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Epeirophoresis, and origin of ore deposits

ABSTRACT: Findings of recent years indicate that a new geotectonic position of some ore deposits, and their relation to continental drift may be suggested. Drift heralding intrusions of tin-bearing granites, intracratonal Ni-Cu-bearing layered intrusions, carbonatites associated with rift structures of frozen drift movements, porphyry copper and molybdenum deposits of the Tethyan and Pacific provinces associated with the middle stage of development of Cordilleran orogens, heterogeneous multistage telethermal ore deposits, and post-collision Sb-Hg deposits are briefly discussed. A new concept of the regenerated ore deposits, spatially associated with the zone of absorption of crust material in the junctions of lithosphere plates, is suggested. Disintegration and agglomeration of metallogenic provinces seem to play an important role in the recognition of regional metallogeny. Older concepts of the metallogenic cycle are reviewed and a new concept of the metallogenic cycle, based on plate tectonics and general principles of the plate tectonics, associated with definite type of the paternal magma, characterized filo- and ontogenetically, also by diagnostic minerals and trace elements, are grouped according to seven geotectonic zones of lithospheric plates. A chart plotting ideas of the classification, depth of formation of ore deposits, and their geotectonic position in epeirophoresis, and connection with their paternal magma, is shown.

INTRODUCTION

Recent important discoveries concerning the structure of oceanic sea floor have resulted in the evolution of the old hypothesis of continental drift into the generally accepted theory of epeirophoresis. The former hypothesis originated in result of attempts to interpret the cause of lateral discontinuity of sialic crust as well as of spacial distribution of orogens and of their origin. The theory of epeirophoresis developed, in the course of revision of older drift hypotheses, based on results of recent detailed investigations of new geotectonic elements discovered during oceanological prospecting of the sea floor. These important data concern the structures of mid-oceanic ridges as well as of strike-slip faults and submarine trenches. The modern theory of epeirophoresis is based on the non-expansive model of the Earth which is considered to be a body displaying dynamic development. Consequently, the present configuration of continents and oceans on the Earth is a completely new feature of our planet. Moreover, this theory accepts the movements of plates of the lithosphere without any considerable deformations. One of its fundamental features is the episodicity of spreading of the sea floor and correlation between the disappearance of this spreading and the accomplishment of cycles of orogenic phases. The beginning of each cycle is manifested by global reorganization of the displacement direction of plates. Epeirophoresis is supposed to be caused either by convection currents in asthenosphere (Ampferer 1906, Griggs 1939, Holmes 1944) or by rotation movement (Wegener 1924, Morgan 1968, Le Pichon 1968) and by secondary compensation currents between the zones of reabsorption of crustal material and the zones where addition of mantle material to the Earth surface is taking place.

The concepts formulated in this paper result from considerations on the influence of revolutionary changes in opinions on some fundamental geological processes in relation to ore deposits. These ideas refer both to existing ore deposits and metallogenic provinces and the origin of ore deposits isogenetic with epeirophoresis. The influence of continental drift on existing ore deposits has been analysed by some geologists in their attempts to reconstruct dismembered metallogenic provinces. However, there are no publications concerning the latter problem.

This paper is dealing essentially with two problems: the global cycle of epeirophoresis and the classification of hypogenous ore deposits based on the new principles.

DISINTEGRATION OF OLDER METALLOGENIC PROVINCES

Disintegration and drift separation of larger plates of lithosphere results in dismembering of ore-existing metallogenic provinces. Reconstruction of formerly integrated metallogenic provinces is of considerable importance both for further development of metallogeny and for the theory of epeirophoresis itself. The latter ought to consider the preexisting ore deposits and mineralization phenomena as an additional "group index of blood", characterizing the evolutions of magmatism in the fragments of pre-drift continents which we are tending to integrate. Practical importance of such reconstructions is connected with compilation of more detailed maps of regional metallogenic prognoses. Several papers concerning the reconstruction of metallogenic provinces have recently appeared.

Besairie (1964), the author of the tectonic map of Madagascar, indicates some petrographic and mineralogic analogies of this island with India. In his opinion it is due to the pre-drift unity of these areas.

The first paper dealing exclusively with this problem was an attempt to reconstruct tin-bearing metallogenic provinces of Africa and America by Schuiling (1967). The map is an excelent compilation of data, but this author did not take into account the age of individual provinces. Consequently, he united in one metallogenic province the Bolivian and the much older Rondonian ore deposits, the ages of which are 200 and 800 million years respectively. In Schuiling's opinion, tin deposits of the Congo-Uganda belt (1200 million years) and Paleozoic Egyptian ore deposits would belong to one metallogenic province.

In 1968, Petrascheck published more detailed considerations concerning some similarities of metallogenic provinces and of individual ore deposits occurring in separated fragments of paleocontinents.

In 1970, Crawford (1970) compared the integrated metallogenic provinces of India and Australia, considered by him to be formed from Indo-Australian paleocontinent.

In 1971, Petrascheck described some analogies of ore deposits of Greenland and those of the NE part of North America. The above cited reconstructions of metallogenic provinces are based on distinct analogies concerning the major elements and mineral composition of the ore deposits. It is supposed that further investigations will concern some other physico-chemical data of composition such as geochemical relationship, isotopic composition, association of trace elements in ores, absolute age and geotectonic position of the compared ore deposits.

ORE DEPOSITS ISOGENETIC WITH EPEIROPHORESIS

On the present day knowledge of epeirophoretic phenomena it is possible to reconstruct the history of development of the deformation zones of the Earth crust and of displacements of continents during at least the last 200 million years (Dietz 1961; Runcorn 1962; Wilson 1964, 1965, 1968; Fourmarier 1967; Le Pichon 1968). On the other hand, actually we have a good deal of informations concerning the absolute age of petrographic provinces and of the comagmatic ore deposits. Consequently, there are sufficient data for a comparative study of epeirophoretic processes and ore deposits isogenetic with them. Such studies have been carried out by the present writer and resulted in an attempt of a new classification of ore deposits and ore formations. The latter are subdivided into groups according to individual geotectonic zones and geomagmatic stages of global cycle of epeirophoresis and by taking into account the conditions of their origin. Isogenetism of ore deposits with tectonomagmatic processes of epeirophoresis results not only from their distribution exclusively within the Cordillera (Andean) orogen at the margin of drifting plates and from spacial and causal relation with disjunctive dislocations within continental shields — platforms and consolidated geosynclines newly incorporated into cratons. This isogenetism results first of all from substantial comagmatic connections with successive stages of development of magmatism which are different for various geotectonic zones and diverse stages of epeirophoresis.

This new approach to the problem under consideration is favored by recent revision of the geotectonic position of numerous ore deposits. Moreover, several hundreds of new ore units have been recognized. Thus, our knowledge concerning some groups of ore deposits has considerably developed and new guide types have been distinguished. Let us now present, in successive chapters, such guide types significant for our considerations on new concept of the metallogenic cycle and the classification of ore deposits.

Intrusions of tin-bearing granites heralding continental drift

Intrusions of tin-bearing granites were until recently erroneously connected with the final stage of development of geosynclines and of the magmatic cycle. Consequently, the largest energetic phenomena, manifested by granitic intrusions, were supposed to be connected with magmatic activity becoming extinct at the end of a magmatic cycle. This inconsistancy was first emphasized by Ramovic (1968). Neither did other facts recently discovered by the students of greisen ore deposits, comply with previous assumptions.

Smirnov (1963) has already observed that the intrusions of tin-bearing granites do not occur within folded eugeosynclines. Thus, if these granites were the final products of differentiation of basic magma, large-scale development of basic and intermediate magmatism would be accompanied by intensive acid magmatism. In Cordillera (Andean) orogens the last stage of evolution of synorogenic magmatism is represented by intrusions of Cu- and Mo-bearing porphyries and by final volcanism. When the evolution of a geosyncline was interrupted by piling up of a collision orogen, the last-stage magmatic products are represented by basic and acid volcanites and comagmatic ore deposits consisting of Sb-Hg, As, Se, Te, Au and Ag minerals. Consequently, there is no place for large intrusions of Sn-W-bearing granites in both types of orogens. Volcanites accompanied by unique Ag-Sn-Bi-mineralization known from the Bolivian province are no exception from this rule.

The most important, however, was the finding that Sn-bearing granites are post-orogenic and intrude simultaneously into various areas where large dislocations are formed within lithosphere plates. These intrusions are located along deep fractures intersecting lineations of magmatic culminations, semicircularly surrounding middle massifs or superposing on previously consolidated peculiar "miogeosynclinal" zones. The time interval between the folding of a geosyncline and the granite intrusion varies from 50 to 500 million years. The latter extreme values refer to the intrusions occurring at the margins of middle massifs and to those situated at the intersections of magmatic lineation by later dislocations as *e.g.* in Nigeria (Wright 1970) and in East Mongolia (Rundkvist & al. 1971).

Simultaneously occurring intrusions of tin-bearing granites in various weak zones in the plates of the lithosphere clearly indicate that newly folded "miogeosynclines" remain still weaker, quasicratonal places in these plates. Consequently, the emplacement of these granites is not due to autonomous development of miogeosynclinal igneous activity. The appearance of this magmatism is connected with other global processes more general than geosyncline-orogen evolution.

Of special interest is the fact of emplacement of Sn-W-bearing granite intrusions in areas where drift disintegration starts to develop (incipiantly in a hidden manner) or in regions closely adjacent to the drift area, probably connected with covection currents in the asthenosphere. Following examples of Sn-W-ore deposits, that directly preceded or simultaneously originated with the early stage of development of disintegration and displacement of plates of the lithosphere, may be cited:

1. Sn-W-ore deposits of the global tin-bearing province (230—200 million years). This metallogenic province comprises the deposits of Cornwall, Armorican peninsula, Spanish and Maroccan Mesetta, Erzgebirge Mts and Mount Pleasant in Canada. Moreover, the older Bolivian and younger Australian tin-bearing province belong to this group.

2. Sn, Nb-Ta-ore deposits of Nigeria, Hoggar and Air massifs, near-shore parts of E Brasilia, SW Africa and Nubia.

The Cornwall deposits excepted, where the evolution of geosyncline and orogen preceded intrusions of tin-bearing granites, in all the other cases no such sequence of events was observed. In general, Sn-bearing granites intruded into considerably earlier consolidated areas (Konstantinov & al. 1969, Rundkvist & al. 1971). As to the Nigerian deposits, Wright (1970) simply indicates, their location to be at the intersection of lineations of magmatic culminations displaying SW strike (parallel with the direction of deep fractures in the gulf of Guinea) with the extension of meridional shoreline of East Africa. Western part of the dissected ore deposits of SW Africa occurs at the opposite east shore of South America.

