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Geomagmatism, Pulsations of the Earth, and Phanerozoic Minerageny

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Abstract—Discontinuity and periodicity of tectonic processes, eustatic fluctuations of the ocean level, volcanic and metallogenic activity, and some other global processes in the Earth's history are indicative of the pulsatory nature of the Earth's evolution. Correlation of geomagnetic field variations with global geological processes shows the geomagnetic field polarity to be an indicator of pulsations. The phases of the Earth's expansion correspond to normal (present-day) polarity, and the planet's contraction to epochs of reversed polarity. In terms of the concept of geopulsations, the diversity of basic geodynamic regimes of continents is determined by the combination of three factors: the phases of the Earth's evolution (contraction–expansion), the effects of deep fluid and heat flows (plumes), and the state of the asthenosphere (its depth, thickness, and degree of heating). The general evolution of Phanerozoic ore deposition and the specific metallogenic features of tectonomagmatic cycles may be considered in a new light in view of the Earth's pulsatory history.

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Problems of the Earth's evolution have been a constant focus of attention of researchers for a long time. The voluminous information acquired on the geological structure of individual regions and the world as a whole, a definite isotopic age of igneous and metamorphic rocks, results of recent geophysical studies, and progress in marine geology allow the evolution of the planet to be considered from a new standpoint.

One promising line in geological research is the study of time-dependent variations in geophysical fields as reflections of the Earth's evolution.

At present, the Phanerozoic geomagnetic field is studied most extensively. A general magnetostratigraphic scale of polarity for the Phanerozoic compiled on the basis of numerous paleomagnetic data (*Paleomagnetology*, 1982; Khramov and Molostovsky, 1997) is in good agreement with scales elaborated for individual periods (Cox, 1969; Irving and Pullaiah, 1976; Harland et al., 1982).

Chrons (10^5–10^6 yr), superchrons (10^6–10^7 yr), and hyperchrons (10–100 Ma) are the time units on this scale that are characterized by specific manifestations of the geomagnetic field polarity.

As the time interval of global geological events that reflect the Earth's history is tens of millions of years long, polarity superchrons are proportional to these events. Superchrons with dominantly normal (present-day) polarity and with reversed polarity are distinguished. Mixed-polarity superchrons, characterized by frequent reversals of the geomagnetic field, were also revealed in the Mesozoic and Cenozoic. Individual short-term polarity variations, which widely show up in those time intervals (Irving and Pullaiah, 1976; Cox, 1981; *Paleomagnetology*, 1982), are of different physical nature in comparison to superchrons of dominant polarity and are related to a nondipole component of the geomagnetic field. Such reversals conceal the dominant polarity, but the detailed consideration of superchrons with regard to the global manifestation of reversals and the total duration of periods of normal and reversed polarity allows the dominant polarity to be determined. The generalization of the paleomagnetic scale carried out resulted in 23 Phanerozoic superchrons that are characterized by the predominance of one polarity being distinguished, which have durations of 10–50 Ma (Fig. 1).

The consideration of the paleomagnetic scale shows that two major hyperchrons with different polarity are recognized in the Phanerozoic: the Paleozoic hyperchron, mainly with reversed polarity (about 70% of the period duration), and the Mesozoic–Cenozoic hyperchron, dominantly with normal polarity (about 75% of the period duration).

In the Paleozoic, against the background of the prevalent reversed polarity, the following superchrons mainly with normal polarity are pointed out: Middle Cambrian (Mayan Age)–Late Cambrian, Middle Ordovician–Early Silurian (Llandoverian), Early Devonian (late Emsian)–Late Devonian (Frasnian), Early Carboniferous (Serpukhovian)–Middle Carboniferous, and Early Permian (Asselian–Artinskian); in the Meso-

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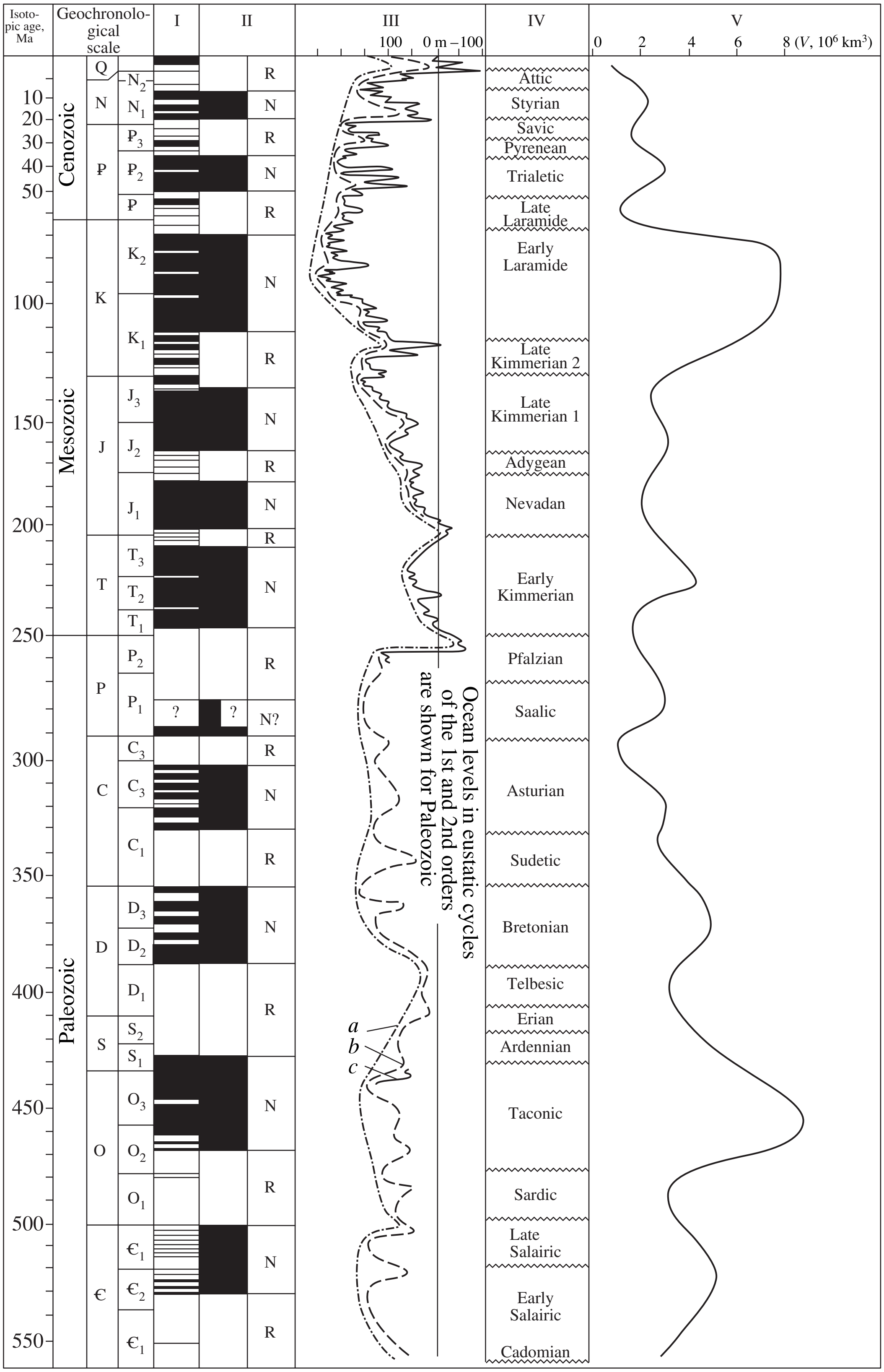

