmatic reactivisation* | | |
| Magmatic formation | Tin-bearing formations | Metallic associations of Sn |
| Subaerial effusions and extrusion of rhyolites | Volcanic group rhyolitic formations | In |
| Near-surface small intrusions associated with effusive acid or intermediate | Subvolcanic group (casiterite-silicate, cassiterite-sulphide formations tin bearing skarns) | Ag, As, B, F, Pb, Sb, Zn |
| *Mobile zones* | | |
| *Late* | | |
| Hypabyssal intrusions of composition associated with acid members | Hypabyssal group (cassiterite-silicate, cassiterite-quartz formations) | Ag, As, Au, Bi, Co, Cu, Pb, Zn, W |
| *Middle* | | |
| Batholithic intrusions of acid and ultra-acid granite and their satellites | Subabyssal (batholithic group) cassiterite-quartz-formations tin-bearing skarns tin-bearing pegmatites | As, B, Be, Bi, Cs, Li, Mo, Nb, Rb, Sn, Ta, W |

## ENVIRONMENTS CONTAINING SIGNIFICANT PRIMARY CONCENTRATIONS OF TIN (*1 See footnotes)

### *General Environment* (1)

Tin deposits associated with granitoids which show a close spatial and temporal relationship with a major period of orogeny, i.e. folding, fracturing, and uplift. Granitoid emplacement predominantly post major folding, i.e. late stage and controlled by major fracture-suture zones. Designated: FOLD BELT TYPE.

Subdivision (a)

Tin concentrations associated predominantly with extrusives and pyroclastics. Minor related intrusives.

Form of associated igneous rocks.

Terrestrial lava flows, tuffs, volcanic breccias. Minor stocksdykes and intrusive sheets with volcanic, non porphyritic to minor porphyritic, textures.

Composition of associated igneous rocks.

Predominately rhyolites with andesites, dacites, and latites.

Economic significance.

Primary ores: Very minor. Secondary ores: Very minor.

Examples.

Mexico (Fig. 1).

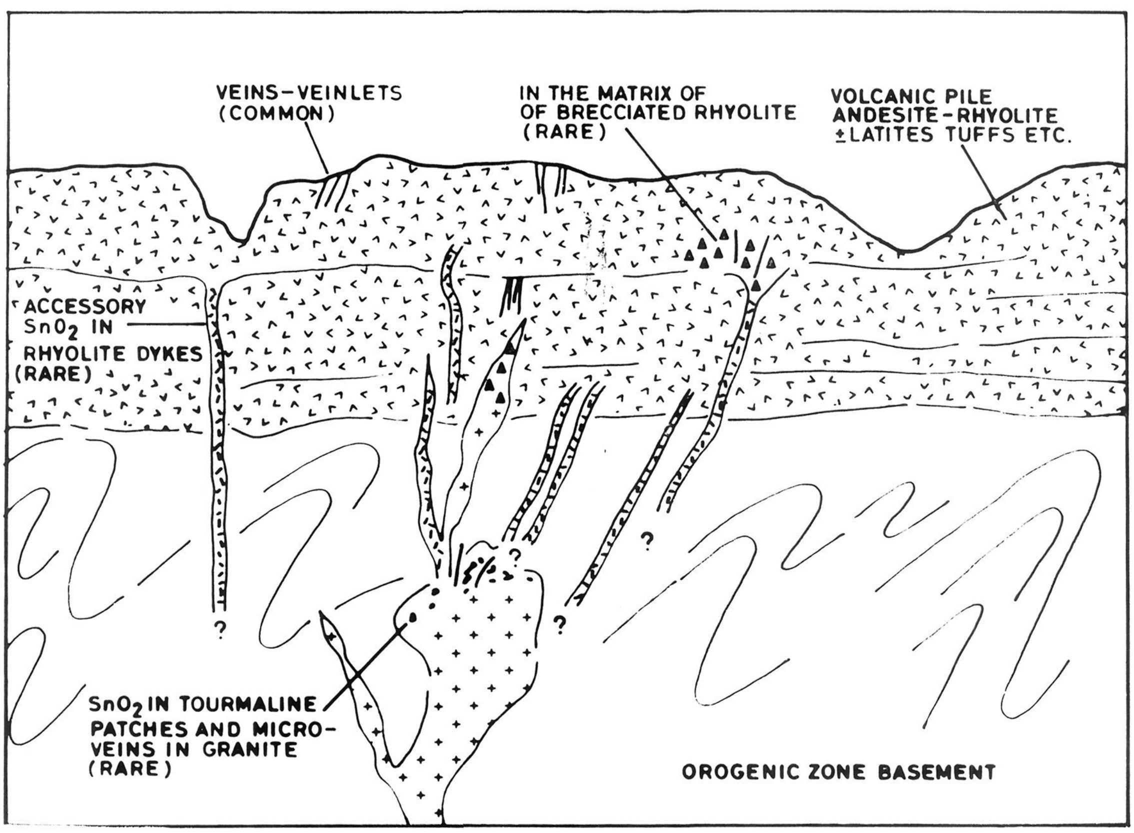


FIG. 1

*Diagram to illustrate the main features of the Mexican style volcanic tin province (Type 1a)*

Subdivision (b)

Tin concentrations associated with intrusive complexes of subvolcanic nature occurring in association with terrestrial extrusives.

Form of associated igneous rocks.

Small stocks, pipes, and irregularly shaped intrusives. Often steep walled and funnel shaped at depth. Associated dykes, dyke swarms, sills, breccia pipes, etc.

Composition of associated igneous rocks.

Diverse composition with porphyritic textures predominate. Granite porphyry, quartz porphyry, dacite, quartz latite porphyry, quartz diorite, granodiorite, granite, etc. Aplites and pegmatites are very rare. Volcanics are predominantly rhyolites and andesites.

Economic significance.

Primary ores: Major to minor. Secondary: Minor.

Examples.

Bolivia (Southern portion).
Southern Maritime Territory, U.S.S.R.
Japan.
Maly Kinghan, U.S.S.R.
Mio Chang, U.S.S.R.

Subdivision (c)

Tin concentrations associated with intrusive complexes of mixed character, i.e. representing a deep volcanic to high plutonic environment. Extrusive rocks mostly absent, but may be present in places.

Form of associated igneous rocks.

Wide diversity in form ranging from small stocks to large scale intrusive complexes. Major massifs-batholiths are often very complex and contain a large number of intrusive phases. Active repeated intrusion prevails over a more passive environment. At upper levels garlands or rosary chains of small granitoids associated with regional fractures reflect the deeper batholith structures. Geochemically specialised granitoids are often present and may form clear end members of a granodiorite-granite differentiation sequence. Dykes, and swarms are normally abundant, although often irregularly distributed. Aplites and pegmatites uncommon.

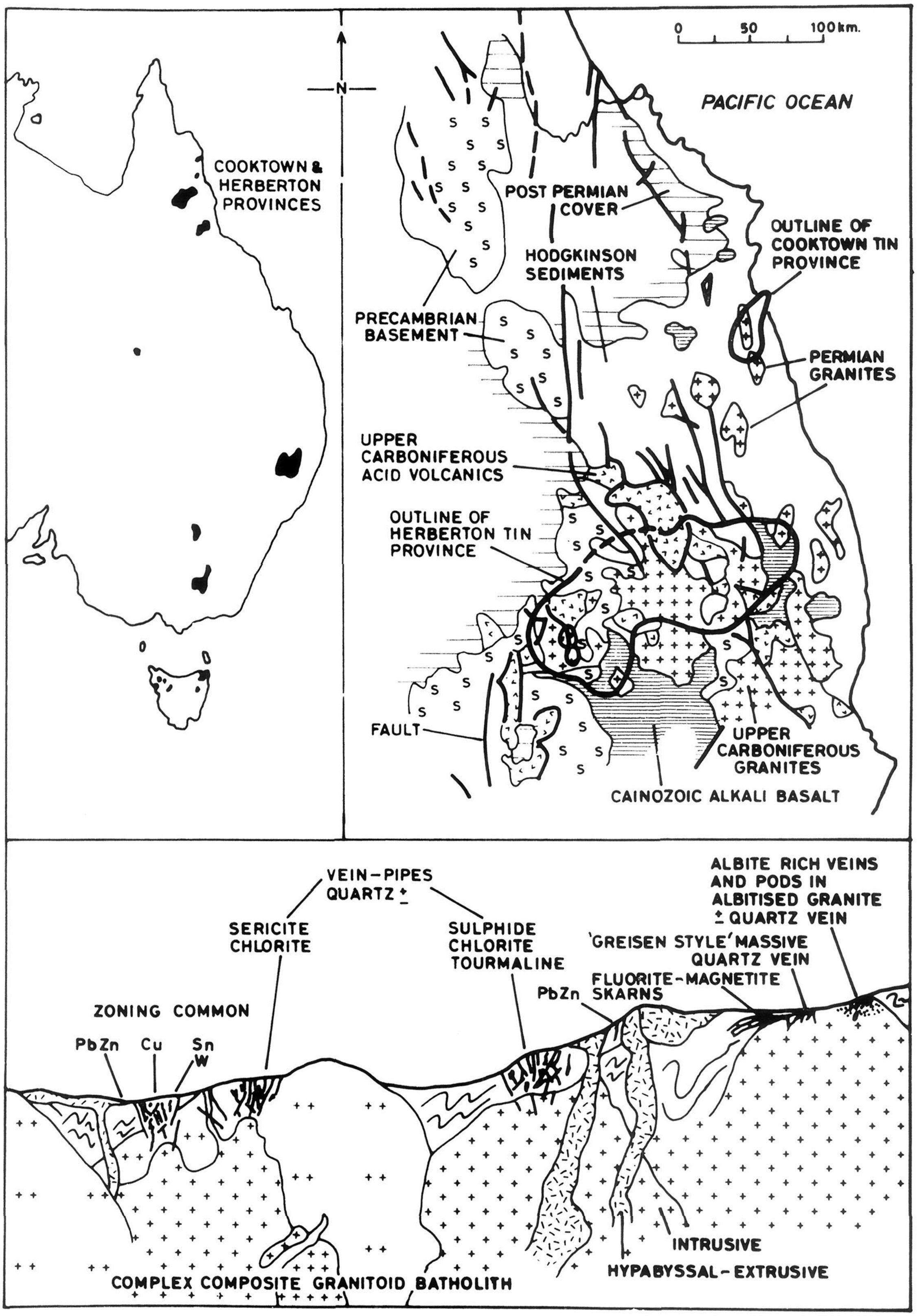


FIG. 2

*Diagram to illustrate the features of the deep subvolcanic style province (Type 1c). Herberton Province, Queensland Australia*

Composition of associated igneous rocks.

Diverse composition, granites and granodiorites prevail with minor monzonites, diorites, etc. Evidence of hybridism occurs in some provinces resulting in «diorites», andesine granites, etc. Hybridism is however rare. Plutonic textures prevail over porphyritic.

Economic significance.

Primary ores: Major to minor. Secondary: Intermediate to minor.

Examples.

Herberton, Australia (Fig. 2).
Kangaroo Hills, Australia.
Chukotka, U.S.S.R.
Yakutia, U.S.S.R.
New England, Australia.
?Northern Territory, Australia.
Transbaikal, U.S.S.R.
New Brunswick, Canada.

Subdivision (d)

Tin concentrations associated with intrusive complexes of plutonic character. Extrusives absent. Dykes and dyke swarms minor.

Form of associated igneous rocks.

Intermediate to large scale intrusive complexes. Massifs-batholiths generally contain a small number of individual plutons. Differentiation sequences are often well established between phases, and a relatively passive intrusion environment is suggested. Geochemically specialised granites are common, and often form minor phase end members of a granodiorite-granite sequence.

Composition of associated igneous rocks.

Predominately granites, granodiorites with minor alaskites, lencogranites and other specialised intrusives. Plutonic textures prevail. Aplites and pegmatites common.

Economic significance.

Primary ores: Major to minor. Secondary ores: Major to minor.

Examples.

Bolivia (Northern portion).
Erzgibirge, Czechoslovakia — G.D.R.
Cooktown, Australia.
Massif Central — Brittany, France.
Central Asia?

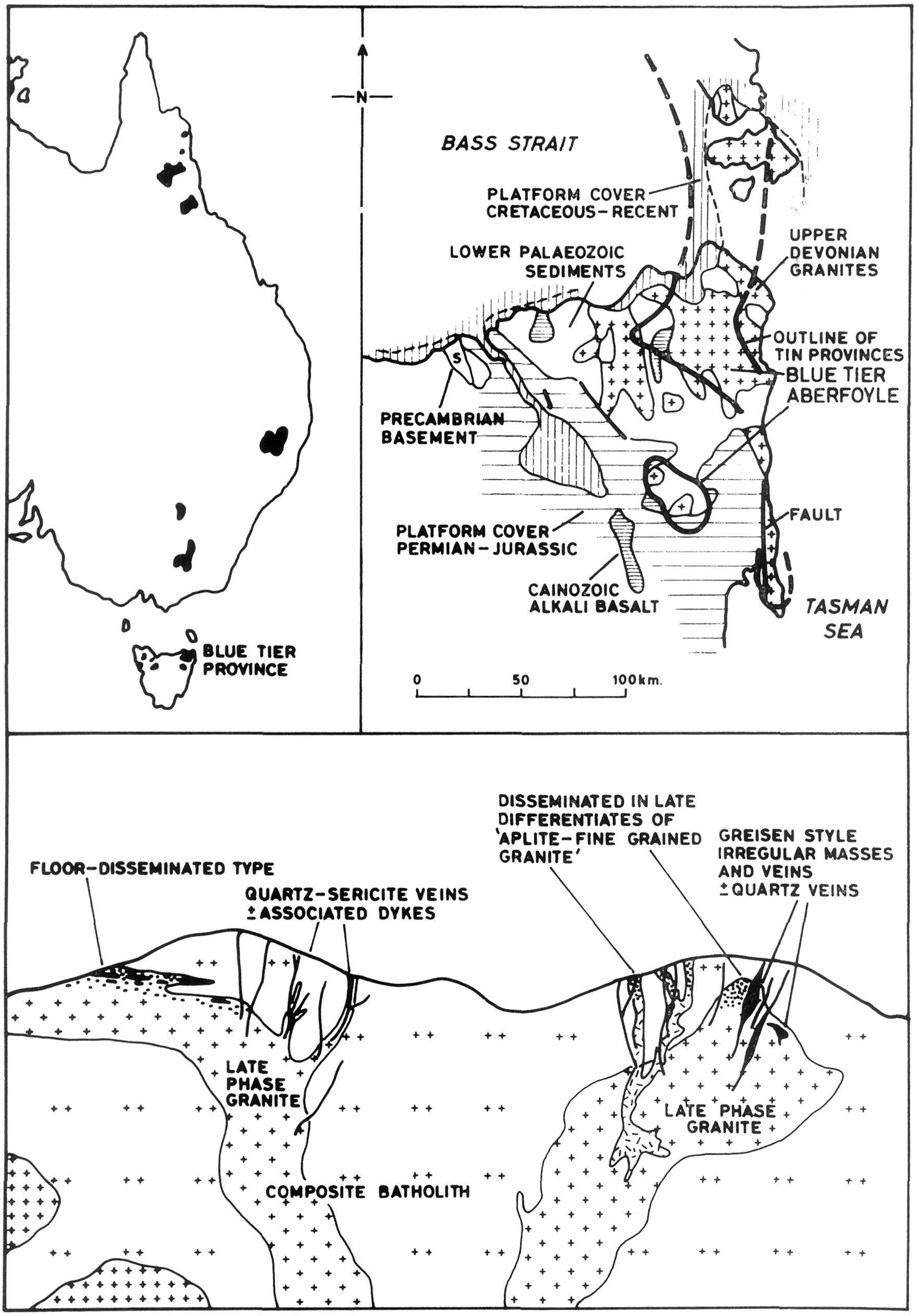


FIG. 3

*Diagram to illustrate the features of the greisen style ("passive") province (Type 1d) N. E. Tasmania Province (Blue Tier) Australia*

Thailand — Malaysia — Indonesia?
Ardlethan-Albury, Australia.
Seward Peninsula, Alaska.
North-East Tasmania (Fig. 3).

Note — Cornwall, England, North-West Tasmania and East Kazakstan, U.S.S.R., are difficult to catagorise and are probably 1c or transitional 1c/1d.

*General Environment* (2)

Tin deposits associated with granitoids emplaced via major zones of fracturing in cratonic shield areas. Granitoids are anorogenic (i.e. not locally associated with major periods of fold development. Designated: ANOROGENIC TYPE.

Form of associated igneous rocks.

Small ovate-circulate intrusive ring complexes. Minor stocks ring dykes are often capped by sheets. Minor volcanics. Groups of complexes show strong linear alignments.

Composition of associated igneous rocks.

Predominantly granite, microgranite, and rhyolite. Alkali granites present in Nigeria. Plutonic and porphyritic textures present.

Economic significance.

Primary ores: Very minor. Secondary ores: Major.

Examples.

Nigeria.
Brazil — Rondonia.
?South-west Africa.

*General Environment* (3)

Tin deposits associated with pegmatites in ancient metamorphic cratonic terrains. Designated: PRECAMBRIAN PEGMATITIC TYPE — Association with granitoids ranges from well established to uncertain. In many regions the geology is not well know. Subtypes may be present.

Form of associated igneous rocks.

Wide range of intrusive forms, e.g. batholiths domed complexes, stocks, sills, etc. Plutonic and gneissic textures predominate. Geology often uncertain.

Composition of associated igneous rocks.

Predominantly granites with minor alaskites. Pegmatites, aplites and granophyric phases are common.

Economic significance.

Primary ores: Minor. Secondary ores: Intermediate to minor.

Examples.

Central Africa.
Pilbara, Australia.
Greenbushes, Australia.
Broken Hill, Australia.
Brazil (Shield area).
Nigeria (Shield area) — See Fig. 4.
Southern Rhodesia.
Swaziland.
South-West Africa.
East Sayan, U.S.S.R.

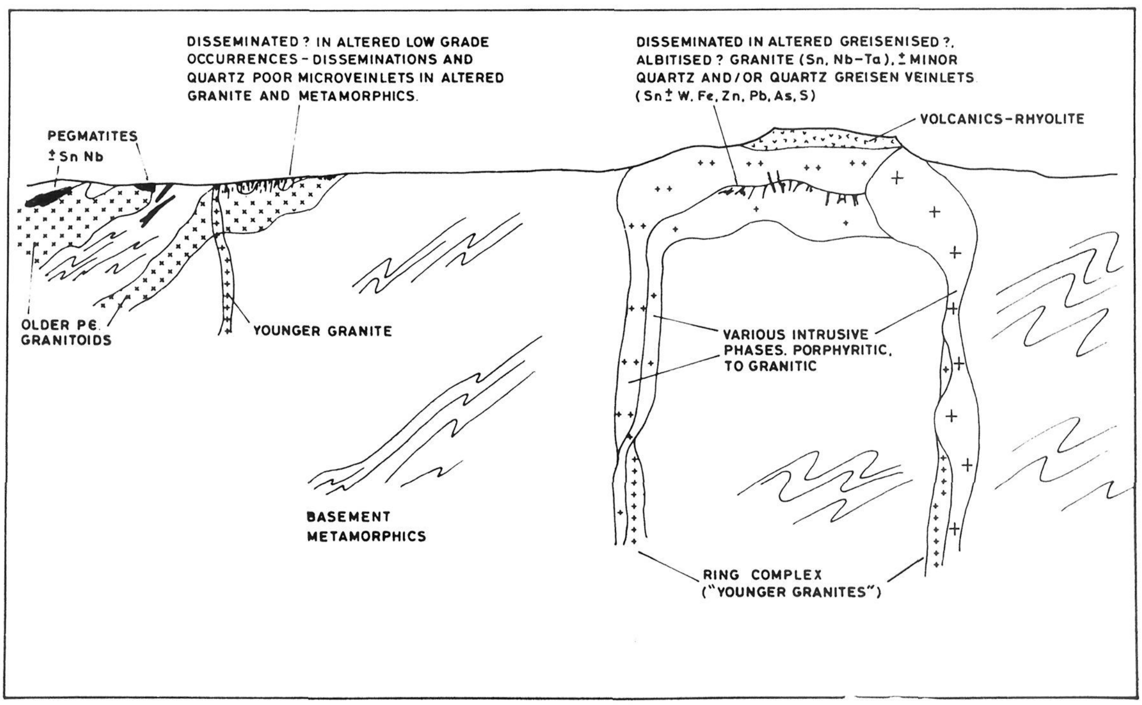


FIG. 4

*General Environment* (4)

Tin deposits associated with rapakivi granites in ancient metamorphic cratonic areas. Designated: PRECAMBRIAN RAPAKIVI. May also be considered as a subtype of (3).

Form of associated igneous rocks.

Massifs-stocks of polyphase granitoids. Plutonic to porphyritic textures. Late phase of massifs are geochemically specialised for tin, and associated with tin mineralisation.

Composition of associated igneous rocks.

Predominately granite with porphyritic and pegmatitic phases. Pegmatites common.

Economic significance.

Primary ores: Very Minor. Secondary ores: Very minor.

Examples.

Lodoga-Karalia, U.S.S.R.

*General Environment* (5)

Tin deposits associated with granitoid members of layered mafic intrusives in ancient metamorphic cratonic terrains. Designated: BUSHVELD TYPE. Unique to Bushveld Complex, South Africa.

Form of associated igneous rocks.

Stratiform granitic sheet associated with felsitic extrusions and pyroclastics. Intruded by stocks of granite, and underlain by sheets of gabbro and norite. Wide textural variation (plutonic to granophyric).

Composition of associated igneous rocks.

Predominantly granite — plutonic, porphyritic, and granophyric.

Economic significance.

Primary ores: Minor. Secondary ores: Very minor.

Examples.

Bushveld district — South Africa.

## FOOTNOTES

*(1)

Significant denotes that local production centres occur with tin as a major product. Tin occurs in other environments as a minor or trace element. Whilst rarely of commercial interest the occurrences are of genetic significance, e.g. rare occurrences in association with pyritic base metal ores of probable volcanogenic origin, Sullivan — British Columbia (SWANSON & GUNNING, 1948). Timmins — Ontario (WALKER et al., 1975) Mt. Lyell — Tasmania. Trace amounts are recorded in the nickel ores of Sudbury (HAWLEY, 1962) etc.

In terms of annual world production, the following first order approximations would apply.

Group 1. (a) Negligible
(b) 90-96% Mostly alluvial, (say 65-75%)
(c) 90-96% Mostly alluvial, (say 65-75%)
(d) 90-96% Mostly alluvial, (say 65-75%)
Group 2. 2.5% All from alluvial sources
Group 3. 2-5% Mostly from alluvial sources
Group 4. Negligible
Group 5. Negligible

ACKNOWLEDGEMENTS.—The classification presented above was sharpened considerably by the critical reading of Professor W. C. LACY, whilst the diagrams were designed and drafted by Mr. J. NGAI. The work was conducted as part of a broad scale tin project suggested by the Australian Research Grants Committee (A.R.G.C.).

## REFERENCES

HAWLEY, J. E. (1962): *The Sudbury ores, their mineralogy and origin.* Canadian Mineralogist, 7: pt. 1, 207 pp.

ITSIKSON, M. I. (1960): *The distribution of tin ore deposits within folsed zones.* International Geological Review, 2: 397-417.

ŠTEMPROK, M. (1969): *Geochemical association of tin.* A second technical conference on tin. Bangkok. International Tin Council, 1: 159-176.

SWANSON, C. O. and GUNNING, H. C. (1948): *Sullivan Mine.* In "*Structural Geology of Canadian Ore Deposits*". A symposium Canadian Institute of Mining and Metallurgy, pp. 219-230.

TAYLOR, R. G. (1974): *Metallogenic provinces as an approach to the problems of classification and genesis of tin deposits with special reference to E. Australia.* In: M. ŠTEMPROK (Editor): *Symposium Metallization Associated with Acid Magmatism* (MAWAN). Geological Survey-Prague, 1: 71-78.

WALKER, R. R.; MATULICH, A.; AMOSS, A. C.; WATKINS, J. J. and MANNARD, G. W. (1975): *The Geology of th Kid Creek Mine.* Economic Geology, 70: 80-89.

STVDIA GEOLOGICA, XIV, 1978 (183-188)

# GEOCHEMICAL ASPECTS OF THE EVOLUTION AND MINERALIZATION OF THE NIGERIAN MESOZOIC ANOROGENIC GRANITES

PETER BOWDEN*

ABSTRACT.—The anorogenic Mesozoic ring-complexes of northern Nigeria are composed of syenite-related granitic rocks. Field studies and geochemical evidence suggest that the peralkaline and peraluminous granites developed consecutively implying that each trend evolved its own residual mineralizing fluid. Granites with Nb-U, Zn-Sn mineralization have high initial strontium isotopic ratios but the other related granites and syenites exhibit intermediate (0.706-0.709) and low (0.704-0.706) values respectively. The geochemical data therefore suggests that sources within the mantle, lower crust and upper sialic crust have all contributed to produce the Nigerian younger granites and their mineralization.