Moreover, the association of intrusions of the Sn-bearing granites with initial phenomena of continental drift is clearly seen in the localization of ore deposits of the Nubian province at the Red Sea shores. The intrusions of younger tin-bearing Gattarian granite are synchronous with the incipiant stage of formation of the Red Sea graben. The distribution and strike of ore veins (Amin 1947, El Ramly & al. 1959, Meshref 1971) indicate a connection with a dislocation system parallel to the coastal line of this sea.

Furthermore, the origin of ore deposits of the great tin-bearing belts of Malaya-Indonesia and of China-Mongolia regions is associated with initial phenomena of continental drift in this area. The age of tin-bearing intrusions of the Malayan-Indonesian belt (200—150 million years) corresponds to the initial drift phenomena in adjacent regions of the globe resulting in the displacement of the Indian subcontinent and its integration with the Eurasian continent in the Himalayan collision which took place approximately 30 million years ago.

Apparently more complex is the relation between ore deposits of the tin--bearing Chinese-Mongolian belt (200—180 million years) and the displacement of continents. This is, however, due mostly to inadequate reconstruction of the sequence of epeirophoretic events in this area, as well as to the so far not clarified role of microcontinents and middle massifs in epeirophoresis. Similarly as in the above described areas, the zones of intrusions display segmental development (Rundkvist & al. 1971). Synchronously formed ore deposits developed simultaneously in platform areas, on margins of the Chinese massif and in the recently folded and consolidated peculiar geosynclines displaying no initial magmatic manifestations. Actual position of the arctic part of the mid-oceanic ridge, perpendicular to the northern shore of the Asiatic continent, near the Taymir peninsula, is another presumptive evidence of such interrelation.

According to Wilson (1964), the Kolyma massif was welded with the Eurasiatic continent during the Tertiary. On this opinion we can suppose that the drifft phenomena were preceded by or developed synchronously with the intrusions of the at present zonally distributed Kimmeridgian leucocratic rock complex of Kolyma, the granodiorites of Okhotsk and Omsukchan granites. Successively developed Sn-W, Sn-sulphides and finally Mo-W-ore deposits are associated with them (Smirnov 1963).

Another fact connected with the initial drift phenomena should also be mentioned. It does not seem to be furtuitous that the local reorganization of the direction of drift displacement in the eastern part of the Pacific ocean, that took place 10—7 million years ago, was manifested by the formation of the new submarine trenches — the Galapagos and the Chilean (Herron & Heirtzler 1967, Le Pichon 1968). This phenomenon was accompanied by volcanic activity within the adjacent young Bolivian metallogenic province. Peculiar subvolcanic Sn-Ag-Bi-sulphide deposits are associated with these phenomena (Ahlfeld 1967, Turneaure 1971).

Similarly, Mexican tin deposits of the Miocene rhyolite province are localized along a lineation of magmatic culminations. Its trend is parallel to the great fractures of the California Gulf (Bracho Valle 1961).

Intracratonal intrusions of Cu-Ni-bearing magmas

Discoveries of the last decade radically changed the opinion on the origin and geotectonic position of intramagmatic Cu-Ni-ore deposits. Previously these were generally assigned to the ore deposits of a geosyncline cycle (Schneiderhöhn 1952). Actually it is evident that their origin is associated with intrusions of ultrabasic magmas into deep fissures within much earlier consolidated continental plates. Such fissures are formed during drift displacement of plates of the lithosphere. Thus, the age of these intrusions corresponds to the periods of intensification of drift movements. Let us discuss the problem of the most important ore deposits of this type.

Copper-nickel sulphide mineralization is a characteristic feature of the Mesozoic trap intrusions of the western part of the Siberian epi-Proterozoic platform. Considerable concentration of sulphides in these rocks are known in ore deposits Norilsk and Talnakh. The intrusion of deep-seated trap magmas penetrated through large meridional fractures formed at the contact of three important structures, *i.e.* the Tungusian syneclise, the Igara block and the Taymir depression (Godlevski 1959). Triassic lavas overlie Paleozoic platform sediments and the Sinian basement. The main dislocation of metallogenic Norilsk intrusion is the Norilsk-Kharayelavsk deep fracture, representing a regional fracture of the Earth's crust at the contact of the above structures. It is supposed to be Kimmeridgian in age.

Intramagmatic Ni-Cu-deposits, connected with Permian and Triassic gabbroid magmas that intruded into the axial part of the Chinese platform, display numerous analogies with the Norilsk deposits. The only difference consists in the quantitative predominance of nickel over copper (Smirnov 1969). Moreover, in the Sechuan province, there occur numerous, economically less important Cu-Ni-ore deposits associated with trap formations.

Other ore deposits synchronous with drift phenomena are those of the Insizwa Mts in South Africa. The Karroo formation is cut by Lower Jurassic dykes of dolerite traps. This magmatism is accomplished by Ni-bearing intrusion of olivine gabbro and picrites. The lower part of the intrusion contains sulphide ore bodies exploited in the Insizwa mine (Scholtz 1936).

The above described peculiar intrusions including rich liquation deposits of Cu-Ni sulphides, are abundant in Co and Se, being economically important. Their origin seems to be not only synchronously but also causally conditioned by drift events. This refers both to the genesis of deep fractures and to the magmatic culmination generating intrusions of molten material from the deeper parts of the mantle. On the base of substantial analogies and similarity of geological mode of occurrence, it may be supposed that older ore deposits of this type, as *e.g.* Moncha, Sudbury and Bushveld might be formed in similar conditions. Even if the Pechenga ore deposits had been formed during the final stage of orogen (Smirnov 1969), all the remaining ore deposits would represent a group which shows consistent features indicating the periodicity of some processes in the history of the Earth's crust.

Porphyry Cu and Cu-Mo deposits of the Tethyan and Pacific provinces

At least several tens of large porphyry deposits of copper and molybdenum have been recently discovered. More than 70% of copper production comes from ore deposits of this type. All these deposits are distributed in marginal parts of continental plates, generally concentrating within the zone of the Cordillera (Andean) orogen.

In the metallogenic province occurring around the Pacific Ocean, the majority of the ore deposits concentrates along the west coasts of North and South America (Billingsley & Locke 1933). Moreover, we know similar deposits from Puerto Rico, Kamchatka (Vorobskoye and other Cu-Mo deposits associated with Miocene granitoid intrusion), Philippine and Bougainville island. Usually the age of the porphyry copper deposits of this province amounts to 60 million years (Laramide phase). On the other side, the age of porphyry Cu-Mo deposits usually corresponds to 30 million years (Miocene), though some of them are considerably younger. The youngest are 8 million years old.

The second older metallogenic province of this type is represented by ore deposits grouped along the north coast of the Tethyan ocean. These are represented by Kounrad in Kazakhstan as well as by Almalyk and Adrasman in Usbekistan, associated with Upper Permian intrusions of quartz and felsitic porphyries (Baluta 1971). They are preceded by earlier Carboniferous granitoids (310 million years in age) with associated W-Mo mineralization. These deposits, and particularly the Adrasman one, contain considerable bismuth mineralization (Magakyan 1969).

The younger metallogenic province of the west part of the Tethyan is represented by Oligocene-Miocene Cu-Mo-ore deposits associated with granitoid intrusions of the Malyj Kavkaz Mts, Iran and the Balkans. The Georgian deposits of Kandzharan, Agarak, Dastakert, Ankavan and Paragachay (Magakyan 1969) as well as Bor in Yugoslavia and Rosenskoye in Bulgaria are assigned to this group. Younger dacites and post-collision poryhyries are accompanied by Au, Ag and Te-Bi mineralization (Bogdanov & al. 1968, Ramovic 1968).

In the above described metallogenic provinces, ore deposits are generally associated with intrusions of quartz monzonites (America) and in other regions with those of granodiorites and quartz diorites. Ore-bearing intrusions themselves are determined as felsitic, consisting even of vitreous groundmass and including scarce phenocrysts. The sizes and global occurrence of the porphyry Cu and Cu-Mo deposits do not correspond to our previous concepts on their circum-batholithic grouping and on the range of metallogenic provinces. All these data indicate panglobal character of some simultaneously developing metallogenic processes. Similarity of this phenomenon in the development of Cordillera orogens at the margins of the Tethyan and Pacific Ocean, as well as its global extension, clearly indicate that these deposits represent an important link of the global metallogenic cycle of epeirophoresis.

Central carbonatite intrusions and kimberlite diatremes

Very rapid development of exploration and recognition of central carbonatite intrusions and kimberlite diatremes clearly indicate that exploration of useful minerals is the driving force of any geological discoveries. Actually we know several hundreds of central intrusions and kimberlite diatremes. Consequently, our knowledge on the conditions of their occurrence has increased considerably (Sobolev 1951).

Though some of these intrusions were formed as early as the Precambrian, the distinct majority originated from the last 200 million years (Tuttle & Gittins 1966, Smirnov 1969). Moreover, we know actually active carbonatite volcanoes Oldoinyo-Lengai and Naliango (Du Bois & al. 1961). Carbonatite-bearing central intrusions are localized within rift structures. Nevertheless, not all of these structures display large-scale development of magmatism of this type. The association of central intrusions with drift processes is stressed by extraordinary localization of some carbonatites as *e.g.* in the Green Cap island (De Assuncao & al. 1968), in NW Pakistan (Fuzail 1967) as well as at the Brasilian and opposite African coasts. The connection of the fields of kimberlite diatremes with rift structures is not so strictly pronounced but nevertheless evident (Odintsov & al. 1969). Their petrologic relation with ultrabasic magmas of the early stage of development of central intrusions is striking (Dawson 1964; Wyllie 1964, 1968; Konkev & al. 1964; Vasilev & al. 1968). However, we do not yet know how and to what extent the development of this magmatism is dependent on the evolution of drift phenomena within a given area.

The complexes of central intrusions consists of successively penetrating concentric zonal intrusions of ultrabasic-alkaline and carbonatite magmas. Carbonatite bodies are often cut by dikes of alkaline rocks. The significance of magmatic culmination and of abyssal pressure of magma is manifested by the formation of circular, cone-shaped or laccolithic forms of successive intrusions. Frolov (1962) has shown that the intrusions of Sayan carbonatites and associated magmas were accompanied by tri-axial deformations, whereas during the earlier and later stages planar bi-axial deformations were formed.