Fig. 1. Correlation of variations in the geomagnetic field polarity with global geological processes in the Phanerozoic. (I) Paleomagnetic scale (*Paleomagnetology,* 1982): black is normal polarity, white is reversed polarity; (II) generalized scale (N is superchrons of normal polarity, R is superchrons of reversed polarity); (III) curves of eustatic level fluctuations (Harland et al., 1982): (a) first order, (b) second order, (c) third order; (IV) phases of folding (modified after Stille, 1964); (V) curve of intensity of volcanic activity (Ronov, 1993).

zoic–Cenozoic, against the background of normal polarity, superchrons with predominant reversed polarity are notable: Late Triassic (Norian Age)–Early Jurassic (Hettangian), Early Jurassic (Toarcian)–Middle Jurassic (Aalenian), Late Jurassic (Volgian)–Early Cretaceous (Hauterivian), Late Cretaceous (Maastrichtian)–Early Eocene, and Oligocene–Miocene (Caucasian Age).

Further, the correlation of geomagnetic polarity regimes with the most important and best studied global geological phenomena, including eustatic fluctuations, peaks of volcanic activity, and phases of folding, is considered.

Curves of eustatic fluctuations (Harland et al., 1982), distribution of volcanic rocks by geological periods (Ronov, 1993), and main folding phases (Stille, 1964) supplemented with information taken from a paper by Milanovsky (1995) were used as indicators of these global geological phenomena.

The comparison of the paleomagnetic scale with curves of global geological events (Fig. 1) shows that ocean transgressions and peaks of volcanism are typical of superchrons with dominant normal polarity. Superchrons with prevalent reversed polarity are characterized by global regressions; waning volcanic activity; and global development of folding, thrusting, and strike-slip deformations (phases of folding).

Thus, the comparison of the Phanerozoic paleomagnetic scale and global geological events demonstrates that the latter are clearly correlated with the direction of the Earth's magnetic field polarity; this relationship has escaped the attention of researchers.

Fixism and mobilism as tectonic paradigms, which explain differently the mechanism of geodynamic processes in the lithosphere and provide different views on the Earth's evolution, are currently predominant in geology. Views of different tectonic schools on the problem are expounded in numerous publications. It should also be noted that in recent years attention has often been focused on models of the planet's evolution that are based on the abandonment of the postulate on immutability of the geometric parameters of the globe (rotary pulsation and contraction models, the model of the expanding Earth, etc.).

I believe that the periodicity and discontinuity of key global geological events can be best explained by the pulsatory evolution of the Earth.

The concept of the pulsatory evolution of the Earth (periodic variations in its volume) emerged in the 1920s and 1930s, being associated with the names of V. Bucher, M.M. Tetyaev, and M.A. Usov. Later, F. Ahmad, V.P. Kazarinov, N.S. Mart'yanov, E.E. Milanovsky, R. Sheridan, and others became engaged in its elaboration.

The model of the pulsatory evolution of the Earth is based on a series of empirically established relationships: periodic multiple alternation of epochs of contraction (folding) and expansion (rifting) (Kaz'min, 1975; Milanovsky, 1984, 1995; Khain, 2000); epochs of relief peneplanation and aggravation of geomorphic contrasts and, accordingly, denudation processes (Kazarinov, 1971); global transgressions and regressions (Ronov, 1993; Harland et al., 1982); epochs of intense volcanic activity and its waning (Ronov, 1993); discontinuity and periodicity of ore deposition (Smirnov, 1982, 1984; Rundquist, 1969, 1997); the cyclic nature of climatic changes (Yasamanov, 1985); biotic crises (Krasilov, 1987; Alekseev, 2000); etc.