The anorogenic Mesozoic ring complexes of northern Nigeria evolved through the early development of trachyte-peralkaline silicic volcanics mirrored at subvolcanic levels by syenite and related peralkaline granites. Isotopic measurements on two small oversaturated syenite intrusions at Zaranda and Pankshin (Fig. 1) suggest that syenitic liquids had initial ratios similar to the mantle, but that related peralkaline silicic variants from the same complexes are depleted in total Sr and have higher $^{87}Sr/^{86}Sr$ initial ratios characteristic of the earth's crust. This variation of initial $^{87}Sr/^{86}Sr$ ratios in syenite-related granitic liquids of the peralkaline spectrum has also been noted at the Shere hills, near Jos, and at Liruei (Fig. 1) and may be representative for all syenite-granite occurrences in the Nigerian younger granite province (Table I). No volcanic equivalent of biotite granite or hastingsite-biotite granite has been found in the Nigerian Younger Granite Province. It is assumed that the biotite granite trend is confined to the late magmatic hypabyssal cycle. Therefore as the magmatic cycle progressed, the granitoid liquids became less alkaline and allowed associated peraluminous biotite granites to dominate

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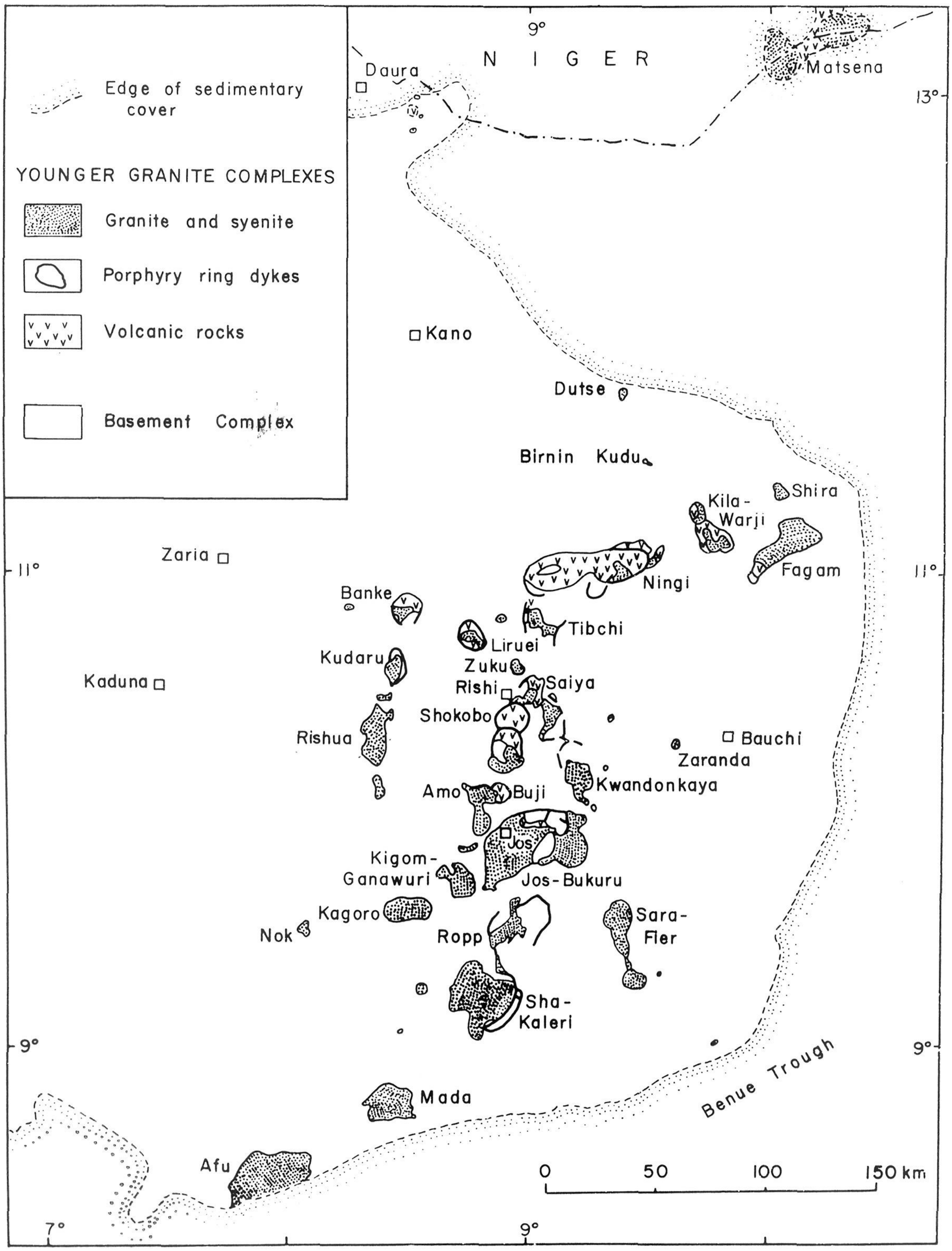


FIG. 1

*Location map of the Nigerian Mesozoic ring complexes showing their distribution and principal rock types. Two petrogenetically related but considerably older centres at Daura and Matsena are depicted in the region of the Niger border*

TABLE I

*Averaged initial strontium isotopic ratios for the syenite-related peralkaline granite trend, Nigeria*

| | $^{87}Sr/^{86}Sr$ (initial) |
|---|---|
| Syenite | 0.705 |
| Quartz syenite | 0.706 |
| Fayalite granite | 0.707 |
| Arfvedsonite-riebeckite granite | 0.708 |
| Albite-riebeckite granite (mineralized) | 0.752 |

and end the magmatic cycle. The coarse grained biotite granites have consistently low $^{87}Sr/^{86}Sr$ ratios in the range 0.706-0.709, but mineralized biotite granites have considerably higher initial strontium ratios (Table II).

The isotopic evidence suggests that a substantial crustal contribution was introduced at some stage during the development of residual fluids either through exchange with country rocks, assimilation or partial melting during the intrusion of syenitic parent magmas to high levels in the crust (van BREEMEN *et al.*, 1975).

TABLE II

*Averaged initial strontium isotopic ratios for the biotite granite trend, Nigeria*

| | $^{87}Sr/^{86}Sr$ (initial) |
|---|---|
| Hastingsite-biotite granite | 0.707 |
| Biotite granite | 0.709 |
| Albite biotite granite (mineralized) | 0.730 |

The petrogenetic evolution of the Nigerian younger granites has been widely discussed by numerous authors (see for example, TUGARINOV *et al.*, 1968; BUCHANAN *et al.*, 1971; MACLEOD *et al.*, 1971; BOWDEN and TURNER, 1974). It is generally accepted that the petrographic and geochemical criteria supports the view that the younger granites are of magmatic origin. It is also accepted that there is peralkaline trend responsible for the formation of arfvedsonite-riebeckite granites from a syenitic parent magma, and a contrasting aluminous biotite granite trend which may have evolved from a similar syenitic source rock. Although it was originally thought that both peralkaline and peraluminous trends evolved simultaneously by divergent differentiation (Jacobson *et al.*, 1958), recent work has shown that the initial alkaline granite trend was completed in its entirety before the later biotite granite trend developed.

This suggestion eliminates one of the major obstacles to the concept of divergent differentiation and further proposes that the peralkaline and peraluminous trends were not concurrent but consecutive. The implication of this proposal is that each trend develops its own residual mineralizing fluid.

## PERALKALINE GRANITES

In the peralkaline granites there was one period of mineralization esentially related to recrystallization and the introduction of albite. It is considered that a high agpaitic coefficient maintained miscibility in the albite-rich ore fluids between silicate and aqueous phases to low temperatures so that mineralizing components continually accumulated together and prevented widespread precipitation of ore minerals. This fluid rich in fluorine albitized and modified the peralkaline granites causing new mineral growth in the sub-solidus and the crystallisation of uraniferous pyrochlore. High initial $^{87}Sr/^{86}Sr$ ratios (up to 0.752) in pyrochlore-bearing albite-rich peralkaline granites suggest a substantial late-stage sialic crustal contribution to the late magmatic fluids.

## PERALUMINOUS GRANITES

If, however, the high agpaitic coefficient could not be maintained, silicate and aqueous fluid phases would have separated resulting in substantial ore formation. This process appears to have occurred in the peraluminous biotite granites. A pre-joint autometamorphic mineralization dispersed columbite, thorite and xenotime into the uppermost parts of biotite-granite cupolas. This early phase of mineralization during the cooling and consolidation of the granite was subsequently followed by a post-joint replacement mineralization with the metasomatic introduction of cassiterite, minor wolfram, and abundant sulphide minerals into crystalline host rocks along cooling joints, fissures, veins, and ring fractures. The degree of albitization in the mineralized biotite granites is far less intensive than in the peralkaline granites, but the proportion and variety of ore minerals is far greater. The initial $^{87}Sr/^{86}Sr$ isotopic ratios for mineralized biotite granites (0.72-0.73) whilst still reflecting a crustal contribution are not as high as in the strongly albitized peralkaline granites.

## SOURCE AND ORIGIN

The anorogenic younger granites of Nigeria vary in age from 200 Myrs in the north to 140 Myrs in the south (Fig. 2). There were therefore sequentially intruded at high levels into the Precambrian 'Basement', and many of the ring complexes at the present erosional levels began life as chains of volcanoes during the Mesozoic. The younger granite group represents an episode of continental mid-plate magmatism during Upper Triassic to Upper Jurassic times in Nigeria (BOWDEN *et al.,* 1976). However despite the frequency of

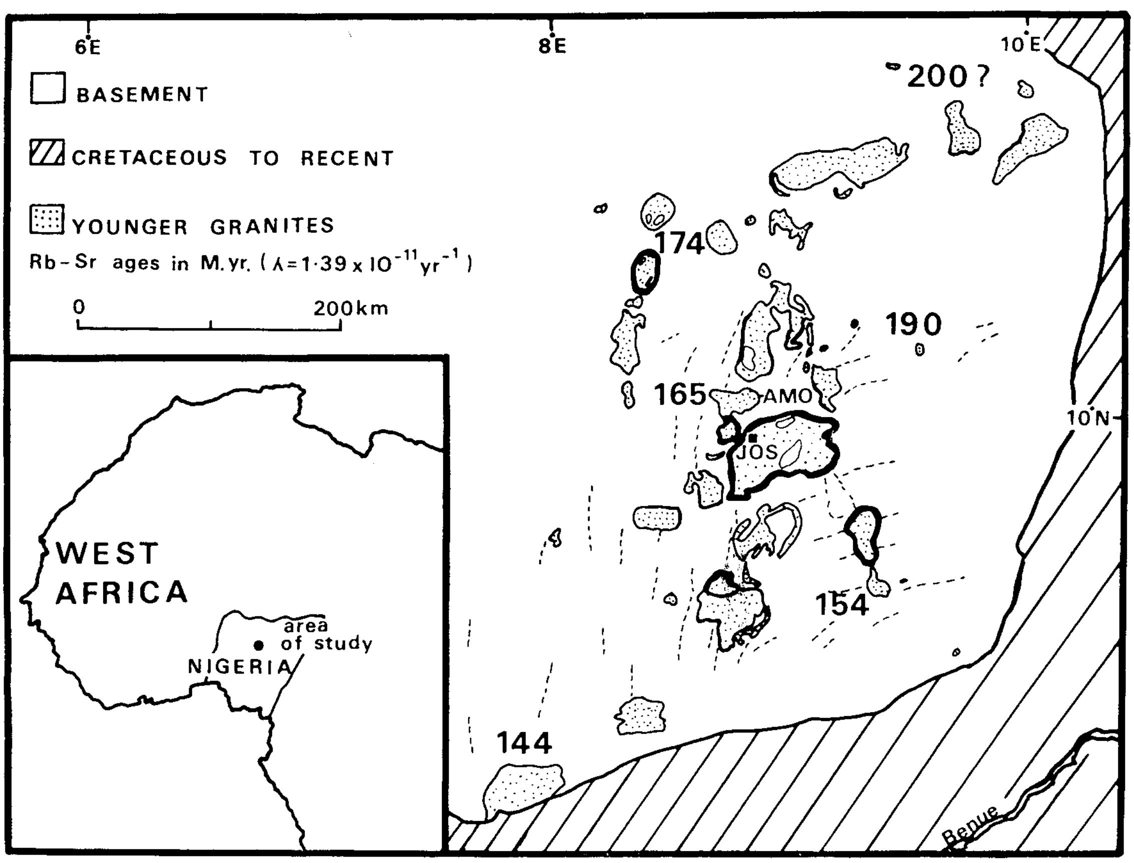


FIG. 2

*Sequential age trends for some Nigerian Mesozoic granites* intrusions and number of complexes it appears that the evolution and mineralization processes discussed above were repeated over 40 times during a 50 Myr cycle. Wherever the source of the metals for mineralization may have been situated it must have withstood repeated tapping and must have been an inexaustable supply of niobium and uranium, zinc and tin.

From the isotopic evidence there are three groups of strontium initial ratios to explain in terms of source and origin of the magmatic liquids and their residual mineralizing fluids i.e. low ratios (0.704 - 0.706) in parental syenites which are close to mantle values; intermediate ratios of 0.706 to 0.709 in most coarse grained granites, and high ratios (0.721 to 0.752) in mineralized granites. We therefore have isotopic evidence for contributions from the mantle, lower crust and sialic upper crust. When this data is examined in conjunction with other geochemical evidence it appears that material from all *three* sources has been utilised to produce the varied and exotic geochemical features of the Nigerian Mesozoic anorogenic granitoid rocks.

ACKNOWLEDGEMENTS.—I would like to express my sincere thanks to my colleagues at the Scottish Universities Research and Reactor Centre, especially OTTO VAN BREEMEN, and to my research group who were financed by grant R 2679 from the Overseas Development Ministry, London. Without their assistance the ideas expressed in this paper would not have materialized.

I am also grateful to Professor E. K. WALTON for his encouragement, and to the Technical Staff at the Department of Geology for their constant help.

## REFERENCES

BOWDEN, P. and TURNER, D. C. (1974): *Peralkaline and associated ring-complexes in the Nigerian-Niger Province, West Africa.* In "*The Alkaline Rocks*" edited by H. SØRENSEN, 330-351, Wiley, New York.

BOWDEN, P.; BREEMEN, O. VAN; HUTCHINSON, J. and TURNER, D. C. (1976): *Palaeozoic and Mesozoic age trends for some ring complexes in Niger and Nigeria.* Nature, 259, 297-299.

BUCHANAN, M. S.; MACLEOD, W. N.; TURNER, D. C.; BERRIDGE, N. G. and BLACK, R. (1971): *The Geology of the Jos Plateau,* Vol. 2, *Younger Granite Complexes.* Bull. Geol. Surv. Nigeria, 32.

JACOBSON, R. R. E.; MACLEOD, W. N. and BLACK, R. (1958): *Ring-complexes in the younger granite province of northern Nigeria.* Mem. Geol. Soc. London, 1.

MACLEOD, W. N.; TURNER, D. C. and WRIGHT, E. P. (1971): *The Geology of the Jos Flateau,* Vol. 1, *General Geology.* Bull. Geol. Surv. Nigeria, 32.

TUGARINOV, A. I.; PAVLENKO, A. S. and KOVALENKO, V. I. (1968): *Geochemical evidence on the origin of apogranites.* Geokhimiya, 12, 1419-1436.

VAN BREEMEN, O.; HUTCHINSON, J. and BOWDEN, P. (1975): *Age and origin of the Nigerian Mesozoic granites: A Rb-Sr isotopic study.* Contrib. Mineral. Petrol., 50, 157-172.

STVDIA GEOLOGICA, XIV, 1978 (189-220)

# MINERALISATION ASSOCIATED WITH THE NIGERIAN MESOZOIC RING COMPLEXES

JUDITH A. KINNAIRD*

ABSTRACT.—The anorogenic younger granites of northern Nigeria have evolved along two separate petrographic trends and each has its differing associated mineralization. The peralkaline trend shows a dominantly dispersed phase while the biotite granites have an early dispersed phase, in which columbite may be important, followed by a late-stage vein controlled cassiterite/sulphide rich phase of mineralization. Throughout these phases zinc is a more abundant element than tin while the associated tungsten plays a less important role than earlier writers imply. An abundance of minor ore minerals associated with the cassiterite and columbite phases of mineralization have also been discovered.

## PART 1

## *MINERALIZATION AND ITS REGIONAL SETTING*

### INTRODUCTION

There are two distinct periods of tin mineralization in Nigeria. An earlier Palaeozoic mineralization possibly related to orogenic calc-alkaline magmatism at the close of the Pan-African thermo-tectonic event and a later Mesozoic mineralization associated with the formation of subvolcanic anorogenic granites as ring complexes. The style of each mineralization as well as the associated minerals is very different and may simply be related to contrasting tectonics and magma evolution. (MARTIN and PIWINSKII 1972).

The Palaeozoic tin mineralization is limited and confined to some quartz-mica-feldspar pegmatites in the Kafanchan region (Fig. 1). These may consist of microcline, oligoclase, biotite, muscovite, lepidolite, apatite and garnet as well as quartz, whilst cassiterite and tantalite are important economically. Varieties of beryl and green and pink tourmalines are also worked on a minor scale for gemstones.

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In contrast the anorogenic Mesozoic granites of Northern Nigeria (Fig. 1), do not contain tourmaline or tantalite but in some localities have high concentrations of columbite. They also contain rare-earths, uranium and thorium-rich accessory minerals and most important of all abundant sphalerite with cassiterite, chalcopyrite, galena, pyrite, topaz and fluorite, whilst monazite, arsenopyrite, genthelvite, pyrrhotite and molybdenite also occur. Zinc is an enriched trace element in the anorogenic granites concentrating in the micas and amphiboles up to 1% wt. ZnO and it is therefore not surprising that the principal ore mineral in many of the mineralized veins is sphalerite which in some instances far exceeds the amount of cassiterite.

## GENERAL GEOLOGY

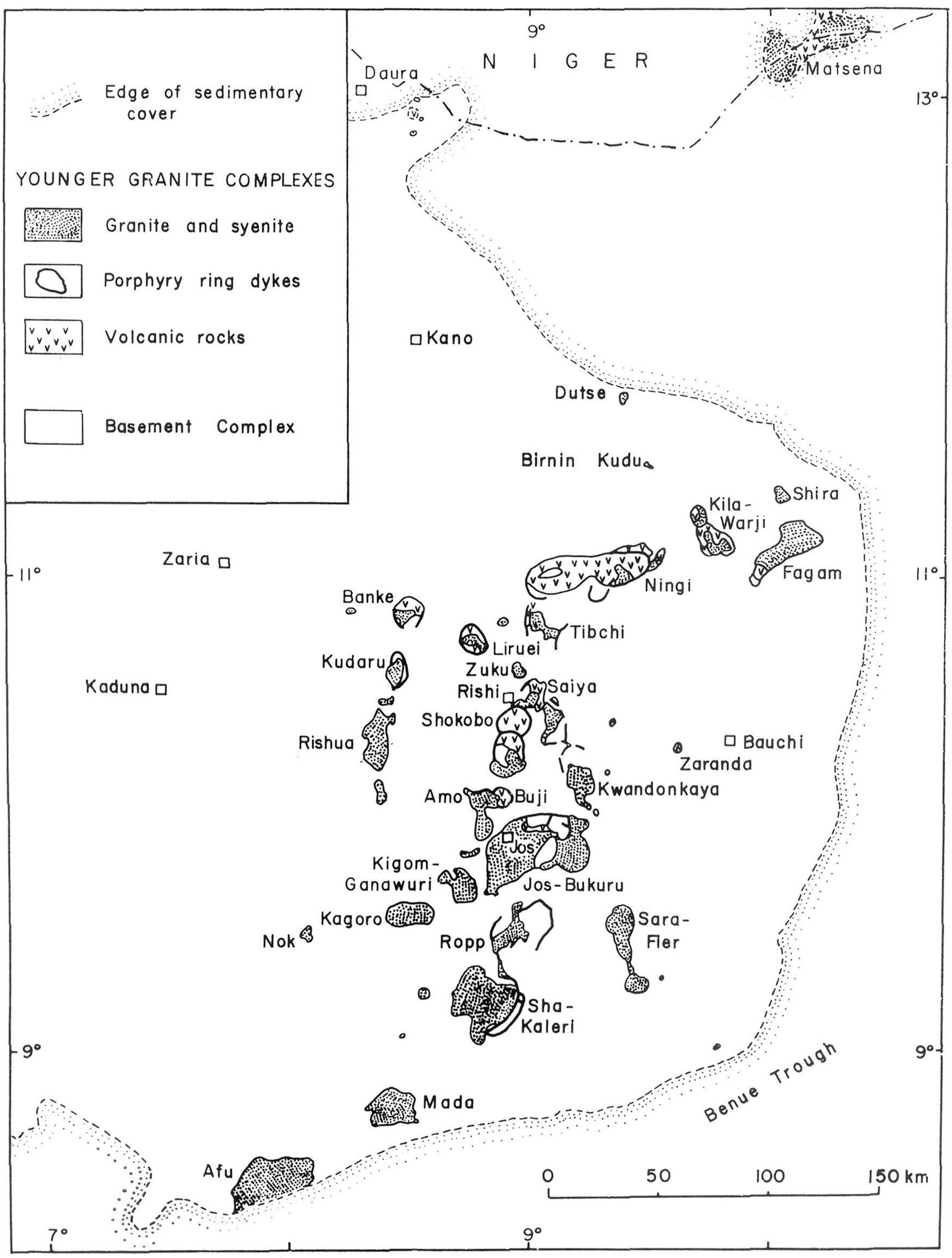
The anorogenic granites of northern Nigeria (the younger granites), were intruded at a high level into the late Precambrian to lower Palaeozoic basement as ring complexes. Over 40 individual complexes occur and range in size from 1.500 $Km^2$ to less than 2 $Km^2$.

In general this suite of complexes is concentrated in a 200 Km. wide zone as chains of complexes extending along the ninth meridian. The zone, which extends from the Niger Republic, 1.200 Km. south to the margin of the Benue trough in Nigeria, represents successive periods of continental mid-plate magmatism which migrated southwards.

Typically, the complexes are circular or elliptical in outline, 10-25 Km. in diameter and defined by an outer fayalite-granite-porphyry ring-dyke surrounded by basement.

Although the distribution of the ring complexes is to some extent controlled by the Pan-African structural trends in the 'basement' rocks the subvolcanic centres vary greatly in structural complexity.

Studies in the north of Nigeria (Bowden and Turner in press.) have shown that the development of these complexes began with the eruption of basalts (olivine tholeiites, quartz tholeiites) from central volcanic vents. These were associated with trachy-andesites, trachytes and minor rhyolites. During subsequent caldera collapse voluminous sequences of rhyolitic ignimbrites dominated the volcanic assemblage. Later, post-caldera acid lava flows and silicic endogenous domes occupied the crater floor. Into this volcanic pile were intruded the subvolcanic granites, some of which contain fayalite, hedenbergite sub-alkaline and alkaline amphiboles and biotite. Also oversaturated syenites and syenomonzonites are a minor but important group of associated rock types, whilst basic rocks are found both predating and post-dating the granite magmas. The petrology of the granites and associated


Edge of sedimentary cover
YOUNGER GRANITE COMPLEXES
Granite and syenite
Porphyry ring dykes
Volcanic rocks
Basement Complex
N I G E R
9°
Daura
Matsena
13°
Kano
Dutse
Birnin Kudu
Shira
Kila-Warji
Fagam
Ningi
Zaria
11°
Banke
Tibchi
Liruei
Kudaru
Zuku
Kaduna
Rishi
Saiya
Shokobo
Bauchi
Rishua
Zaranda
Kwandonkaya
Amo
Buji
Jos
Kigom-Ganawuri
Jos-Bukuru
Kagoro
Sara-Fler
Nok
Ropp
Sha-Kaleri
9°
Mada
Benue Trough
Afu
0
50
100
150 km
7°

rocks has been well described by BUCHANAN *et al.* (1971), but whilst many of these granites are known to be the source of cassiterite, columbite and wolframite, little has been written on primary mineralization. Current research has shown that zinc also plays an important role not only as a dispersed element substituting in the ferromagnesian lattice sites in many of the granites but also forms sphalerite and genthelvite in mineralized veins. Zinc is more abundant than tin within the province and shows a much greater enrichment than tungsten or niobium in granites and mineralized veins. It also seems likely that the importance of tungsten in the Nigerian Province has previously been overstated.

To understand the Mesozoic mineralization related to the granites it is convenient to consider the peralkaline and peraluminous granites separately. It is not proposed to consider the evolution and origin of these rock types as this has been dealt with elsewhere. (BOWDEN and MARTIN, in prep.; BOWDEN and KINNAIRD, in press.).

### *Peralkaline Granites*

The peralkaline albite riebeckite granites show a dispersed mineralization associated with recrystallization and formation of sub-solidus albite and microcline. They may also contain pyrochlore, chyolite and fluorite. The peralkaline granites, which are rather limited in distribution, confirm the abundance of zinc although no separate zinc mineral has been found. Whole rock analyses show up to 1.000 ppm. zinc which is concentrated in the amphiboles which may contain as much as 1% wt. ZnO (BORLEY 1976). In addition to these obvious increases in Na, Nb, F and Zn there is an enrichment in many other elements such as Zn, Th, Sn, Be, Li, Cs, Sb, Cd, Mo, Rb and Sr. Only five of these peralkaline granites occur in Nigeria and all are adjacent to, or near mineralized biotite granites.

### *Mineralization in Aluminous Granites*

In contrast with the one dispersed phase of mineralization associated with the peralkaline granites, the biotite granites belonging to the aluminous trend show two distinct stages of mineralization:

1) The early dispersed phase of mineralization, in which columbite is an important mineral, affects the marginal and apical parts of biotite granite intrusions. It is an early postmagmatic stage which takes place during cooling and sub-solidus recrystallization. A textural change is effected by recrystallization, with new growth of microcline and albite, whilst columbite,

xenotime, thorite and Hf- and U- rich zircons are introduced. High columbite content coincides with high thorite content.

This stage of mineralization is represented by many of the fine grained biotite granites in the Nigerian Province, but the best known enrichment is found in localised parts of the Jos-Bukuru complex. The most extensive fine-grained granite within this complex in two narrow zones has given values up to 0.4% $Nb_2O_5$. (WILLIAMS *et al.*, 1956). Table I shows the abundance of $Nb_2O_5$ compared with $SnO_2$ in a series of samples taken by the writer from the granite.

TABLE I

*Comparative* $Nb_2O_5/SnO_2$ *values in samples from the Rayfield Gona Granite*

| | ppm $Nb_2O_5$ | ppm $SnO_2$ | | ppm $Nb_2O_5$ | ppm $SnO_2$ |
|---|---|---|---|---|---|
| 88 A | 90 | 25 | 10 D | 900 | 520 |
| 88 B | 770 | 200 | 10 E | 2290 | 1450 |
| 88 C | 510 | 165 | 10 F | 1200 | 68 |
| 88 D | 460 | 165 | 10 G | 30 | <20 |
| 88 E | 470 | 70 | 10 H | 1280 | 350 |
| 88 F | 610 | 140 | 10 J | 1720 | 430 |
| 88 G | 55 | 50 | 10 K | 750 | 360 |
| 88 H | 470 | 130 | 10 L | 500 | 20 |
| 88 J | 770 | 50 | 10 M | 1050 | 28 |
| 88 K | 520 | 56 | 10 N | 820 | <20 |
| 88 L | 1115 | 50 | 10 O | 320 | <20 |
| 88 M | 590 | 120 | | | |
| 88 N | 630 | 120 | | | |

2) The later phase of mineralization associated with the aluminous granites is late post-magmatic. It takes place after the host rock has recrystallized and consolidated and is displayed as mineralized replacement veins. Sphalerite predominates in these veins although cassiterite, pyrite, galena and chalcopyrite are also abundant. Monazite, arsenopyrite, genthelvite, pyrrhotite and molybdenite are also common though not abundant whilst siderite, greenockite, chalcocite, covellite, native copper, phenakite, bismuthinite and uraninite may also occur at one or more localities. The niobium of the previous phase is unimportant in this phase although high niobium values may sometimes occur in veins which cut granites with high niobium values (Table II).

