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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.

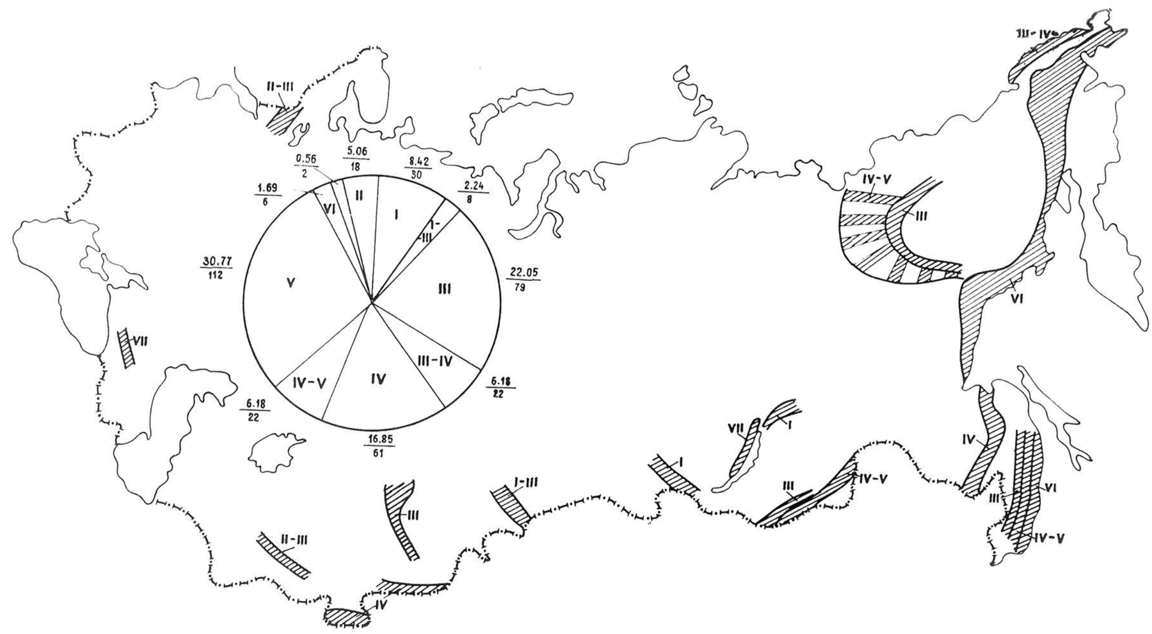

FIG. 1

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 Albitization Microclinization Amazonitization
Cassiterite-quartz, greisen (III)	Veins, stockworks, mineralized domes, zones	rarely-Be, W, Mo, rare metal Bi, As (Ta, Nb)	Greisenization Albitization K-feldspatization Muscovitization
Cassiterite-skarn (II)	Sheet bodies, bodies of irregular form	Cu, Zn, Pb, Fe, Bi, rare metal	Scarnization Amphibolization Greisenization Fluoritization 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 Silicitization Sericitization Chloritization
Cassiterite-(stannite) sulphide (V)	Veins, bodies, stockworks, domes	Pb, Zn, Cu, Ag, Bi, Au, Sb, Co, Cd, Ni (In)	Chloritization Sericitization Silicification Carbonatization Pyrrhotitization
Cassiterite-pyrite (VII)	Banded bodies, lenses, representing zones of stockwork metasomatic changes breccia	Fe, As, Cu, Zn, Pb, Bi	Chloritization Silicification Sericitization Tourmalinization Axinitization Actinolitization Diopsidization
Cassiterite-rhyolite (woody tin) (VI)	Dissemination in rhyolites, pockets	Fe, sometimes F, (In)	Propylitization Sericitization Silicification 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.