As Milanovsky (1984, 1995) stated, the stages of the Earth's expansion (increase in its volume) were characterized by pull-apart structures on continents (rifts, aulacogens, mobile belts); generation of oceanic basins as zones of intense spreading and ascent of mantle rocks; global transgressions related to a decrease in the average depth of the ocean floor due to more intense rise and growth of intraoceanic ridges as compared to continents; and intensification of volcanic activity as a response to energy release from the Earth's interior and an increase in lithosphere permeability. Variations in the water volume of the World Ocean owing to mantle degassing also play a part in the rise in the ocean level. Degassing becomes more intense in phases of the Earth's expansion, when magma and fluid conduits open up and volcanism reactivates. Epochs of the Earth's contraction are characterized by global intensification of folding and thrusting, mountain building, global lowering of the sea level (regression) caused by a relative submergence of the ocean floor due to the rising of continents and the sagging of mid-ocean ridges, and waning volcanic activity related to cooling of the Earth's interior and decreasing permeability of the lithosphere.

Thus, the correlation of global geological processes with the geomagnetic field polarity may be stated in terms of pulsations of the Earth as follows: phases of the planet's expansion correspond to periods of normal (present-day) polarity of the geomagnetic field, and phases of its contraction, to epochs of reversed polarity.

This relationship is also confirmed in considering the history of the Phanerozoic at the hyperchron scale. In the opinion of Khain and Bozhko (1988) and other specialists in tectonics, the Paleozoic hyperchron of dominantly reversed polarity is characterized by the closure of ancient oceans and the formation of the Pangea II supercontinent, which, in terms of geopulsations, corresponds to the planet contraction. The Mesozoic–Cenozoic hyperchron, in which normal (present-day) polarity predominates, is characterized by the supercontinent breakdown, the formation of young oceans, and an increase in the Pacific area, which accords with an increase in the Earth's volume.

One of the key problems of each global tectonic model is the energy of the process. The correlation of the Earth's pulsation with variations in the geomagnetic field polarity is indicative of the interrelation of these phenomena. The magnetostriction effect as a possible mechanism causing geopulsations was suggested previously by Popov and Stromov (1996). This physical phenomenon, known since the 19th century, implies a change in the dimensions of a magnet under the effect of external magnetic fields. The phenomenon was described in detail by N.S. Akulov, K.P. Belov, and R. Bozorth and is widely used in engineering, for instance, in ultrasound oscillators. The greatest changes in the geometric parameters of the magnet take place during magnetization reversal. The magnet contracts or expands depending on the direction of the external magnetic field. According to laboratory studies, the changes in the geometry of magnets vary from hundredth fractions to 3–7% depending on their composition (Belov, 1980).

Moving within the Universe, our planet, possessing its own magnetic field, is subjected to magnetic fields of outer space. Sources of such fields may be magnetic stars revealed by astrophysicists and the regular magnetic field in the spiral arms of the Galaxy (Parker, 1979). Being affected by external magnetic fields, the Earth experiences contraction or expansion depending on the direction of field lines crossing it.

Of great importance in accounting for tectonomagmatic processes is also the magnetothermal effect, which accompanies the interaction of magnetic fields. When a magnet is magnetized by an external field, thermal energy is released, and demagnetization is accompanied by magnetic cooling, which is used in practice, for instance, in obtaining ultralow temperatures.

It should be noted that the suggested mechanism of geopulsations is described here only schematically and elaboration of a physical model of the process requires the involvement of specialists on magnetism and astrophysics.

Based on the concept of the pulsatory evolution of the Earth, let us consider the origin and evolution of the main geodynamic settings of continents. Magmatism is one of the most important indicators of endogenic regimes. In analyzing the distribution curves of volcanic rocks on continents (Fig. 2) plotted after Ronov (1993), one can clearly see that volcanism in the Phanerozoic mobile belts and platforms developed nonuniformly: peaks of volcanic activity alternate with periods of waning.

Maxima of volcanic activity in mobile belts often correspond to its waning on platforms, and, vice versa, peaks of platform volcanism accompany its waning in mobile belts. The lag of volcanic activity on platforms relative to its peaks in mobile belts amounts to 30–40 Ma. The only exception is the Late Mesozoic–Cenozoic volcanic activity, when Cretaceous, Eocene, and Miocene volcanic peaks coincided in both tectonic settings.

According to the current ideas (Larson and Olson, 1991; Grachev, 2000), platform (intraplate) volcanism is closely related to the so-called plumes and hot spots that mark fluid and heat flows ascending from the lower mantle. The existence of such plumes has recently been confirmed by seismotomographic results that revealed large through seismic heterogeneities in the Earth's mantle (Su et al., 1994). A high geothermal gradient, intense tholeiitic basaltic volcanism, and alkaline magmatism are characteristic of present-day areas of plumes in oceans and on continents. Alkaline magmatism is the main indicator of plumes in ancient foldbelts.

In systematizing isotopic ages of Phanerozoic alkaline complexes on different continents (The Alkaline Rocks and Carbonatites of the World, 1967, 1987, 1995) with allowance for generalizations made by Lazarenkov (1988) and Kogarko and Khain (2001), particular epochs of active alkaline magmatism are readily recognized in the Phanerozoic. This magmatism was the most intense in the Vendian–Early Cambrian, Silurian–Early Devonian, Late Devonian–Early Carboniferous, Late Permian–Early Triassic, Late Triassic–Early Jurassic, Late Jurassic–Early Cretaceous, Middle Paleogene, and Neogene and was less intense in the Early Ordovician and Late Carboniferous. Thereby, epochs of alkaline magmatism on platforms are nearly synchronous to those in mobile belts. The Phanerozoic epochs of active alkaline magmatism are also correlated with periods of intense volcanism on platforms (Fig. 2).

According to calculations (Larson and Olson, 1991), fluid and heat flows (plumes) ascend from the core/mantle boundary at a rate of about 10 cm/yr and reach the surface after about 30–40 Ma, which corresponds to the lag established for epochs of intense volcanism on platforms relative to peaks of volcanism in mobile belts (Fig. 2). Such a lag of plumes results in their reaching the asthenosphere during a phase of the planet's contraction. In some Mesozoic–Cenozoic epochs, plumes reached the asthenosphere in a phase of the Earth's expansion. The regime of mobile belts is not characteristic of this period, and the main manifestations of endogenic activity are related to tectonomagmatic reactivation.