Evidence from the Rishi area of the Saiya-Shokobo complex demonstrates that vein distribution is related to the marginal and apical parts of the biotite granite intrusions. Although, southwards where erosion has proceeded to deeper levels and where successive granite intrusions have tended to modify earlier contacts, replacement veins are less abundant and their relationship to the host rock is less obvious. The veins, which are primarily associated with biotite granites may also form in basement gneiss, fayalite granite and volcanics but have not been found in peralkaline granites.

The veins appear to form by a series of replacement processes which take place in a distinct sequence although in many cases the processes overlap in time and space.

The main replacement processes which have been recognised include argillic alteration, fluorization (chloritic alteration), sericitic alteration, greisenization and silicification. The order in which these stages occur has not been firmly established but preliminary evidence indicates that it may vary from the established order in other metallogenic provinces.

The argillic alteration which involves partial alteration of feldspars to clay minerals, although accompanied by a minor introduction of sphalerite, is not an important phase of ore development.

In contrast, the fluorization phase is the most important phase of ore development since the bulk of the sulphides and also monazite appear to be introduced at this stage. There is a direct correlation between fluorine content and ore concentration. In addition to the input of fluorine there is a significant increase in iron content from $< 2\%$ for the averave of biotite granites to over 20% in some veins. Increases of Zn, Cu, Pb, Li, Ce and As are also recorded and all form separate minerals except the lithium which is accommodated in the mica lattice. The original biotite of the host rock may be partially chloritised in these veins or may undergo replacement. Therefore, mineralized veins effected by the fluorization phase may contain — in addition to quartz, Fe-biotite or chlorite and abundant fluorite — sphalerite, cassiterite, galena, chalcopyrite, pyrite, monazite, genthelvite, greenockite, arsenopyrite, and molybdenite. No other alteration phases show such an abundance, or mixed assemblage of ores and locally these veins may become a solid sulphide mass exceeding 30 cm. across.

In the sericitic phase of alteration, which has minor amounts of associated sulphide minerals, only sphalerite, galena and cassiterite are common. The sericitic alteration which forms as a result of the breakdown of feldspars is very small in comparison with the degree that has been described in other provinces. The resulting sericite forms fine-grained aggregates with quartz and a little topaz.

Greisenization which is more common, results in the formation of veins containing unstrained quartz, large flakes of bright blue-green siderophyllite or less commonly, white protolithionite, with minor topaz. Cassiterite is the only ore mineral commonly associated and is often found within mica clusters as twinned and zoned crystals or as anhedral brown to colourless grains.

Chemically these veins show a wide range in composition but this is largely due to the percentage of siderophyllite within the rock. The varying siderophyllite content also affects the appearance of the vein in hand specimen and these may vary from almost white and fine-grained to a dark greeny-black often more coarsely grained rock. The two analyses below indicate this varying chemical composition.

| Composition | White fine grained vein | Greeny black more coarse vein |
|---|---|---|
| | Sample 5 L<br>Saiya Shokobo Complex | Sample 5 AL<br>Saiya Shokobo Complex |
| $SiO_2$ | 90.9 | 54.2 |
| $TiO_2$ | 0.1 | 0.1 |
| $Al_2O_3$ | 1.2 | 9.7 |
| Total Fe (as FeO) | 3.4 | 27.3 |
| MnO | 0.05 | 0.31 |
| MgO | $<0.02$ | 0.02 |
| CaO | 0.24 | 0.12 |
| $Na_2O$ | 0.15 | 0.11 |
| $K_2O$ | 0.81 | 5.85 |
| $SnO_2$ | 0.14 | 0.88 |
| ZnO | n. d. | 0.10 |
| | 97.01 | 98.69 |
| Li | 760 ppm | 4645 ppm |
| Be | 2 | 6 |

Only a small amount of ore minerals are associated with the silicification phase of alteration but it is an important ore stage since it is with this phase that the wolframite is associated. Wolframite is generally only abundant in quartz veins in country rock marginal to the granites whilst for most of the mineralised veins within the granites the tungsten content is less than 4 ppm. Locally wolframite may be abudant as bladed crystals parallel or perpendicular to the strike of the vein but large areas of the quartz vein may also be barren. Misconceptions in past literature about the abundance of wolframite appear to be due to the poor identification of dark metallic-looking sphalerite with an enriched iron content.

Zinc mineralization is associated with a minor pegmatitic vein development, which appears to be very late stage. The zinc forms genthelvite ($Zn_3Fe Be_3Si_3O_{12}S$) which appears as brownish-red crystals up to 5 cms. across. The genthelvite is associated with albite/oligoclase quartz and rarely — with crystals of uraninite.

It is apparent that zinc is abundant at all stages of granite development. In the mineralized veins it occurs as sphalerite and genthelvite and in some instances the sphalerite content far exceeds the amount of cassiterite. The following table indicates the comparative values of tin, tungsten, zinc and niobium in some biotite granite samples and mineralized veins. Samples N58A and N58C are altered granite on either side of a mineralized vein — sample 58B. This vein is the only one contained within a granite complex that shows high tungsten values and this is believed to be related to the intrusion of a fine-grained biotite granite at depth.

TABLE II

*Comparative tin, zinc, tungsten and niobium values in biotite granites, altered biotite granites and mineralized veins in Nigeria*

| | Sn | Zn | W | Nb | |
|---|---|---|---|---|---|
| N 75 | 40 ppm | | 4 ppm | | biotite granite |
| N 77 | 110 | | 4 | | " |
| N 91 | 25 | | 4 | | " |
| N 92 | 50 | | 4 | | " |
| N 94 | 25 | | 4 | | " |
| N 58 A | 160 | 292 | 1320 | | altered granite |
| N 58 C | 100 | 331 | 720 | 180 | " |
| N 58 B | 350 | 2400 | 860 | 93 | mineralized vein |
| JB 22 | 520 | 0.82 % | 4 | 84 | mineralized vein |
| JB 118 A | 120 | 1.92 | 4 | 74 | " |
| JB 64 H | 1000 | 0.04 | 4 | 132 | " |
| JB 120 | 200 | 40 ppm | 4 | 249 | quartz vein |
| SS 117 | 6150 | 0.1 % | 40 | 122 | mineralized vein |
| SS 2 C | 330 | 0.65 | 12 | 500 | " |
| SS 106 A | 200 | 1.73 | 4 | 7 | " |
| SS 102 | 850 | 1.68 | 4 | 7 | " |
| SS 109 A | 840 | 1.35 | 4 | 2 | " |
| SS 109 C | 190 | 2.16 | 8 | 2 | " |
| SS 109 B | 1.94 % | 0.82 | 4 | 10 | " |

N = Liruei Complex. JB = Jos Bukuru Complex. SS = Saiya Shokobo Complex.

# PART 2

## *MINERAL DESCRIPTIONS*

*Cassiterite*

The Nigerian tin province is the world's sixth biggest producer of tin: cassiterite is the only tin mineral as yet recorded from the Mesozoic granites although nigerite has been recorded from the basement pegmatites. (JACOBSON & WEBB 1946).

Cassiterite occurs widely in the anorogenic granite province but because alluvial workings for the minerals are situated principally on the Jos Plateau, it has often been incorrectly assumed that tin mineralization is restricted to this small area in northern Nigeria. In fact similar styles of mineralization have been recognised in the majority of the Mesozoic granites in Nigeria and in petrographically similar, but chronologically older anorogenic granites in Niger.

Compositionally, cassiterite contains oxide impurities of Fe, Nb, Ta, Ti, Cu, Zn and Mn. An analysis of cassiterite from the Jos-Bukuru complex by Amalgamated Tin Mines of Nigeria showed the following composition:

| | |
|---|---|
| $SnO_2$ | 89.50 |
| $Nb_2O_5$ | 4.70 |
| $Ta_2O_5$ | 1.60 |
| $Fe_2O_3$ | 1.64 |
| $TiO_2$ | 0.12 |
| $Sc_2O_3$ | 0.01 |
| Loss on ignition | 3.30 |
| | 100.87 |

Cassiterite occurs as a minor constituent in many granites and is not confined to albitized variants. The values of cassiterite in a particular granite may vary from nothing to over 400 ppm. $SnO_2$ (Table I). In addition to these occurrences, abundant cassiterite, varying from small or large anhedral to perfect crystals which may exceed 1 cm. in size (Fig. 2), is found in mineralized veins throughout the province.

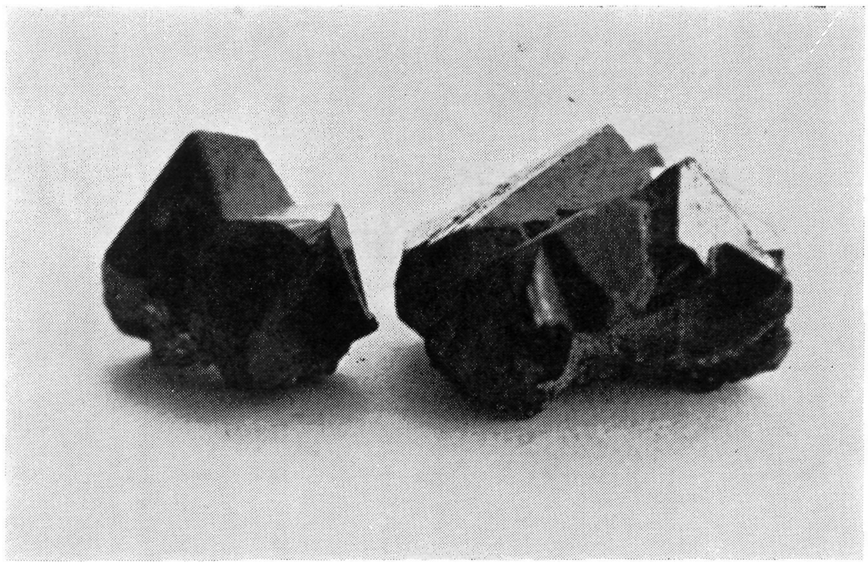


FIG. 2

*Cassiterite crystal from a mineralized vein. Liruei complex*

Cassiterite varies in colour according to its source, ranging from dark brown to black, occasionally crystals may show an adamantine lustre but more commonly it displays a sub-metallic lustre or it may be brown, friable and hackly. Translucent ruby, yellow and white varieties have been recorded and there is a small amount of colloidal wood tin from Gindi Akwati and south Ropp in the Ropp complex and from the Gaiya River in the Liruei complex.

Cassiterite occurs in several phases of mineralized veins. It is present in the sulphide assemblage associated with the fluorization phase of alteration (Fig. 3) and it occurs within and around micaceous clusters in greisens. Cassiterite has also been introduced in addition to wolframite in the silicification stage. In thin section the cassiterite associated with quartz veins or silicified veins is pale yellowish, brownish or colourless, whilst the cassiterite found associated with green mica in greisens is dark reddish brown in colour and may show zoning, from dark coloured at the centre to colourless at the margins. Some of this darker coloured cassiterite is intensely pleochroic from pale yellow to a dark reddish colour which may be attributed by many authors to a high niobium content.

Polished sections of cassiterite from the sulphide-fluorite rich veins show few, if any, inclusions, and those so far observed appear to be of pyrite. Inclusions in cassiterite from quartz veins at Ropp Adit are more numerous and so far seem to be solely quartz.

Some cassiterite is magnetic and ATMN * geologists have found that the

* ATMN = Amalgamated Tin Mines (Nigeria) Ltd.

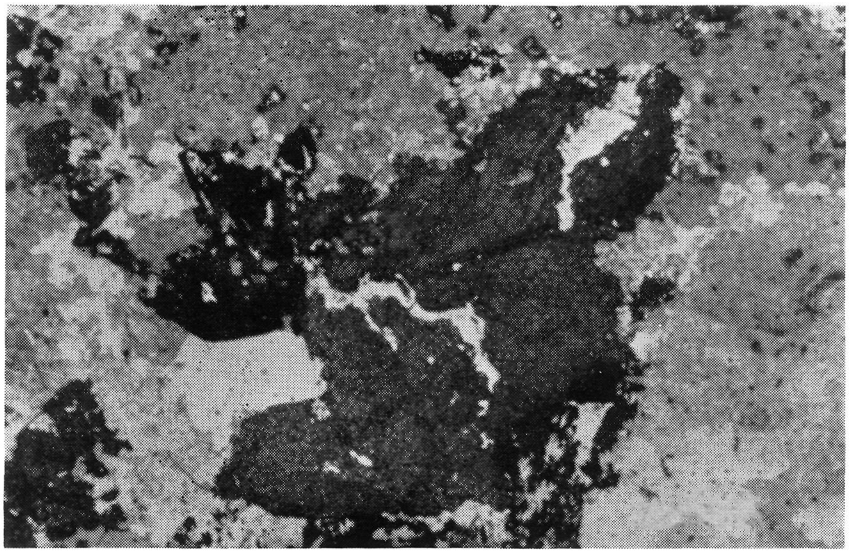


FIG. 3

*Twinned cassiterite with chalcopyrite in a groundmass of quartz, fluorite and chloritised mica (Low power magnification).*

magnetic quality does not vary with colour and that even transparent varieties may be magnetic. Unlike the cassiterite from the Australian localities described by GREAVES *et al.* (1971), the Nigerian magnetic tin is neither localised nor apparently restricted to certain rock types.

The bulk of cassiterite is won by alluvial mining since the accessory cassiterite in granites is not of high enough concentration to justify extraction costs. In localised parts of the Jos-Bukuru complex however, cassiterite forms a valuable by-product of columbite extraction from heavily decomposed albitised granites (Table I).

The way in which tin is transported in hydrothermal fluids appears to be in doubt although most workers agree that it is transported in fluids rich in chlorine and fluorine. Some advocate a Sn fluoro-hydroxyl complex (SHCHERBINA 1963, BARSUKOV and KURIL'CHIKOVA 1966) whilst HESP and RIGBY (1972) more recently have considered stannic chloride complexes to be more prevalent and therefore more stable. Shcherbina believes that Sn, W, Al, Li, Be, Y, Ti and Zr are fluorophile whilst Cu, Ag, Fe and Pb are chlorophile elements. However, as Part 1 indicates, in many of the Nigerian mineralized veins it is not uncommon to get cassiterite, sphalerite, galena and chalcopyrite together in one sample.

In the Nigerian model it is suspected that most tin partitions towards the aqueous chloride phase although this does not preclude the occurrence of some tin in the silicate-fluoride phase. At the time of writing there is little fluid inclusion data to support this hypothesis.

*Columbite and associated minerals*

Nigeria is the world's leading producer of columbite and whilst there is a small production of pegmatitic columbo-tantalite from the basement, the vast bulk of the material is won from elluvial and alluvial deposits associated with the Mesozoic fine grained biotite granites.

Columbite is known to occur in varying quantities in all complexes where fine-grained biotite granites occur, the best-known enrichment being that found in localised parts of the Jos-Bukuru complex (Fig. 1). From an early date it was known that some granites within this complex contained more columbite than others and MacLeod (1956) and Williams *et al.* (1956) analysed all the granites and found that only the Rayfield-Gona, which is the principal fine-grained biotite granite, contained economically significant values. These values ranged between 150 and 2.875 ppm. $Nb_2O_5$ and in two narrow zones varied between 760 ppm. and 0.4%. An analysis of fifty samples by the author from two different areas produced values which ranged up to 2.290 ppm. $Nb_2O_5$ and some of these results were presented in Table I. There appears to be no correlation between high columbite and cassiterite content but it appears that high columbite content coincides with a high thorite content.

The columbite occurs as small, black opaque crystals which are variable in shape from platy to acicular. It is rarely coarser than 20 mesh — the greater portion lying between 60 and 200 mesh.

Columbite from the Mesozoic granites, in contrast to that from the basement, is more niobium rich. An analysis of this columbite from the granites shows an $Nb_2O_5 : Ta_2O_5$ ratio of 8 : 1. In contrast, analyses of columbo-tantalite from basement pegmatites show a whole range of the isomorphous series.

*Analysis of Columbite from Harwell*

| | |
|---|---|
| $Nb_2O_5$ | 64.8 % |
| $Ta_2O_5$ | 8.1 |
| FeO | 15.1 |
| $Sc_2O_3$ | 0.02 |
| $TiO_2$ | 0.49 |
| $Mn_3O_4$ | 1.95 |
| ZnO | 0.15 |
| $SnO_2$ | 1.60 |
| $U_3O_8$ | <0.05 |
| Loss on ignition | 1.40 |
| | 93.66 |

Thorite, xenotime and hafnium-bearing zircon are commonly found associated with the columbite as accessory minerals within the granite and MacLeod (1971) also records pyrolusite and anatase in association.

*Sphalerite*

In contrast to previous literature on Nigerian mineralization it has been found by the writer that sphalerite is the dominant mineral of the hydrothermal mineralization phase and occurs to a greater or lesser extent in several of the alteration phases recognized by the writer. It may occur in masses 30 cm. across, especially in the fluorization phase of alteration. In massive form it varies from reddish brown to almost black with a resinous to submetallic lustre.

In thin section it shows characteristic dodecahedral cleavage and varies in colour from light yellow to orange or deep blood red. Deer, Howie and Zussman (1969) suggest that the different colours of sphalerite may be associated with certain elements, in particular that tin may be responsible for the red colouration, but increase of iron may mask this red colouration. In dark coloured sphalerites with a metallic lustre, the iron content varies from 6.5-10% with corresponding zinc values of 52.5 and 69.9%. Cadmium content decreases with increasing iron content. Analyses of two dark metallic looking sphalerites are shown below:

| | Rishi | | Liruei |
|---|---|---|---|
| Cu | 4.21 % | | 0.25 % |
| Pb | 0.14 | | 0.96 |
| Zn | 52.5 | | 60.9 |
| Fe | 10.2 | | 6.48 |
| Mn | 0.02 | | 0.04 |
| Cd | 0.19 | | 0.59 |
| Co | 137 ppm | | $<$ 16 ppm |
| Ag | 61 ppm | | 5 ppm |
| S $\equiv$ Cu | 2.05 | S $\equiv$ Cu | 0.12 |
| S $\equiv$ Zn | 24.87 | S $\equiv$ Pb | 0.14 |
| | | S $\equiv$ Zn | 28.85 |
| S $\equiv$ Fe | 5.66 | S $\equiv$ Fe | 3.59 |
| | 99.84 | | 101.92 |

The Rishi sphalerite is associated with the fluorization stage of alteration whilst the sample from Liruei comes from a vein affected mainly by greisenisation and silicification. The Rishi sphalerite contains 3.5% more Fe than the Liruei sample but part of it is contained within the exsolved chalcopyrite. Occasionally both red and yellow varieties occur in the same thin section, the former occurring as large anhedral patches with exsolved cubes of chalcopyrite along the cleavage, whilst the latter occurs as rims around patches of chalcopyrite. It seems likely that there are several phases of sphalerite formation: an early well crystallised, uniformly grey phase and a later slightly darker phase full of blebs of chalcopyrite. Polished sections of sphalerite show inclusions of chalcopyrite, molybdenite and replacement of galena. The blebs of chalcopyrite are attributed to exsolution on cooling from a higher temperature ZnS-$CuFeS_2$ solid solution.

In sulphide rich veins associated mainly with the fluorization stage of mineralization, and to a lesser extent the sericitic stage, sphalerite occurs in association with cassiterite, galena, pyrite, chalcopyrite, molybdenite, greenockite, chalcocite, covellite, bornite, monazite and genthelvite (Fig. 4 and 5). However in greisens it is associated with cassiterite, and occasionally galena and chalcopyrite.

In replacement veins that show some crude zoning, the sulphide-rich portion generally occurs towards the centre of the vein. However, in a section of one of the greisens of the Liruei lode sphalerite occurred marginally.

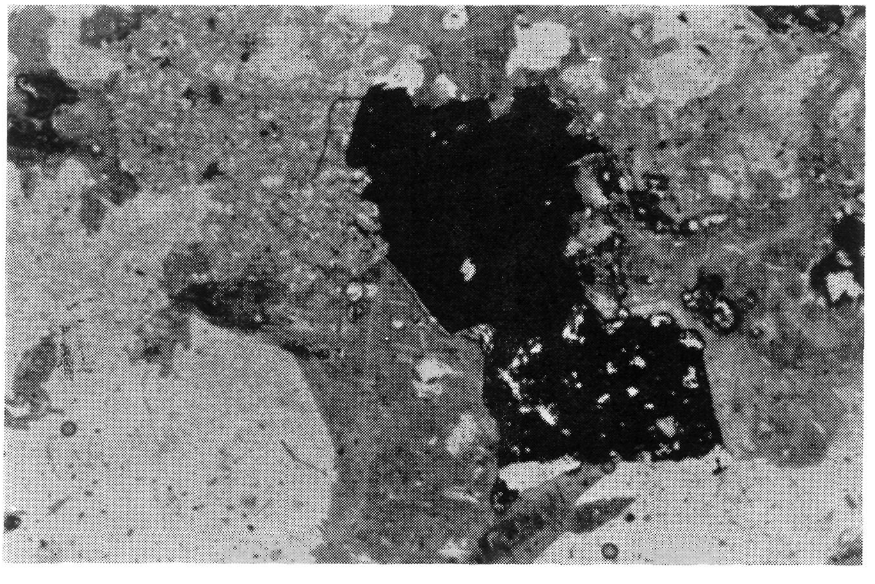


FIG. 4

*Sphalerite full of inclusions adjacent to molybdenite (opaque centre). Cassiterite (partly visible top right) is also abundant. The groundmass is composed of blue-green siderophyllite, quart, fluorine and siderite (Low magnification)*

Only recently has sphalerite been identified in large quantities. It does not survive as an alluvial mineral and since the attention paid by the mining companies to primary mineral veins has been small on account of uneconomic tin values, the abundance of sphalerite remained unrecognised. It has been observed and described by the writer from veins in several widely-spaced complexes while at Liruei, Ririwai Mines Ltd. estimate that the ratio of Zn to Sn in a lode currently being mined is 3 or 4:1.

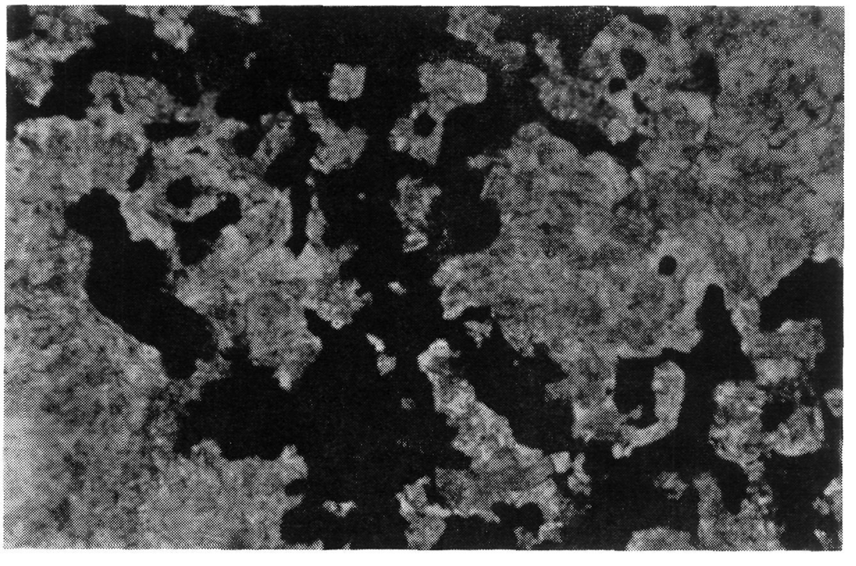


FIG. 5

*Sphalerite veinlet, 2 mm in width, cutting a mineralised vein consisting of quartz, fluorite and chloritised mica*

## *Chalcopyrite and other copper minerals*

Chalcopyrite is the most common copper mineral and is widely distributed in replacement veins. It may be exsolved along cleavage traces in sphalerite, it may form rims around sphalerite and other minerals, or it may occur in massive form.

Chalcopyrite is not as abundant as some of the other sulphides and is only abundant in the fluorite-rich replacement veins although it may be found in minor quantities in other veins.

Very small amounts of other copper minerals may be associated with the chalcopyrite. Bornite has been identified in some of the veins in the Rishi area and chalcocite and covellite have been observed in polished ores. Native copper was found in altered pyroxene granite at the adit in the Ropp Complex (Fig. 1) whils azurite, malachite and chalcanthite have been found as secondary copper minerals.

In polished sections, chalcopyrite may contain silicate gangue in the form of streaks and blebs and may show minor replacement by chalcocite at its margin. A very characteristic feature observed in the Nigerian polished ores is the blebs of chalcopyrite occurring as trains or in an irregular fashion within sphalerite. Those from Dawa show that chalcopyrite is most abundant in sphalerite near its margins.

*Molybdenite*

Small flakes of molybdenite are common in mineralized veins and altered granite, but the only large scale occurrence is in riebeckite-aegirine granite in the Kigom Hills. The molybdenite is scattered through the granite in rich clusters several centimetres across and in small disseminated flakes; it also forms a coating on joint surfaces.

Most commonly small quantities of molybdenite occur in veins, or in veins and adjacent altered granite. The molybdenite in the veins is in association with cassiterite, sphalerite, galena and copper minerals at Ropp, and with a similar assemblage and has been proved to a depth of 20 metres. The vein follows a fine-grained granite porphyry dyke, presumed to be of younger granite age. The galena which contains 0.5% silver has been found at depth in cubes as large as 15 cm. across but usually occurs as cubes less than 5 mm. in size. The maximum width of the galena-bearing vein is recorded by BUCHANAN *et al.* (1971) as 20 cm. but the vein rapidly pinches and swells and often dies out altogether further along the strike.

A galena-rich vein is also known to occur in the south Ropp area 1.5Km.-west of the outer ring-dyke. It is 30 to 45 cm. wide and strikes 325°, parallel to the ring-dyke.

Galena appears to be associated with a slightly later stage of mineralization than the bulk of the sphalerite, chalcopyrite and pyrite. However, in the polished section from the west of the Liruei lode there is evidence to show that galena is being replaced by chalcopyrite and sphalerite which indicates that one of the phases of sphalerite formation described earlier has formed after the galena of the lode.

*Greenockite (CdS)*

Greenockite has been identified in one of the replacement veins from the basement near Dutsen Rishi. It was identified on an X ray scan of a thin section and shown to occur as discrete grains and not as a coating on sphalerite, although sphalerite does occur in other parts of the vein. It is associated with choritised mica, chalcopyrite, monazite, fluorite and cassiterite. An analysis of sample 103 showed a cadmium content of 150 ppm. Greenockite has also been recorded from the Kaffo valley albite-riebeckite granite at Liruei (BUTLER & THOMPSON 1970). It is in the form of thin yellow disseminations and patches on quartz and feldspar and is not associated with sphalerite since the only zinc bearing mineral in the granite is riebeckite. These authors considered that the greenockite as evidence of a later mineralisation than the albitisation. The writer considers therefore that greenockite has been introduced as a result of the intrusion of the adjacent Liruei biotite granite.