Central carbonatite intrusions are closely related both with large intrusions of peralkaline magmas (Greenland, Canada, Kola peninsula) and with apatite, magnetite intrusions of the Kirunavaara-Gelivaara type. In Smirnov's opinion (1968) magmatic bodies of the Kola peninsula intruded into the platform area synchronously with orogenic paroxism in the Urals. Numerous younger carbonatite intrusions connected with other development stages of alkaline magmatism also occur within the Kola peninsula. Luesh carbonatites in Congo represent an intermediate genetic position between peralkaline and central carbonatite intrusions. It is manifested *e.g.* by cupola-shaped batholithic form of alkaline rock intrusion (parental for carbonatites), lack of initial ultrabasites and intermediate mineral composition of major and accessory constituents. Apatite-magnetite carbonatites are also known. These are represented by carbonatites of Kovdor, Tororo, Jacupiranga, Sirotti (containing hundreds million tons of iron ore) and Arasa where 100 million tons of apatites have been proved. The last stage of development of central intrusions can yield considerable masses of sulphides forming specific carbonatite sulphide deposits. Bornite-

-chalcopyrite ore deposits associated with carbonatite Palabora in South Africa (Herbert 1967) and galena-sphalerite-molybdenite deposit associated with one of Siberian carbonatites (Frolov 1971) have recently been discovered.

On the above data we can suppose that central intrusions can be compared with tube transporters carrying products of the processes developing deep within the mantle and indicating (better than batholithic intrusions) that the generation of apatite, magnetite, Nb-Ta-TR and sulphide ore deposits are associated in some degree with epeirophoretic processes.

Multi-stage heterogeneous and polymagmatic ore deposits

From genetical and classification point of view, the most difficult and complex are multi-stage deposits, being heterogeneous with regard to the association of successive ore formations of various parental magmas. If one of the generations of their mineral succession correspond to a definite classification position, the remaining ones contradict it. Sometimes these deposits were included into a separate group. Solution of the problem of their comagmatism may explain general regularities concerning the metallogeny of the adjacent areas, emphasizing a marked substantial uniformity of mineralization phenomena developed simultaneously within vast continental areas.

This may be exemplified by the results of recent Rösler & Baumann's study (1970). In these authors' opinion, Fe-U, Ba, Bi-Co-Ni-Ag and Ge-Ag ore formations in the Erzgebirge Mts and in Central Europe in general (in writer's opinion most probably in the whole world) are associated with basic magmas and formed within a very long span of time. Formerly these deposits were supposed to be associated with tin-bearing intrusions in the Erzgebirge Mts and consequently the scheme of metallogenic development of a simple magmatic chamber was extremely complicated. When considering these phenomena from the point of view presented here we must emphasize their more pronounced substantial homogeneity with ore deposits of the Silesian-Cracovian type occurring within the adjacent areas. By applying these authors' findings we can also explain the presence of thallium-enriched youngest iron sulphides in the Freiberg deposits and the occurrence of germanite in these ore deposits as well as in those of the Rhine graben (Wiesloch) and in Tertiary bismuth deposits in Wittichen. Similarly, much clearer is some similarity of germanium-bearing wurtzite generation of the Aachen-Moresnet and Silesian-Cracovian ore deposits associated with alkali-basaltic magmatism (Harańczyk & Gałkiewicz 1970). From this point of view we can more easily interpret the occurrence of younger ore formations in the multi-stage Cornwall ore deposits and in other similar ones. These formations should be treated separately in the classification based on co-magmatic relations.

Hydrothermal ore deposits associated with lineations of magmatic culmination

Numerous Zn-Pb-Ba-ore deposits occurring in the platform cover of cratons are not spacially associated with batholiths. This fact was a sufficient basis for some geologists to speculate neptunic interpretations of their origin. However, there is much evidence indicating that they belong to a large group of polymetallic ore deposits localized within the platform covers in zones, where there are trends of magmatic lineation in the basement intersected by fractures of dislocations. Consequently, these ore deposits appear to represent a certain kind of linearly distributed phenomena of ore occurrences and magmatic manifestations. We shall present several examples of these deposits.

The zinc-lead deposits of the Silesian-Cracovian type are situated at the opposite terminals of the European magmatic lineation, stretching from the Rhine area toward Silesia, marked by acid Hercynian magmatism and Tertiary alkali-basalts (Harańczyk 1965, Harańczyk & Gałkiewicz 1970). According to Boncev (1965), this lineation and numerous occurrences of disjunctive dislocations could indicate an embryonic stage of a rift which through the Balkan peninsula could join with the African rifts. Moreover, the line of Pawłowski's tectodrome (1971) is situated in this area. It is the dislocation that is supposed to extend around our globe. The Zn-Pb-ore deposits of the Rhine area and Aachen-Moresnet region are localized at the intersection of this lineation with the rift structures of the Rhine graben. These grabens cut across another lineation in the environs of Nussloch defining the Wiesloch and Gärnsburg Zn-Pb deposits. Further southwards, within the Alps, there is another intersection point indicated by Binnental ore deposit. The Silesian-Cracovian ore deposits are localized at the intersection of the above mentioned lineation, displaying WNW strike, with a dislocation (Pawłowski's tectodrome) showing NW strike. Moreover, in this area there occurs another magmatic lineation manifested by Tertiary (Mesozoic?) teschenitic petrographic province which exhibits SW strike. At the opposite end of this lineation there occur related Zn-Pb-Ba-F-ore deposits of Bleiberg, Kreuth, Mezica etc.

Another example of this type mineralization are the Tertiary Zn-Pb-Ba ores occurring within dislocations parallel to the coastal lines of the African continent. These are known in Kenya and at the Red Sea coasts (Harańczyk 1965). Along the same dislocations there occur central carbonatite intrusions as *e.g.* Mrima and other volcanic rocks. In USSR this group is represented by those of Karatau, Kvaisa, Yukunzh etc. It is supposed that the majority of Zn-Pb-ore deposits, the origin of which could not be explained by older batholithic hypothesis, may be assigned to this group.

PREVIOUS CONCEPTS OF METALLOGENIC CYCLE

Discovery of the fact that essential geotectonic and geomagmatic processes have often been repeated in the history of the Earth, also the origin and evolution of the concept of geotectonic and geomagmatic-metallogenic cycles have considerably contributed to the development of ore geology, establishing modern metallogeny (minerogeny) as an independent branch of science. The inspiring ideas on this subject have been expressed by Stille (1940) who was the first to pay attention to simultaneous development of orogenic and geomagmatic cycles and to accept a general consolidation of rock masses as the end of a geotectonic cycle.

This idea was applied by Schneiderhöhn (1941, 1944, 1952) as the basis for grouping are deposits and ore formations according to successive geomagmatic stages.

In the above authors' opinions, a metallogenic cycle begins with intense simatic magmatism, manifested essentially as basic initial geosynclinal volcanism. This is followed by intrusions of ultrabasic and basic magmas and these, in turn, during the synorogenic stage, by intermediate and acid intrusions. The cycle is closed with subsequent volcanism, usually producing rhyolites, dacites and andesites which, in Stille's opinion (1940) are connected with intercedent plutonism manifested by intrusions occurring closer to the Earth's surface than the synorogenic ones.

Further evolution of the definition and subdivision of the cycle and of isogenetic ore deposits is due to detailed studies by Petrascheck (1942), Niggli (1947,1948), Cisarz (1956), Borchert (1957), Bilibin (1959), Magakyan (1959) and Smirnov (1963).

When comparing successive approaches to metallogenic cycles, initially comprising only geosynclines and then platform areas too, it is observed that the diversity of opinions usually concerns the same types of ore deposits.

Let us present several examples of such controversial ore deposits. According to Bilibin (1959) the porphyry Cu-Mo-ore deposits of the Kounrad type should be assigned to a transition stage between the initial and final stage of the cycle, whereas Magakyan (1959) includes them into a group associated with the middle stage of the latter. Similar is the case with greisen, pegmatite and hydrothermal ore deposits associated with intrusions of acid granites and alaskites. In Schneiderhöhn's and Magakyan's opinions these ore deposits correspond to a late stage of the metallogenic cycle, whereas Bilibin and Smirnov assign them to the middle one. Recently Konstantinov (1969) and Rundkvist & al. (1971) consider them to represent an independent post-orogenic stage. Hydrothermal ore deposits of non-batholithic relation to paternal magma, called by Schneiderhöhn "regenerated ore deposits", were generally assigned to various stages of the cycle in question; *e.g.* according to Magakyan the Sb-Hg-ore deposits appear in the middle stage, whereas Bilibin places them in the final one.

Another tendency in interpreting the metallogenic cycle is a gradual increase of the family of ore deposits originated under conditions of cratonal areas. These ore deposits were formerly erroneously assigned to those formed during the evolution of geosynclines. Schneiderhöhn (1941, 1944) supposed that under cratonal conditions only metamorphic and regenerated ore deposits might have been formed. Consequently, in his opinion, *e.g.* the magnetite-apatite ore deposits of the Kiruna type, nepheline syenite intrusions of the Kola peninsula and paragenetic ore deposits belong to the synorogenic stage of the geotectonic cycle. Bilibin (1959) assigned the Ta-Nb and Rare Earth deposits to the middle stage of the cycle, while Magakyan (1959) places them in the late one.

The first ideas deviating from the general trend of opinions have been presented by Ramovic (1968) in his stimulating treatise dealing with metallogeny of the youngest geological times. In his opinion, the geomagmatic cycle begins with the largest energetic phenomena manifested by granitic intrusions and ends with quiet activity of basaltic volcanism. Ramovic's idea is illustrated by numerous examples of ore deposits and petrographic provinces of the Balkan peninsula.

Another objection against the proposed concept is the non-repetition of successive geomagmatic cycles and the unique character of individual ore deposits resulting from irreversibility of development processes of the Earth's crust. In the present writer's opinion, this condition refers, first of all, to all the processes taking place within the Earth's mantle. This conclusion is based on the frequency of occurrence of metallic ore deposits in remote geological epochs (Blondel 1936, Icikson 1958, Ramovic 1968). Similar ideas were presented by Smirnov (1963); in his opinion, regardless, a general approach to the metallogenic cycle it is advised to present absolute schemes of magmatism and paragenetic ore deposits for individual geological eras.

Let us consider the above concepts of the cycle taking into account the recently recognized epeirophoretic processes. It should be noticed that the former concepts tended to obliterate the differences in tectonic evolutions of orogens preceded by geosynclinal stage and formed at the contact of oceanic and continental plates. Such orogens are represented by the mountain ranges of the west coasts of South and North America and are called the Cordillera (Andean)type. Other orogenic piled up structures can be formed by a collision of two continental plates preceded by approaching of continents, accompanied by subduction of the oceanic plates of the foreground. The latter process results in the formation of island arcs and oceanic trenches or of a geosyncline similar to that of the first type. Thus, the first stages of evolution of geosynclines are generally similar and produce ore deposits of similar type. However, the collision process can lead to better exposition of ultrabasic rocks, when compared with the later stages of evolution of a Cordillera orogen. The contact area of the African and Eurasiatic continents is in the region of occurrence of a collision orogen. The latter, however, is complicated by incorporation of microcontinents forming some middle massifs (Dewey & Bird 1970). Similarly, the Himalayas represent a collision welding of the Indian subcontinent (previously a part of the Australian plate) with the Eurasiatic continental plate. According to Wilson's hypothesis (1964), the mountain ranges of the Verkhoyansk Land were formed by welding of the Kolyma massif with Eurasiatic continent.