Thus, the data obtained confirm the link of platform magmatism with deep fluid and heat flows (plume magmatism) and indicate that volcanism in mobile belts, which takes place during the stages of rifting and spreading, is of a different nature.

According to geophysical data, a low-velocity layer (the asthenosphere) is detected in the upper mantle. The asthenosphere beneath platforms is 80–100 km thick and is located at a depth of 100–200 km as a series of isolated lenses (Vol'vovsky, 1996; Pavlenkova, 2002). In mobile belts and oceans, the asthenosphere is established at a depth of 30–80 km and reaches 200–300 km in thickness. It is assumed that the asthenosphere consists of a mixture of olivine and pyroxene crystals (~75–95%) and basaltic melt (5–25%).

In the areas where the thick and rather heated asthenosphere occurs close to the surface, the additional decompression melting of silicates caused by

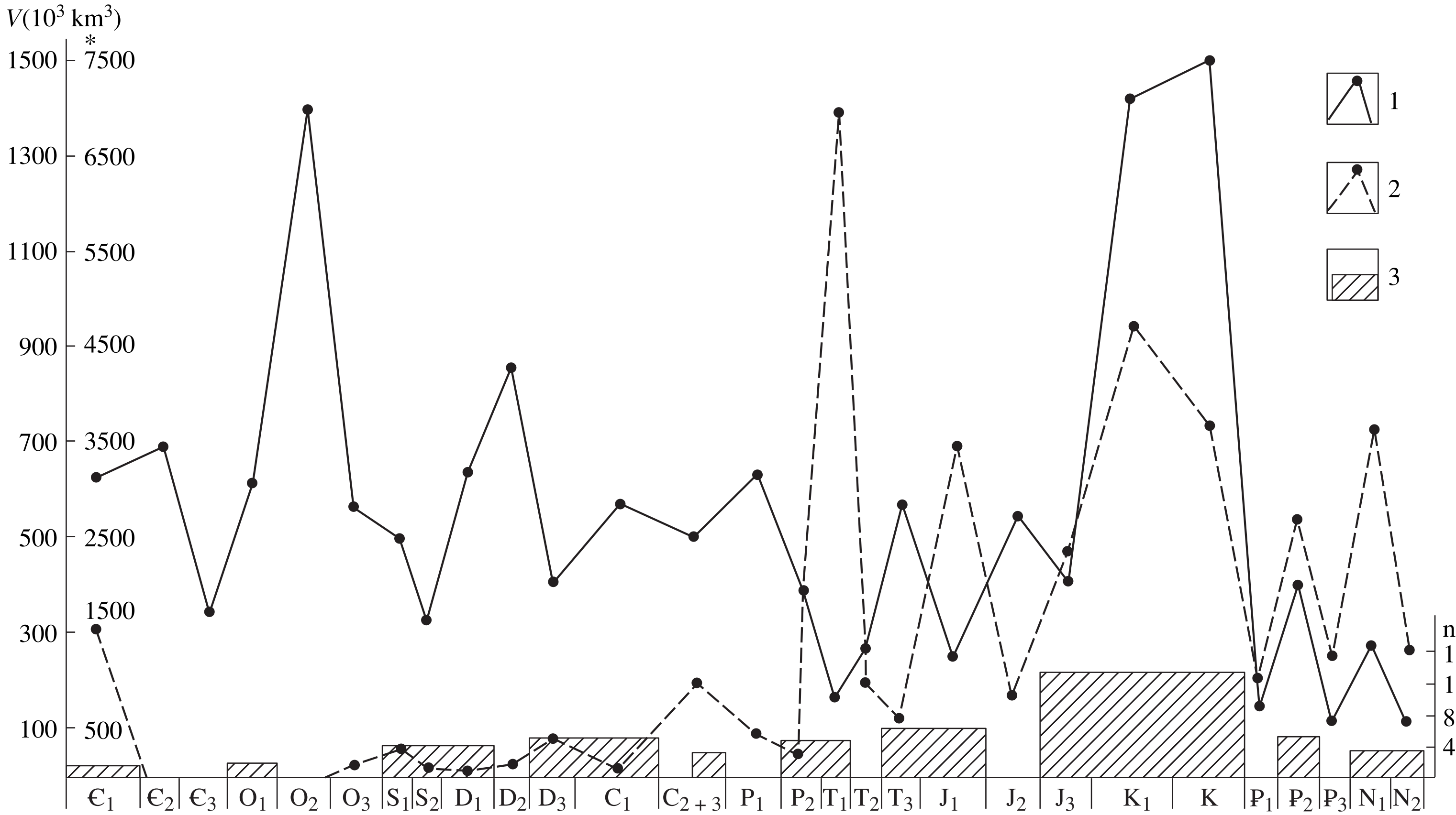

Fig. 2. Distribution of volcanic rock volumes (Ronov, 1993) and alkaline intrusions in the Phanerozoic. (1, 2) Distribution of volcanics: (1) in mobile belts, (2) on platforms (the scale for mobile belts is indicated by an asterisk); (3) histogram of number (n) of alkaline intrusions.

faulting in the lithosphere during the Earth's expansion results in the amount of basaltic melt increasing manyfold. Further, as the lithosphere expands, rifts appear first and then a mobile belt is formed in their place. Its origin is accompanied by intense volcanic and intrusive mantle mafic–ultramafic magmatism related to the asthenosphere (asthenospheric magmatism).