*Bismuthinite*

As yet bismuthinite has only been identified in the Liruei Complex, where it has been found underground in the mine recently initiated to exploit the Liruei lode. It has been found growing in vugs in association with cassiterite and clay minerals and forms long fragile, slender greyish needles, with a metallic lustre, up to 10 cm. long.

*Fluorite*

Fluorite forms a common accessory mineral in many of the biotite granites and is colourless or pale green. It is also abundant in replacement veins, where it is predominantly colourless with occasional deep purple patches.

Both topaz and fluorite may occur in the same rock sample although the two minerals are never abundant when co-existing. Abundance of one appears to preclude the other.

There appears to be a direct correlation between ore concentration and fluorite content. Highest enrichment in sulphide ores, particularly of sphalerite, pyrite, arsenopyrite and chalcopyrite are always associated with fluorite-rich chloritised veins.

*Topaz*

Topaz may occur in association with beryl and quartz in the marginal pegmatitic vugs of some biotite granite. Crystals 7.5 cm. long have been collected from the Tega granite of the Amo complex (Fig. 1) in the Timber Creek area. They have also been found *in situ* in the Juga area of the Kwandonkaya complex and have been found in the river gravels ot the Ganawuri and Jarawa Hills.

The topaz is usually colourless but blue-green, yellowish and brownish varieties have been found. It is rarely of gem quality but should prove useful for fluid inclusion techniques.

Very fine-grained topaz also occurs in replacement veins formed by the breakdown of feldspar into sericite, topaz and quartz.

Topaz is a constituent of the greisen phase of alteration in addition to forming an accessory in the sericitic phase, although the topaz content is small in comparison with the amount in greisens from Czechoslovakia (BAUMANN *et al.,* 1974) or Alaska (SAINSBURY 1960). The individual topaz grains are small rarely forming greater than 1 mm. in size.

In contrast to the fluorite rich veins however, topaz-bearing veins contain cassiterite with only minor sulphide minerals. In thin section it appears as small colourless anhedral grains associated with either sericitic or siderophyllite mica.

*Zircon*

Zircon is a common accessory mineral in many of the younger granites. It occurs in two forms:

1) In the metamict state it may be associated with xenotime, thorite, and columbite in the late stage albitised granites and with pyrochlore and other minerals in the albite riebeckite granites. In the former the zircon may contain up to 5% Hf and when Hf is present to this extent the mineral is in the form of almost opaque brown grains and is usually uraniferous — this is the variety described as malacon. Some of the metamict zircon in anomalously magnetic and MacLeod and Jones (1955) showed that this is due to a high proportion of loosely combined iron. The degree of magnetic permeability is thought to be controlled by the relative proportions of non-magnetic $Fe_2O_3$ and magnetic $Fe_3O_4$ in the mineral. It is probable that cyrtolite is also present in the albitised granites and albitites but there is difficulty in recognition of the mineral since both cyrtolite and malacon contain uranium and thorium in addition to rare earths, Hf and water. Also, both minerals are metamict. CARUBA *et al.* (1975) believes that in certain cases metamict zircons arise from normal hydroxyled zircons that have crystallised out of a medium rich in fluorine and radioactive elements and that fluorine leads to the substitution $(SiO_4)^{4-}$ $(OH)^{-}_4$. This leads to weaker bondings causing the lattice to be vulnerable to the particles given off during the decay of radioactive elements.

2) In contrast, the zircons from other granite sources are colourless, brownish yellow to amber or grey and are transparent to sub-translucent. In the Jos/Bukuru complex, WILLIAMS *et al.* (1956) describe their technique for differentiating various granite types by the zircon colour. This method of granite identification is sometimes useful where the granite is badly weathered and decomposed.

*Thorite*

Thorite is found in the late-stage albitised granites in close association with columbite. It occurs as anhedral, resinous grains averaging 1 mm. in size and they have either a reddish brown or orange (variety orangite) colour. There seems to be a direct proportional relationship between thorite and columbite content and visible thorite is a good indicator of high columbite content.

The thorite collected from the Harwell area of the Jos-Bukuru complex is strongly radioactive as a result of the replacement of some of the thorium by uranium giving the variety uranothorite. Because of the radioactive content the thorite is in a metamict state.

Thorite and zircon appear to form a structural series and it appears that there is a definite trend from zircon, malacon (a uranium-thorium zircon) and cyrtolite (a thorium-uranium zircon) to thorite.

PETROVA (1961) records replacement of malacon by thorite in Siberian albitites and evidence from a limited number of Nigerian thin sections indicates that a similar phenomenon takes place. In the zones in malacon that have become isotropic, point-like aggregations which discolour the metamict malacon unevenly in shades of brownish red are suggested by Petrova to be ferrothorite. Petrova presumes that the development of isotropic properties in malacon is associated with the activity of thorium during replacement of the mineral by thorite.

*Beryl: Genthelvite: Phenakite: Danalite*

Beryllium minerals, although not common, occur in mineralised veins and pegmatites in many areas of the Mesozoic granite province. Most occurrences are situated in the northern part of the province where granitic members of the ring complexes are exposed at or near their upper contact with pre-existing rocks. Southward where erosion has proceeded to deeper levels beryllium mineralisation is less conspicuous.

Beryl has been recorded from numerous localities, most notably in the pegmatites in the Tega biotite granite of the Amo complex, near the contact with the Teria biotite granite. Aquamarine can occasionally be found there in association with large colourless topaz crystals. Aquamarine has also been found in a pegmatitic vein in the Kulfana biotite granite of the Kwandonkaya complex — again from a contact facies.

The mineral genthelvite appears more common than beryl. It has been noted in the Dawa-Rishi area of the Saiya-Shokobo complex where it is usually restricted to mineralized veins in biotite granites less than 30 metres from their contacts it has also been described by von Knorring and DYSON (1959) from the Harwell area of the Jos-Bukuru complex and by Berridge in BUCHANAN *et al.* (1971) from the Jarawa Hills.

Genthelvite, resembling massive almandine, appears as a late stage replacement mineral in the albitised granite at Harwell and the following description is given by von Knorring and Dyson (op cit). «In the locality it occurs as irregular knots and veins up to 18 cm. across within an irregular vein of almost pure albite. Commonly, these knots consist of pure genthelvite, but may contain stumpy laths of albite. A selvedge of protolithionite from 0.5-2 cm. thick with accessory thorite frequently crystallised as a peripheral growth on euhedral genthelvite». They also describe genthelvite in microcline pegmatitic veins as anhedral masses up to 5 cm. across. In thin section the genthelvite is greyish or very pale pink and isotropic. It may be almost pure genthelvite or may be intimately intergrown with albite. Some triangular sections occur and the mineral is intersected by numerous cracks. It has inclusions of columbite, zircon and cassiterite and occasionally orangite in the specimens studied by von Knorring and Dyson (op cit). A chemical analysis of the mineral from Harwell (von Knorring and Dyson, op. cit.) shows that it is very similar in composition to that from silicified syenites from U.S.S.R. described by GURVICH *et al.* (1963). The Harwell sample showed 12.9% BeO compared to 11.9% in the genthelvite analysed by Gurvich and 40.56% Zn compared to 41.3% Zn. The formula for the Harwell genthelvite is:

$$Zn_3FeBe_3Si_3O_{12}S$$

In the sample described by Gurvich the associated minerals are willemite, fluorite, cyrtolite, tantalo-columbite and other minerals.

An analysis of genthelvite from the Ladini area of the Saiya-Shokobo complex showed greater Fe and Mn content than the Harwell sample, and a corresponding decrease in zinc content, although the zinc is still predominant so the name genthelvite still applies.

GURVICH *et al.* (1963) believe that genthelvite forms in the late stages of mineralisation as a result of pneumatolytic processes leading to the formation of quartz veins and silicification. The circulating solutions were rich in Si, S, Be, Zn and other cations (Fe, Mn, Pb, and Mo) and were poor in alumina; as KALENKOV (1959) has shown, that in the absence of Al genthelvite will form instead of beryl.

BEUS (1956, 1962) describes occurrences of genthelvite similar to those in the younger granite province of Nigeria. He believes that in granites which consolidate at comparatively high in the crust and where the formation of mineralised pegmatites is restricted, such Be as is present will precipitate

*Analyses of Genthelvite*

| | Harwell | | Ladini |
|---|---|---|---|
| $SiO_2$ | 30.70 | | 31.5 |
| $TiO_2$ | n. d. | | 0.1 |
| $Al_2O_3$ | 0.18 | | n. d. |
| FeO | 11.73 | | 23.7 |
| MnO | 1.72 | | 3.1 |
| BeO | 12.39 | | 12.2 |
| ZnO | 40.56 | | 25.5 |
| MgO | tr. | | 0.04 |
| CaO | tr. | | 0.08 |
| $Na_2O$ | tr. | | 0.15 |
| $K_2O$ | n. d. | | 0.07 |
| S | 5.50 | | 5.00 |
| | 102.78 | | 101.00 |
| O = S | 2.74 | O = S | 2.49 |
| | 100.04 | | 98.51 |
| Li | n. d. | | 400 ppm |

in a hydrothermal-pneumatolytic environment. He concludes from the available data that formation of high concentrations of Be in the hydrothermal process coincide in time and space with the formation of high concentrations of tungsten, tin and molybdenum. Some of the veins at Dawa contain genthelvite, cassiterite and molybdenite but no genthelvite-tungsten association has been found here yet.

Danalite ($Fe_4[Be_3Si_3O_{12}]S$) has also been identified by TAYLOR (1959) from the Dawa area; it is dark red with a slightly greasy lustre and in thin section is pale pink. He quotes the specific gravity as 3.44 and R.I. as 1.754. X-ray spectroscopic analysis showed Fe as the major constituent with subordinate zinc and minor manganese with a trace of chromium. BeO content is given as 13.0%.

Phenakite ($Be_2SiO_4$) has been found by TAYLOR (1961) in small amounts in greisens from the Ladini-Dawa area of the Saiya-Shokobo complex in association with cassiterite, topaz, fluorite, danalite and sphalerite; it has also been recovered from crushed ore and from alluvials in the same area.

Further investigations of mineralised veins both in hand specimen and thin section will probably show that beryllium minerals are even more widespread.

*Mica*

The mica in the Nigerian Younger Granite Province belong to two related tri-octahedral series. There are only small amounts of dioctohedral micas in the granites and these usually take the form of sericite, derived from the alteration of feldspars during successive stages of replacement vein formation.

Micas have been analysed from biotite granites, albitised granite and replacement veins (Table III). The results have been plotted on a triangular diagram devised by LANGE *et al.* (1972) and the structural formulae have been calculated using the method of FOSTER (1960).

The magnesium content of nearly all the micas is extremely low and the biotites are therefore characterised by a high $Fe^{2+}/R''$ ratio which is greater than 0.94 except for the biotite from Sara Fier (Table III) where the ratio is 0.78. The $Fe^{3+}/R'''$ ratio is also high:

$$(R'' = Mg + Fe^{2+} + Mn)\ (R''' = Al^{vi} + Fe^{3+} + Ti^{4+}).$$

In the aluminous granites the micas are iron rich and belong to the phlogopite $\rightarrow$ annite series. During the processes of replacement vein formation there is a progressive alteration of the micas and they become enriched in alumina and lithium; those micas belong to the siderophyllite $\rightarrow$ protolithionite $\rightarrow$ zinnwaldite series. Thin sections show that during alteration there is a progressive destruction of the brown iron-rich annitic mica of the granite and a replacement by chlorite, with the growth of new blue-green siderophyllite which in turn may be overgrown or partly replaced by pale green, grey or almost colourless protolithionite. Early breakdown of feldspars releases potassium which forms sericite and related minerals. This sericite forms small clustered grains at first marginal to, or within the feldspar and then completely replacing it. The sericite itself may further be altered and break down to give silica with released potassium and aluminium. Perhaps some is transformed to tri-octohedral mica, since in the latest stages of replacement only blue-green siderophyllite or colourless protolithionite is found. Thin section comparisons of mica-rich greisens and host biotite granite reveal that not all the siderophyllite can have formed at the expense of the original annitic mica. Thus, late-stage mica formation, derived from sericite enriched in lithium and iron by volatiles, seems likely.

During the early dispersed phase of mineralization in the biotite granites the albitization, which affected the perthites, is accompanied by a modification of the micas. The biotites become enriched in alumina and lithium and depleted in Fe, and protolithionite appears to be the ultimate composition.

TABLE III

*Analysis of the micas from some of the granites*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| $SiO_2$ .... | 35.94 | 33.10 | 35.36 | 30.72 | 35.14 | 37.58 | 37.38 |
| $Al_2O_3$ ... | 11.71 | 9.77 | 10.90 | 11.54 | 6.44 | 15.43 | 11.89 |
| $Fe_2O_3$ ... | 5.00 | 12.19 | 3.76 | 11.62 | 4.40 | 4.96 | 4.38 |
| FeO .... | 23.91 | 24.48 | 31.38 | 26.49 | 34.92 | 25.00 | 28.65 |
| MgO .... | 6.35 | 1.95 | 1.06 | 0.15 | 0.43 | 0.32 | 0.22 |
| CaO .... | 1.65 | 2.37 | n.d. | 1.70 | 0.97 | 1.15 | 0.16 |
| $Na_2O$ ... | 0.42 | 0.41 | 0.97 | 0.44 | 0.74 | 1.67 | 0.39 |
| $K_2O$ .... | 6.95 | 5.43 | 9.04 | 4.35 | 8.92 | 7.34 | 8.78 |
| $H_2O^+$ ... | 4.15 | 5.55 | 3.74 | 8.27 | 3.12 | — | 1.84 |
| $H_2O^-$ ... | 0.03 | 1.94 | n.d. | 0.27 | 0.06 | 0.52 | 0.67 |
| $TiO_2$ .... | 3.33 | 2.96 | 3.04 | 3.04 | 2.87 | 1.42 | 1.84 |
| $P_2O_5$ .... | nil | nil | nil | 0.06 | 0.03 | tr. | n.d. |
| F ...... | n.d. | n.d. | n.d. | n.d. | n.d. | 2.01 | 4.36 |
| MnO .... | 0.50 | 0.64 | 0.65 | 0.64 | 0.53 | 0.20 | 0.41 |
| $Li_2O$ .... | n.d. | n.d. | n.d. | n.d. | n.l. | — | 0.77 |
| | 99.94 | 100.55 | 99.90 | 99.29 | 101.04 | 101.85 | 97.60 |
| Less O.. | | | | | 1.04 | 1.86 | |
| | | | | | 100.00 | 99.99 | |

*Formula calculated to 24*

| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Si ...... | 5.616 | | 5.282 | | 5.798 | | 4.744 | | 5.984 | | 6.05 | | 6.03 | |
| Al ...... | 2.156 | 8.0 | 1.842 | | 2.107 | 8.0 | 2.106 | | 1.274 | 7.72 | 1.95 | 8.0 | 1.97 | 8.0 |
| Fe''' .... | 0.228 | | 0.876 | | 0.095 | | 1.150 | | 0.544 | | — | | — | |
| Al ...... | — | | — | | — | | — | | — | | 0.98 | | 0.29 | |
| Ti ...... | 0.392 | | 0.354 | | 0.374 | | 0.352 | | 0.362 | | 0.17 | | 0.22 | |
| Fe '''.... | 0.360 | | 0.588 | | 0.368 | | 0.202 | | — | | 0.64 | | 0.53 | |
| Fe" .... | 3.124 | 4.418 | 3.268 | 4.728 | 4.303 | 5.395 | 3.428 | 4.10 | 4.912 | 5.452 | 3.36 | 5.26 | 3.86 | 5.51 |
| Mn ..... | 0.066 | | 0.054 | | 0.091 | | 0.084 | | 0.074 | | 0.03 | | 0.06 | |
| Mg ..... | 1.476 | | 0.464 | | 0.259 | | 0.034 | | 0.104 | | 0.08 | | 0.05 | |
| Li ...... | — | | — | | — | | — | | — | | — | | 0.50 | |
| Ca ...... | 0.276 | | 0.406 | | — | | 0.284 | | 0.172 | | 0.20 | | 0.01 | |
| Na ...... | 0.128 | 1.690 | 0.126 | 1.638 | 0.309 | 2.201 | 0.128 | 1.268 | 0.240 | 2.320 | 0.52 | 2.23 | 0.12 | 1.94 |
| K ....... | 1.286 | | 1.106 | | 1.892 | | 0.856 | | 1.908 | | 1.51 | | 1.81 | |
| OH .... | 4.328 | | 5.902 | | 4.091 | | 8.544 | | 3.498 | | 3.01 | | 1.98 | |
| | | | | | | | | | | 4.798 | | | | 4.20 |
| F ...... | — | | — | | — | | — | | 1.300 | | — | | 2.22 | |

1. Fe-biotite from Fier hastingsite biotite granite, Sara Fier. Nigeria.
2. Lepidomelane (Foster) from Kula hastingsite biotite granite, Pankshin.
3. Annite from early hastingsite biotite granite, Amo.
4. Lepidomelane taken from Daffo hastingsite biotite granite, Sha Kaleri.
5. Annite taken from riebeckite biotite granite, Amo.
6. Li-siderophyllite from Kudaru biotite granite. Analysis taken from Bain (Jacobson, 1947).
7. Li-siderophyllite from Liruei biotite granite. Source of data 1-5, 7, BUCHANAN *et al.* (1971).

TABLE III (contd)

*Analysis of the micas from greisens and pegmatitic veins*

| | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|
| $SiO_2$ | 39.2 | 36.10 | 45.50 | 41.11 | 42.24 | 43.60 |
| $Al_2O_3$ | 12.24 | 13.26 | 10.42 | 16.59 | 19.62 | 19.09 |
| $Fe_2O_3$ | 2.98 | 7.29 | 2.48 | 2.00 | 2.02 | 2.57 |
| FeO | 29.0 | 25.30 | 28.10 | 22.61 | 18.64 | 14.80 |
| MgO | 0.03 | 0.05 | 0.13 | 0.13 | 0.08 | 0.10 |
| CaO | 0.15 | 0.20 | 0.40 | n.d. | 0.11 | 0.21 |
| $Na_2O$ | 0.10 | 0.11 | 0.10 | 0.16 | 0.14 | 0.18 |
| $K_2O$ | 8.15 | 8.82 | 6.09 | 9.92 | 8.84 | 9.54 |
| $H_2O^+$ | 2.28 | 1.40 | 2.50 | 1.12 | 2.35 | 4.58 |
| $H_2O^-$ | 1.61 | 1.27 | 1.56 | 0.29 | 0.48 | 0.82 |
| $TiO_2$ | 2.58 | 3.07 | 2.47 | 0.30 | 0.18 | 0.88 |
| F | — | — | — | 5.49 | 5.02 | — |
| S | — | — | — | — | 0.02 | — |
| MnO | 0.43 | 0.51 | 0.40 | 0.67 | 0.30 | 0.84 |
| $Li_2O$ | 1.40 | 2.73 | 1.96 | 1.85 | 1.90 | 3.34 |
| | 99.57 | 100.27 | 98.87 | 102.24 | 101.94 | 98.93 |
| Less O | | | | 1.85 | 2.11 | |
| | | | | 99.93 | 99.83 | |
| Be | 6 ppm | 16 ppm | 19 ppm | | | 32 ppm |
| Cr | 10 ppm | 20 ppm | 30 ppm | | | 10 ppm |
| Zn | 1660 ppm | 2510 ppm | 3140 ppm | | | 1350 ppm |
| Cd | 6 ppm | 10 ppm | 30 ppm | | | < 6 ppm |

*Formula calculated to 24*

| | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|
| Si | 6.36 | 5.74 | 6.96 | 6.30 | 6.22 | 6.16 |
| | 8.00 | | 8.00 | | 8.00 | |
| Al | 1.64 | 2.26 | 1.04 | 1.70 | 1.78 | 1.84 |
| Al | 0.69 | 0.22 | 0.84 | 1.30 | 1.62 | 1.34 |
| Ti | 0.31 | 0.37 | 0.28 | 0.03 | 0.02 | 0.09 |
| Fe''' | 0.39 | 0.93 | 0.30 | 0.23 | 0.22 | 0.29 |
| Fe'' | 3.93 6.30 | 3.36 6.71 | 3.60 6.31 | 2.90 5.72 | 2.29 5.33 | 1.75 5.4 |
| Mn | 0.06 | 0.07 | 0.05 | 0.09 | 0.04 | 0.10 |
| Mg | 0.01 | 0.01 | 0.03 | 0.03 | 0.02 | 0.02 |
| Li | 0.91 | 1.75 | 1.21 | 1.14 | 1.12 | 1.90 |
| Ca | 0.26 | 0.03 | 0.07 | — | 0.01 | 0.03 |
| Na | 0.03 1.98 | 0.03 1.85 | 0.03 1.29 | 0.03 1.97 | 0.04 1.71 | 0.05 1.8 |
| K | 1.69 | 1.79 | 1.19 | 1.94 | 1.66 | 1.72 |
| OH | 2.47 | 2.80 | 2.55 | 1.15 | 2.30 | 5.09 |
| | | | | 3.81 | 4.63 | |
| F | — | — | — | 2.66 | 2.33 | — |

8. Li-siderophyllite from greisen in Rishi biotite granite, Saiya / Shokobo Complex. Analysed by R. Batchelor, St. Andrews.
9. Li-Fe-siderophyllite from pegmatitic vein in Rishi biotite granite. Analysed by R. Batchelor.
10. Li-siderophyllite from greisen in Rishi biotite granite, Saiya / Shokobo Complex. Analysed by R. Batchelor, St. Andrews.
11. Protolithionite from Rayfield Gona granite, Harweg area, Jos / Bukuru Complex. Analysed by von Knorring and Dyson (1959).
12. Protolithionite from greisen in biotite granite, Liruei. Analysis taken from Bull. 32 of Geol. Survey. (BUCHANAN *et al.*, 1971).
13. Protolithionite from quartz-mica pegmatitic vein, Sabon Gida South biotite granite, Jos / Bukuru Complex. Analysed by R. Batchelor, St. Andrews.

*Physical properties*

The annitic micas in thin section are pleochroic from dark green, brown or reddish brown to light brown, straw yellow or pale green with Refractive Indices of 1.65 to 1.68.

Micas which plot in the siderophyllite field are very dark green, almost black, in hand specimen, and in thin section are pleochroic from dark blue-green to pale green, straw yellow or almost colourless (Fig. 6). NOCKOLDS and RICHEY (1939) give Refractive Indices of 1.582-1.625 for similar micas. These are low refractive indices for iron-rich micas and the authors believed that this is partly due to the low amount of ferric iron and partly to the presence of relatively abundant fluorine which constitutes 2%.

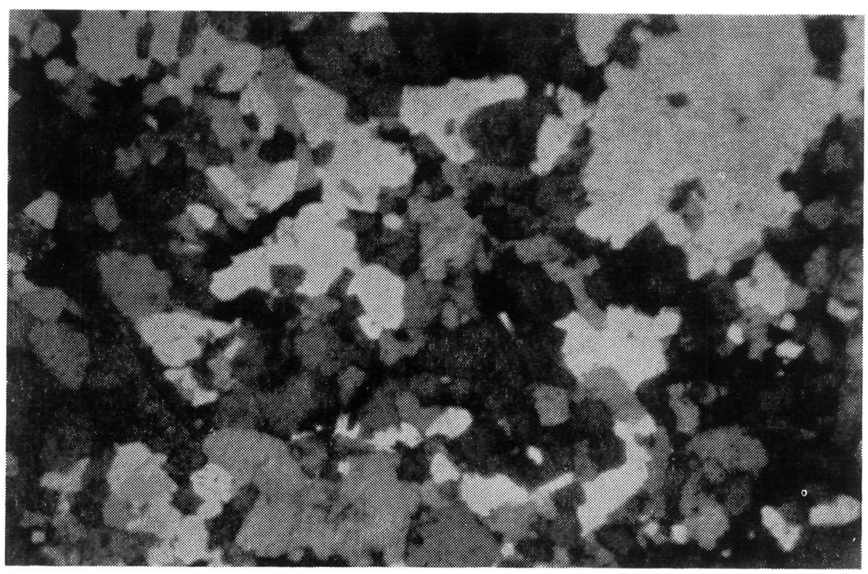


FIG. 6

*Blue-green siderophyllite with cassiterite and large quartz grains in a greisen from the Saiya-Shokobo Complex.* × *20*

The micas in the protolithionite field range in hand specimen from a pale blue-green colour (i.e. those near the protolithionite/siderophyllite boundary) to colourless. In thin section they may be pleochroic from very pale green to colourless or they may be grey to colourless with no pleochroic scheme. Von KNORRING and DYSON (1959) give one refractive index of 1.612 for protolithionite.

*Chemistry*

The annitic micas are rich in both $Fe^{3+}$ and $Fe^{2+}$ and during albitisation or replacement vein formation there is a gradual decrease of $Fe^{3+}$ together with a marked decrease of $Fe^{2+}$ and Ti between siderophyllite and protolithionite. There is also a gradual decrease of Na and a slight decrease of Mg although the Mg content is initially low. Variations in trace element proportions have yet to be investigated although preliminary evidence suggests that along the trend lithium-iron biotite $\longrightarrow$ siderophyllite $\longrightarrow$ protolithionite, there is a gradual increase in Zn and Be.

Considering the compositions of the iron-rich biotites from non-albitised granites it appears that they are relatively poor in $Al_2O_3$ since their values are generally less than 12%. In contrast, the micas from the albitised granites and replacement veins have $Al_2O_3$ values which exceed 12%. These micas also contain more $Al^{3+}$, $Fe^{3+}$, $Ti^{4+}$ ions than those from the nonalbitised granites.

It is possible that the relative proportions of $TiO_2$ and $Fe_2O_3$ influence the colour. HAYAMA (1959) has shown that $TiO_2$, which is responsible for brown or red colour, is in general in very small amounts in greisen biotites. The green colour may also result from a high proportion of $Fe_2O_3$ to an average value of $TiO_2$.

Microprobe analysis (C. Abernethy pers. comm.) across a zoned mica, with a brown core and colourless zone followed by a green rim and white overgrowth, showed a progressive decrease, from the centre, in total iron and titanium, with increased aluminium.

It is concluded therefore that primary biotites from the perthitic granites are rich in «annite» whilst the composition of green or white biotites characterising the albitised granites is comparable to the biotites from mineralised replacement veins and these range between siderophyllite and protolithionite. FABRIES and ROCCI (1965) have also reached similar conclusions about the biotites from the Tarraouadji massif in the Niger Republic.

Further work on mica composition is intended, especially using microprobe analyses, to study the trace element distribution between micas from perthitic granites, albitised granites and mineralised veins.

