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GEOLOGY

Absolute Paleogeographic Reconstructions of the Siberian Craton in the Phanerozoic: A Problem of Time Estimation of Superplumes

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Abstract—The intraplate activity within the Siberian Craton in the Phanerozoic is related to continental migration above the hot spot agglomeration compared to the African superplume. The continuity of intraplate activity within this superplume testifies to its age identity to the antipodal to the Rodinian superplume that destroyed the Rodinia supercontinent. This allowed us to conclude that the African superplume has existed for no less than 1 Ga. Because the Rodinian and Pacific superplumes are compared, it may be gathered that superplumes are the most long-lived deep-seated structures of the Earth. Their relation to the formation of supercontinents probably reflects the antiphased activity caused by the thermostating effect and energy accumulation by superplumes when being overlapped by supercontinents. When analyzing the evolution and generation of modern continents, it is necessary to consider both processes related to the plate boundaries and the activity of superplumes determining the intraplate magmatism therein.

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The elaboration of the plate tectonics conception in the 1960s clearly brought out that the main endogenic geological activity is restricted to plate boundaries. But in the same years, J. Wilson [1] paid attention to intraplate magmatism not related to them and designated it by products of the mantle hot spots the position of which is determined by the uplift of deep mantle plumes to the surface. In 1983, L.P. Zonenshain and M.I. Kuz'min showed [2] that the Late Cenozoic (0–5 Ma) hot spots are not randomly distributed on the Earth's surface but are grouped in certain regions that were determined as hot fields of the Earth's mantle. The development of seismography completely confirmed the presence of both hot and cold mantle areas on the Earth [3, 4]. The hot areas are related to the zones of decreased velocity that could be traced from the lithosphere foot down the core, whereas the cold areas correspond to the mantle regions with high seismic wave velocities. The latter areas represent locations of the subduction of lithospheric plates. The large accumulations of low velocity zones established in the basement of the two largest mantle hot fields (African and Pacific superplumes) are the corresponding large low shear velocity provinces (LLSVP) (Fig. 1).

The LLSVP formation and functioning in the Earth's geological history is traditionally related to the origin and breakup of supercontinents [3–5]. It was established that, during the Earth's evolution, its continents were periodically combined into supercontinents [3, 7], accompanying by generation or activization of superplumes under them, further breakup, and centrifugal "scattering" of their constituents. On the time scale background, Fig. 2 shows the cycles of origin of various continents and their destruction on continental blocks because of superplumes. At present, the history of formation and breakup of two last supercontinents—Rodinia and Pangea—is well studied [3], whereas the nature of the superplumes that destroyed them, particularly the time of their generation, duration, and character of functioning, remains almost unknown. Based on the analysis of occurrence of the mantle hot spots within the Siberian Craton and suggestions about prolonged existence, at least, of the Iceland hot spot, this work presents the absolute paleogeographic reconstructions of Siberia and shows that the African superplume responsible for the breakup of Pangea existed in the Phanerozoic.

The Rodinia supercontinent was formed about 1 Ga ago and was broken about 750 Ma ago under the influence of the Rodinia superplume located below [3, 4]. It is assumed that the antipodal to the Rodinian superplume existed simultaneously and was localized in the ocean situated in the Earth's sector opposite Rodinia. Z. Li and S. Shong [3] used an analogy with Pangea,

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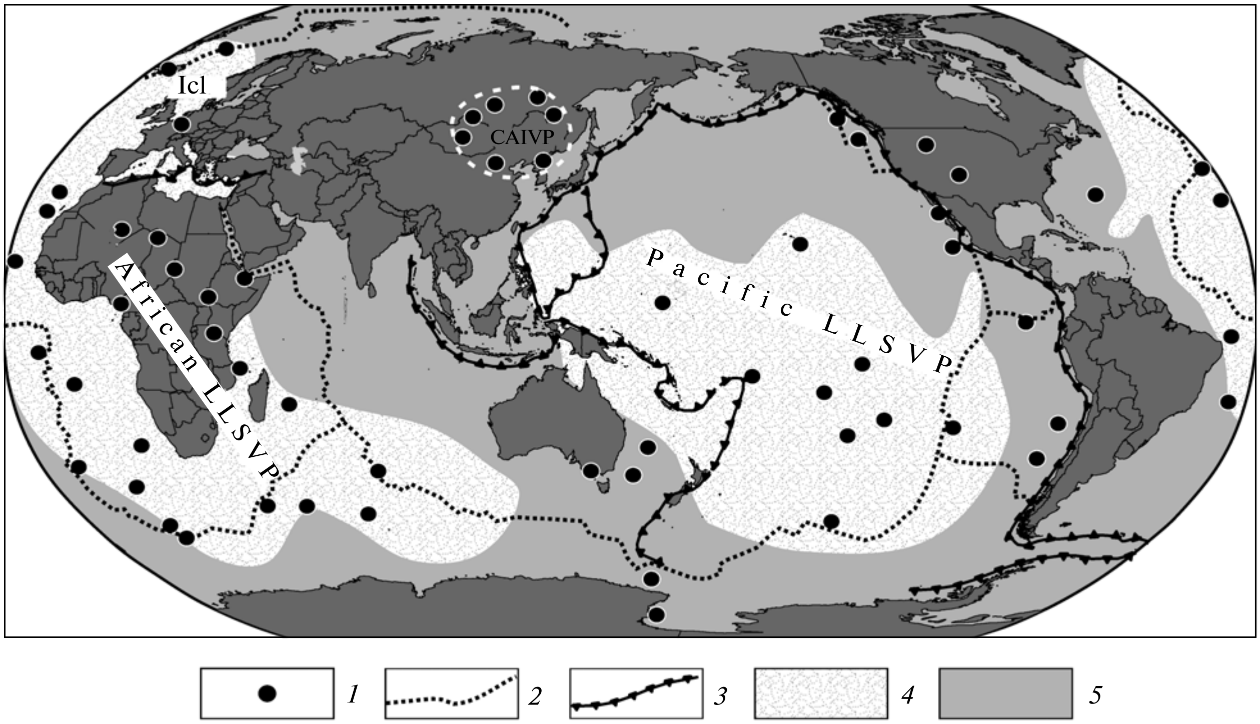