The next stage of mobile belt evolution corresponds to the contraction phase and is characterized by intense folding and thrusting. Before the collision stage, the temperature in the asthenosphere substantially drops after the loss of volatiles and a part of the basaltic melt and the amount of melt abruptly decreases. The ascending fluid and heat flow (the plume) is unable to activate significantly the cooled asthenosphere and to melt the overlying mantle material, so that the interaction of the plume with the lithosphere results in processes that develop within the crust. Under effect of the plume, the volcanosedimentary rocks that fill a trough experience metamorphism, metasomatism, and granitization with generation of anatectic magma in the lower crust. The magmatism of this stage is characterized by the coexistence of residual basaltic magma chambers in the crust and granitoid magma chambers related to the melting of crustal rocks. In other words, the magmatism bears a crustal–mantle character and comprises gabbro–diorite–granodiorite, granite–granodiorite, and plagiogranite intrusions, which are controlled by deep faults; large granitoid batholiths; and basalt–andesite–rhyolite volcanics. Sudovikov (1950), Mehnert (1959), and some other researchers suggested that batholiths are of metasomatic origin; in terms of the model under discussion, their formation is related to high-temperature fluid flows of plumes.

Folding and recrystallization of rocks during metamorphism and granitization make the Earth's crust poorly permeable; magmatism ceases, and the mobile belt enters into the orogenic stage of its evolution.

The continued contraction of the Earth causes the fold system to rise, and deep-rooted faults are formed thereby. Further, the planet enters into an expansion phase, when the faults open and the area is broken into a series of blocks undergoing autonomous vertical oscillatory motion that creates a contrasting topography of the orogenic belt. The magmatism of the early orogenic stage is represented by intrusions of moderately acid granitoids and eruptions of andesites, dacites, and rhyolites derived from the residual crustal magma chambers formed at the collision stage. The final stage in the evolution of the fold system is during a phase of planet contraction and at the time when the plume approaches the surface. The contraction regime is evidenced from folding, which is often observed within intermontane troughs and foredeeps, and sporadic magmatism (discrete minor granitoid bodies and small andesite–dacite eruptions) related to the closure of the main magma conduits. The high alkalinity and enrichment of igneous rocks in volatiles indicate that these rocks are plume-related.

The subsequent evolution of the fold system is related to the tectonomagmatic reactivation during the phases of planet expansion, when the deep-rooted faults become more active and fault-line troughs are formed. The crustal magma sources generated under the effect of the plume in the previous phase are thought to be a source of melts. The magmatism is represented by granitoid fissure intrusions and continental volcanism.

In the Mesozoic–Cenozoic, when powerful plumes reached the tectonosphere in a phase of planet contraction, taphrogenesis (epiorogenic rifting) occasionally developed in mobile belts. Magmatic reactivation in deep-rooted fault zones of older fold systems and median masses, as well as the formation of extended continental volcanic belts crossing different crustal structural features, is characteristic of these epochs.

The discontinuous asthenosphere beneath platforms is represented by isolated lenses. In the platform areas where the asthenosphere is deep-seated, thin, or completely missing, amagmatic spreading structural elements (aulacogens, grabens, fault-line troughs, etc.) are formed under conditions of the Earth's expansion. The effect of plumes in these areas is insignificant because of the missing asthenosphere and is expressed as diaphthoresis of basement rocks and metasomatic alteration of the sedimentary cover. In platform areas with asthenosheric lenses, the tectonomagmatic reactivation is developed in various ways and controlled by different combinations of three key factors: the permeability of the lithosphere depending on the phase of the Earth's evolution (contraction or expansion), the effect of fluid and heat flows, and the state of the asthenosphere (its depth, thickness, and degree of heating).

In the cases of a vigorously expanding lithosphere, the deep-rooted faults completely violate the integrity of the lithosphere to form intercontinental rifts of the Red Sea type. In other cases, where the lithosphere expansion is less advanced and does not provoke the violation of its integrity, intracontinental rifts of the East African type are formed and serve as zones of intense volcanic activity. The further evolution of rifts proceeds according to different scenarios. The rifts located in a zone of fluid and heat flow ascending in a phase of the Earth's contraction experience the inversion stage and evolve as a mobile belt. The rifts located beyond the field of plume influence experience slight tectonic deformations in the subsequent phase of the Earth's contraction and stop evolving. The polycyclic intracontinental rift systems, where younger rifts form again after a long break inside an older rift zone, are the only exceptions.

In addition to the formation of large rifts, the plateau-basalt (trap) regime of reactivation is typical of platforms. Flood basalts erupted on platforms have been known since the Proterozoic, but only in the

Mesozoic and Cenozoic did they reach enormous volumes. The Mesozoic–Cenozoic time is characterized by predominant expansion of the lithosphere and powerful manifestation of plumes. In this connection, in those platform regions where the thick and shallow-seated asthenosphere highly heated by a plume occurs and where numerous faults are formed (scattered spreading), areal basaltic magmatism is widely developed in the form of volcanic eruptions and sheet intrusions covering vast areas.

Thus, the origination and evolution of tectonic regimes on continents is determined by three principal endogenic factors: the phases of the Earth's evolution (contraction–expansion), the effect of deep fluid and heat flows (plumes), and the state of the asthenosphere. Various combinations of these factors provide all the variety of geodynamic settings on continents. The scale of manifestation of these factors—the intensity of geopulsations (the degree of lithosphere expansion–contraction), the power capacity of plumes and the fluid content therein, and the state of the asthenosphere (its depth, thickness, and degree of heating)—is of great importance for each geological epoch and for particular regions.

At present, a great body of statistical and analytical data on the ore potential of vast regions and the world as a whole has been gained on the basis of numerous isotopic age determinations for ores and host complexes. Based on these data, the distribution of specific mineral resources in the Earth's history has been summarized. To consider the relationship between the concentration of ore elements and pulsations of the Earth, a diagram illustrating the distribution of the main types of ore deposits typical of the Phanerozoic (Fig. 3) was compiled taking into account the data reported by Asanaliev et al. (1988), Berger (1978), Bogdanov (1973), Denisenko et al. (1986), Krivtsov et al. (1986), V.V. Popov (1980), V.E. Popov (1985), Rundquist (1988, 1997), Smirnov (1982), Fedorchuk (1983, 1985), and other researchers directly involved in studying these mineral resources.