### *Xenotime/Monazite*

These rare earth phosphates have been mistakenly considered in the past to have the same paragenesis. However, the present study has shown that xenotime (yttrium phosphate) belongs to the early phase of mineralization in aluminous granites whereas monazite belongs to the later phase.

Monazite, a cerium phosphate, has been identified as a euhedral mineral in altered veins predominantly associated with the chloritic stage of alteration in the Rishi area. Xenotime has not been observed by the writer. Analyses of the two minerals for ATMN produced widely differing results at different laboratories — the following analyses are an average of these results.

| | Monazite | Xenotime |
|---|---|---|
| $P_2O_5$ | 26.7 | 26.9 |
| $SiO_2$ | — | 1.5 |
| $Fe_2O_3$ | — | 0.48 |
| $Y_2O_3$ | 1.45 | 28.9 |
| $La_2O_3$ | 11.8 | — |
| $CeO_2$ | 29.6 | — |
| $Pr_6O_{11}$ | 4.1 | — |
| $ZrO_2$ | — | 1.08 |
| $Nd_2O_3$ | 9.4 | 0.23 |
| $Sm_2O_3$ | 0.95 | 0.64 |
| $Gd_2O_3$ | 1.2 | 1.24 |
| $Tb_4O_7$ | — | 0.64 |
| $Dy_2O_3$ | 0.39 | 6.15 |
| $Ho_2O_3$ | — | 1.5 |
| $Er_2O_3$ | — | 6.55 |
| $Tm_2O_3$ | — | 1.55 |
| $Yb_2O_3$ | — | 12.7 |
| $Lu_2O_3$ | — | 1.55 |
| $U_3O_8$ | 0.32 | 0.2 |
| $THO_2$ | 5.45 | 0.94 |
| Loss on ignition | 4.8 | 1.7 |
| | 96.16 | 94.45 |

In thin section, monazite forms colourless to greyish euhedral crystals which are generally less than 0.01 mm. and commonly forming rosettes of crystals, but may reach 3 mm. in size. It has a very high relief and generally has strong to very strong birefringence with upper third or lower fourth order interference colours. Cross sections of the crystal (Fig. 7) have a very weak birefringence.

Two directions of cleavage are clearly visible in the few anhedral patches of monazite. In hand specimen the monazite is seen as small irregular reddish brown patches with a resinous-greasy lustre.

*Wolframite*

Wolframite has rarely been identified in mineralized veins within the Younger Granite complexes and analyses generally show less than 40 ppm

FIG. 7

*Euhedral monazite set in a matrix of fluorite, quartz and chloritised mica with a large anhedral isotropic sphalerite adjacent to the monazite.* × *30*

W within such veins. Instead it usually occurs in quartz veins in Basement granite or gneiss, usually within 1 Km. of a younger granite contact. Within each of these veins the distribution of the wolframite is most irregular. It may be found at the centre of the quartz vein or marginal to it, and the bladed crystals may be parallel or perpendicular to the strike of the vein. Wolframite is locally abundant but large areas of the quartz vein are barren which makes any comparison of relative tungsten values very difficult. The wolframite is commonly found on its own, although it may be accompanied by cassiterite.

The wolframite-bearing veins are usually vertical or subvertical and vary considerably in width. Occasionally, as in the Rishi area, they form a parallel series *en échelon.*

In the Durumi area of the Ropp complex, wolframite with cassiterite occurs in basement in a vertical quartz vein 23 cm. wide trending north-south over a distance of 200 metres. Prospecting by ATMN showed that the lode contained approximately the same proportions of cassiterite and wolframite with the wolframite forming coarse bladed crystals in comparison with small cassiterite grains. HAAG (1943) has suggested that cassiterite occurs with wolframite near the contact with younger granite and that wolfram alone occurs further from the contact. It has not been possible here to study this suggestion but it is a valid concept to apply on a prospectory basis in the

Nigerian Province. Wolframite from the Ropp complex proved on analysis to be ferberite.

| | |
|---|---|
| FeO | 14.7 % |
| MnO | 2.1 % |
| $WO_3$ | 86.0 % |
| | 102.8 % |

Analyst: R. A. BATCHELOR

This compares with an analysis of wolframite from El Meki in Aïr presented by RAULAIS (1948).

| | |
|---|---|
| $WO_3$ | 69.1 % |
| $SnO_2$ | 3.0 % |
| FeO | 21.0 % |
| MnO | 2.5 % |
| $SiO_2$ | 0.8 % |
| CaO | 3.4 % |
| | 99.8 % |

The wolframite at El Meki occurred in quartz veins in a dome composed essentially of migmatite in contact with cassiterite bearing younger granite.

At Rishi a series of *en enchelon* veins with wolframite and cassiterite occur. The veins may reach three metres in thickness and trend 320°. They occur in porphyritic older granite a short distance from the contact with the Rishi biotite granite but no wolframite was found by the writer in the veins within the contact. HAAG (1943) records large masses of wolframite «the size of a fist» in these basement veins but mining activity has long since removed many of these occurrences and where wolframite is found *in situ* now it is as small bladed crystals.

In the Bukuru area of the Jos Complex, small quantities of wolframite have been recorded by MACLEOD (1956) in a sheer zone in the Jos granite. It has also been recorded by ATMN geologists in quartz veins in the Sabon Gida south biotite granite.

In the Liruei complex, JACOBSON (1947) describes wolframite from quartz veins within the Younger granite at the western end of the Liruei lode as dark brown to black, bladed crystals up to 8 cm. or more in length. The wolframite is often orientated at right angles to the walls of the vein, especially where comb structure is well developed in the quartz. Towards the western end of the lode wolframite is frequently associated with adularia and quartz in drusy cavities.

Although no such crystals were observed by the writer the abundance of tungsten in the lode is unquestionable. The lode is the only vein system within a Younger granite ring complex to show enrichment in tungsten. Values in reddened wall rock adjacent to a greisen vein varied from 1.320 ppm W on one side to 720 ppm on the other side, whilst the vein itself contained 860 ppm W. (Table II). These high tungsten values are probably related to the intrusion of a fine-grained biotite granite at depth within the main Liruei medium-grained biotite granite giving the only example so far of multiple veins.

In general, wolframite mineralization is sporadic and unpredictable, both along the strike and at depth and only those lodes which carry a reasonable amount of cassiterite have proved payable. Despite its widespread occurrence only a few localities have been of economic importance and these have mostly been worked out. Wolframite is only mined as a primary mineral as it does not survive in the alluvials. Misconceptions in past literature about the abundance of wolframite appear to stem from the misidentification of dark brown, metallic looking sphalerite.

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## BIBLIOGRAPHY

BARSUKOV, V. L. & KURIL'CHIKOVA, G. YE (1966): *On the forms in which tin is transported in hydrothermal solutions.* Geokhimiya, 8; 943-948.

BAUMANN, L.; ŠTEMPROK, M.; TISCHENDORF, G. & ZOUBEK, V. (1974): *Metallogeny of Tin and Tungsten in the Krusne Hory-Erzgebirge.* IGCP Metallization Association with Acid Magmatism Symposium, Karlovy Vary, 1974. Published by the Geological Survey Prague.

BEUS, A. A. (1956): *Beryllium.* The State Publishing Office of Scientific and Technical Literature on Geology and Conservation of Mineral Resources.

— (1962): *Beryllium. Evaluation of Deposits during prospecting and exploratory work.* W. H. Freeman and Company.

BORLEY, G. D. (1976): *Ferromagnesian Mineralogy and Temperatures of formation of the Younger Granites of northern Nigeria.* In "*Geology of Nigeria*". Ed. C. A. KOGBE. Elizabeth Publishing Co. of Nigeria.

BUCHANAN, M. S.; MACLEOD, W. N. & TURNER, D. C. (1971): *The Geology of the Jos Plateau,* vol. 2, *The Younger Granite Complexes.* Bull. Geol. Surv. Nigeria, 32.

BUTLER, J. R. & THOMPSON, A. J. (1967): *Cadmium and zinc in some alkali acidic rocks.* Geochimica et Cosmochimica Acta, 31; 97-105.

CARUBA, R.; BAUMER, A.; MANO, J. & TURCO, G. (1975): *Etude comparative des proprietes respectives de zircons hydroxyles synthetiques et de zircons metamictes naturels; hypothese de genese des malacons.* Petrologie, 1 (1); 57-70.

DEER, W. A.; HOWIE, R. A. & ZUSSMAN, J. (1969): *An Introduction to the Rock Forming Minerals.* Longmans.

FABRIES, J. & ROCCI, G. (1965): *Le massif granitique du Tarraouadji (Republique de Niger). Etude et signification petrogenetique des principaux mineraux.* Bull. Soc. franc. Miner. Crist., LXXXVIII; 319-340.

FOSTER, M. D. (1960): *Interpretation of the Composition of trioctohedral micas.* Prof. Paper. U.S. geol. Surv., 354 B; 11-49.

GREAVES, G.; STEVENSON, B. G. & TAYLOR, R. G. (1971): *Magnetic cassiterites from North Queensland.* Econ. Geol., 66; 480-487.

GURVICH, S. I.; ZUBKOV, L. B. & GALETSKIYM, L. S. (1963): *Genthelvite from silicified syenites.* Doklady Akademii Nauk SSSR., 150 (5); 1123-1124.

HAAG, H. L. (1943): *Wolfram in Nigeria: With notes on cassiterite, wolfram and columbite.* Trans. Inst. Min. Metall., 52.

HAYAMA, Y. (1959): Journal Geol. Soc. Japan, 65 (21).

HESP, W. R. & RIGBY, D. (1972): *The transport of tin in acid igneous rocks.* Pacific Geology, 4; 135-152.

JACOBSON, R. R. E. (1947): *The Younger Granite Complex of the Liruei Hills, Nigeria.* Unpubl. thesis Univ. of London.

JACOBSON, R. R. E. & WEBB, J. S. (1946): *The pegmatites of central Nigeria.* Bull. Geol. Surv. Nigeria, 17.

KALENOV, A. D. (1959): *A greisen type of helvite mineralisation.* Zap. Vses. Min. ob-va, ch. 88, vyn. 4.

VON KNORRING, O. & DYSON, P. (1959): *An occurrence of genthelvite in the Younger Granite Province of Northern Nigeria.* Amer. Min., 44; 1294-1298.

LANGE, H. L.; TISCHENDORF, G.; PÄLCHEN, V.; KLENN, I. & VALTRAUT, O. (1972): *Zur petrographie und geochemie der granite des Erzgebirges-Fortschritte der Metallogenie in* Erzgebirge. B. Geologie, 21; 457-493.

MacLeod, W. N. (1956): *The Geology of the Jos-Bukuru complex with particular reference to the distribution of columbite.* Rec. Geol. Surv. Nig., 17-34.

MacLeod, W. N. & Jones, M. P. (1955): *The effects of heat and hydrochloric acid on the properties of some Nigerian minerals.* Colon. Geol. Miner. Resour., 5; 166-173.

MacLeod, M. N.; Turner, D. C. & Wright, E. P. (1971): *The Geology of the Jos Plateau,* Vol. 1, *General Geology.* Bull. Geol. Surv. Nigeria, 32.

Martin, R. F. & Piwinski, A. J. (1972): *Magmatism and Tectonic Setting.* J. Tectonophys. Res., 77; 4966-4975.

Nockolds, S. R. & Richey, J. E. (1939): *Replacement veins in the Mourne Mountain granites, Northern Irelaand.* Am. Journ. Sci., 237 (1); 27-47.

Petrova, E. A. (1961): *Malacon from albitites in Siberia.* In "*New Data on Rare Element Mineralogy*", Ed. A. I. Ginzburgh, p. 121-129.

Raulais, M. (1948): *Sur la decouverte de wolfram dans le jeune granite a biotite de l'Aïr (Niger).* CR. Ac. Sc. No. unknown.

Sainsbury, C. L. (1960): *Metallisation and Post Mineral Hypogene Argillisation, Lost River Tin Mine, Alaska.* Econ. Geol., 55; 1478-1506.

Shcherbina, V. V. (1963): *The occurrence of elements as chlorides and fluorides in nature, depending on the position of the elements in the Periodic Table.* Geochem., 8; 751-764.

Taylor, J. (1959): *Occurrences of Beryllium in the Younger Granites of Northern Nigeria.* Geol. Surv. of Britain Atomic Energy Division, Report No. 221.

— (1961): *Investigations of the Economic Potentialities of Danalite-Genthelvite Occurrences in Northern Nigeria.* Geol. Surv. of Britain Atomic Energy Division, Report No. 237.

Williams, F. A.; Meehan, J. A.; Paulo, K. L.; John, T. U. & Rushton, H. G. (1956): *Economic Geology of the Decomposed Columbite Bearing Granites, Jos Plateau.* Econ. Geol., 51 (4); 303-332.

STVDIA GEOLOGICA, XIV, 1978 (221-222)

# TIN-BEARING ROCK TYPES IN KOREA

SOO JIN KIM*

ABSTRACT.—Tin deposits of Korea are nearly confined to the central east area of South Korea. They are mainly found in a N30W-trending Precambrian anticlinal belt. The original rocks have been subjected to considerable metamorphism, resulting in schists, gneisses, marble and quartzite. Granitic bodies of various ages are emplaced within the area. Most of the old granitic rocks appear to be synorogenic. Regionally, the Paleozoic and partly Mesozoic formations are developed in the north, and the Mesozoic formations are developed in the south from this belt.

## *Classification of tin deposits of Korea*

Tin deposits of Korea can be grouped genetically into the following classes.

A) Magmatic dissemination
   1) Albitite
   2) Quartz albitite
   3) Greisen

B) Pegmatitic
   1) Pegmatite
   2) Aplite

C) Hydrothermal
   Sulfide vein and pipe

## *Albitite and quartz albitite*

Albitite is widely developed in the Uljin area. It occurs mainly as sheets or rarely as dykes in the Pre-cambrian schists around the granite gneiss mass. Granite gneiss intrudes into the schists. Albitite sheets range from 0.3 m. to 15 m. thick in width and from 5 m. to 150 m. in extension. Albitite grades toward quartz albitite. Albitite sheets or dykes are greisenized along the contact with country rocks, but not always the case.

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Albitite consists of albite only or albite plus various amounts of sericite and quartz with minor disseminated cassiterite, grading to quartz albitite. In some quartz albitite, quartz partly has the form of veinlet parallel to the long direction of the sheets or dykes.

### *Greisen*

As described above, greisens is developed mainly along the contact of albitite with schists. The contact of greisen and albitite is more or less gradational. It appears that albitite and greisen have been metamorphosed together with the country rocks. Sericites in greisen are alligned parallel to the general structure of the country rocks.

Greisen consists mainly of sericite (or muscovite) and quartz, with occasional major or minor amount of cassiterite, lepidolite, beryl, scheelite and fluorite. Greisen or strictly speaking, greisen schist (or sericite schist) is the main source of cassiterite in the Uljin area.

### *Pegmatite and aplite*

Pegmatite is widely developed in the Sangdong area. In places, it accompanies aplite. Pegmatites are parallel to or cut the structures of the country rocks that consist of schists and gneisses. They range from 0.1 m. to 18 m. in width and from 10 m. to 600 m. in extension.

Pegmatite consists of very coarse-grained quartz, microcline and muscovite, with minor cassiterite, tourmaline and scheelite. Aplite also has the similar mineral composition. In places, pegmatite contains a lot of tourmaline. Pegmatite in granite gneiss in Uljin area has the mineral composition similar to that of the country rock.

### *Occurrence of cassiterite*

Cassiterite occurs as aggregates or as isolated crystals that are characterized by short euhedral to anhedral prisms and dipyramidal terminations. However, some grains of cassiterite are more or less flattened or crushed.

Stvdia Geologica, XIV, 1978 (223-260)

# MINERAL PARAGENESIS IN THE VARISCAN METALLOGENY OF SPAIN *

A. Arribas **

Resumen.—Se definen en este trabajo ias paragénesis características de los más importantes yacimientos españoles relacionados con la metalogenia varíscica de la Península Ibérica.

En la primera parte se delimitan las áreas ocupadas por las formaciones hercínicas y se resumen los rasgos geológicos, tectónicos y metalogénicos del basamento, tanto del que forma el Macizo Hespérico como del que constituye el núcleo de las zonas arogénicas alpinas.

En la segunda parte se definen las paragénesis en función de sus asociaciones minerales y rocas encajantes, lo que permite clasificarlas en 3 grupos: Varíscicas, pre-Varíscicas y Varíscicas tardías.

Al primer grupo, que es el estrictamente varíscico y por ello el más importante, corresponden 32 asociaciones minerales —(K.U-Ce), (K.Be), (na.U-Ti), (na.Li), (K.Na-Sn), (q.Sn), (q.Sn-W), (q.W), (q.W-B), (q.As-U), (q.Mo-Au), (q.P), (sk.U-Mo), (sk.Pol-Fe), (q.Co-Ni-Bi), (Co-Ni-Cu), (q.Ba-Pb-Ag), (q.Cu), (q.Pb-Ba), (q.Pb-Zn), (f.Zn-Pb), (c.Zn), (e-Fe-Cu), (e.Fe-Pol), (e.q-Mn), (q.U-Cu), (q.U-Fe), (q.U-BG), (q.U-F), (Sb), (q-Sb), (Sb-W) y (Sb-Hg)— de carácter pegmatítico, filoniano, metamórfico y volcano-sedimentario.

En el segundo grupo hay 12 paragénesis —(a.Ti-Zr), (a.Sn-Ce), (sk.W), (Fe), (v.Fe-Pol), (v.Fe-Cu), (v.Ba-Mn), (v.Hg-Fe), (m.Ti-Cr), (m.U-Ni-Co), (m.BGPC) y (m.Hg-Ba)— de naturaleza ígnea y metamórfica. Y en el tercero se incluyen 2 asociaciones minerales —(F.Ba) y (Ba-Fe)—, una sedimentaria y otra filoniana, situadas en sedimentcs triásicos cuya edad es superior a 220 m.a., ya que ésta se ha considerado como el límite superior de los fenómenos metalogénicos alpinos.

Summary.—The mineral paragenesis which characterize the most important Spanish ore deposits re:ated to the Variscam metallogeny are given in this paper.

In the first part, the limits of the Hercynian orogenic belt of the Iberian Peninsula are established, and summarized the main geological, tectonic and

* Lecture presented at the seminar "Mineral Paragenesis of the European Variscan Zone", held by the Paragenetic Commission of the IAGOD at the Department of Geology and Mineralogy of the University of Salamanca in April 1977. An abridged version of this lecture will appear in a special issue of the *Freiberger Forschungshefte* dedicated to that seminar.

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metallogenic features of the basement which makes up both the Hesperian Massif and the inner zones of the Alpine orogen.

In the second part, the paragenesis are defined. This is made according to their mineralogy and host rocks, which allows to classify the mineralogical associations in three groups: Variscan, pre-Variscan, and late-Variscan.

The first group is the most important as it is formed by the strictly Variscan mineral associations. It includes 32 paragenesis —(K.U-Ce), (k.Be), (na.U-Ti), (na-Li), (k.Na-Sn), (q.Sn), (q.Sn-W), (q.W), (q.W-B), (q.As-U), (q.Mo-Au), (q-P), (sk.W-Mo), (sk.Pol-Fe), (q.Co-Ni-Bi), (Co-Ni-Cu), (q.Ba-Pb-Ag), (q.-Cu), (q.Pb-Ba), (q.Pb-Zn), (f.Zn-Pb), (c.Zn), (e.Fe-Cu), (e.Fe-Pol), (e.q-Mn), (q.U-Cu), (q.U-Fe), (q.U-BG), (q.U-F), (Sb), (q.Sb), (Sb-W) and (Sb-Hg)— of pegmatitic, vein-like, metamorphic and exhalative-sedimentary origin.

In the second group, 12 igneous and metamorphic paragenesis —(a.Ti-Zr), (a.Sn-Ce), (sk.W), (Fe), (v.Fe-Pol), (v.Fe-Cu), (v.Ba-Mn), (v.Hg-Fe), (m.Ti-Cr), (m.U-Ni-Co), (m.BGPC) and (m.Hg-Ba)— are included. Finally, in the third group, 2 paragenesis —(F.Ba) and (Ba-Fe)—, one sedimentary and other hydrothermal, occur in Triassic sediments, the age of which is older than 220 m.y. This age has been considered as the upper limit of the Alpine metallogenic processes.

## I.—LIMITS AND GEOLOGY OF THE SPANISH HERCYNIAN BASEMENT

The Iberian Peninsula is a well defined although a rather complicated geotectonic unit in the southwestern corner of Europe (Fig. 1).

From the stratigraphic point of view, the Peninsula consists of four main geological formations: (1) a few Precambrian units which were folded prior to the Hercynian orogeny; (2) the Paleozoic and most of the Precambrian, folded simultaneously during the Hercynian orogeny; (3) the Mesozoic and Cenozoic sedimentary rocks included in the Alpine orogen; and (4) the Cenozoic and some rare Mesozoic sediments which were not involved in this orogenic system. It should be pointed out that all the Precambrian was incorporated into the Hercynian orogeny. Therefore, it crops out only in the cores of some Hercynian anticlines. The Paleozoic rocks not deformed by the Hercynian orogeny are very scarce.

Structurally, the Peninsula is build up of two main tectonic assemblages (Fig. 2): the Hercynian basement and the Alpine cover. The two are always present in the major geotectonic units of the Peninsula.

The Hercynian basement, which extends mostly to the west, occupies a broad surface of Spain and Portugal. It has been called the Hesperian Massif, and represents the southernmost part of the West European Variscan orogenic Belt. On both sides, especially to the east, the basement is largely covered by the Mesozoic and Cenozoic sediments of the Alpine orogene, but it still outcrops in the innermost parts of the other five major tectonic units of the

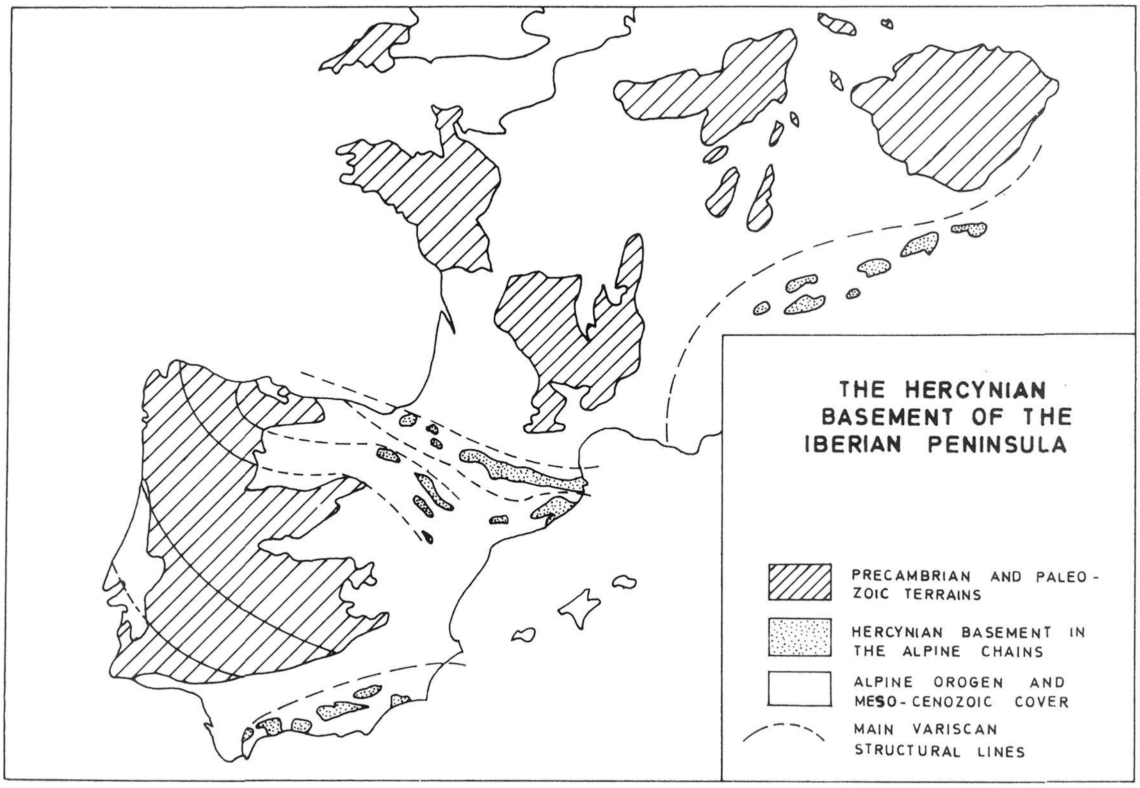


FIGURA. 1

Peninsula: the Cantabrian and Iberian Chains, the Catalonian Coastal Range, the Portuguese Mesozoic Belt, the Betics, and the Pyrenees. However, in some of these units, it is sometimes difficult to establish the relationship between the Paleozoic formations and the Hercynian basement because the original features of the rocks have been strongly modified by the Alpine movements.

During the Alpine orogeny, a faulting tectonics was superimposed on the basement and gave place to the formation of five main tectonic basins: the Ebro, Duero, Tajo, and Guadalquivir Basins in Spain, and the Sado Basin in Portugal. All belong to the same fracture system which has developed in Europe since the beginning of the Tertiary. Important uplifts such as the Axial Zone of the Pyrenees, the Sierra Nevada, and some units of the Central Cordillera, resulted from the same tectonic event.

## 1. Geotectonic evolution of the Hesperian Massif

The Hesperian Massif, named henceforth the Iberian Meseta when referring to the Spanish side, has been a broad platform of relative structural stability since the beginning of the Tertiary. It is limited by the Basque-Cantabrian Chain on the north; by the Iberian Range on the east; by the Guadalquivir Fault, which can be traced along more than 400 k., on the south; and by the Porto Fault, which separates the Meseta from the Portuguese Mesozoic Coastal Range, and the Sado Basin, on the west.

The Meseta consists of plutonic and metamorphic rocks ranging in age from Precambrian to Permian. In general, they strike NW from the Guadalquivir Fault up to beyond the Portuguese and Galician border, then bend to the N and even to the NNE when approaching the Atlantic coast in Northern Spain.

The oldest geological formations in the Hesperian Massif belong to the upper levels of the Precambrian. In Galicia, they consist of several lithological units: the mafic and ultramafic plutonic and polimetamorfic rocks of the Ortegal, Ordenes and Lalin Complexes, and the acid volcanics, pelitic schists and graywackes of the Narcea Anticline and the core of the Mondoñedo recumbent fold. In the central areas of the Meseta, these pelitic rocks are quite similar to those of the pre-Ordovician formations. Therefore, when no Cambrian quartzites or limestones are present, it is impossible to discern the limits of these formations, and they are represented as a unit in the geological maps of Spain and Portugal. This unit is named the «Pre-Ordovician schist and graywake complex» or the «Beiras formation», because it is in this Portuguese province where their outcrops are more important.