All the previous classifications of geomagmatic-metallogenic cycles were based on the assumption that all the ore-forming processes in consolidated continental masses (cratons) are connected with the last stage of evolution of geosynclines. This principal idea was the basis of Stille's (1949) and Schneiderhöhn's (1952) concepts of the existance of "Hochkratons" and "Tiefkratons" in the Earth's crust as well as of the distinction of ore deposits of the platform stage as the last stage of the metallogenic cycle (Magakyan 1959, Smirnov 1963). On this principle, Shcheglov (1968) subdivided the platform stage into two periods of the so called autonomous activation comprising all the geotectonic processes taking place within consolidated continental masses in the old and regenerated periods of activity that may lead to the formation of specific ore deposits.

Actually, this general principle ought to be changed. The theory of epeirophoresis claims for a synoptic approach to the history of our globe and, by indicating an interrelation of all the geological phenomena, suggests another interpretation of the metallogenic cycle. Geological processes connot be considered exclusively from the point of view of evolution of a given rock mass, consisting in its transition from mobile into stable stages, *i.e.* into cratonal consolidation. It seems much more reasonable to group and order geological processes taking place simultaneously in different parts of drifting plates of the Earth's crust. The thesis of synchronism and interrelation of geological phenomena, taking place within different tectonic areas of the globe, is manifested by successive stages of panglobal evolution of magmatism and of paragenetic ore-forming processes. The latter develop simultaneously in geosynclinal areas, submarine trenches, mid-oceanic ridges, magmatic lineations and transcontinental deep fractures in cratonized continental areas. Similar regularites should be found in the distinguished stage of a metallogenic cycle. When presenting this new concept of metallogenic cycle based on the theory of epeirophoresis, it should be emphasized that no matter of general acceptation of this theory and the comparative maturity of the science of ore deposits, our knowledge concerning the influence of epeirophoretic processes on the origin of magmatism in the plates of lithosphere is still insufficient. Therefore, we have to be cautious, particularly in choosing the examples. The factologic material is taken first of all from the great cycle which started approximately 230 million years ago by the opening of the Atlantic Ocean. In reality, however, this picture is more complicated. We can distinguish two cycles: this of the Tethyan ocean and that of the disappearance of the tectonic plate of the Pacific and of the development Atlantic Ocean (Wilson 1968). The former was accomplished in the eastern part of the sea by the Himalayan collision but its beginnings are not clear. According to Stille (1949) the latter can range down to the Algonkian age. The old stage of development is observable in the western, Mediterranean part (Wilson 1968). The second cycle still continues and recent phenomena at the American coasts of the Pacific Ocean indicate further complication of this apparently simple picture as repercussion of changes following the disappearance of the Tethyan ocean. Because of global scale of epeirophoresis, the drift processes in one area influence the origin of magmatic phenomena in our whole planet. This can be exemplified by the episode of Himalayan collision accompanied by an abrupt development of magmatism in all the remaining weak parts of the Earth's crust.

Further complications in an ideal concept of the cycle result from the fact that a collision of continents (depending on their initial distance and average drift velocity) probably interrupts geosynclinal development of a Cordillera (Andean) orogen at various stages of its evolution. Consequently, there are collision endings of real cycles during various stages of geosynclinal development. According to Schneiderhöhn (1952) the abundance of ultrabasic rocks and of intramagmatic ore deposits in the Urals might have resulted from erosional destruction of the main masses of this orogen. It is possible, however, that the collision could weld together the continents before later stages of evolution of the Cordillera orogen developed. Our actual state of knowledge on plate tectonics is as yet inadequate to interpret all the above facts.

Some caution is also necessary because of the abundance of information coming from various laboratories and research centres carrying out intense investigations in this field. Consequently, some of the postulates presented here should be considered as working hypotheses requiring further confirmation.

GLOBAL GEOMAGMATIC-METALLOGENIC CYCLE OF EPEIROPHORESIS

Initial stage

The global cycle of epeirophoresis begins with a reorganization of displacement patterns of the plates of lithosphere (Morgan 1968, Le Pichon 1968, Bird & Dewey 1970). This period is dated by the formation of new deep faults in continental blocks (Wilson 1968) and by the breaking of the oceanic crust plate in the area adjacent to the marginal part of the continental floe — within the zone of a generating geosyncline — subduction zone (Bird & Dewey 1970). The breaking of the oceanic plate, its submergence and remelting within the asthenosphere together with overlaying sialic rocks, considerably influences the chemistry of subsequently developed geosynclinal magmatism. Some deep fractures within continental plates are transformed into rift valleys because of prolonged action of tangential forces caused by epeirophoretic processes. These rifts can be transformed in turn into grabens of the Red Sea type and, finally, due to further divergence of continents and advective addition of material from the Earth's mantle — into mid-oceanic ridges of the Atlantic type (Wilson 1968). Divergent drift is accomplished by the formation of deep fractures called the strike-slip faults. The latter, together with mid-oceanic ridges, from the characteristic global system of dislocations (Heezen & Tharp 1968). Nevertheless, under conditions of oceanic floor, they are not generally the sites of magmatic activity as is the case in mid-oceanic ridges, trenches developed at the foreground of island arcs and guyots. However, along their extension in the adjacent continents, there often occur lineations of magmatic culminations and of associated mineral deposits. Initial drift phenomena are accompanied by the formation of deep fractures intersecting contemporaneous and older magmatic culminations. Through these fractures acid and alkaline granitoids intrude, bearing rich Sn-W, Sn-Nb-Ta mineralizations (Wright 1970).

Early stage

Acceleration of the relative drift velocity of the plates of lithosphere, the underthrusting of the invasive oceanic plate under the continental one within the subduction zone along the Beniof inclination and the destruction of the latter plate by resorption in the Earth's mantle resulted in further subsidence of the geosyncline formed at the frontal margin of the drifting continent. Thus, the evolution of the geosyncline entered into the stage of initial basic volcanism. Following the interpretation of plate tectonics after Dewey & Bird (1970) this volcanism appears when rocks of the oceanic plate are buried at depth exceeding approximately 100 km. It is the product of remelting fragments of the oceanic crust at the foreground of the continental plate, pushed down and underthrust into the asthenosphere within the fundament of a geosyncline. The development of the initial submarine geosynclinal volcanism, spilite-keratophyric in character, is accompanied by the formation of copper-pyrite deposits like these of Rio Tinto, Ergani, Nizhnyj Tagilsk and Fe-Cu-Zn sulphide deposits of the Rammelsberg, Meggen and Atasu type which are known from older geosynclines. Moreover, similar Kuroko ore deposits are Tertiary in age. We known as well the oxide-silicate deposits of the Lahn-Dill type described by Schneiderhöhn (1941).

In the areas of submergence and absorption of the Earth's crust, at the junction of oceanic and continental plates of the lithosphere, surrounded by island arcs, submarine trenches are formed and andesitic volcanism develops (Hess 1938, Wilson 1968, Dewey & Bird 1970). It is known that these processes are not directly associated with the origin of larger ore deposits.

On observations of the rift of the Red Sea (which we can consider to represent an early stage of evolution of frozen submarine ridge) we know that the hydrothermal submarine activity can yield larger concentrations of Fe-Cu-Zn-Ag ores in the bottom deposits of tectonic depths.

In the meantime, within the fundament of drifting plates of the lithosphere (which are not surrounded by marginal Cordillera zone), magmatic culmination can gradually develop. Intrusion of central type penetrate through the newly formed and reopened deep fractures. Initially these consist of alkali ultrabasic magmas representing an early stage of a sequence, terminating with carbonatite volcanism. In the adjacent areas, there appear aggressive emanations giving way to intrusions of mica peridotites, picrite porphyres, proper kimberlites and explosive breccias — forming specific kimberlite diatremes. Locally they are accompanied by zonally distributed effusions of basic lavas.

Table 1

Geomagmatic-metallogenic cycle of the epeirophoresis

Stages of the cycle	General characteristics of the drift	Synchronous processes /geotectonic elements/						
		I Geosynclines formed at the junction of continental and oceanic plate	IIA Continental floe – type A with marginal geosyncline	III Midoceanic ridges	IVB Continental floe – type B surrounded by rift seas	V Zones of collision of two continents /Welds/	VI Submarine trenches at the junction of oceanic and continental plates type O–C	VII Submarine trenches at the junction of oceanic plates type O–O
I Initial pre-drift	Global reconfiguration of the drift	The origin of geosyncline and early stage of subsidence	Linear trends of intrusions of Sn–W-bearing granites in cratonized geosynclines and at the margins of central massifs /Armorican, Czech, Meseta, Malayan-Indinesian/	Initial rifts	Intrusions of Sn- and Sn–Nb–Ta-bearing granites at the intersections of older disjunctive magmatic lineations by dislocations: Egypt-Sudan, Nigeria, SW Africa, E Brasil		Formation of new submarine trenches	Formation of new submarine trenches
II Early	Acceleration of drift movement	Initial magmatism, submarine volcanism. Ore deposits of the Lahn-Dill type, Rammelsberg, Meggen, Urals /older/, Rio Tinto, Ergani /younger/		Further wedge-like opening of rifts, formation of midoceanic ridges. Ore deposits of the Red Sea type	Central alkali-ultrabasic intrusions kimberlites	Preceding trenches and foregrounds of the O–O or O–C type and geosynclines		
III Middle	Maximal drift velocity	Synorogenic peridotite, gabbroic, pyroxenite, dunite, plagiogranite intrusions. Chromite, titanomagnetite deposits, Cordilleras, Andean Mts	Intersection of magmatic lineations by disjunctive dislocations Zn–Pb deposits of the Silesian-Cracovian type, Aachen, Bleiberg	Submarine basalts effusions /exceptionally ultrabasic/	Transition areas Submerged epeirogenic ultrabasic intrusions. Cu–Ni deposits of the Norilsk type Talnakh Insizwa Emerged epeirogenic alkali intrusions of the Kola pennins type. Priazovsk Al–RE			Andesite, basalt volcanism
IV Late	Decrease of the drift velocity	1. Posterogenic granodiorite intrusions 2. Granitoids 3. Small intrusions 4. Skarn magnetite deposits 5. Porphyry Cu, Cu–Mo deposits 6. Various Sn–Ag–Pb–Sb sulphide deposits	Magnetite lineations, volcanic effusions, alkali basalts, teschenites. Zn–Pb deposits Wiesloch. Pb–Sb, Sb–Hg deposits of the Almaden, Hunan type	Submarine basalt effusions	Carbonatites, kimberlites, plateau-basalts	Collision of two continents Uplifted elements: I. Alpine ophite intrusions – Chromite deposits – Pyrite Cu deposits, Caucasus	Overthrusting of oceanic plate on continental one. Pyrite Cu deposits of the Cyprus type, Troodos, New Guinea. Ni deposits /New Caledonia/	
V Final			Volcanic effusions Alkali basalts	Submarine basalt effusions		II. Small intrusions – Hg–Sb–Ag–Au deposits of Transcaucasus, Mediterranian, Okhotsk area		

Middle stage

Further increase of drifting velocity leads to episodic maximal acceleration of the movement, resulting in considerable deformations at the juncture of the plates of lithosphere. In the zones of convergence, at the juncture of drifting plates, such processes as submergence, thermal alteration and assimilation of the Earth's crust will occur. This zone is marked by trends of submarine trenches. Simultaneously, in other parts of the globe, considerable ascension is effected of material from the Earth's mantle. These intrusive processes take place within submarine ridges, deep faults developed within continental floes as well as in areas more distant from marginal zones of a geosyncline.