The diagram shows that alternation of contraction and expansion phases results in a regular discontinuity and periodicity of ore formation. As was mentioned above, rifting and spreading, the orogenic and reactivation stages of the evolution of mobile belts, the reactivation of older fold systems and median masses, and the formation of continental volcanic belts are related to the phases of Earth's expansion. These phases are characterized by magmatic (Cr, Ti, Fe, Cu, Ni, Co, Pt) and volcanosedimentary (Cu, Pb, Zn, Mn, Fe) ore deposits related genetically to mafic–ultramafic magmatism, as well as a wide range of hydrothermal deposits (Cu, Pb, Zn, Au, Ag, Sn, W, Mo, Be, etc.) related to orogenic and reactivation granitoids. On platforms, Fe, Cu, Ba, and Iceland spar deposits in traps, as well as Ti, Fe, Cr, Ni, Cu, and Pt deposits related to mafic–ultramafic intrusions, are formed during these epochs.

Contraction phases are characterized by collision stages of mobile belt evolution. The metallogeny of these stages is mainly determined by the effect of plumes, which reach the Earth's crust mainly in the epochs of the planet's contraction (see above), with the exceptions being the Late Mesozoic and Cenozoic. Fe, W–Mo, and Pb–Zn skarn deposits; hydrothermal Au deposits; and W, Mo, and Sn deposits in batholiths and minor intrusions are localized in mobile belts, being related to the crustal-derived magmas formed under the effect of fluid and heat flows. Sedimentary–hydrothermal stratiform deposits of copper, lead–zinc, antimony–mercury, and rare and noble metals, as well as telethermal Ag–Pb–Zn, Ni–Bi–Co, and fluorite ores, are related directly to the mantle fluid flows, which serve either as sources of ore material or transportation agents (Shcheglov, 1987). Iron and rare-metal (REE included) deposits related to alkaline complexes, diamond deposits in kimberlites and lamproites, and stratiform ore mineralization (copper, lead–zinc, uranium, salts, etc.) are formed during these periods on platforms.

The specific character of the metallogeny of large intervals of geologic time (tectonomagmatic cycles), which is reflected in predominant development of certain types of ore, is also controlled by geopulsations and the effect of plumes.

The Caledonian tectonomagmatic cycle is characterized by the predominance of the contraction regime with two pulses of the planet's expansion in the Middle and Late Cambrian and the Middle Ordovician–Early Silurian. Platform volcanism and alkaline magmatism as indicators of deep fluid and heat flows are poorly developed due to the low supply of energy coming from the Earth's interior. As a result, crustal (granitoid) and alkaline magmatism remains rare and the main mineralization is related to basaltoid magmatism at the early stages of mobile belt evolution: base-metal massive sulfide deposits of Norway (Fossen), Sweden (Stekenjåkk), Canada (Caribou, Buchan), Burma (Bawdwin), Australia (Mount Reed), the Altai–Sayan area (the Salair group), and the Urals (Komsomol'sky, Krasnogvardeisky, etc.); copper–nickel deposits of Norway (Bruwan, Rhein Fjord); chromite deposits of the Urals (Kempirsai, Rai-Iz); and others.

Ore formation at the collision, orogenic, and reactivation stages of mobile belt evolution is poorly developed, being represented by insignificant deposits of rare-metal pegmatite, albitite, and greisen in Africa (El Dob, Abu Hammad) and Brazil (Bodo, Abaisho); porphyry copper ores in Kazakhstan (Bozshakol) and Norway (Telemarken); and gold in Kazakhstan (Stepnyak) and Great Britain (Doldgellad). Stratiform hydrothermal–sedimentary deposits formed largely in phases of the Earth's contraction (Vendian–Early Cambrian, Late Cambrian–Early Ordovician, Early Silurian–Early Devonian) are also characteristic of the Caledonian cycle. Their genesis is likely related to the fluid compo-