Most of the Iberian Meseta is made up of Paleozoic rocks, metasediments and metavolcanites, which have been metamorphosed to varying degrees, mainly in the greenschists facies. Quartzites, shales, carbonate rocks, mica-schists, and differente kind of gneisses, as well as lava flows and tuffs, ranging from basalts to rhyolites in composition, with interbedded spilites and keratophyres and flysch deposits, particularly in the northwestern corner of the Meseta, are the most common rock formations. The whole sequence was intruded by large volumes of granitic rocks during the Hercynian orogeny (Fig. 3).

The geology of the Iberian Meseta has been synthesized in many papers, among others, LOTZE (17), SOLÉ (21), CAPDEVILA et alt. (7), and JULIVERT et alt. (15). On this base, the Meseta can be subdivided in five units running parallel to the Hercynian fold axes (Fig. 2). They are, from north to south, the Cantabrian (I), West Asturian-Leonese (II), Middle Galicia-Tras-os-Montes (III), Central Iberian (IV), Ossa-Morena (V), and South Portuguese (VI) Zones. All are well characterized by their lithological, paleogeographical, tectonic and metallogenic features. And it is interesting to note that, for most of these features, the Hercynian orogenic belt shows a roughly bilateral symmetry: Upper Paleozoic formations occur towards the margins, and Upper

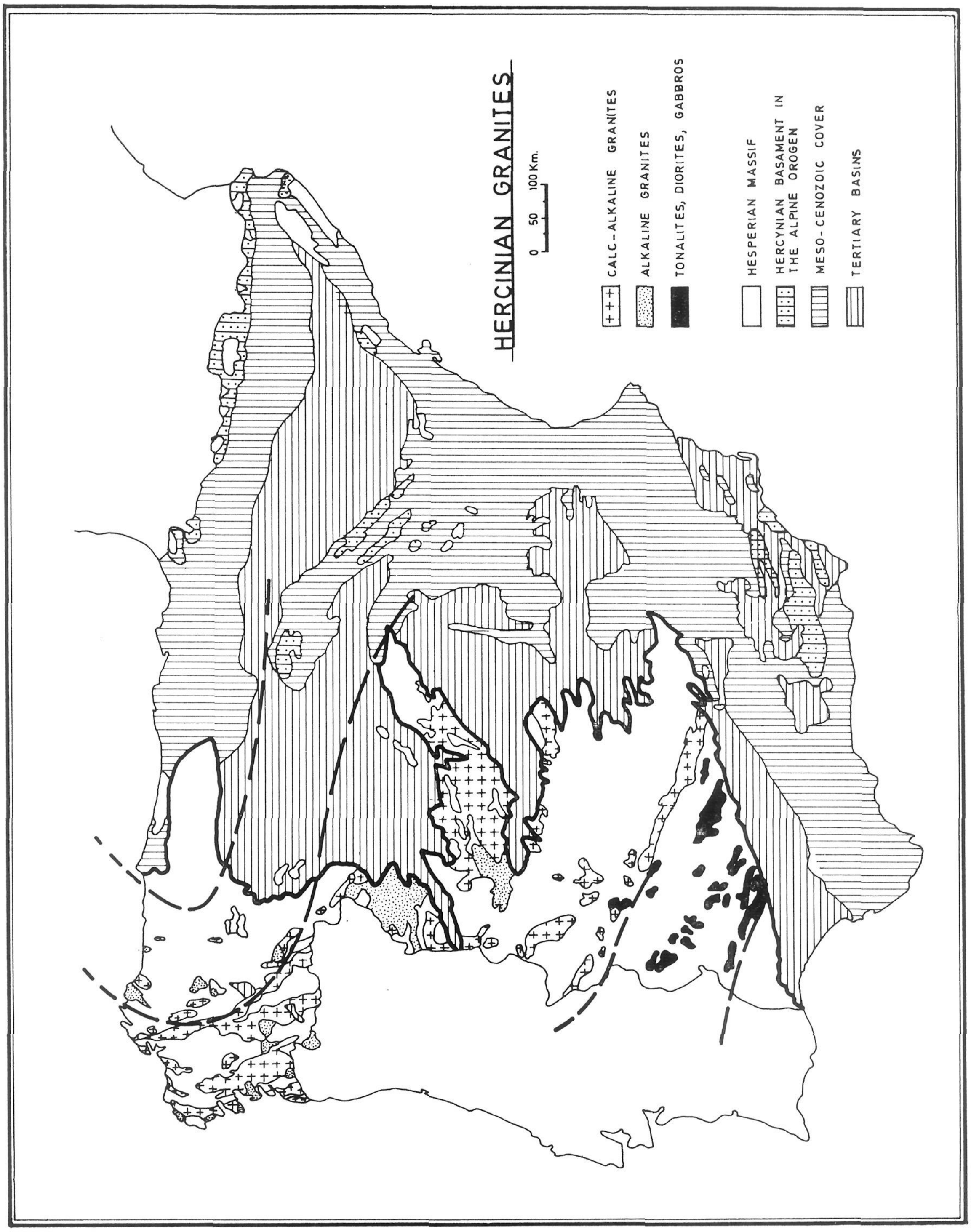
HERCINIAN GRANITES
0 50 100 Km.
CALC-ALKALINE GRANITES
ALKALINE GRANITES
TONALITES, DIORITES, GABBROS
HESPERIAN MASSIF
HERCYNIAN BASAMENT IN THE ALPINE OROGEN
MESO-CENOZOIC COVER
TERTIARY BASINS

FIG. 3

Precambrian, Lower Paleozoic and plutonic rocks prevail in the central areas. As the younger formations show opposite overturns, the Meseta seems to be a big anticlinorium in which the mineral deposits broadly follow a pattern of symmetrical distribution.

Although pre-Hercynian orogenic movements, probably related to the Caledonian Sardian phase, are known in some scattered points of the Iberian Meseta, the most important tectonic, magmatic, and metamorphic features displayed in the basement are Hercynian, and took place 340 to 280 m.y. ago between the Lower Visean and Upper Stephanian times.

Later on, a new period of deformation gave place to an important Late Hercynian fracture system in which long strike-slip faults, trending dominantly to the NE, NW and E-W, prevail. Some of these fractures were reactivated during the Alpine orogeny, at the end of the Tertiary, giving place to a block tectonics that sometimes produced vertical displacements of more than 1.500 m.

A summary of the geology of the Portuguese part of the Hesperian Massif is included in the paper presented by THADEU (22) at the IAGOD Seminar. Therefore, as the main geological features of the Meseta are very much the same in Spain and Portugal, this contribution should be consulted for a better understanding of the geotectonic and magmatic evolution of the Zones (III) and (IV) which are shared by both countries. For the whole of the Massif, the most relevant metallagenic features are summarized below.

### a) *The Cantabrian Zone (I)*

The Cantabrian zone occupies the inner part of the Hercynian arc in northern Spain, the so-called Asturian knee. This zone is characterized for a small development of the Lower Paleozoic, mainly Cambrian to Ordovician. From Devonian to Lower Carboniferous, an important transgresion took place in the area. It reached its maximum extent during the Westphalian, when a sequence of sandstones, shales, and carbonate rocks, several thousands of feet thick, was deposited. These rocks were deformed by two tectonic phases —one between the Namurian and Westphalian, the other before the Stephanian— which produced overthrusts and upright folds respectively. Metamorphism, when existent, is regional and low grade. Several important coal deposits occur in this zone as well as some minor mercury, copper, barite, and antimony ores.

### b) *The West Asturian-Leonese Zone (II)*

This zone is bounded by two antiforms which correspond to the Narcea and «Ollo de Sapo» anticlines. It consists mainly of monometamorphic rocks, Lower Paleozoic in age, made up of Cambrian, Ordovician, and to a lesser extent Silurian quartzites, schists, and occasional limestones. All these materials have undergone two main Tectonic deformations. The first, pre-Visean in age, produced overturned and recumbent folds, such as those of Mondoñedo and Caurel, whereas the second gave place only to upright folds in pre-Westphalian times. Both the number of granitic intrusions and the intensity of the regional metamorphism increase to the west. Several anthracite beds and two ironstones deposits are being mined here. Also, some significant lead-zinc orebodies are either being worked or explored in this zone, mainly in the Cambrian limestones and the Ordovician quartzites.

c) *The Middle Galicia (III) and Central Iberian (IV) Zones*

This zone is the largest geotectonic unit in the Meseta. It extends for more than 600 k. from Galicia, in the north, through the northern half of Portugal, to the Pedroches batholith, in the south, making up the real backbone of the Iberian Peninsula.

Two lithological formations have been recognized in this unit. The oldest, which consists mainly of pre-Ordovician rocks —Precambrian and Lower Paleozoic, some of them pertaining to the monotonous Beiras formation— extends mainly to the north, its metamorphic degree varying from the chlorite to the sillimanite zone. However, within the northern part of Galicia, three overthrusts of old Precambrian polimetamorphic rocks, the Ortegal, Ordenes and Lalin basic complexes —which could be mantle plumes according to van CALSTEREN et alt. (6)—, as well as the so-called blastomilonitic graben, show mineralogical assemblages of the amphibolite, granulite and eclogite facies which occasionally have been retrograded by a regional metamorphism of lower degree. All these rocks, which make up the Middle Galicia Zone (III) and its continuation in Portugal with the Trás-os-Montes complexes of Braganca and Morais, have been subjected to an intense mineral exploration. So far, one workable copper orebody and some minor chromite occurrences, all associated with mafic and ultramafic rocks, have been found there.

The younger formation, made up essentially of Cambrian to Silurian and, in a few places, Devonian slates, conglomerates, basic and acid volcanics, and occasionally limestones, underlies the southern half of the zone. In this area, regional metamorphism, when existing, is only of the greenschist facies. Besides this, three important geological features make this zone clearly different from the others of the Hercynian Meseta: (1) the sharp unconformity between the thick Lower Ordovician quartzites and the underlying Cambrian and Precambrian basement; (2) the regularly spaced, parallel, synform structures of the sedimentary sequences; and (3) the large amount of syntectonic and post-tectonic granitic intrusions to which several important ore deposits are genetically associated (Fig. 3).

In the Central Iberian Zone, two main tectonic phases have been recognized. They are similar in age and style to those of the western Asturian Zone, but in the southern part, the axial planes of the pre-Visean folds are subvertical.

The magmatic activity was dominantly granitic, and gave place to granitoids of different age and composition. The geochemical features of these rocks are given in several papers, among them, those by OEN (18), CAPDEVILA et alt. (7), CORRETGÉ et alt. (8) and APARICIO et alt. (1). As these granitoids could have been affected by the last main Variscan tectonic phase, there are syn to late kinematic and postkinematic plutons, the so-called younger and older granites.

The first type, consisting mainly of leucogranites rich in alcalis and alumina, with almost exclusively muscovite, frequently contains appreciable amounts of cordierite, andalucite, sillimanite and tourmaline, and show high $^{87}Sr/^{86}Sr$ ratios. The emplacement of these granites is closely dependent on the tectonic processes and metamorphism of the basement. They were apparently formed by humid anatectic fusion in the middle levels of the crust. Occasionally they show a later albitization stage which sometimes is clearly related to the formation of the uranium and tin deposits.

The second type of granitoides consists mostly of rocks of calc-alkalic composition, adamellites and granodiorites, which intruded the crust during the latest episodes of the Hercynian orogeny, mainly after the climax of the major tectonic events. Their emplacement took place in zones of structural weakness, and they were probably originated by melting of lower crust materials contaminated by basic rocks of infracrustal origin in a dry environment during regional metamorphism. The deep-seated origin of these granitoides is also confirmed by the low $^{87}Sr/^{86}Sr$ ratio.

Important uranium deposits, mostly veins in the granites and surrounding metasediments, and some interesting pegmatites, which contain beryl, niobium, tantalum, lithium, and rare earth minerals occur in this zone. The most significant ore deposits, however, are those of tin, tungsten, antimony, lead, zinc, copper, and mercury.

The Sn-W ores are associated with intrusions of syn- and late kinematic granites. They occur as veins and lodes which traverse both the granite and the adjoining schists, or as greisen bordered veins in the extremely altered apices of the granitic bodies. The possibility that some deposits can be associated with older granites is not precluded.

Several Au-Ag occurrences in the Meseta are genetically related to the

Sn-W mineralizations. The same is true of some Sb-Au ores which frequently contain scheelite as an accesory mineral.

The Pb-Zn, Pb-Zn-Cu, and Pb-Ag ores occur as sulfide vein-type deposits. They lie both within the granite and far from the igneous rocks, and they are nearly always fault controlled. Several important deposits are widely distributed along this Central Zone. Special atention should be drawn on the Linares and Peñarroya mining districts, which for a long time were the most important lead producers in Europe. They are located on the eastern and southern margins of the Pedroches batholith, which stands out for its remarkable mineral zoning. Here, closest to the plutonic body, or extending well into them, some pegmatites and uraniferous veins, and several small Sn-W occurrences are present. Next to the granite, there are some minor Ni-Co-Bi occurrences, all mined out, which are followed outward by numerous Pb-Zn-Ag ores. Although most of them are exhausted, some are still in operation. For example, the Los Guindos vein, to the NE of Linares, is more than 9 mi long; in some places, the oreshoots of silver-rich galena were more than 6 ft across. Finally, farthest from the granite, several Cu-Fe, hematite, and mercury deposits occur.

The most important and famous mineral deposit in this zone is Almaden, the world's biggest mercury mine. The deposit is located on the northern slope of Sierra Morena, on a ridge of Silurian quartzites which makes up the southern flank of the so-called Almaden syncline. Some layers of siltstones, carbonaceous shale, and minor basic lavas and tuffs are interbedded in the quartzites. Faulting is clearly post-ore, as the faults cut off the mineralized beds, and are barren. The Almaden orebody, as well as three other exhausted mines, and several minor occurrences located along the northern flank, now under exploration, are all in the same stratigraphic unit of the Silurian quartzite. Accordingly the mineralization is now regarded as typically strabound.

During the Tertiary, the faulting tectonics gave rise to a number of important structural features in the Iberian Meseta. Among other zones of the basement, Galicia, in the NW corner of the Peninsula, was intensely fractured with development of several tectonic basins in which thick beds of lignite were deposited. In the Central Iberian Zone an outstanding NE- trending horst, the Central Cordillera, with vertical displacements of more than 2.000 m., led to the development of the Tajo and Duero Basins where some evaporite deposits of glauberite and mirabilite are in operation.

### d) *The Ossa-Morena Zone (V)*

It consists mainly of slightly to highly metamorphosed Cambrian and

Precambrian rocks, locally reaching the amphibolite facies, conformably overlain by some minor monometamorphic Silurian and Devonian sediments. The zone is separated from the Central Iberian by a major overthrust, which accounts for the strong paleogeographic differences between the two zones. The Precambrian, more than 5.000 m. thick, includes polimetamorphic slates, graywackes, micaschists, quartzites, amphibolites, and gneisses. The Cambrian, locally as thick as 2.500 ft., is made up of slates and carbonate rocks, with interbedded volcanites. The same kind of rocks build up the scarce Silurian and Devonian formations present in the Zone.

Two main tectonic events are recognizable here. The first, probably Visean in age, gave place to overturned and recumbent folds towards the foreland. The second, represented by upright folds, took place during Westphalien times.

The granitoids differ considerably from those of the preceding Zone, Now, the dominant calc-alkalic rocks, mostly granodiorites, are accompanied by tonalites, quartzdiorites, and even more basic types such as diorites and gabbros. In that case, some of the rocks were probably formed by magmatic differentation.

The ore deposits are also of a completely different kind, and seem to be transitional to those of the following Zone. In the western side of the area, there are some workable iron and sulfide deposits which are associated with a Cambrian to Silurian volcanic-sedimentary sequence. Along with the country rock, the ores have been repeatedly metamorphosed in differing degrees, mostly in the amphibolite and greenschists facies, during the Hercynian orogeny. They occur both in the volcanites, which are mainly highly silicified rhyolites, and in the interbedded carbonate layers. In contrast, in the eastern side, several pyrometasomatic iron deposits stretch along the contact of granodiorites and diorites with the Cambrian limestones.

e) *The South Portuguese Zone (VI)*

This Zone lies almost entirely in Portugal. It is separated from the Ossa Morena Zone by an overthrust, with the Cambrian and Precambrian formations lying on the Upper Devonian to Upper Westphalian epimetamorphic rocks which make up this southernmost part of the Iberian Meseta. A generalized stratigraphic sequence of this region shows, from bottom to top: (1) Siliceous and pelitic schists of unknown thickness, containing some fossiliferous limestones of Famenian age near the top: (2) A volcanic-sedimentary formation made up of a big pile of tuffs and lava flows, basaltic to rhyolitic in composition, and (3) A thick flysch sequence, consisting of shales and graywackes, and interbedded conglomerates, Upper Visean to Upper Vestphalian in age.

The volcano-sedimentary formation makes up the so-called Iberian Pyrite Belt, which extends from the north of Sevilla in Spain, to Lousal, near the Atlantic coast, in Portugal. The Belt, a typical eugeosynclinal rock sequence, consists of carbonaceous black shales, andesitic to rhyolitic tuffs and lavas, rocks of the spilite-quartz keratophyre association; volcanic chemical sediments; rocks and ores of the manganese-jasperoid and the pyritic iron formations, and some very large stratiform sulfide deposits of the marine-volcanic association. Along the Belt, which occupies an area 120 K long and 10 K wide, there are 60 operating or abandoned mines, and more than 300 sulfide occurrences. The Belt contains more than 500 million tons of proven ore and another 500 million tons of estimated reserves. Most of the orebodies are lenses of massive pyrite, occasionally copper-bearing, which can be, as in the case of the Río Tinto orebody, as large as 3 K long, 300 m thick, and 400 m deep. Other deposits consist of very thin, alternating layers of chalcopyrite, pyrite, sphalerite and galena, in which the remaining sedimentary structures —load casts, slumpings, gradded bedding— can be still observed. Most of the deposits occur between the extremely altered lavas and the overlying pyroclastics, within the tuffs, or between these rocks and the overlying shales.

The tectonic deformations in the South Portuguese Zone are not so intense as in the preceeding one. However, during the Middle Westphalian, isoclinal folding, overturned and recumbent folds towards the SW., and imbrications, specially conspicuous when the more competent masses of pyrite are present, are regular features in the area. The magmatic events are also less important than in the Ossa-Morena Zone, and the granodiorites are restricted to the boundary with it.

## 2. The Hercynian basement in the Alpine orogene

During the Mesozoic, the Hesperian Massif tended to be an upthrown block sourrounded by areas of marine sedimentation, the margins of which offer important differences. So, on the north, northwest and southwest, the Iberian Meseta is bounded by oceanic basins; on the southeast, by a mountain chain of the alpine type, the Betics, and its foredeep, the Guadalquivir Basin; and on the northeast, by a broad and highly deformed platform which gives support to the Cantabrian, Iberian and the Catalonian Coastal Ranges. This platform contains also an important marginal depression, the Ebro Basin, which to some extent could be considered as the foredeep of the Pyrenees. In all these units, the Hercynian basement outcrops (Fig. 2).

a) *The Basque-Cantabrian Range*

It borders the Meseta to the north, representing the western extension of the Pyrenees. The eastern half corresponds to and axial depression where Mesozoic and Cenozoic sediments are present. To the west, the fold axes rise again, and the Hercynian basement crops out on the northern border of the already mentioned Cantabrian Zone of the Meseta. Here, a block of slightly folded and strongly faulted Mesozoic and Cenozoic sediments forms the western end of the Range, and is abruptly cut off by the northern coast of Spain. However, the most recent works carried out on the continental shelf have proved that the Mesozoic and Cenozoic sediments extend offshore, under the Atlantic Ocean, at the bottom of a west-trending submarine basin which extends all along the coast from the Bay of Biscay to Galicia. This basin is bounded by an outstanding tectonic structure, the Labrador-Biscay Fault, striking WNW, which seems to coincide with one of the longest transform faults of the North Atlantic.

Some important mineral deposits occur in the Range. The biggest fluorite deposits in the Peninsula occur in the Triassic. There are some minor mercury and barite occurrences, and several important salt domes which pierce through the Tertiary. In the Upper Cretaceous, there are numerous stratiform lead-zinc orebodies of the Mississippi-Valley type, and the iron ores of Bilbao.

b) *The Iberian and the Catalonian Coastal Ranges*

They consist of an irregular network of mountains in which the Hercynian basement is overlain by an episcontinental sequence of Mesozoic, locally Eocene, sediments. The main character of these mountain chains is their irregularity. They consist of several «en échélon» faults which cut across the Paleozoic basement and the overlying sediments. Both the Iberian Range, which occupies and intermediate position between the Meseta and the Ebro Valley, and the Catalonian Coastal uplift are minor chains comparable in structure to the epidermic folding of the Jura. In the Iberian chain, the Paleozoic formations show analogous composition —schists, quartzites, and occasionally limestones— to those of the West Asturian Zone. The Mesozoic consists of a whole sequence extending from the Triassic to the Jurassic and Cretaceous. All these terrains, along with a few Eocene outcrops, show predominantly a carbonate facies. There are two important exceptions: the arkosic sandstones and the conglomerates of the Lower Cretaceous, namely the continental sediments of Weald and Albian age.

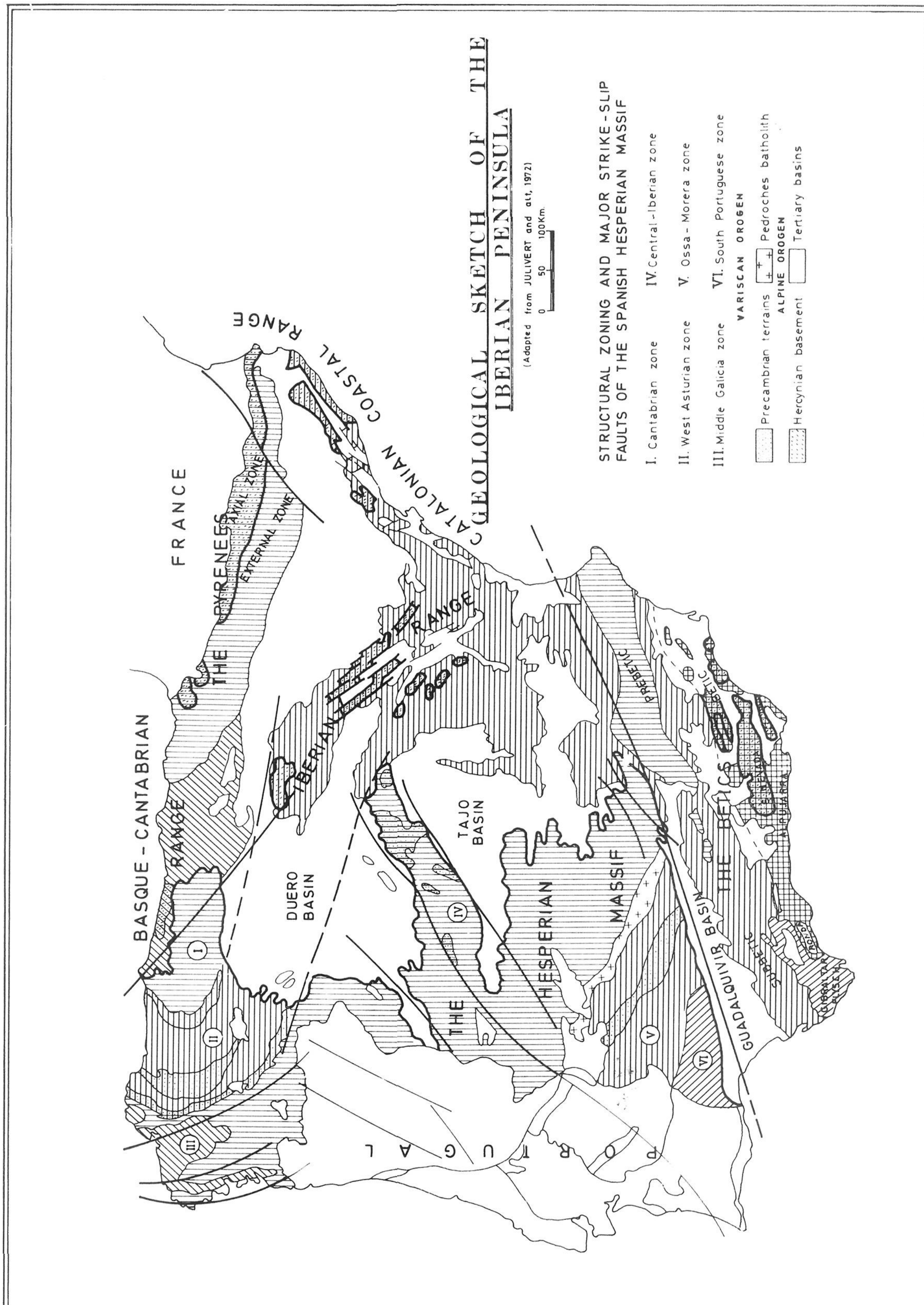
GEOLOGICAL SKETCH OF THE IBERIAN PENINSULA
(Adapted from JULIVERT and al., 1972)
0 50 100Km.
STRUCTURAL ZONING AND MAJOR STRIKE-SLIP FAULTS OF THE SPANISH HESPERIAN MASSIF
I. Cantabrian zone
II. West Asturian zone
III. Middle Galicia zone
IV. Central-Iberian zone
V. Ossa-Morera zone
VI. South Portuguese zone
VARISCAN OROGEN
Precambrian terrains
Hercynian basement
Pedroches batholith
ALPINE OROGEN
Tertiary basins
FRANCE
THE PYRENEES
AXIAL ZONE
EXTERNAL ZONE
BASQUE - CANTABRIAN RANGE
CATALONIAN COASTAL RANGE
IBERIAN RANGE
DUERO BASIN
TAJO BASIN
THE HESPERIAN MASSIF
GUADALQUIVIR BASIN
THE BETICS
PREBETIC
SUBBETIC
PORTUGAL

FIG. 2

Consequently with the composite character of these tectonic units, the mineral deposits are also diverse. In the Paleozoic basement there are several mineable Pb-Zn-F-Ba hydrothermal veins and some minor Ni-Co-Au occurrences, both related to the Hercynian granites. Also in the Paleozoic of the Iberian Range, some workable coal measures, nearly all mined out, and two relatively large iron deposits of Silurian age occur. The Mesozoic of the Iberian Range contains some small metasomatic and vein-type iron deposits, and several Pb-Zn occurrences of the Mississippi-Valley type which occur in the same stratigraphic member as those of the Cantabrian Range. Furthermore, there are some important and occasionally radioactive lignite deposits. Also, the largest and most significant radioactive occurrences in the peninsula are now under exploration in this zone. They are Wyoming-type arkosic sandstones.