In the deep fundament of geosynclinal zones of the Cordillera orogen, there proceed large-scale processes of thermal transformation and remelting of the underthrusted part of the oceanic crust. Mobilized melts originated from the Earth's mantle are subjected to gradual differentiation producing magmas. The latter intrude through fractures in both continental and oceanic plates as pre-orogenic ultrabasic intrusives bearing isogenetic intramagmatic chromite deposits. These are followed by synorogenic gabbros. Subsequently, there appears an uplifting of geosynclinal deposits grading into tectogenic and inversion phases (Dewey & Bird 1970). The conditions of magma generation gradually change and basic igneous melts are replaced by intermediate magmas. The latter produce numerous intrusions consisting of the sequence: gabbro-diorite, granodiorite-plagiogranite and gabbro, monzonite, syenite. Granodiorite intrusions are usually surrounded by very widespread skarn ore deposits of the Divrik type, occurring *e.g.* in Iron Springs, Utah, and in Magnitnaya in the Urals.

During this stage of the cycle the process of maximal submergence and annihilation of the oceanic crust continues within submarine trenches developing at the juncture of oceanic plates. This process is accompanied by seismic phenomena and andesite-basalt volcanism.

According to Morgan (1968) and Le Pichon (1968) the drift of plates of the lithosphere is caused not by convection currents but by rotation movement. Because of some inertion of mass motion between the areas of convergence and absorption of the Earth's crust and those where the ocean floor is spreading due to addition of the mantle material, there originate zones of excess of the latter material resulting in the formation of magmatic culminations under the continental plates. Consequently, the weakened parts of the latter are penetrated by igneous intrusions. Because of synchronous epeirogenic movements of plates of the lithosphere the conditions of magma generation can be diversified. Under conditions of epeirogenic submergence of fractured continental blocks, ultrabasic magmas might intrude forming layered lopolithic complexes containing liquation and segregation Ni-Cu deposits of the Norilsk-Talnakh type. Similar ore deposits occur within the Chinese platform and in Insizwa Mts in South Africa. On the other hand, in continental plates, subjected to epeirogenic emergence, alkali magmas intrude. These are abundant in the Kola peninsula (Khibiny and Lovozersky massifs) and the Azovsk sea. In zones where no larger vertical movements had taken place, magmatic culmination in the asthenosphere was manifested by intrusions of numerous kimberlite diatremes and basic effusions. In areas where lineations of culminations of alkali-basic magmas were intersected by younger deep faults, episodic reccurrence of drift phenomena (after longer intervals) causes a revival of hydrothermal activity. Its products from successive ore generations occurring in multi-stage telethermal ore deposits represented *e.g.* by the Silesian-Cracovian Zn-Pb-ore deposits as well as the deposits of Moresnet-Aachen, Cave del Predil, Bleiberg and Sedmocislenici in Europe, and Karatau and Mirgalim in Kazakhstan.

Late stage

A decrease in the displacement velocity of plates of the lithosphere is manifested in geosynclines of marginal continental plates by the increase of isostatic movements and the intrusions of enormous amounts of intermediate and acid magmas to form granodiorite and granite batholiths. This process is separated from the intrusions of preceding stage by a short but intense folding of geosynclinal sediments. The batholiths in question display no symptoms of tectonic phenomena. Their formation is followed by shallow intrusions representing the intercedent plutonism of Stille (1949) and Schneiderhöhn (1952). This plutonism is accompanied by porphyry Cu or Cu-Mo deposits.

The late stage of drift activity is accomplished by collision and welding of continental plates. The Alpine-Himalayan collision corresponds approximately to the age of the above mentioned younger Cu-Mo-bearing intrusions. In some areas the collision of continents ends the cycle under consideration. Moreover, it strongly influences the development of later reconfiguration of drift movements initiating a new cycle. The collision of continents causes a piling up and introduction of large blocks of ophiolitic intrusions formed earlier in eugeosynclines. These contain intramagmatic chromite and titanomagnetite deposits as well as pyritic copper deposits. This type is represented by chromite Guleman deposits in Turkey and Kempirsay in the Urals, whereas magnetite deposits are those of Kusinsk in the Urals as well as pyrite-copper deposits of Rio Tinto (Huelva) in Spain, Ergani Maden in Turkey and Nizhnyj Tagilsk in the Urals.

The overthrusting of the oceanic plate onto a continental one may be another form of collision, probably a derivative one. This mechanism was applied to interpret the structures of Cyprus, New Caledonia and New Guinea (Wilson 1964). The overthrust ultrabasic and basic rocks of the oceanic crust locally contain sulphide copper deposits, represented *e.g.* by those of Troodos masif in Cyprus and Ertsberg in New Guinea. The weathering of ultrabasic rocks in question often results in the formation of secondary silicate nickel deposits, *e.g.* in New Caledonia.

Final stage

No stronger magmatic activity is associated with the period of quiet post-collision epeirophoretic movements, except for periodical basaltic effusions within old mid-oceanic ridges and andesitic volcanism of oceanic trenches. No larger deposits are connected with this weak activity. Only within the collision zones there appear low-temperature hydrothermal activity localized around small post-collision intrusions of acid and alkali basaltic magmas ascending along compensative tectonic fractures: telethermal Hg-As-Sb-Au-ore deposits are formed, such as Almaden in Spain, Monte Amiata in Italy, Idria in Yugoslavia, Dzulfa and Lukhumi in Armenia, Hsi Kuang Shan in China. Investigations of the drift velocity of plates of the lithosphere show that if this velocity is less than 2 inches per year, the juncture zones are aseismic (Le Pichon 1968).

PROBLEM OF REGENERATED ORE DEPOSITS

In the light of the theory of epeirophoresis and of the plate tectonics, the problem of regenerated ore deposits lost its previous meaning. This concept has been introduced by Schneiderhöhn (1952) to explain the origin of the deposits which could not be coordinated with the scheme of metallogenic cycle, constructed for a classical area of geosynclinal evolution. In his opinion, this type of deposits is represented by Zn-Pb Silesian-Cracovian ore deposits as well as by numerous Alpine, Spanish and Tri States deposits, mercury ore deposits, young Sn-Ag-Bi deposits of Bolivia etc.; these have been formed by remobilization of Hercynian ore deposits occurring in the basement. However, the concept of regenerated ore deposits, as proposed by Schneiderhöhn, is actually untenable due to the following facts:

1. Hercynian metallogen was equally barren in Europe as in the Appalachians.

2. Assimilation of underthrusting fragments of the Earth's crust during epeirophoresis within the juncture zones of the convergent plates of the lithosphere leads to a complete homogenization of reabsorbed rock masses and to a dispersion of metal concentrations.

As follows from recent investigations, the number of Hercynian deposits in Europe is negligible (Rösler & Baumann 1971). They are represented only by tin-bearing post-orogenic granites (*e.g.* in Cornwall) or similar deposits occurring outside the zones of Hercynian orogens and are rather associated with initial drift phenomena of continental plates in a give region. The metallogenic sterility of Hercynian intrusions is due to the non-Cordillera type of the orogen. It is obvious that the metallogenic province of the Urals was not taken into account in these considerations on Middle Europe metallogeny (Beloussov & al. 1971).

Outside the Cordillera zone, reabsorption of the downthrusting part of the Earth's crust in the mantle is not accompanied by any stronger hydrothermal activity. If in the neighbourhood of these zones, the absorbed and wholly homogenized material had spread in the mantle and contributed to the formation of hydrothermal ore deposits in the geosyncline and adjacent fractured platform, such ore deposits can, to some extent, be considered as regenerated. This refers, first of all, to ore deposits associated with basic and alkali basic magmas, which are localized in the areas adjacent to the zone of continental collision. These ore deposits are formed before the collision, being synchronous with the period of convergent drift movements. Consequently, we have to consider here the ore deposits localized within the zone of the Himalayan collision (Dar 1968) and in adjacent areas in the Alpine zone. Thus, we have to deal with Zn-Pb-ore deposits of the Alpine zone in Europe and in North Africa as well as with the Silesian-Cracovian ones assigned by Schneiderhöhn to the regenerated ore deposits. An epeirophoretic interpretation of the origin of regenerated deposits is supported by the occurrence of anomalous lead of the Bleiberg type (older than the surrounding rocks) in the first generation of the Silesian-Cracovian ore deposits and in all ore generations of the Alpine deposits. On the other hand, the next generations of ores contain younger lead and the last one — again anomalous lead of the Olkusz type displaying negative model age. The latter is impoverished in post-radioactive isotopes.

It is a problem whether such homogenization of rock masses in the asthenosphere, their subsequent transport into other areas and new emplacement into the Earth's crust can be called regeneration and, consequently, whether ore deposits formed from emanations connected with generation and differentiation of magma may be regarded as regenerated ore deposits. In the present writer's opinion all the deposits considered previously as regenerated will be assigned in this classification to the group associated with basic and alkali-basic magmas.

PREVIOUS CLASSIFICATIONS OF HYPOGENOUS ORE DEPOSITS

So far all the classifications of ore deposits have been based on different criteria. The evolution of the classifications depended on the development of economic geology. The first ones, rather artificial and based on morphological data, were replaced by genetic classifications. The latter were still improved, reflecting the developments in genetic economic geology. Nevertheless, in all the previous classifications attempts were made to take into account possibly all the essential common features delimiting a given type of ore deposits and allowing their distinction. Before presenting the writer's new classification based on epeirophoretic principles, let us briefly sum up the history of the development of these classifications.

The first geognostic descriptions of ore-forming processes and of the resulting ore bodies are due to Agricola (1530) who distinguished such forms as beds, stockwerks and ore veins and presented original interpretations of their genesis. However, the first pertinent attempts of classification are presented by Werner (1791) who, on the composition of ore deposits, distinguished 11 types of ore veins in the Freiberg mining region. Similar criteria were applied by Breithaupt (1849), the author of the concept of ore formation. The latter term was introduced in the course of controversial discussion on the ascension and descension hypotheses.