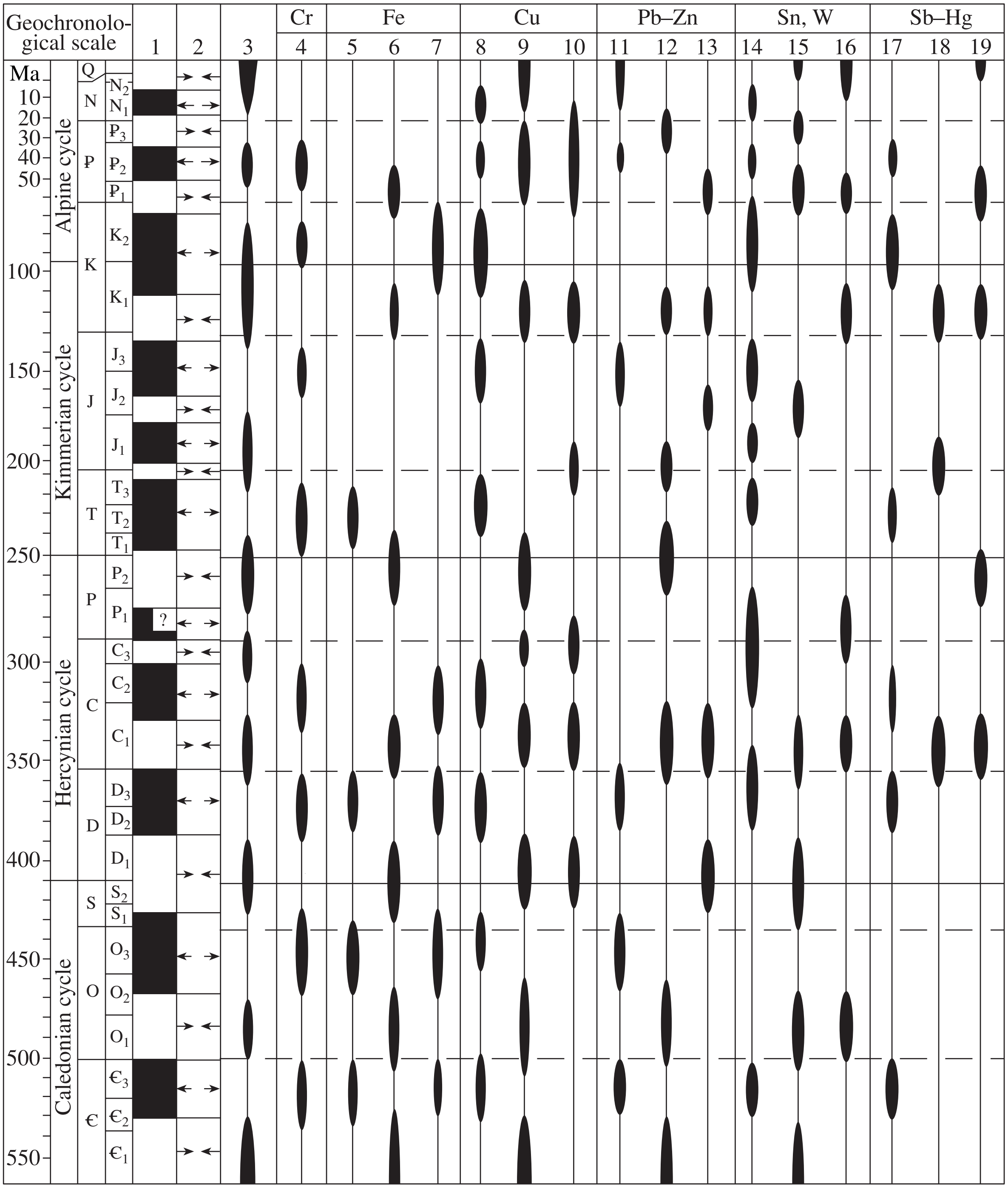

Fig. 3. Distribution of main types of Phanerozoic mineral deposits. (1) Paleomagnetic scale (black is normal polarity, white is reversed polarity); (2) phases of the Earth's evolution (← → is expansion, → ← is contraction); (3) epochs of alkaline magmatism (indicators of plumes); (4–19) mineral deposit types: (4) chromite, (5) titanomagnetite, (6) magnetite skarn, (7) volcanosedimentary iron formation, (8) copper massive sulfide, (9) copper sandstone, (10) porphyry copper, (11) base-metal massive sulfide, (12) lead–zinc siliceous–carbonate, (13) lead–zinc skarn, (14–16) rare-metal deposits: (14) hydrothermal, (15) stratiform, (16) skarn, (17) cinnabar–stibnite jasperoid, (18) gold–stibnite, (19) stibnite and stibnite–ferberite argillic.

nent of plumes. Lead–zinc stratiform deposits are known in Canada (the Anvil zone), the United States (Mississippi), and Russia (the Siberian Platform, the Polar Urals); molybdenum–vanadium mineralization hosted in black shales is known in Sweden and Kazakhstan; and antimony–mercury mineralization in Spain (Almaden), Turkey (Karaburun), and China (Guizhou Province) is also known. Stratiform rare-metal occurrences were revealed in Korea (Sandong), Austria (Felbertal), and elsewhere.

The Hercynian tectonomagmatic cycle begins with an intense pulse of the Earth's expansion in the Devonian, which is characterized by a peak of rifting and spreading regimes in mobile belts with extensive basaltoid magmatism and related ore formation. This period is the main epoch of volcanic-hosted massive sulfide deposits known in the Urals (Gai, Uchaly), Rudny Altai (Zyryanovsk, Ridder-Sokol'ny), Australia (Mount Fayel, Mount Morgan), and some other regions.

Two other periods of the planet's expansion in this cycle (Early–Middle Carboniferous and Early Permian) were less intense and did not result in new mobile belts being formed. The orogenic and reactivation stages of mobile belt evolution were intensely developed and were preceded by a powerful release of energy from the Earth's interior during the previous stage as evidenced by intense alkaline magmatism in the Late Devonian–Early Carboniferous and the Late Carboniferous. Abundant mineral deposits are related to granitoid magmatism: rare-metal pegmatites, albitites, greisen, and skarn in Kazakhstan (Aqshatau, Nura-Taldy), the Erzgebirge (Cinovec, Altenberg), and Australia (Herberton); porphyry copper–molybdenum deposits of Mongolia (Tsagaan-Suvarga, Erdenetiin-Ovoo), Central Asia (Kal'makyr), and the United States (New Ross, Mount Pleasant); gold deposits in Kazakhstan, Central Asia, and Australia; and others.

Periods of contraction (Late Devonian–Early Carboniferous, Late Carboniferous, Permian–Early Triassic) alternating with phases of the Earth's expansion correspond to the time when fluid and heat flows reached the upper shell of the Earth. Stratiform sedimentary–hydrothermal mineralization, as well as deposits related to alkaline intrusions, was widely developed during these periods. Large lead–zinc deposits in the United States (Three States, Park City), Canada (the Driftpile Creek area), Central Asia (Jergalan region), and Kazakhstan (Greater Karatau); deposits of copper sandstone in western Europe (Poland, Germany, France), Russia (the Urals, Minusa Basin), Kazakhstan (Zhezqazghan), and the United States (Kansas, Oklahoma); and antimony–mercury ores in Central Asia (Khaydarkan, Jijikrut, Kadamjay), China (Xigunshan), and Mexico (Sonora) are related to this time. Diamond deposits of Yakutia and Arkhangel'sk oblast and apatite–magnetite and rare-metal (REE included) deposits of the Baltic Shield, Mongolia, Africa, and other regions are related to alkaline magmatism.