Between the Iberian and the Catalonian Coastal Ranges, on the south, and the Pyrenees, on the north, is the Ebro Basin. It corresponds to a large downthrow block which was largely covered by thick Tertiary sediments produced by the fast erosion of the mountains built by the Alpine orogeny. Since the Upper Eocene, the Basin has been almost completely isolated from the Mediterranean by the uplift of the Catalonian Coastal Range. The environment then created favored the formation of the big halite and potash deposits of the Navarre and Catalonia areas. Here, gentle folds of Miocene age trended across the Oligocene salt basins, giving place to intensely distorted salt domes which pierced to the surface and are still growing at a rate of one inch per year.

The Basin subsided more strongely to the NW, where more than 13.000 m of Oligocene conglomerates and other clastic sediments have been drilled for oil without reaching the underlying Cretaceous limestones. However, it has been in the Cretaceous sediments underlying the Tertiary on the eastern side of the Catalonian Coastal Range where the first economic, offshore oil wells, now in production, have been found in Spain. The later uplift, which was also stronger on the NW, resulted in the slight tilting of the Basin to the South. In this part of the Basin, other deposits occur, such as the Miocene glauberite deposits of Logroño, and the Oligocene and Miocene lignite beds, sometimes uraniferous, of Aragon and Cataluña.

c) *The Pyrenees*

The Pyrenees, 400 k long and 45 to 80 k wide, separate France from Spain and stretch all the way from the Mediterranean to the Atlantic coasts in the same WNW direction. Geologically, the Pyrenees are a symmetrical fold belt with and elongated core, the Axial Zone, made up of Paleozoic rocks, and two External Zones consisting of Mesozoic and Tertiary sediments. The Pyrenees have been often considered as a good example of a land-locked orogen located between the main continental part of Europe and the Iberian subcontinent. This has resulted in a relatively thin cover of Mesozoic and Cenozoic sediments, which are not truly geosynclinal, but rather epicontinental in character. The Axial Zone consists of granodiorites and Cambrian to Carboniferous sediments which have been intensely folded and subjected to varying degrees of metamorphism during the Hercynian orogeny. The southern border of the Zone consists of many small imbricated thrusts which separtes the Axial from the External Zone.

The External Zone, which has been called the Prepyrenees, corresponds to a shallow geosyncline in which the Mesozoic and Cenozoic sediments were structurally deformed during the Alpine orogeny. The Prepyrenees are subdivided in three parts: (1) The Interior Range, made up of intensely folded and faulted Mesozoic strata, Permotriassic to Cretaceous in age; (2) The Medial Basin, an elongated east-west trending synclinorium of gently folded Paleocene sedimentary rocks which coincides with an important tectonic structure, the South Pyrenean Fault; and (3) the Exterior Range, which consists mainly of folded and faulted Mesozoic strata.

The magmatic activity related to the Alpine orogenic cycle was not important in the Pyrenees. Some acid and basic lavas are interbedded in the Triassic and Cretaceous, and some basalts were extruded in the eastern end of the chain during the Quaternary. But they are clearly post-tectonic, and must be ascribed to the rift system of Western Europe.

The most important mineral deposits in the Pyrenees are all related to the Hercynian orogeny, and occur both in the granites and in the metamorphic rocks. Although in no case is the metallogeny of the Pyrenees comparable, qualitatively or quantitatively, to that of other regions of the Peninsula, some interesting mineral occurrences can be mentioned here. Among them, some Pb-Zn-F and Ni-Co veins, tungsten pyrometasomatic and talc deposits, stratiform lead zinc deposits of Silurian age, Stephanian coal beds and several U-V-Cu occurrences. However, the most interesting orebodies, both from the metallogenic and economic standpoint, are the magnesite deposits of Devonian age in Navarra.

### d) *The Betics*

They are one of the main structural units of the Peninsula, which stretches from Cadiz and Gibraltar in the west, to Cartagena and Valencia in the east, bordering the southwestern end of the Mediterranean. Like the Alps, the Betics developed, at least in part, from a true geosyncline. Although this cordillera is only 480 k long and 100 k wide, the tectonic structures extend toward the NE up to the Balearic Islands.

The Betics have been subdivided in three main tectonic assemblages. South of the Iberian Meseta lies the Guadalquivir Basin, which becomes more and more shallow to the east, and is finally replaced by a thin epicontinental cover called the *Prebetic.* It consists of very gently folded Mesozoic sedimentary rocks. To the south of the Prebetic, lies the *Subbetic,* which contains truly geosynclinal rocks of Triassic to Lower Miocene age. Although not intensely deformed, these rocks were sheared off over the evaporites of the Triassic, giving place to epidermic structures —«décollements»— of the Jura-type. The souternmost unit is the *Betic* proper. Very schematically, it consists of five main tectonic units: the allochtonous Sierra Nevada Complex, the Alpujarra and Malaga Nappes, the so-called Gibraltar Flysch, and the Ronda Ultramafic Complex.

The *Sierra Nevada Complex,* which represents the Hercynian basement, is made up of crystalline rocks —micaschists, gneisses, marbles, amphibolites, and serpentines—, several thousands of meters thick. They range in age from Paleozoic, and perhaps Precambrian, to Lower Triassic.

The *Alpujarra Nappe System* consists of three telescoped overthrusts, made up of Triassic shales and carbonate rocks, which contain some Paleozoic schists at the base of the lower unit.

The *Malaga Nappe,* consisting of Paleozoic to Miocene rocks, is the highest structural unit in the Cordillera. It is generally regarded as an allochthonous unit, originated several tenths of kilometers south of the Betic, which moved over the crystalline basement before the uplift of Sierra Nevada. At present, most of the nappe lies to the north of the Paleozoic Complex.

The *Gibraltar Flysch* occupies the westernmost part of the Cordillera. Here, the tectonic structures bend to the south, and extend along the Ultra Rif unit in Northern Morocco. The so-called «flysch» of most writers consists of a sedimentary sequence made up of Cretaceous-Eocene marls and thin-bedded limestones, as well as some Oligocene clastic rocks. This allochthonous unit is supposed to be the cover of the Betic orogene, which slid off to a more external, presently landward position, following the Sierra Nevada uplift. This gravity-driven allochthony should have preceded the counterclockwise rotation, relative to Africa, of the Iberian Peninsula.

Special mention should be made of the *Ronda Ultramafic Complex.* It consists of Alpine-type peridotites, predominantly harzburgites, with minor amounts of dunite and lherzolite, occasionally serpentinized. These rocks also crop out across the Strait of Gibraltar, in Ceuta and Beni Bouchera, on the Moroccan coast. For a long time, these peridotites were considered to be ultramatic intrusions either of Silurian or of Jurassic age. Later on, two other origins have been proposed: (1) Tertonic emplacement of upper mantle material along the border of the European and African plates during the Alpine orogeny. However, no mafic igneous rocks which could represent and oceanic crust, are present. (2) Intrusions of high-temperature mantle material into thin zones of the continental crust subjected to regional lithospheric extension during the Miocene. According to LOOMIS (16), the more recent data concerning the K/Ar age of the contact metamorphic aureole, as well as the fabric of the peridotite bodies and the existence of two zones radiating NE and SE from Gibraltar, both characterized by high positive Bouguer gravity anomalies, seem to support the validity of the last theory.

The magmatic activity was limited to two preorogenic and one postorogenic epochs in the Betics. The preorogenic rocks consist of basalts, spilites, and pillow-lavas of Jurassic and Lower Cretaceous age. The postorogenic epoch is the mos important from the metallogenic standpoint. It includes eruptions of late Miocene to Pleistocene andesites and dacites, and Mediterranean-type potassic volcanites which overlie several areas between Almeria and Cartagena.

The mineral deposits of the Betic Cordillera are numerous and diverse, and occur in both the basement and the Alpine cover. However, the occurrences of the Hercynian basement are limited to some small Pb-Zn, Cu-Fe and Pb-Ag veins in the Sierra Nevada Complex.

The most important orebodies in the Betics lie within the Meso-Cenozoic sediments, mainly in the Alpujarra Nappe System. Here, the Triassic carbonate sequence contains stratiform, finely banded, galena-barite-fluorite —more rarely sphalerite— orebodies. There are also workable iron ores of sedimentary or metasomatic origin, namely on the northern slope of Sierra Nevada, and some small talc deposits which have been originated by silicification and hydration of the carbonate rocks along the shear zones of the Alpujarra dolomites.

In any case, the most interesting mineral occurrences in the Betic Cordillera are related to the Neogene volcanic activity. Among them, the most important are the Pb-Zn-Ag deposits of the Cartagena district and the Au-Te ores of Cabo de Gata.

The famous mineral deposits of the Sierra de Cartagena have been worked, like those of Río Tinto, Almadén and many others, since Phoenician and Roman times. They are of two types: (1) Vein-like, originated in the dacitic and andesitic igneous bodies which cut across the Paleozoic and Triassic rocks of the imbricated Alpujarra Nappe System; (2) Metasomatic, originated through massive replacement of carbonate beds when these beds were invaded by hidrothermal solutions. The carbonates underwent a thorough silicification and greenalitization, and were later mineralized with magnetite, pyrrhotite, and Pb-Zn-Cu-Fe sulfides.

In the Betic Zone, apart from these occurrences, there are two small magnetite deposits and several minor W and Ni-Cr mineralizations near to or in the Ronda Ultramafic Complex, and two strontianite deposits in the Miocene sediments which fill two postorogenic tectonic basins located south of Granada and Murcia respectively.

## II.—MINERAL PARAGENESIS OF THE HERCYNIAN BASEMENT

There are many different paragenetic associations in the Hercynian basement of Spain, although only a few are or have been or economic interest *. Most of the mineral associations are found in several deposits; others, in only a few scattered occurrences of the basement.

### 1. Variscan paragenetic associations

#### 1. *Uranium-cerium potassic pegmatites (k.U-Ce)*

There is only one occurrence in Spain, which is famous for its large brannerite and uraninite crystals. It is located in Sierra Albarrana (Córdoba) where the pegmatite bodies occur in biotite and amphibolite gneisses. They consist of quartz, micas, feldspars, and some beryl and tourmaline, as well as monazite, brannerite (up to 20 cm long), uraninite, rutile, ilmeno-rutile, magnetite, chalcopyrite and pyrite. Among the secondary uranium minerals, autunite, becquerelite, schoepite and torbernite are always present (3).

#### 2. *Beryl potassic pegmatites (k.Be)*

Thet are very abundant and widespread in the metamorphic rocks which surround numerous granitic bodies, especially the leucogranites, of the Central Iberian zone (5).

The mineral assemblage consists of k-feldspars, acid plagioclases, late albite, quartz, micas, and small to large crystals of tourmaline, apatite —sometimes of the wilkeite variety—, and beryl.

* References quoted henceforth refer only to publications containing significant information on the geology of the most important Spanish mineral occurrences.

3. *Uranium-titanium sodic aplites (na. U-Ti)*

Only one locality has been reported, Villanueva del Fresno (Badajoz), in the Ossa-Morena Zone. The ore minerals, pyrite and davidite, the latter up to 2 mm across, are distributed in a albite dyke consisting of fine grained quartz, biotite and albite. The host rocks are Cambrian micaschists and tourmalinized spotted hornfelses (3).

4. *Lithium sodic pegmatites (na. Li)*

They are quite rare, and always related to the cassiterite deposits of the Central Iberian Zone.

In Lalín (Pontevedra), the pegmatite dykes extend in a zone more than 5 km long made up of garnet and staurolite micaschists of Ordovician or Silurian age. They consist of quartz, microcline, albite, muscovite and beryl, with big crystals of spodumene up to 20 cm long. The dykes are crossed by veinlets of quartz with cassiterite, molybdenite, pyrite, and chalcopyrite.

In El Trasquilón (Cáceres), there is a pegmatite body, made up of quartz, albite, k-feldspar and ambligonite, in a leucogranite containing disseminated cassiterite.

In La Fregeneda (Salamanca), a large pegmatite dyke with Li-muscovite and lepidolite is associated with a stockwork of quartz-cassiterite veins crossing the Cambrian schists and amphibolites.

5. *Cassiterite-columbite microgranites (K. Na-Sn)*

Rather numerous, in big dykes or small stocks, they are related to the final evolution of the leucogranites. Many of them have been or are still worked for their tin, niobium, and tantalum content. All these aplitic granites are located in the Central Iberian zone; among them, Penouta and Laza (Galicia), Losacio (Zamora), Golpejas (Salamanca), and Cañaveral, Torrecilla, and Trasquilón (Cáceres) are the best known deposits (4, pp. 109-160).

The mineralogical assemblage consists of quartz, albite, k-feldspar, muscovite (rare biotite), cassiterite, columbite-tantalite, tapiolite (free or included in the cassiterite), ilmenite, rutile, apatite and, occasionally, gold and fluorite. Locally, albitization, muscovitization and caolinization may be very strong.

6. *Quartz-cassiterite association (q.Sn)*

Very frequent, both in quartz veins and stockworks crossing Paleozoic schists and hornfelses, in the exocontact or in the proximity of the Hercynian leucogranites. All the deposits are located in the Central Iberian zone, especially in Zamora (Calabor, Arcillera and Carbajales), Salamanca (Lumbrales, Cubito and Fregeneda), and Cáceres (Teba, Torrecilla, Valdeflores). Tourmalinization of the host rocks is usually very well developed.

Quartz, muscovite, beryl, apatite and tourmaline are the most important minerals accompanying the cassiterite, arsenopyrite and pyrite. Scheelite and wolframite are very rare or absent. However, in some occurrences, like Bustarviejo (Madrid) and Trasquilón (Cáceres), the paragenesis contains small amounts of chalcopyrite, stannite, bismuth, bismuthinite, schapbachite, pyrrhotite, marcasite, sphalerite and galena.

### 7. *Quartz-casiterite-wolframite association (q.Sn-W)*

This association is very frequent in the Central Iberian Zone. It differs from the preceding type because wolframite and usually some sulphides accompany the cassiterite. Scheelite, although in very small quantitites, may be present. Tourmalinization and greisenization of the host rock is well developed, especially when the veins and stockworks are located in the exocontacts of the granite. Apart quartz, muscovite, apatite, topaz and beryl, the ore minerals are: cassiterite, wolframite, scheelite, arsenopyrite, pyrite, chalcopyrite, molybdenite, bismuthinite, ilmenite and rutile.

Deposits of this type are: San Finx, Lovios, Casayo, Fontao, and Santa Comba (Galicia); Guadalix and S. Rafael (Madrid); Garrovillas (Cáceres); San Nicolás (Badajoz); and several occurrences in the Pedroches batholith (13, pp. 129-131).

### 8. *Quartz scheelite-wolframite association (q.W)*

This paragenesis is not so widespread as the preceding one, but its deposits are sometimes very important. In fact, the main differences are the absence or scarcity of cassiterite and the presence of scheelite together with wolframite as the tungsten minerals. Copper and bismuth ores are also common, but their amounts differ greatly from one deposit to another.

The mineral assemblage consists of quartz, wolframite, scheelite, pyrite, chalcopyrite, arsenopyrite, ilmenite and bismuthinite. According to the geological setting, two types of deposits can be distinguished here.

8a. *Quartz veins and stockworks in the Cambrian schists* surrounding two micas granites, e.g., Navasfrías and Masueco (Salamanca), La Parrilla and Oliva (Badajoz). In this locality, quartz veins, containing siderite, chalcopyrite, bornite, enargite, chalcocite, covellite, bismuthinite and gold, are present in the same area of the tungsten lodes. Greisenization and tourmalinisation are rare or conspicuosly absent.

8b. *Quartz veins and stockworks in the granite,* near the top of the batholit.

The paragenesis is rather simple, and consists of scheelite —which is the most important W mineral—, wolframite, pyrite and very abundant arsenopyrite. Chalcopyrite, bismuthinite, emplektite, fluorite cassiterite, and tourmaline appear in minor amounts. Sometimes, traces of gold.

The type deposit is Barruecopardo (Salamanca), at present the biggest producer of tungsten in Spain. The so-called stockwork, consisting of a swarm of parallel, subvertical veins, is more than 3 km long, 200 m wide, and 100 m deep. Microclinization is widespread, especially in depth, whereas albitization and greisenization prevail near the cupola of the granite. Here, wolframite, is predominant, accompanied by some cassiterite.

Santa Genoveva, in Salamanca; Santibáñez, in Cáceres; and Ponferrada, in León, are also deposits of this type.

## 9. *Quartz-scheelite-dravite association (q.W-B)*

This paragenesis occurs in vein-type deposits. It consists mainly of quartz, arsenopyrite and scheelite, ocassionally some tourmaline (dravite), and minor amounts of pyrite, pyrrhotite, apatite, chlorite, muscovite, ilmenita, magnetite and fluorite.

The veins are always associated with stratiform skarn-type scheelite deposits existing in the basement —pre-Variscan (sk.W) association—, to which they cut almost at right angle. The veins are blind and usually restricted to the area of the «skarnoïds», and range in lenght from several centimeters to some meters. Apparently, they are due to the reworking of pre-existing tungsten ores during the Hercynian orogenic cycle. The main differences with the quartz-scheelite association of the preceding type, which is always related to the final stages of the granite evolution, are: the absence of tin; the higher amounts of tourmaline, which is always dravite, as is explained by the high magnesium content of the enclosing carbonate rocks; the lack of connection with any kind of intrusive rocks; and the close spatial relationship with the pre-existing tungsten ores.

## 10. *Arsenic-gold association (q.As-Au)*

Although gold is frequently found in numerous alluvial placers of the Iberian Meseta, as well as in some stream sediments coming from the Hercynian basement of the Betics, no true gold deposits have been found connected with the Variscan metallogeny. So far, the most significant occurrences correspond to a system of parallel veins and veinlets which cross some strongly oriented muscovite leucogranites in Galicia. They occur near Carballo and Santa Comba, located to the W and NW of Santiago respectively. Besides quartz and gold-bearing arsenopyrite, these veins contain pyrite, chalcopyrite, pyrrhotite, scheelite, and some tourmaline.

### 11. *Molybdenite-gold association (q.Mo-Au)*

This paragenesis has been found in only one place, in the Salave granitic stock, near Tapia, on the coast of the West Asturian zone. This stock is made up of diorites and granodiorites, and even of more basic differentiates, which have been strongly silicified in some definite areas, especially in the contact with the surrounding Paleozoic schists. In these areas, a stockwork of quartz veinlets, with minor carbonates, contains the following ore minerals: pyrite, molybdenite, stibnite, and gold-bearing arsenopyrite.

It should be emphasized that quartz veins with molybdenite are just mineralogical curiosities in some Variscan plutonites of the Central Iberian Zone, namely in the Guadarrama Mts. Apart from quartz and molybdenite, pyrite, chalcopyrite, stannite and arsenopyrite are the ore minerals most frequently found in these occurrences.

### 12. *Quartz-apatite association (q.P)*

This is a very peculiar and widespread paragenesis in the leucogranites of the southern half of the Central Iberian zone, more precisely in Extremadura, where they are called «fosforites» (12). The veins —sometimes 1 km long, 1 to 3 m wide, and up to 100 m deep— consist almost exclusively of quartz and apatite, namely of the radial-fibrous variety dahllite.

The veins are found both in the endocontact of some leucogranites (Albalá, Ceclavín, Alburquerque), which themselves are frequently tin- or uranium-bearing, or in the surrounding Lower Paleozoic schists (Aldea Moret, Logrosán, Aliseda).

### 13. *Scheelite-molybdenite skarns (sk.W-Mo)*

So far, this paragenesis has been reported in the Costabona Mts, in the Hercynian basement of the Pyrenees. It is of the same type than those located on the other side of the French border. Another occurrence is to the north of Alós de Isil, on the northern border of the Beret granite.

The skarns develop at the contact of lower Paleozoic limestones and Hercynian granodiorites, and consist of a calc-silicate assemblage containing scheelite, molybdenite, pyrrhotite, bismuthinite, chalcopyrite, pyrite, arsenopyrite, magnetite and sphalerite. Some wolframite is also present (13, pp. 156-157).

In Sierra Bermeja, close to the Alpine ultrabasic complexes of Ronda, in the Málaga province, there is another skarn-type occurrence with good crystals of scheelite, garnets and magnetite. The host rocks are metamorphosed Paleozoic limestones, but no molybdenite has been reported in this deposit.

14. *Iron-polimetallic sulphides skarns (sk.Pol-Fe)*

Iron skarns are rather frequent at the contact of Cambrian dolomitic limestones and intrusive bodies of monzonites, quartzdiorites, and minor syenites, in the Ossa-Morena Zone. Massive or vein-like pyrometasomatic deposits of this kind, worked out or in operation, are El Pedroso, in Sevilla, and Cala and San Guillermo, in Badajoz. Their paragenesis is rich iron oxides and silicates, polymetallic sulphides, and occassionally radioactive minerals, namely in the orebodies of Tauler and Burguillos (Badajoz) (3).

The mineral assemblage consists mainly of diopside, hedenbergite, hornblende, tremolite-actinolite, hastingsite, andradite, forsterite, brucite, spinel, feldspars, carbonates, biotite, chlorite, allanite, sphene, axinite, clinozoisite, epidote, scapolite and quartz. The ore minerals are mainly magnetite, chalcopyrite, pyrite, marcasite, arsenopyrite, pyrrhotite, cobalthite, löllingite, vonsenite, and uraninite; goethite, malachite, azurite, melanterite and sulphur are frequently found in the oxidation zone.

15. *Co-Ni-Bi association (q.Co-Ni-Bi)*

This association is found in quartz-carbonate veins crossing the contact between the Pedroches granodiorite and the Carboniferous schists sourrounding it in the Córdoba province (5). The small deposits which have been operated there are located on both the northern (Torrecampo, Conquista) and southern (Pozoblanco, Villanueva) borders of the batholith.

The mineral assemblage consists of quartz, carbonates, bismuthinite, bismuth, Ni-Co arsenides, niccolite, gersdorffite, cobaltite, emplektite, tetrahedrite, pyrite, arsenopyrite, and traces of galena, gold and pitchblende. A similar paragenesis, not so significant and showing a poorer mineralogical assemblage, exists at the contact of a granodiorite and the Paleozoic schists and limestones of Gistain, in the Pyrenees of the Huesca province.

## 16. *Co-Ni-Cu association (Co-Ni-Cu)*

This paragenesis is just a mineralogical curiosity, although some mining was carried out in the Carboniferous limestones of the Villamanin area (León), where most of the occurrences are located (19). It consits of villamaninite —type locality—, linnaeite, chalcopyrite, pyrite, bravoite, niccolite and tetrahedrite, with minor amounts of pyrolusite, psilomelane, heterogenite, malachite and azurite as seccondary minerals.

## 17. *Pb-Ag-Barite association (q.Ba-Pb-Ag)*

Although at the present time no veins of this type are in operation, this paragenesis has been significant because it produced paying ore in both the Hesperian Massif and in the Hercynian basement of the Catalonian Coastal Range and the Betics.

Among the main deposits of this type are the Atrevida mine, near Vinbodí, and the Eugenia mine, near Bellmunt, both in the Tarragona province. They consisted of large quartz-barite veins which crossed, respectively, the Cambro-Ordovician schists of the Sierra de Prades and the Lower Carboniferous quartzites of the Bellmunt area, in both cases at a short distance of the granite. The paragenesis is: galena, sphalerite, niccolite, gersdorffite, Ni-Co arsenides, maucherite, silver, siegenite, millerite, argyrose, pearceite, hessite and marcasite. In the Bellmunt mine there are also minor amounts of tetrahedrite.

Another important deposit was Hiendelaencina, in the Guadalajara province. Here, the paragenesis is made up of sphalerite, galena, pyrite, chalcopyrite, tetrahedrite, freieslebenite, myargyrite, stephanite, ruby silver, argentite, and only traces of Ni and Co (5). The quartz-barite veins, in that case containing abundant carbonates —mostly siderite and ankerite— cross the facoidal gneisses of the so-called «ojo de sapo» Cambrian formation. The origin of these veins is to be related with the Hercynian granites which outcrop not far from the mine.

## 18. *Quartz-copper sulphides association (q.Cu)*

Around the Pedroches batholith, a number of quartz veins, containing a paragenesis made up almost exclusively of copper sulphides, is frequently found. These deposits have been worked both in the granite (La Virgen, Villaviciosa) or, most frequently, in the surrounding schists (Hornachuelos, Navalespino, Posadas). When in the granite, they are usually uraniferous and therefore related to the (q.U-Cu) association (4).

Apart quartz, this paragenesis consists of chalcopyrite, pyrite, bornite, tetrahedrite, freibergite, chalcocite, covellite, cuprite, tenorite, and minor amounts of sphalerite and galena. Malachite, azurite, and some barite may also be present.

19. *Pb-Zn association (BGPC)*

This paragenesis is very important in the metallogeny of the Hercynian basement all over Spain. For instance, the Pedroches batholith, especially the Linares district, was the first lead producer in Europe for many years (10). The following paragenetic types can be distinguished according to the peculiarities of the mineral assemblages.

a) *Quartz-galena-barite association (q.Pb-Ba)*

Numerous veins of this group have been or are still being worked in Sierra Morena, both in the granite and in the surrounding rocks. They consist namely of quartz, carbonates, barite, galena —always more or less silver-bearing—, and minor amounts of pyrite, marcasite and chalcopyrite. The age of some galenas coming from deposits of this group has given the following results: Los Guindos, 250 m.y; San Antón, 220 m.y; El Cobre, 220 m.y; and San Juan, 190 m.y. As in other Hercynian areas of Europe the ores belong to a Late-Variscan stage.

Other examples of these lead deposits are located near Pozoblanco, Peñarroya, Almadén and Azuaga, all in the Córdoba province. Alosno (Huelva) and Sotillo (Madrid) are also of the same type. Bono, in the Lérida province, is an example of the deposits located in the Hercynian basement of the Pyrenees.

b) *Quartz-galena-sphalerite association (q.Pb-Zn)*

The gange minerals are still the same, but the sphalerite and galena appear in almost equal amounts. Examples of this intermediate type are Béjar (Salamanca); Guadalcanal, Cazalla and Constantina (Sevilla), and Corumbel (Huelva), where pyrite was predominant. Some deposits such as Escalona (Toledo) and Lumbrales (Salamanca) are uraniferous.