Further classifications took into account not only the form and composition but also the origin of ore deposits (v. Cotta 1853, v. Sandberger 1877, v. Groddeck 1879, Steltzner & Bergeat 1904—1906). These classifications were developing in the period of discussion concerning the role of lateral secretion in the formation of ore deposits. It should be remembered that this idea, then practically rejected, is recently being revived by White (1957) and Boyle (1970).

More modern classifications introduced an order into economic geology by taking into account physico-chemical processes dominating during their genetical processes. Their elaboration was connected with more detailed studies on magmatic differentiation and the main ore-forming processes. On this principle magmatic-liquation and hydrothermal ore deposits were successively distinguished (Posepny 1893; Vogt 1893; Bohdanowicz 1912; Lindgren 1913; de Launay 1913; Spurr 1907, 1923; Beck & Berg 1922) and the ore deposits subdivided into magmatic, contact, hydrothermal and emanation ones. Hydrothermal ore deposits were in turn subdivided by Lindgren (1913) into hypo-, meso- and epithermal ones, depending on the depth of their formation and by applying P-T criteria. Graton (1933) has supplemented Lindgren's classification by distinguishing leptothermal deposits which he placed between the meso- and epithermal ones while his telethermal deposits were considered as originating closer to the surface than epithermal ones. Those formed at shallow horizons but including high-temperature mineral parageneses were called xenothermal by Buddington (1935).

Regularities of spatial distribution of ore formations relative to the paternal magmatic centre were described by Spurr (1907, 1923) and Emmons (1924, 1927, 1940) in the theory of zonality. Moreover, Emmons (1927) introduced the idea of erosion levels of a batholith, distinguishing hypo-, endo-, em-, epi-, acro- and crypto--batholithic ore levels. Exaggerated vertical extensions of the zones of ore formation, as proposed by Graton (1933), were not confirmed by investigations. Actually it is generally accepted that the majority of hydrothermal ore deposits have been formed at depths not exceeding 5—8 km.

The most logical classifications of ore deposits, taking into account all the previously mentioned criteria, seem to be those proposed by Niggli (1925) and Schneiderhöhn (1944). According to them, the ore deposits are first subdivided into those connected with magmatic intrusions and extrusions. The first group comprises plutonic and volcanic ore deposits. The former are in turn subdivided into: liquid--magmatic including Cr-Pt, Ti-Fe and Ni-Fe-Cu formations, pegmatite-pneumatolytic represented by Sn-W-Mo, Fe and Cu-Bi-Au formations and hydrothermal represented by Au-Ag, Fe-Ni, Cu-Fe-As, Pb-Zn-Ag, U-Fe, Fe-Mn-Ba-F, Bi-Co-Ni-Ag and Sb-Hg formations. The ore deposits associated with extrusive magmatic activity are subdivided into extrusive-hydrothermal and submarine hydrothermal. Moreover, further two groups of ore formations were distinguished: Au-Ag, Cu, Pb-Zn-Ag, Sn-Bi, Sb-Hg and Fe, Mn, Cu-Pb-Zn, S. All together the above classification includes 23 ore formations. Later on, Schneiderhöhn (1952) distinguished a special group of regenerated ore deposits. Not all the names proposed by this author were accepted. Thus, *e.g.* the term "pyrometasomatic ore deposits" was replaced by "skarn ore deposits". The history of development of the concept of ore formation has recently been presented by Rösler & Baumann (1970).

For many years the classifications of Lindgren, Niggli and Schneiderhöhn were considered to meet the requirements of scientific precision and unversality. Consequently, they were generally accepted and applied in economic geology. Gradually, however, these classifications lost their usefullness in prospecting and prognosing of ore deposits. Noble (1955) in his critical revue of these ideas, clearly emphasized that their most important classification criteria are the ore associations, *i.e.* Schneiderhöhn's isogenetic mineral parageneses, the best indices of the primary composition of ore-forming fluids.

Another classification criterion was proposed by Schneiderhöhn (1942) and consisted in determining the relation of the place of origin of ore-forming solutions and the place of deposition of minerals. So far this criterion has not been fully utilized due to lack of data concerning provenance of mineralizing solutions. In this respect numerous divergent hypotheses has been proposed lacking satisfactory premises for classification of ore deposits.

Another helpful criterion was the determination of paternal magma furnishing definite ore metal parageneses. This concept, proposed first by Spurr (1923) and developed by Buddington (1935) and Fersman (1934—1939) was not properly utilized. The difficulty consists, among others, in critical phenomena proceeding in magmatic environment, barring direct transition from crystallizing silicate melt to residual solutions mixing with water. Consequently, except for the extremely alkaline magmas, we do not know in nature any direct transitions manifested by co-occurrence of intramagmatic and pegmatitic as well as of pegmatitic and hydrothermal deposits. The only exception will be found in the occurrence of pegmatites of nepheline syenites with gradual transitions to hydrothermal ore deposits (Ginzburg 1970), also in the association of skarn and greisen ore deposits described by Sokolov & Komarov (1968). Accordingly, any connections of mineral composition of ore deposits and even of individual ore formation with definite magma type can be traced directly only in the case of intramagmatic deposits. In general such relations are deduced indirectly by assignment to the comagmatic petrographic province with which the ore deposits in question are spatially and chronologically associated (Bateman 1942). In spite of the stimulating note by Niggli (1948) that the ore formations are analogous to petrographic ones, the problem remains more complex. Its solution consists not only in determining the primary magma of a given petrographic province, reconstruction of the mineral capacity of parent igneous centre as well as of the mobilization processes and of the mechanism of separation of metal-bearing solutions. Indeed, all the above phenomena are connected with deep-seated processes. This is indicated *e.g.* by recent attempts to connect the mineral composition of more and more ore deposits with the processes within the Earth's mantle. Moreover, very constructive in this respect are studies of the isotope composition of elements (particularly of lead) and the first attempts to explain the association of elements, *e.g.* Zn-Ga met in ore deposits, by radiogenic processes proceeding deep inside our globe (Zakharova 1971). Consequently, in the present attempt of new classification of ore deposits, indication of the parent magma is conditioned by the above limitations.

The concept of a continuous genetic series of orthomagmatic ore deposits (Niggli 1929, 1941) and of the deposits associated with geosynclinal development (Schneiderhöhn 1941) were assumed on the existence of one paternal basaltic magma. Borchert (1957) postulated the evolution of two primary magmas, connecting them with the origin of separate continuous series of endogenous ore deposits; in his opinion, tin and tungsten deposits are associated with palingenetic granites, actually considered to be barren or producing no larger ore deposits. A similar genetic scheme was presented by Kuznetsov (1960). In his opinion, the majority of ore deposits is associated with differentiation of basic magmas, whereas the remaining ones — with hybrid granitic magma and only Sn, W, Be and Nb-Ta-ore deposits with pure granitic magma.

The tendency to explain the formation of ore deposits on the existence of one paternal magma for the whole petrographic province was strongly undermined by the theory of pyrolitic structure of the Earth's mantle and by the results of experimental investigations on fractional melting of various rocks occurring at considerable depths (Green & Ringwood 1967, Green 1968, Wyllie 1968). Actually, we know that there may exist several independent mechanisms of magma generation, depending on geotectonic conditions. It should be mentioned that similar conclusions result from the development of ideas trying to connect ore formation with petrographic provinces and with various types of parent magmas. This idea was further developed by studies of the evolution of geosynclines as well as of the stages of magmatism and associated ore formations (Turner & Verhoogen 1960, Kuznetsov 1964, Wager & Brown 1968). On the other hand, examination of ore deposits occurring within geosynclinal areas resulted in large-scale application of geotectonic criteria for their classification. This concept was initiated by de Launay (1913) but essential data concerning the geotectonic position of ore deposits were given no sooner than by Schneiderhöhn (1944). More details on this subject were presented by Borchert (1957) and others. Important contributions to the development of geotectonic classification of ore deposits have been made by Soviet geologists: S. S. Smirnov (1947), Bilibin (1955), Kuznetsov (1960), V. I. Smirnov (1963), Konstantinov & al. (1969), Zakharov (1963), Tvalchrelidze (1966) and Shcheglov (1968, 1971). Their papers were devoted mainly to ore deposits of geosynclinal zones; they distinguished in general the ore formations of folded eugeosynclinal zones and of the platform areas (parageosynclines). In their opinion, following Stille (1940) and Schneiderhöhn (1941), the formed deposits were associated with ultrabasic initial, intermediate synorogenic and final acid magmatism. Similarly, they distinguish eu- and mio-geosynclines depending on the occurrence or lack of initial magmatism. Nevertheless, numerous data could not be included into an uniform classification system based on one model of evolution of the geosyncline orogen and initial cratonal stages. Some new tendencies in this branch of metallogeny were first presented by Smirnov (1963). However, a completely new occasion of classifying ore deposits has been mainly furnished by the theory of epeirophoresis and the recently developed plate tectonics.

NEW CLASSIFICATION OF ORE DEPOSITS BASED ON EPEIROPHORETIC PRINCIPLES

The establishment of the theory of epeirophoresis was accompanied by many geotectonic ideas being discredited and replaced by new ones. The global scale of numerous synchronously developing geotectonic phenomena was the basis for distinguishing a superior cycle of epeirophoresis. It comprises both the cycle of geosynclinal-orogenic evolution of the Cordillera (Andean) type, developing within the marginal zone of continental plates and the origin of submarine trenches succeeded by geosynclinal development interrupted by the collision of two continents. This superior ideal cycle also comprises geotectonic and geomagmatic phenomena taking place synchronously within continental plates. An analysis of these processes, viewing the possibilities of the formation of ore deposits, leads to a new geotectonic classification of these deposits based on the theory of epeirophoresis and on general principles of plate tectonics (Table 2 and Fig. 1).

In this attempt it is intended to take into account all the accepted concepts of previous classifications based on Lindgren's, Niggli's and Schneiderhöhn's physico-chemical criteria. The new concept of classification elaborated by the present writer on actual geotectonic principles, unites in one uniform system all the available data concerning the common features of ore deposits. It takes into account the geotectonic position of ore deposits from the point of view of the theory of epeirophoresis as well as the type of parent magma, and the depth of their formation. Typical forms of ore deposits and geotectonic structures are illustrated by means of corresponding symbols. Accepting the theory of epeirophoresis and the principles of plate tectonics, the following main zones showing uniform type of tectonomagmatic processes are distinguished.