The Kimmerian cycle is characterized by an increase in the volume of the Earth along with two relatively short periods of contraction in the Late Triassic–Early Jurassic and Late Jurassic–Early Cretaceous (Hauterivian). Unlike the Paleozoic, pulses of deep energy indicated by intense basaltic eruptions on platforms (traps of the Siberian, South African, and Antarctic platforms) and epochs of active alkaline magmatism are largely related to the phases of the Earth's expansion. This circumstance violates the traditional scheme of magmatism evolution in mobile belts and, as a consequence, leads to recognition of a special Verkhoyansk type (Smirnov, 1984) with prevalent granitoid magmatism. In terms of the suggested model, this is related to the effect of deep fluid and heat flows during the expansion phases. These flows promoted generation of numerous sources of palingenetic granitoid magma and, as a result, the prevalence of silicic igneous rocks in the mobile belts forming at that period. Widespread granitoid magmatism in zones of deep-rooted faults that transect older fold systems and median masses is also related to this process.

The Kimmerian cycle is characterized by waning mobile belts, which remained only along the Pacific and Mediterranean margins. The ore mineralization of mobile belts related to basaltic magmatism was poorly developed and is represented by massive sulfide deposits of the Caucasus (Kyzyl-Dere, Filizchai), Serbia (Bor), and North America (Big Bull, Island Mountain), as well as small chromite occurrences in Armenia (Takhat), Turkey (Gelemen), and Iran (Mir Maḫmud). The main ore productivity of the Kimmerides is related to granitoid magmatism and is represented by skarn and hydrothermal deposits of tungsten, tin, and molybdenum in eastern Russia (Deputatsky, Kan'on, Tigriny, etc.), Indonesia (Selimar, Klappa-Kamnit), southeastern China (Jiangxi and Gejiu ore regions), northern Bolivia (Llarashcota, Avicaya), and the Appalachians (Hemm, Irish Creek); gold deposits of Russia (the Yana–Kolyma and Chukchi zones) and North America (Yukon, British Columbia, California); and porphyry copper–molybdenum deposits of the Cordilleras (Lornex, Highmont).

A great role in the metallogeny of the Kimmerides belongs to processes of reactivation of older fold systems and median masses, which are responsible for rare-metal mineralization in the Transbaikal region (Khapcheranga, Dzhida) and the Pamirs (Zarechny, Trezubets) and gold mineralization in the Aldan Shield (Lebediny, Kuranakh) and the Transbaikal region (Balei, Darasun). The metallogeny of reactivated platforms is represented by Iceland spar, barite, celestine, copper, and iron occurrences and large nickel deposits (Noril'sk district) in trap provinces and rare-metal mineralization in alkaline complexes of Nigeria (Jos Plateau) and Brazil (Rondônia State). Stratiform sedimentary–hydrothermal ore mineralization is also widespread (North Africa, central and western Europe, and other provinces).

The Alpine tectonomagmatic cycle is, in general, similar to the Kimmerian and is characterized by the predominant expansion of the Earth with short contraction pulses in the Late Cretaceous, Paleocene, Oligocene, and Pliocene. The plumes ascending from the core reach the crust in epochs of global expansion as confirmed by intense basalt eruptions on ancient platforms (traps of the Indian, Brazilian, and Greenland platforms) and intense alkaline magmatism in the Late Cretaceous–Eocene and Miocene. This cycle differs from the previous one in a more intense expansion of the planet as confirmed by the formation of young ocean basins and the highest rise in the ocean level in the Phanerozoic in the Late Cretaceous.

The regime of mobile belts during this period disappeared almost completely and was retained only in small isolated zones in the Mediterranean and Pacific belts. Alpine troughs are characterized by locally developed basaltic magmatism accompanied by massive sulfide ore mineralization in the Lesser Caucasus (Madneuli), Cyprus (Skuriotissa), Turkey (Murgul), and Japan (Kuroko) and by small chromium and nickel deposits (Kamchatka, Sakhalin). Small magnetite skarn, porphyry copper, gold, and rare-metal deposits (the Lesser Caucasus, Kamchatka, the United States, Mexico, the Philippines) are known as associated with granitoids of the collision and orogenic stages of the Alpides.

Ore deposits of the Alpine cycle are mainly related to widespread reactivation. The global expansion, more intense than in the Kimmerian time, in combination with powerful plumes, resulted not only in widespread faulting in fold systems and median masses but also in the formation of volcanic belts (hundreds and thousands of kilometers in extent) superimposed on crustal structures of different types and ages and characterized by intense intermediate and acid volcanism and granitoid intrusions. Volcanic belts are localized at continental margins within the Pacific ring and in the Mediterranean fold system. Their metallogeny bears a lithophile–chalcophile character and is represented by the entire range of nonferrous, rare-, and noble metal deposits related to granitoid magmatism (eastern Russia, southeastern China, the Pamirs, the United States, Bolivia, Peru, Chile, etc.). During this period, young deep-rooted faults appear on platforms (Siberia, China, Africa). The faults control diamond-bearing kimberlites and alkaline intrusions with rare-metal mineralization.

Thus, discontinuity and periodicity of global geological processes in the Earth's history are indicative of the pulsatory character of global evolution. The correlation of variations in the geomagnetic field with global geological processes shows that the polarity of the field is an indicator of geopulsations. The expansion phase corresponds to epochs of normal (present-day) polarity, and the contraction phase, to epochs of reversed polarity. The modeling of the main geodynamic regimes of continents in terms of the concept of geopulsations shows that their diversity is determined by the combination of three factors: the phases of the Earth's evolution (contraction–expansion), the effect of deep fluid and heat flows (plumes), and the state of the asthenosphere (its depth, thickness, and degree of heating). The pulsation model sheds new light on the general evolution of ore formation in the Phanerozoic and specific metallogenic features of tectonomagmatic cycles. In conclusion, the exceptional complexity of the problem considered should be emphasized. The prime objective of this work is to attract attention to the revealed correlation of global geological processes with geomagnetic polarity and to the model of the pulsating Earth, which was undeservedly forgotten.

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