Some poorly known BGPC vein-like occurrences, containing minor amounts of magnetite and pyrrhotite, located in the Cambrian and Ordovician quartzites of the West Asturian zone, such as Oscos, Fonsagrada, Mondoñedo and Caurel, probably are of pre-Variscan age. They have been strongly deformed by the Hercynian orogeny.

c) *Fluorite-sphalerite-galena association (f.Zn-Pb)*

The only difference with the preceding type is the presence and abundance of fluorite. Deposits of this association occur in the Hercynian basement of the Hesperian Massif —Castillo de las Guardas (Sevilla), Cerro Muriano (Córdoba), and Colmenar del Arroyo (Madrid)—; The Catalonian Coastal Range —Osor (Gerona)—; and the Basque-Cantabrian Zone —Arditurri (Guipúzcoa). All are intragranitic except the latter, which is close to the contact.

d) *Carbonates-sphalerite association (c.Zn)*

This type occurs mainly in the Paleozoic schists, mostly Carboniferous, of the Basque-Cantabrian Zone, not far from the granite. The Modesta mine, in Guipúzcoa, is an outstanding example of this paragenesis. It consist of predominant carbonates —mostly siderite—, barite and quartz. The ore minerals are black sphalerite and minor amounts of chalcopyrite, tetrahedrite, pyrite, and galena.

20. *Pyrite-chalcopyrite exhalative association (e.Fe-Cu)*

This paragenesis, consisting mostly of pyrite and minor amounts of chalcopyrite, sphalerite and galena, is characteristic of the sulphide orebodies of the Río Tinto district, the Spanish side of the Iberian Pyrite Belt (4).

The origin of these deposits is clearly exhalative-sedimentary. They are closely related to the submarine, explosive, acid volcanism so extensively developed in the South Portuguese Zone of the Iberian Meseta. However, due to the removilization of some stratiform orebodies during the low-grade metamorphic processes developed contemporaneously with the folding phase, this paragenesis may also be found in some hydrothermal veins, especially in the northern part of the area.

Apart the main constituents of the ore —pyrite, chalcopyrite, sericite, chlorite and quartz—, the following minerals can also be found in different quantities: pyrrhotite magnetite, hematite, marcasite, melnikovite, tetrahedrite, stannite, sphalerite, galena, bornite, linnaeite, enargite and gold. Among the secondary minerals, goethite, cuprite, tenorite, chalcocite, covellite, gratonite, melanterie, voltaite, poitevinita, smolzenikite, jarosite, chalcantite, malachite, azurite, copper and sulphur may be present.

The deposits belonging to this association can be divided in three types: massive, stockworks, and layered pyrite mineralizations, each one presenting some peculiarities in their paragenesis.

The huge size of some massive lenses and layered deposits, e.g., Tharsis, La Zarza, and Río Tinto, especially the latter which consists of two different orebodies —San Dionisio and the Southern Lode—, making up one single orebody more than 3 km long, 200 m wide, and 400 m deep, can be explained by the inflow of sulphide muds and or detrital sulphides into topographical depressions more or less distant from the volcanic centers. Then, the sulphides could concentrate on or amid acid pyroclastic rocks, giving place to massive, autochtonous or subautochtonous orebodies, or in more distant sedimentary facies, originating layered, allochtonous orebodies. In that case, the sulphides are interbedded in shales, frequently with a great amount of carbonaceous matter.

The stockwork type —well developed in Cerro Colorado, San Dionisio, San Miguel and Nuevo Planes— represents the feeder channels, i.e., the original sites of the fumarolic activity through which the arrival of the mineralizing fluids took place. They are normally found directly under or in the vicinity of the pyritic layers.

21. *Fe sulphides-polymetallic exhalative association (e.Fe-Pol)*

This paragenesis is closely related to the preceding one. The main differences are: richer mineralogical assemblages, higher sphalerite and galena content, and an almost exclusive layered structure of the orebodies which frequently show typical sedimentary textures.

Besides the primary and secondary minerals named in the pyrite-chalcopyrite association, the following species can be found, or have been reported, in this paragenesis: arsenopyrite, bournonite, cobaltite, Ni-Co arsenides, freibergite, jamesonite, ullmanite, löllingite, bismuthinite, gersdorffite, argentite, ruby silver, bismuth, stromeyerite, and silver. Usually, baritine and iron rich carbonates are present among the gangue minerals.

Typical deposits of this polymetallic sulphide association, e.g., S. Antonio, Aznalcóllar, Sotiel and San Telmo, are usually found far from the exhalative centers, and sometimes without showing any apparent relation with the volcanic rocks. Their minerals were deposited in a shaly environment, frequently interbedded with tuffs or siliceous layers. The sedimentary textures of the ore, such as graded bedding, breccias, slumpings and load casts, indicate submarine erosion of solidified sulphides and redeposition into new bassins formed by continued volcano-tectonic activity of the sea-floor.

22. *Manganese-jasper exhalative association (e.q.Mn)*

This paragenesis is restricted almost exclusively to the Río Tinto district, where it exists in more them 300 occurrences, mostly of a very small size.

Only two of them have been worked until very recently, but in the past they led to a production of more than 3 million tons, mainly Mn-oxides.

The mineral assemblage is made up of rhodochrosite, rhodonite, ocasionally spessartite, hematite, haussmanite, polianite, braunite, pirolusite, psilomelane, quartz, chalcedony, ankeritic carbonates, dialoguite, sericite, chlorite, and traces of pyrite and chalcopyrite.

The manganese ores occur mostly in lenses of gray, black and red hematitic jasper, derived from radiolarian chert and siliceous shales, interbedded with purple red shales and tuffs, mainly rhyolitic in composition. Sedimentary structures are conspicuous, and sometimes the manganese layers with oolithic texture are more than 1 m thick.

### 23. *Quartz-uranium association (U)*

Most of the Spanish uranium deposits belong to this group. They are located in the Hesperian Massif, both in the leucogranites or in the peribatholitic, slightly metamorphosed lower Paleozoic sediments. According to their mineral composition, this paragenesis can be divided in four categories.

#### a) *Quartz-uranium-copper sulphides association (q.U-Cu)*

So far, this paragenesis has been found only in the northern border of the Pedroches batholith. It is closely related to the (q.Cu) association, but when the uranium minerals accompany the copper sulphides, the veins occur only in the granite or in the exocontacts —La Virgen, Navalasno and San Valentín mines, near Andújar (Jaén)—, and no traces of other sulphides have been reported.

The mineral assemblage consists of quartz, minor carbonates, chalcopyrite, bornite, chalcocite, covellite, tetrahedrite, coffinite, pitchblende, and traces of fluorite. Among the secondary minerals, cuprite —sometimes of the chalcotrychite variety—, tenorite, seudomalachite, crysocholla, uranophane, autunnite, torbernite, uranopilite, zippeite and johannite, are the most important (3).

#### b) *Quartz-pitchblende-Fe sulphides association (q.U-Fe)*

It consists almost exclusively of pitchblende, coffinite, pyrite, marcasite and melnikovite distributed in a siliceous gangue —quartz and jasper, usually hematitic— with traces of calcite. Among the secondary uranium minerals, gummites, autunnite, torbernite, saleite, fosfuranilite, uranophane, iantinite, sabugalite, renardite, kasolite, and francevillite, are frequently found. The nature of the hexavalent minerals depends on the availability or certain cations in the same vein of in other pre-existing mineralizations.

Vein deposits of this group exist both in the leucogranites, e.g., Albalá, Trujillo, and Alburquerque, in Cáceres (3), or in the peribatholitic schists, like C. Rodrigo (Salamanca), Ceclavín (Cáceres) and D. Benito (Badajoz) (2). Due to the oxidation and reconcentration of the uranium near the surface, the occurrences in the schists are so far the most important uranium resources in Spain.

c) *Quartz-ptichblende-polymetallic association (q.U-BG)*

This type differs from the preceding one in which the amount of sphalerite and galena is higher, and because minor amounts of chalcopyrite and barite are also present. Among the secondary uranium minerals, uranocircite and parsonsite are frequently found in these deposits. The best examples of this association occur in Lumbrales (Salamanca) and Escalona (Toledo) (3).

d) *Quartz-coffinite-fluorite association (q.U-F)*

This paragenesis has been found only in the Peralonso deposit, in Salamanca. Here, the most important uranium mineral is coffinite, which occurs in a strongly brecciated granodiorite along a regional tectonic structure (3).

The ore-shoot consists of coffinite, pyrite, marcasite, fluorite (antozonite), gray and red jasperoid quartz, minor amounts of pitchblende, sphalerite and galena, and traces of chalcopyrite. Among the secondary uranium minerals, autunnite, renardite and uranophane are the most frequently found.

24. *Antimony association (Sb)*

Although some deposits have been worked in the past, stibnite deposits are rare in the Hercynian basement and no important producers exist today.

According to the accompanying minerals and the geological setting, three different types of stibnite associations can be distinguished here.

a) *Quartz-stibnite association (q.Sb)*

The veins consist almost exclusively of quartz and stibnite, some pyrite, and traces of sphalerite and galena. This paragenesis is characteristic of the stibnite deposits of Almuradiel (C. Real), Linares (Jaén) and Herrera (Badajoz), which are located in a wide belt running parallel to the Pedroches batholit, in the Central Iberian Zone. Other small deposits of this type have been reported in the West Asturian Zone (11, pp. 19-28).

b) *Antimony-tungsten association (Sb-W)*

Only one operating occurrence is known in the Hesperian Massif: La Codosera mine, near Alburquerque (Badajoz). It consists of stibnite, scheelite, pyrite, and calcite, as well as traces of gold. These minerals fill small fractures and breccias of the enclosing Devonian limestones which extend parallel to the southern border of the Alburquerque batholit (14).

c) *Antimony-cinnabar association (Sb-Hg)*

This paragenesis has been found only in the Cantabrian zone, in the sheared Carboniferous limestones of Mieres, Riaño, Pola, and Somiedo, in the Cantabrian zone. The ore shoot is made up of realgar, orpiment, pyrite, cinnabar, and minor arsenopyrite.

As the tectonic structures with which the ores seem to be connected are probably of Alpine age, the posibility that the mineralization is contemporaneous with this orogenic period has been suggested.

### 2. Pre-Variscan paragenetic associations

There are many and important pre-Variscan mineralizations in the Hesperian Massif. They are related either to sedimentary processes, namely the Ordovician or Devonian iron deposits, or to the Upper Precambrian and Lower Paleozoic plutonites and metamorphites. All of them have been more or less affected by the Hercynian tectonic movements which resulted in the formation of new, and sometimes workable, deposits by remobilization and enrichment of the pre-existing ores.

## A) MINERALIZATIONS ASSOCIATED WITH SEDIMENTARY PROCESSES

### 1. *Rutile-zircon association (a.Ti-Zr)*

This association is found in a consolidated littoral placer formed along a beach in the Lower Ordovician. The quartzite, which is an excellent marker bed, extends discontinuosly from Despeñaperros, in the Jaén Province, through

Almadén and Puertollano, to the San Pedro Mts, in Portugal, for more than 400 km. Its thickness varies from 5 to 60 cm (3).

The paragenesis consists of rutile, zircon, ilmenite titanite, tourmaline, magnetite, monazite, pyrite, graphite, quartz, sericite and chlorite. Ocassionally, it may contain zoisite and detrital feldspars. In some places, the concentration of zircon and titanium minerals may be up to 21 % and 49 % of the rock, respectively.

2. *Alluvial monazite-cassiterite association (a.Sn-Ce)*

Near Conquista (Córdoba), along the northern border of the Pedroches batholith, some workable alluvial deposits, resulting from the weathering of the granite, contain significant concentrations of cassiterite and monazite, with minor amounts of zircon, ilmenite and xenotime. Traces of scheelite, wolframite, gold, and cinnabar are also present. The alluvium urderlies a surface of 1.500 x 300 m, and extend downwards up to 35 m.

3. *Scheelite-calc-silicate association (sk.W)*

In fact, this is a pre-Variscan paragenesis which has been reworked during the Variscan metallogenic cycle, and therefore it could be related to the (q.W-B) association.

Scheelite-bearing calc-silicate assemblages of the skarn type are often found in the strongly folded Cambrian schists of the Central Iberian Zone, in the Salamanca (Morille, Santo Tomé) and Cáceres (Perales) provinces. The «skarnoïds» occur in medium to highly metamorphosed rocks of the «schist and graywacke complex», but they are never found in contact with intrusive rocks.

According to the structure, two types of deposits can be recognized here: stratiform and vein-like. The stratiform orebodies consist of plagioclase, quartz, hornblende, diopside tremolite-actinolite, clinozoisite, titanite, grossularite, idocrase, epidote, biotite, moscovite, calcite, and ocassionally piedmontite. The scheelite is disseminated among these minerals, especially around the garnets, together with apatite, rutile, albite, pyrite, arsenopyrite, chalcopyrite, pyrrhotite, ilmenite, magnetite and fluorite.

Due to their high competence to folding, boudins of these calcsilicate rocks, grading in thickness and length from several centimeters to some meters, are frequently found in all mineralized areas. A metasomatic diffusion of Ca, Mg, Al and Si at the contact of the marly and pelitic layers is responsible for the development of an amphibolite zone at the margin of the boudin plagioclase-zoisite-garnet core.

Later on, at the end of the Hercynian orogeny, a retrograde metamorphic phase gave place to a mineral assemblage of a lower metamorphic grade, and to the recrystallization of scheelite in the quartz-albite veins related to the (q.W-B) association.

4. *Iron oxides association (Fe)*

In this association, four different paragenesis can be distinguished (9):

a) Hematite, goethite, barite and chalcopyrite, in the Cambrian limestones of Peña del Hierro (Sevilla).
b) Hematite, chamosite, magnetite and siderite, in the Ordovician ironstones of Ponferrada (León).
c) Goethite, hematite and barite, in the Silurian sandstones of Sierra Menera (Teruel).
d) Goethite and hematite, in the Devonian sandstones of Furada (Asturias).

All these ores have been more or less modified during the Hercynian orogeny, especially the ironstones, which were partially contact-metamorphosed by the Hercynian granite of Ponferrada.

## B) MINERALIZATIONS ASSOCIATED WITH VOLCANIC-SEDIMENTARY PROCESSES

1. *Iron sulphides-polymetallic association (v.Fe-Pol)*

This paragenesis occurs in metamorphic pyroclastic rocks and dolomitic limestones of a volcanic-sedimentary sequence which is very similar to that of the Río Tinto district. The occurrences of this type are numerous along the Aracena anticline, an important structure in the Ossa-Morena zone which runs more or less parallel to the Iberian Pyrite Belt.

The mineral assemblage found in La Nava (Huelva), at present the only operating mine in the district, consists mainly of pyrite, magnetite, hematite, sphalerite, galena, chalcopyrite, pyrrhotite, tetrahedrite, arsenopyrite, bornite, chalcocite and covellite. Among the gangue minerals, quartz, barite, carbonates, diopside, garnet, tremolite-actinolite, zoisite, epidote and micas are the most important. During the Hercynian orogeny, the orebody was strongly folded and faulted, and underwent the effects of a medium to high-grade metamorphism which was followed by a retrograde stage in the greenschists facies.

Of the same paragenetic type are the lead-zinc deposits occurrying in the Hercynian basement of the Pyrenees, namely in the moderately metamorphosed Cambro-Ordovician siliceous schists and tuffs of the Arán Valley, and in the Devonian limestones of Bonabé, both in the Lérida province. The paragenesis consists mostly of pyrite, chalcopyrite, sphalerite, galena, magnetite, and hematite. These deposits, which have been considered for a long time only as vein-like, are now regarded as metamorphosed lead-zinc orebodies of sedimentary-volcanic origin, although sometimes they have been remobilized and given place to vein-like structures.

### 2. *Pyrite-chalcopyrite association (v.Fe-Cu)*

This paragenetic type has been found in two pre-Variscan volcanic-sedimentary formations in Galicia, one in the Silurian and the other in the Precambrian. However, as they differ a little in their mineralogy and geological setting, two types can be distinguished here.

#### a) *Hematite-pyrite-chalcopyrite association*

This mineral assemblage occurs near Moeche, in the Coruña province, in an Upper Silurian greenstone sequence which contain interbedded limestones and serpentines.

The ore minerals are mainly hematite and pyrite, and minor amounts of chalcopyrite, all disseminated in a matrix made up mostly of albite, chlorite and calcite. Sphene, rutile, magnetite, apatite, epidote and quartz are the main accessories.

The host rock, a slightly metamorphosed spilite, tops a thick stratigraphic sequence of quartzites, lydites, phyllites, and acid metavolcanites.

#### b) *Pyrite-chalcopyrite (Ni) association*

This paragenetic type differs from the preceding one in as much as it contains traces of nickel, but no hematite. It occurs in several places (Fornás, Arinteiro) of the «Ordenes polymetamorphic complex», near Santiago (Coruña). The rock sequence, Upper Precambrian in age, is made up of gneisses, micaschists and amphibolites, very often garnetiferous, and minor amounts of peridotites. It belongs to the Portuguese Central Galicia-Trás-os-Montes zone.

The amphibolites, consisting mostly of anthophyllite, plagioclase, biotite and sphene, and the micaschists and gneisses, made up of quartz, feldspar, micas, kyanite, staurolite, and sometimes amphibole, represent a volcanic-sedimentary sequence metamorphosed in the granulite facies in pre-Variscan times.

The ore minerals, mainly pyrite, chalcopyrite and pyrrhotite, with minor marcasite and traces of pentlandite, were deformed simultaneously with the host rock by the Hercynian orogeny. During this period, the Precambrian basement was also affected by a metamorphic phase of the greenschists facies.

### 3. *Barium-manganese association (v.Ba-Mn)*

Stratiform deposits and occurrences of barite and manganese are quite frequent in the NW trending synclines of Vide and San Blas, in the Zamora province. The ore forms a layer, 0.5 to 15 m thick, made up of massive or nodular barite, carbonates —some with a high Mn content—, minor pyrite, and traces of sphalerite. The mineralized bed, which has been strongly folded and faulted, is located between limestones and carbonaceous shales and schists, some of them corresponding to slightly metamorphosed pyroclastic rocks. Similar mineral assemblages, but with minor amounts of chalcopyrite, are found near Llerena, in the Badajoz province.

### 4. *Cinnabar-Fe sulphides association (v.Hg-Fe)*

This paragenesis characterizes the remarkable Almadén orebody, the biggest mercury mine in the world. The ore is precisely located in the so-called «criadero quartzite», Llandovery in age, the only host of workable mercury mineralization. It consists of cinnabar, pyrite, pyrrhotite and marcasite, and traces of chalcopyrite, sphalerite, galena, barite and dolomite. Mercury, bilinite, hexahydrite and calcite are secondary minerals; calomel, guadalcazarite —a discredited mineral species—, natrolite and chabasite have been also reported (20).

The «criadero quartzite» is built up of two members, framed in and separated by shales. The lower member consists of a sandstone which progressively looses its argilo-carbonaceous matrix from the bottom to the top. The lower and upper limits of this quartzite are black shales and sandstones, and those of the hanging wall grade into an upper quartzite member which is, in turn, overlain by a graptolite shale and a volcano-sedimentary sequence. Metamorphism is of a very low grade, or completely absent.

The Almadén deposit, for a long time regarded as hydrothermal, is in fact a typical stratabound orebody. However, the source of the metal, for which some have postulated to a volcanic origin, still remains uncertain.

## C) MINERALIZATIONS ASSOCIATED WITH MAGMATIC AND METAMORPHIC PROCESSES

### 1. *Chromite-ilmenite association (m.Ti-Cr)*

Ilmenite and rutile, associated with some pyrite, pyrrhothite, magnetite and chromite, and traces of chalcopyrite and pentlandite, have been reported in a few isolated points of the ultrabasic complexes of Cap Ortegal and Ordenes, in northern Galicia. None of them are of economic interest, but ilmenite is, or has been recovered, from alluvial placers in a few localities.

### 2. *Uranium-Ni-Co sulphides association (m.U-Ni-Co)*

It consists of quartz and quartz-carbonates veins containing the following mineral assemblage: pitchblende, niccolite, Ni-Co arsenides —mainly safflorite—, millerite, pyrite, marcasite, chalcopyrite, chalcocite, covellite, erytrine, and annabergite.

The veins occur in a granitic orthogneiss, 460 $\pm$ 65 M.Y. old, which probably corresponds to a Silurian granite highly deformed by the Hercynian tectonic movements. This granite is intruding the carbonaceous quartzites of the Precambrian «Black Series» of Monesterio (Badajoz) in the Ossa-Morena Zone (3).

### 3. *B.G.P.C. association (m.BGPC)*

This paragenesis, apparently restricted to the contact between the Cambrian schists and limestones, and the calcareous shales and quartz-feldespathic siltstones of the Cándana Series, in the León and Lugo provinces, has been known for a long time but only recently has got attention because of the important Pb-Zn deposists which have been discovered in this part of Spain (4).

The paragenesis is very simple: sphalerite, galena, pyrite, marcasite, carbonates, quartz, fluorite, barite, and minor amounts of chalcopyrite, tetrahedrite, chalcocite, covellite and arsenopyrite. Occasionally, albite is also present, due to the recrystallization of the sodic feldspar which is sometimes very abundant in the enclosing silstones.

The age of the galena from the two main orebodies, Rubiales and Toral, which show a vein-like and a stratiform structure respectively, gave the same value, 390 $\pm$ M.Y. As the deposits seem to be pre-Variscan, this age probably corresponds to a later recrystallization of the galena during pre-Hercynian or young Hercynian tectonic processes.

4. *Cinnabar-barite association (m.Hg-Ba)*

This paragenesis exits only in one point of the Ossa Morena Zone, near Usagre, in the Badajoz Province. The ore minerals, mainly cinnabar and pyrite, with minor galena, quartz and barite, occur as veinlets and impregnations in strongly deformed Cambrian limestones and quartzites.

## 3. Late variscan paragenetic associations

Only those mineralizations occurring in Triassic sedimentary rocks, and for which the age determinations in galena show values older than 220 m.y., have been taken into consideration as Late-Variscan deposits.

On the contrary, as no precise data exist as yet on the age of the veins crossing the Mesozoic formations, and as, therefore, an Alpine age could be attributed to these deposits, we would rather not comment them at this time.

1. *Fluorite-barite association (F.Ba)*

This is a very simple paragenesis consisting mainly of fluorite, barite and carbonates, minor amounts of quartz, galena, sphalerite and pyrite, and only traces of chalcopyrite. In many deposits, only fluorite and carbonates are found. This mineral assemblage is always bound to Lower Triassic sediments, both of marine and continental origin. According to the relative abundance of the sulphides, two different paragenesis can be distinguished here (4).

a) *Fluorite-galena association*

The main minerals are banded fluorite and dolomite, and disseminated galena. The deposits of this type are numerous in the Sierras of Gádor, Lújar and Baza, in the Betics, and in the Gijón area, in Asturias, where they show sometimes a vein-like structure. Here, the deposits occur just above the unconformity between the Carboniferos limestones and the Triassic sandstones and conglomerates. In the Betics, the mineralized horizons are at a higher level, in a marine sedimentary sequence, Lower Triassic in age, made up of pelitic and carbonate rocks.

b) *Fluorite-sphalerite association*

This association also occur in stratabound deposits, both in the metamorphosed carbonate rocks of the Betics —Sierra Almijara, in the Málaga province— and in the Basque-Cantabrian Mts. —Arditurri, in Guipúzcoa—, where there are several mines in operation. In this region, galena is not so abundant, chalcopyrite is present in higher amounts, and siderite is the most important mineral among the carbonates.

2. *Barite-hematite association (Ba-Fe)*

Veins made up almost exclusively of barite and hematite, sometimes with traces of chalcopyrite, are found in numerous localities crossing the Triassic rocks surrounding the Pedroches batholit and the Hercynian basement of the Iberian and Catalonian Coastal Ranges, the Betics and the Pyrenees.

## REFERENCES

1. Aparicio, A.; Barrera, J. L.; Casquet, C.; Peinado, M. and Tinao, J. M. (1977): *Caracterización geoquímica del plutonismo postmetamórfico del SO del Macizo Hespérico.* Stvd. Geol., 9; 9-39.
2. Arribas, A. (1970): *Las pizarras uraníferas de la Provincia de Salamanca.* Stvd. Geol., 1; 7-45.
3. Arribas, A. (1975): *Caracteres geológicos de los yacimientos españoles de uranio.* Stvd. Geol., 9; 7-63.
4. Arribas, A. (1978): *Distribución geoquímica de los elementos en trazas de los yacimientos españoles del tipo BGPC.* Fund. J. March (in press).
5. Calderón, S. (1910): *Los Minerales de España.* Madrid, pp. I, 52 and II, 126.
6. Calsteren, P. W. C. van, and den Tex E. (1978): *An early Paleozoic continental rift system in Galicia (NW Spain).* Tect. and Geophy. of Cont. Rifts, Reidel, pp. 125-132.
7. Capdevila, R.; Corretgé, G. and Floor, P. (1973): *Les granitoides varisques de la Meseta Ibérique.* Bull. Soc. Geol. France, 7, XV; 209-228.
8. Corretgé, L. G.; Ugidos, J. M. and Martínez, F. J. (1977): *Les series granitiques varisques du secteur centre-occidental espagnol.* In. Coll. Intern. CNRS, Rennes, 243; 453-461.
9. Dirección General de Minas (1971): *Minería del hierro.* PNEM, 18; 31-128.
10. — (1971): *Minería del plomo y cinc.* PNEM, 20; 64-156.
11. — (1971): *Minería de minerales metálicos.* PNEM, 21; 291.
12. — (1971): *Minería de minerales no metálicos.* PNEM, 23; 233-234.
13. — (1972): *Mapa metalogenético.* PNEM, 7; 157.
14. Gumiel, P.; Arribas, A. and Saavedra, J. (1976): *Geología y metalogenia del yacimiento de estibina-scheelita de Alburquerque.* Stvd. Geol., 10; 61-93.
15. Juliver, M.; Fontbote, J.; Ribeiro, A. and Conde, L. (1974): *Memoria explicativa del Mapa Tectónico de la Península Ibérica y Baleares.* Inst. Geol. Miner. España, Madrid.
16. Loomis, T. P. (1972): *Diapiric Emplacement of the Ronda High. Temperature Ultramafic Intrusion, Southern Spain.* Bul. C.G.A., 83; 2475-2496.

17. LOTZE, F. (1945): *Zur Gliederung der Varisziden der Iberischen Meseta.* Geotekt. Forsch., 6; 78-92.
18. OEN, I. SOEN (1970): *Granite intrussions, folding and metamorphism in central northern Portugal.* Bol. Inst. Geol. Min. de España, 81-83; 271-289.
19. RAMDOHR, P. (1969): *The Ore minerals and their innergrowths.* Pergamon, pp. 805-806.
20. SAUPE, F. (1973): *La géologie du gisement de mercure d'Almaden.* Sci. de la Terre, Nancy, 29; 342.
21. SOLÉ, L. (1952): *Geografía de España y Portugal.* I. *Geografía Física.* Montaner y Simón. Barcelona.
22. THADEU, D. (1977): *Hercynian Paragenetic Units of the Portuguese Part of the Hesperic Massif.* Bol. Soc. Geol. Portugal, 20; 247-276.

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