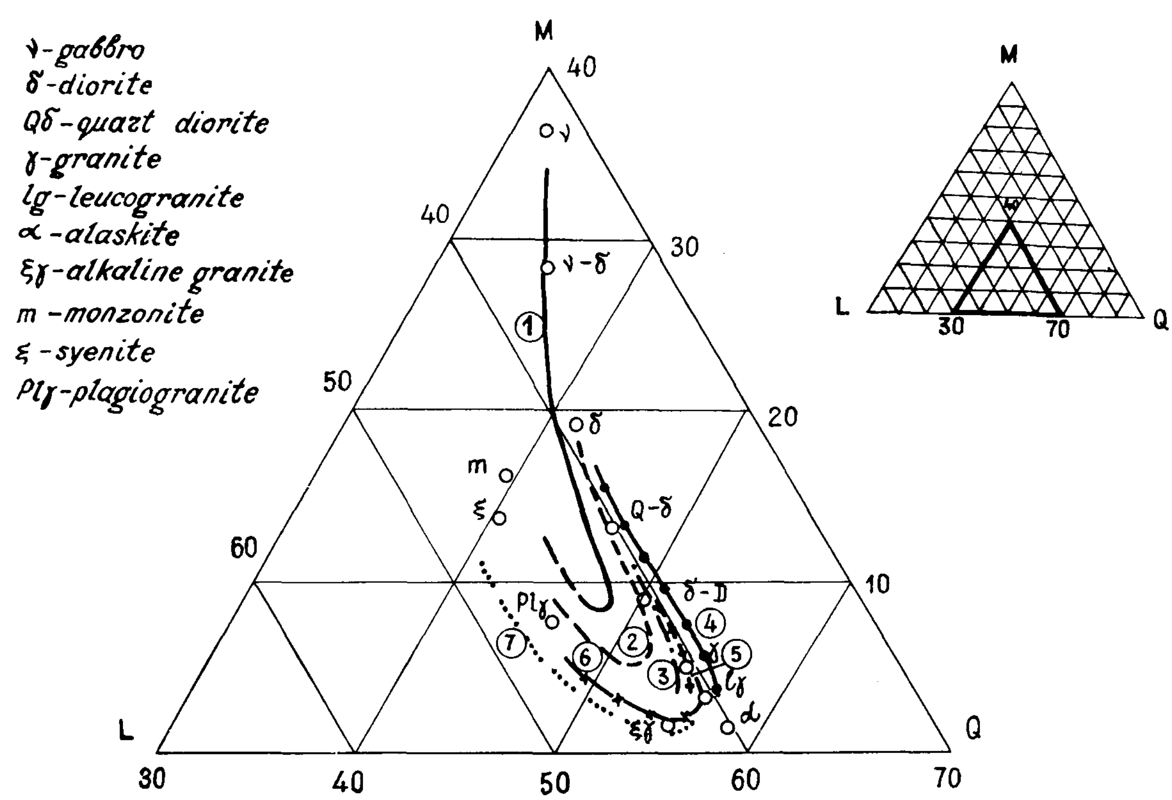

FIG. 2

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 – gabbro-leucogranite	① gabbro-diorite	$\nu - \delta - Q\delta - \xi\delta - \mu - \gamma\delta$	Fe — Cu (W) — Mo — Cu Au — Zn Pb — Ag Au	Fe Fe Cu (Mo) skarns Cu Mo propylites Au Cu	①	I
	② granodiorite-plagiogranite	$\delta - Q\delta - \gamma\delta - Pl\gamma - \gamma$	Mo(Au) W(Au) — Au (FeAs) — Au Zn Pb — (Sb Au)	Au W beresites Au As gumbeites Au Mo	②	
	③ granite-leucogranite	$\gamma\delta - \gamma - l\gamma$	Mo W — Mo Be W — W Bi — (CuZnPb) — (Au)	Mo gumbeites Mo W, W beresites Mo W Bi greisens skarns	③	
II – 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 Sn Cu	Sn (Fe) tourmaline-chlorite Sn Cu „sulphide" Sn Pb Zn	④	II
	⑤ granite-alaskite	$\gamma\delta - \gamma - l\gamma - \alpha$	Sn Be — W Sn — W Bi As	Sn Sn W skarns 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) Nb Ta — Sn Be W	Sn Be Nb Ta greisens 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 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