1. Geosynclines developed at the juncture of continental and oceanic plates, later transformed into orogens of the Cordillera (Andean) type;
2. Orogenic piling up in the zone of collision of two continents (weld of continents) usually preceded by submarine trenches and by eugeosynclinal evolution;
3. Submarine trenches resulting from reabsorption of the oceanic crust below the island arcs and taking place at the juncture of oceanic and continental plates;
4. Submarine trenches at the juncture of oceanic plates;
5. Mid-oceanic ridges;
6. Continental plates surrounded by geosynclinal zones;
7. Continental plates surrounded by rift sea.

Because of their subordinate significance in economic geology, the zones of submarine trenches have not been distinguished in this classification. Trenches and eugeosynclines formed at the juncture of oceanic and continental plates are presented jointly in the final stage of their development, *i.e.* after the collision of continents and uplifting of ultrabasic rocks bearing intramagmatic deposits. The case of thrusting the oceanic crust over the continental one is discussed in the chapter dealing with the epeirophoretic cycle. In general, it also leads to the formation of ore deposits associated with basic and ultrabasic rocks. These were omitted in the proposed projection since ore deposits of this type represent but one of he cases of a more general rule. Consequently, only one type of collision was presented uplifting and piling up ultrabasic rocks. Typical ore deposits of this type were chosen first of all from the Alpine zone and from the Urals, since both these orogens display some evidence of similar development during early geosynclinal stages.

Indeed, the first stages of evolution of a geosyncline interrupted by collision of continents or leading to Cordillera orogen, are only apparently the same. In fact, the rock series of orogens of the first type contain large chromite and pyrite-copper deposits while those of the second type bear considerably smaller mineralization. Though this difference may be due to the squeezing of rocks from the depths of the Earth only, it is essential enough for their separation in the proposed classification.

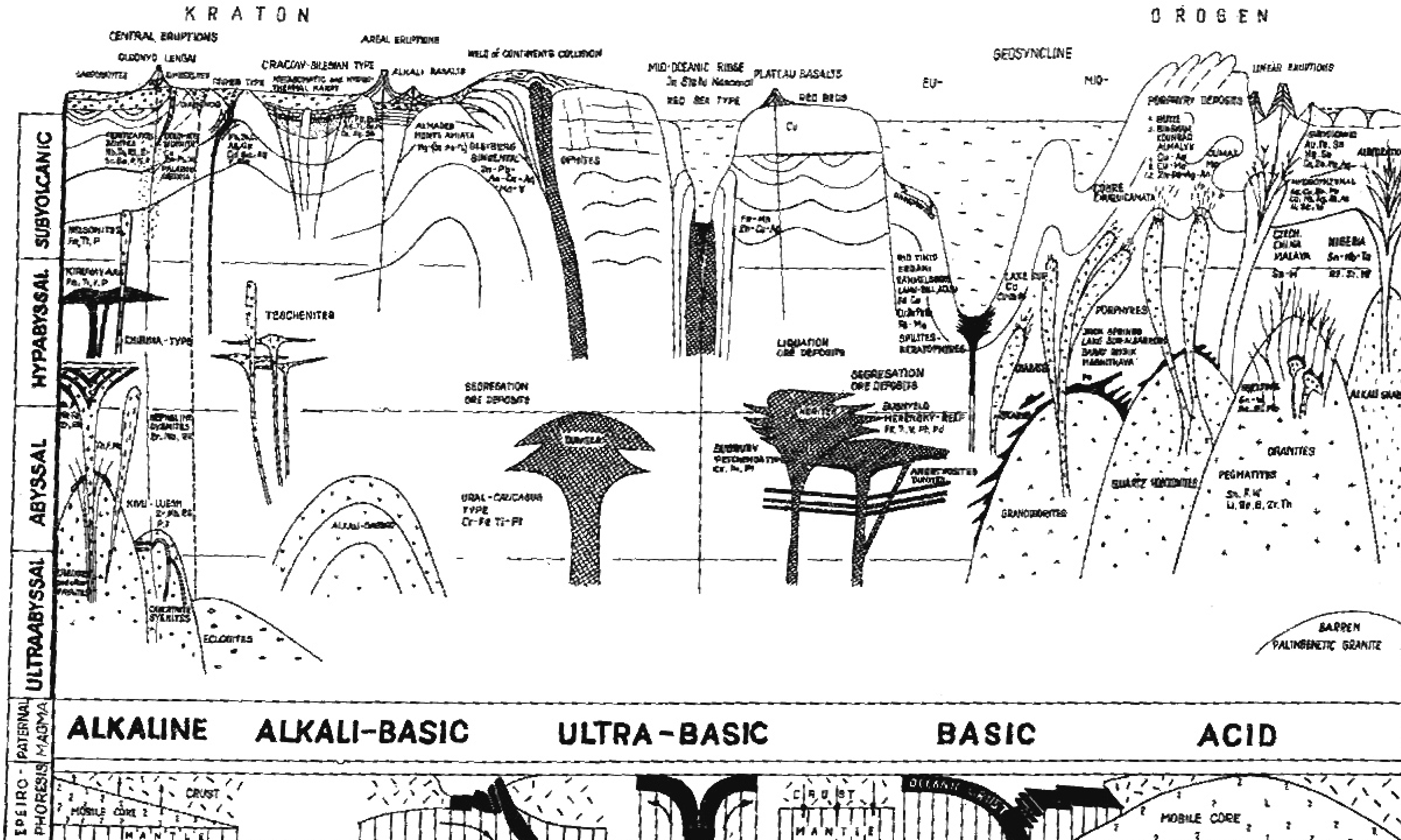
Table 2

New classification of ore deposits

Geotectonic zone of the lithosphere plates	Parent magma	Magmatic formation	Conditions of origin: Phylogenesis*	Conditions of origin: Ontogenesis*	Ore formation	Characteristic minerals of the formation	Characteristic trace elements	Typical ore deposits
1	2	3	4	5	6	7	8	9
I Riftogenic	Basic	Basalts, ultrabasites	Subaqueous hydrothermal activity associated with operation of the ridge	Sediments	1. Zn-Cu-Fe-Mn	Hydrated oxides, sulphides		1. Atlantis and Chillinger deep in the Red Sea
II Zone of Cordillera /Andean/ orogens at the margin of continental plate	Ultrabasic	1. Diabase-keratophyre; 2. Gabbro-pyroxenite-diorite	Subsidence of geosyncline	Sediments, lava flows, shallow intrusions	2. Fe-Cu	Pyrite, chalcopyrite		2. Shasta County, [illegible], Britannia Beach /Cordilleras/
					3. Cu-Zn-Pb-Ba	Chalcopyrite, sphalerite, galena, barite		3. Rammelsberg, Meggen, [illegible] /Europe/, Atasu /Kazakhstan/, Kuroko /Japan/
	Basic	3. Gabbro-diorite	Cordillera /Andean/ orogen		4. Fe-Mn	Iron silicates, Mn oxides, Fe oxides	P, Sr, Ba	4. [illegible], Precambrian jaspilites
		4. Gabbro-plagiogranite		Skarn	5. Fe	Magnetite		5. [illegible], Banat /Europe/, Iron Springs /USA/, El Algarrobo /Chile/, Magnitnaya /Urals/
		5. Gabbro-diorite-granodiorite			6. Fe-B	Magnetite, ludwigite, kotoite, szaibelyite, garnet		6. Iron [illegible], [illegible] /USA/, [illegible] /Europe/, [illegible] /E Siberia/, [illegible] /Korea/
	Acid				7. Fe-Co-Cu-Zn-Pb	Magnetite, safflorite, cobaltite, glaucodot, hematite		7. Co: Dashkesan /Caucasus/, Khovu-Aksy /Tuva/; Cu: Clifton Mts /USA/, Sayak /Kazakhstan/; Zn: Tetyukhe /USSR/
		6. Gabbro-[illegible]		Pegmatites	8. Au-B	Tourmaline, pyrrhotite, native gold		8. Morro Velho, Kirkland Lake, [illegible] /USA/, Kolar /India/
				Porphyry deposits hypomesothermal	9. Cu-quartz; 10. Cu-As	Chalcopyrite; Chalcopyrite, enargite	Re, Te, Se, Bi, Ag, Au	9–12. Chuquicamata, [illegible], Butte, Bingham /America/, [illegible], Almalyk, [illegible], Agarak, [illegible] /USSR/
					11. Cu-Mo	Chalcopyrite, molybdenite		
					12. Zn-Pb-Ag-Au	Chalcopyrite, sphalerite, galena		
		7. Effusive: dacite-andesite-liparite	Intermediate volcanism		13. Cu-Zn-Pb-As-Au-Se-Te	Gold selenides and tellurides		13. Kalgoorlie
					14. Ag-Sn-W-Bi-Pb	Sn sulphosalts	In	14. Llallagua, Poopo, Potosi
III Zone of collision of two continents	Ultrabasic	1. Diabase-spilite-keratophyre	Geosynclinal intrusions exposed by collision	Sediments, lava flows, extrusions	15. Fe-Cu	Pyrite, chalcopyrite	Co	15. Rio Tinto, Ergani Maden, [illegible]
		2. Gabbro-peridotite /serpentinized/		Intramagmatic, segregation	16. Cr	Chromite	Pt, Ir, Os	16. Guleman, [illegible] /Caucasus/, [illegible] and others /Urals/
		3. Basalt-andesite-liparite	Hydrothermal post-collision activity	Teletherm	17. Hg-Sb	Cinnabar, antimonite	As, W	17. Almaden, Monte Amiata, Idria, [illegible]
					18. Sb-Hg-W	Antimonite, cinnabar, ferberite	As	18. [illegible]
					19. As-Tl-Hg-Sb	Realgar, orpiment, vrbaite, lorandite		19. Allchar, [illegible]
				Subvolcanic	20. Ag-Au-Se-Te-Bi	Gold and silver selenides and tellurides		20. Cripple Creek, Baia Mare, Baia Sprie, Kapnik, [illegible]
IV Zone of initial drift fractures of continental plate and quasi-consolidated geosynclines	Acid	1. Sn-W-bearing granites	Intrusions heralding continental drift	Skarns	21. W-Mo-Cu	Scheelite, molybdenite, cassiterite		21. Azegour /Morocco/, [illegible] /China/
				Greisens	22. Sn-W-F	Cassiterite, wolframite, topaz, sericite	Be, In, Nb, Li, Cs	22–24. Erzgebirge Mts, [illegible], Malayan Peninsula, China
				Hypothermal	23. Sn-quartz; 24. W-Mo-quartz	Cassiterite, quartz; wolframite, molybdenite, quartz	Li	
					25. Sn-Cu-Zn-Pb	Cassiterite, stannite, Cu, Zn and Pb sulphides		25. E Siberia
		2. Nb-Ta-bearing alkali granites	Central intrusions	Pegmatites	26. Li-Be-Cs-Ta-Nb	Lepidolite, beryl	Nb, Ta, Cs, Hf, Rb, Be, TR_{Ce}	26. Uganda
				Hypothermal albitization zone	27. Sn-Nb-Ta	Columbite, cassiterite		27. Nigeria, SW Africa
				Rare skarns	28. Fe-B	Magnetite, ludwigite, fluorite		28. Iron Mountain /USA/, Nigeria
		3. Granitoids		Hypothermal	29. Fe-Zn; 30. Be-F	Franklinite, zincite; Fluorite, bertrandite, phenakite	Sn	29. Franklin Furnace; 30. [illegible] /Alaska/, E Siberia
					31. quartz-Au-As	Pyrite, gold, arsenopyrite		31. Mother Lode, Fairbanks, Yukon, [illegible], Verkhoyansk Mts, [illegible]
V Zone of fractures and of epeirogenic submergence of continental plate	Ultrabasic	1. Anorthosite	Lopolithic layered intrusions	Intramagmatic, segregation	32. Fe-Ti	Titanomagnetite, ilmenite	V, sometimes Cu, Pt	32. Bushveld, Merensky Reef, [illegible]
		2. Ultrabasite		Liquation	33. Cu-Ni-Pt	Pyrrhotite, pentlandite, sperrylite, Pt minerals, nickel and cobalt sulphides and arsenides	Pt, Os, Ir, Pd, Rh, Ru, Co, Se, Te, Ag, Au, S	33. Norilsk, Talnakh, [illegible], Sudbury, Stillwater, [illegible]
		3. Trap	Diatremes	Segregation	34. Fe	Magnesioferrite, magnomagnetite, hematite, carbonates	Co, Ni	34. [illegible]
VI Zone of fractures of continental plate	Alkali-basic	1. Alkali olivine basalts and basanites	Magmatic liquations with points of hydrothermal activity	Multi-stage epi- and teletherm	35. Fe-U; 36. Fe-Ba /Mn/	Pitchblende; Barite, fluorite, iron and manganese oxides	Se, Te	35. Joachimov, [illegible]; 36. [illegible], Erzgebirge Mts, Harz, Sardinia
					37. Ag-Co-Ni-Bi-U	Ni and Co arsenides, native As and Bi		37. Freiberg, Schneeberg, Wittichen, Kongsberg, Cobalt-Ontario
		2. Alkali nepheline basalts			38. Pb-Ag; 39. Hg-Sb-Pb-Ba	[illegible], calcite, wurtzite, [illegible], [illegible], [illegible], jordanite	As, Tl, Ge, Mo/Cu, Ag, Sb, Ga	38. Freiberg, Wittichen, [illegible]; 39. Silesian-Cracovian, Cave del Predil, Pine Point, Tri-States
					40. Cu-As-Pb-Zn-Cd-Ge-Ga	Chalcocite, enargite, germanite, reniérite	V, Mo	40. Tsumeb
VII Fractured zone of epeirogenically continental plate	Alkaline	1. Agpaitic nepheline syenite	Layered intrusions	Intramagmatic	41. Al-P	Apatite, nepheline, loparite	Nb, Ta, Zr, TR_{Ce}, Hf, Th	41–42. Khibiny, Lovozero massif
				Pegmatites	42. Li-Ta-Nb-Be-Zr-TR_{Ce}-Cs-Sn-Mo	Li micas, phlogopite, zircon, tantalo-columbite, cassiterite, ilmenite, molybdenite		
	Alkali-ultrabasic to alkaline	2. Alkali-ultrabasic-carbonatite	Central intrusions	Fluidization zones, volcanic necks, hydrothermal subvolcanic	43. P-Nb-Ta-TR_{Ce}-Zr-Fe-F	Calcite, dolomite, apatite, phlogopite, pyrochlore, bastnäsite, parisite, zircon, magnetite, apatite, perovskite	Sr, U, Th	43. Africa, Siberia, Scandinavia, North America, Brazil, Australia
					44. Cu-Zn-Pb-Mo	Bornite, sphalerite, molybdenite		44. Palabora, Siberia
		3. Kimberlite	Diatremes	Eluvium, alluvium	45. C	Diamond, pyrope, chromium diopside, magnesium ilmenite, magnochromite		45. Africa, Siberia, Brazil
		4. Syenite magnetite-apatite rocks	Intrusions	Intramagmatic	46. Fe-P	Magnetite, apatite	V	46. Kiirunavaara, Gällivare
		5. Nelsonite	Dykes	Intramagmatic	47. Fe-Ti-P	Rutile, magnetite, ilmenite, apatite		47. Nelson, Amherst, County, Virginia /USA/, St. Charles, Quebec

* Onto- and phylogenesis — biological terms applied to ore deposits by Grigorev ([illegible]).

Magma and ore deposits



As follows from previously discussed general petrologic tendencies and the theory of epeirophoresis, the actual approach to the problem of primary magma of the whole petrographic and associated metallogenic provinces differs slightly from that formerly accepted. The same refers to the genetic interpretation of the sequence of intrusions. Much greater role is assigned to geotectonic processes and their development. It is supposed that these very processes determine the origin of various magmas and that the role of fractional crystallization during the cooling of silicate melts is much less important than it was previously considered. Seven main independent petrographic associations, genetically connected with various groups of ore deposits, are distinguished. It is assumed that the rocks of these associations were formed from different "primary magmas" originated under definite, periodicly repeating geotectonic processes of epeirophoresis. The latter generate successively various magmas and definite differentiation series as well as comagmatic ore deposits of global metallogenic provinces.

These associations are as follows:

1. Intrusive granite and alkali granite magmas appearing in continents and heralding new evolution of epeirophoretic processes. Greisen and hydrothermal Sn-W, Be and Nb-Ta-ore deposits are herein associated.
2. Magmas of petrographic sequence of geosyncline — orogen of the Cordillera (Andean) type development consisting of a great variety of intrusive rocks from ultrabasic to acidic. All these series display rather low alkalinity. It is known that small chromite and pyrite deposits, larger skarn ore deposits and very large porhyry Cu and Cu-Mo as well as Mo-ore deposits are associated with this magmatism. These are accompanied by smaller Zn-Pb-Ag sulphide deposits and magmatically heterogeneous Bi-Ag-Sn sulphide deposits.
3. Ultrabasic magmas of geosynclinal ophiolite intrusions of the Alpine type. This magmatism precedes collision of continents. Post-collision volcanic phenomena are usually represented by alkali-basaltic and acid lavas. The former is accompanied by large intramagmatic Cr, Fe-Ti and Pt-ore deposits and geosynclinal pyritic copper deposits. Hydrothermal Hg-Sb-As-Tl-ore deposits can also be associated with post-collision magmatism.
4. Gabbro and ultrabasic magmas of lopolithic intrusions occurring in fractured, epeirogenically depressing cratonic blocks. Segregation Fe, Fe-Ti, V, Pt and Pd--ore deposits and liquation Cu-Ni (Co-Pt) deposits are associated with them.
5. Alkali-basaltic lavas (alkali gabbro suite) of continental areas are aligned in volcanic chains. The associated hydrothermal ore deposits formed intermittently between the periods of volcanic activity are controlled by the same fractures. These deposits are mainly represented by Zn-Pb-Ba hydrothermal-karst mineralization in carbonate platform cover.
6. Alkali magmas of layered intrusions and ultrabasic magmas grading into carbonatite ones, forming central intrusions and bearing Nb-Ta, Zr, TR, Al and P-deposits.
7. Specialized magmas of eutectic phosphate-magnetite composition, nelsonites, kimberlites, mica peridotites of diamond-bearing diatremes with associated iron and diamond deposits.

In the proposed classification 47 main ore formations are distinguished. Less important and transitional ore formations and groups of ore deposits as well as mineral associations of polygenic origin and peculiar cases connected with heterogeneous topomineral conditions were not taken into account. Moreover, it was not possibly to present heterogeneous deposits, the ore formation of which associated with various mineralization phases are ascribed to different types of parent magma.

It should be mentioned that transitional ore deposits, derivates of alkali-acid magma, are presented in the classification chart within the field of acid magmas. For simplification purposes, the differences in thickness of sialic crust were neglected in the scheme shown here.

FINAL REMARKS

This first geotectonic classification of endogenous ore deposits, based on principles of the theory of epeirophoresis, plate tectonics and on the new concept of global metallogenic cycle, seems to represent further progress toward better understanding of ore-forming processes and of the source of mineral substances concentrated in endogenous ore deposits. The reality of the present classification and of the new concept of the cycle depends on the correctness of the theory of epeirophoresis and its implications to economic geology. This theory enables better understanding of the nature of magmatic processes, developed in different tectonic zones of the Earth's crust. Moreover, it throws a new light on direct relation between the chemical composition of deeper parts of our globe, mobilization processes taking place during magma generation by complete or partial melting and degasification of pyrolite — and the composition of the formed ore deposits. It is supposed that further development of the theory of epeirophoresis and a more detailed reconstruction of the history of the Earth's crust will promote our knowledge concerning geological processes determining the formation of endogenous ore deposits.

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POWSTAWANIE ZŁÓŻ RUD W PROCESACH EPEJROFOREZY

(Streszczenie)

Przedmiotem pracy jest dyskusja nad genezą złóż rud pochodzenia magmowego i związek ich z procesami przesuwania się (dryftu) kontynentów, czyli epejroforezy. W pracy przedstawiono rozwój poglądów na pozycję geotektoniczną szeregu gromad złóż, wskazując na przeddryftowe pochodzenie intruzji granitów cynonośnych i synchroniczne z dryftem pochodzenie śródkratonalnych intruzji magm zasadowych (Cu-Ni-nośnych), centralnych intruzji karbonatytowych i diatrem kimberlitowych oraz niektórych złóż hydrotermalnych. Omówiono ponadto porfirowe złoża (Cu i Cu--Mo) pasa metalogenicznego Tetydy i Pacyfiku, oraz wieloetapowe heterogeniczne złoża hydrotermalne. Przedstawiono nowe sformułowanie pojęcia cyklu metalogenicznego, a obejmujące rezultaty synchronicznych zjawisk w różnych strefach płyt tektonicznych. Na tle dyskusji o dawniejszych klasyfikacjach przedstawiono nową, geotektoniczną klasyfikację złóż endogenicznych, opracowaną z uwzględnieniem teorii epejroforezy. Porządkuje ona główne typy złóż i 47 formacji złożowych w poszczególnych strefach geotektonicznych, a mianowicie — grzbietu śródkowooceanicznego, orogenu typu kordylierowego, obszaru kolizji dwóch kontynentów, oraz w czterech typach stref płyt kontynentalnych pociętych dyslokacjami (tab. 1—2). Rozpatrzono także charakter magmy macierzystej złóż, formacje magmowe poszczególnych stref, warunki formowania złóż, paragenezy mineralne i pierwiastków śladowych, przedstawiając jednocześnie liczne przykłady złóż wzorcowych (*por.* fig. 1).

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