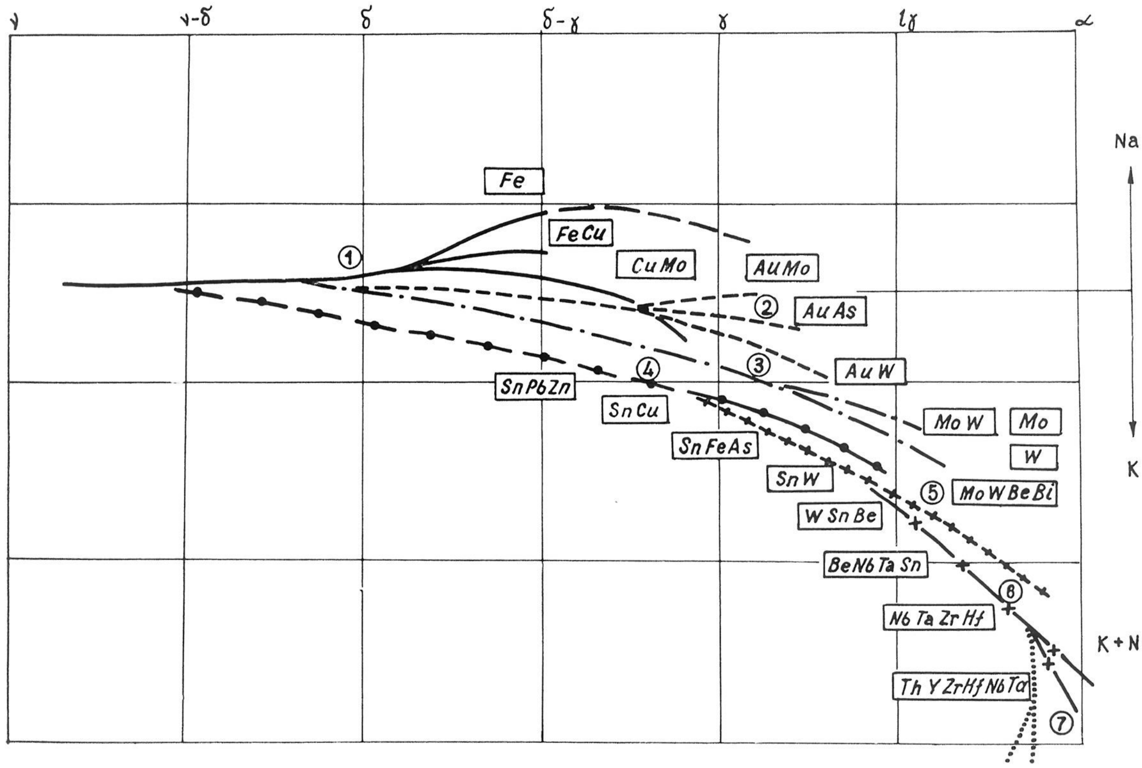

FIG. 3

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).

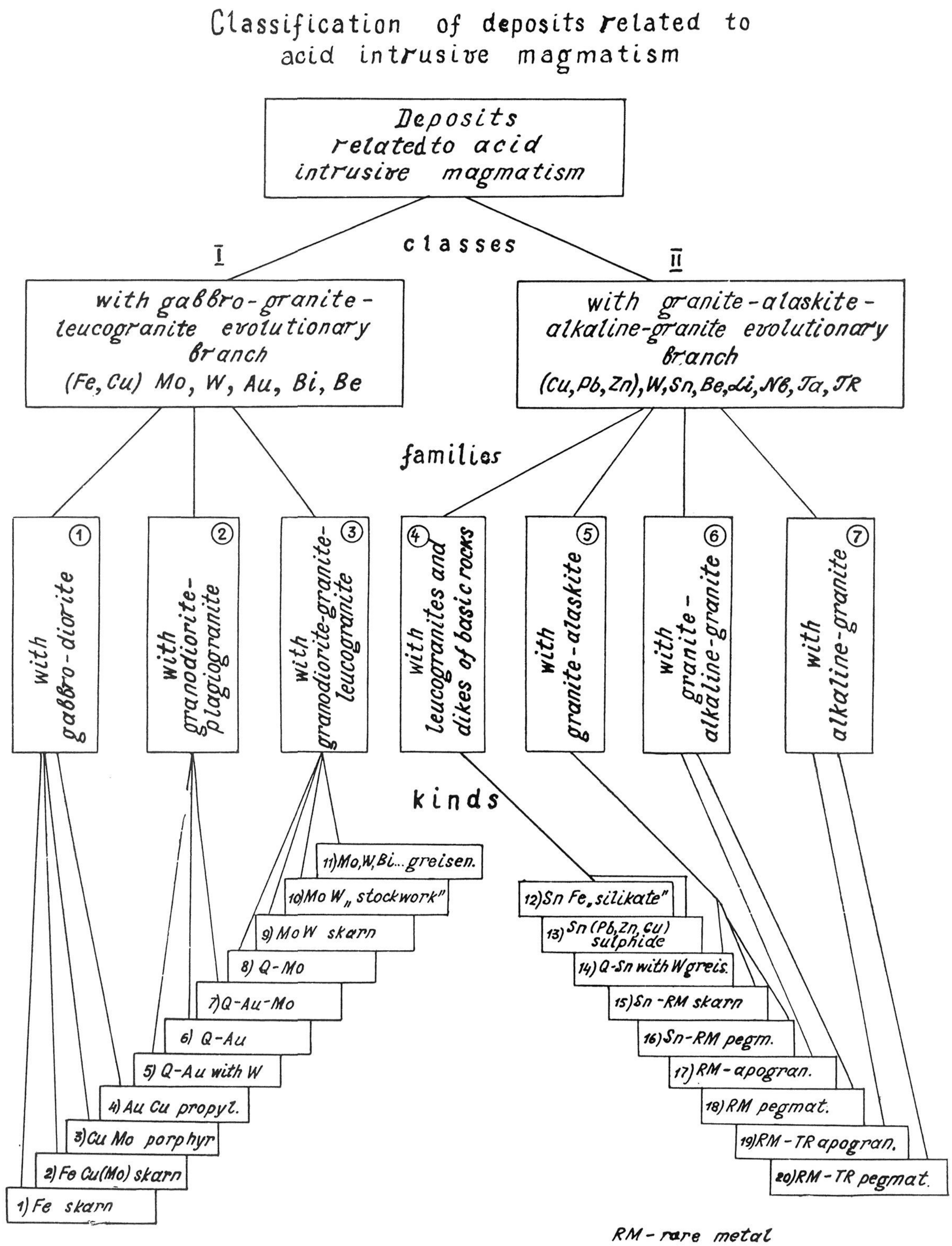

FIG. 4

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.