Fig. 1. Distribution of hot spots relative to the mantle hot fields, after [2]. Iceland hot spot (Icl), Central-Asian intraplate volcanic province (CAIVP) [9]. Mantle hot spots (*1*), spreading zones (*2*), subduction zones (*3*), large low velocity mantle provinces (LLSVP) (*4*), areas of development of the other mantle (*5*).

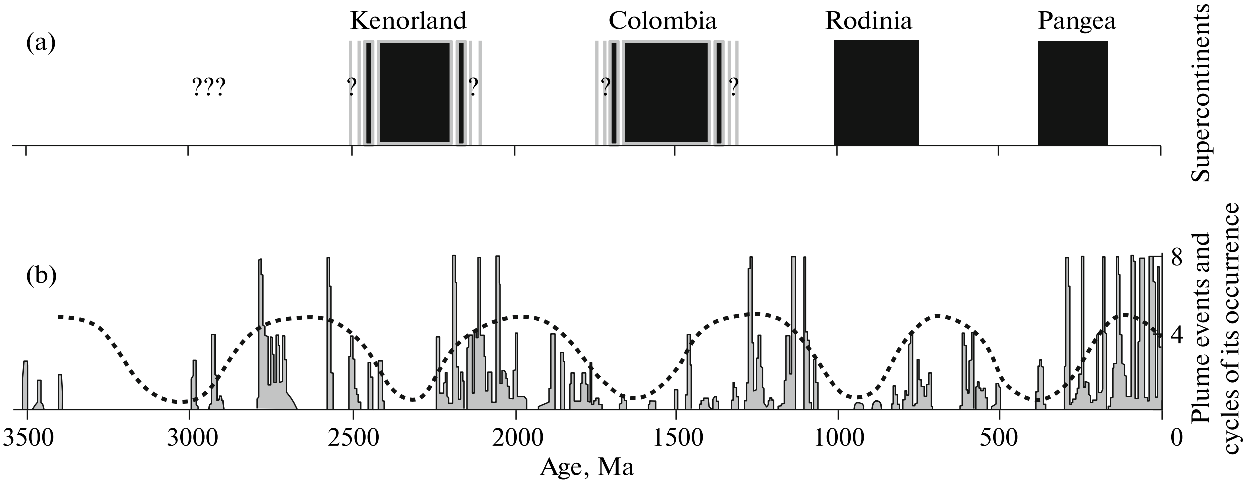

Fig. 2. Age of origin of supercontinents (a) and distribution of the large igneous provinces through the Earth’s history (b). The sinusoid curve shows the possible cycles of superplumes destroying the supercontinents, after [3].

the breakup of which was promoted by the African superplume, antipodal to the contemporary Pacific superplume. In compliance with this, the location of the antipodal to the Rodinian (or Great-Pacific [4]) superplume should be expected in the hemisphere opposite to Rodinia. After the destruction of Rodinia, the constituent continents, including Siberia, could have been moved in the corresponding areas of the Neoproterozoic Ocean. The numerous products of oceanic hot spots in the fold belts of the Siberian Craton and intraplate intrusives [9, 10] indicate the high intraplate activity in those sectors of the Earth through which Siberia moved after the breakup of Rodinia in the Phanerozoic. There are two short breaks (pauses) of this activity: ~350–320 and ~190–160 Ma. In addition, weak magmatic activity occurred 100–25 Ma ago

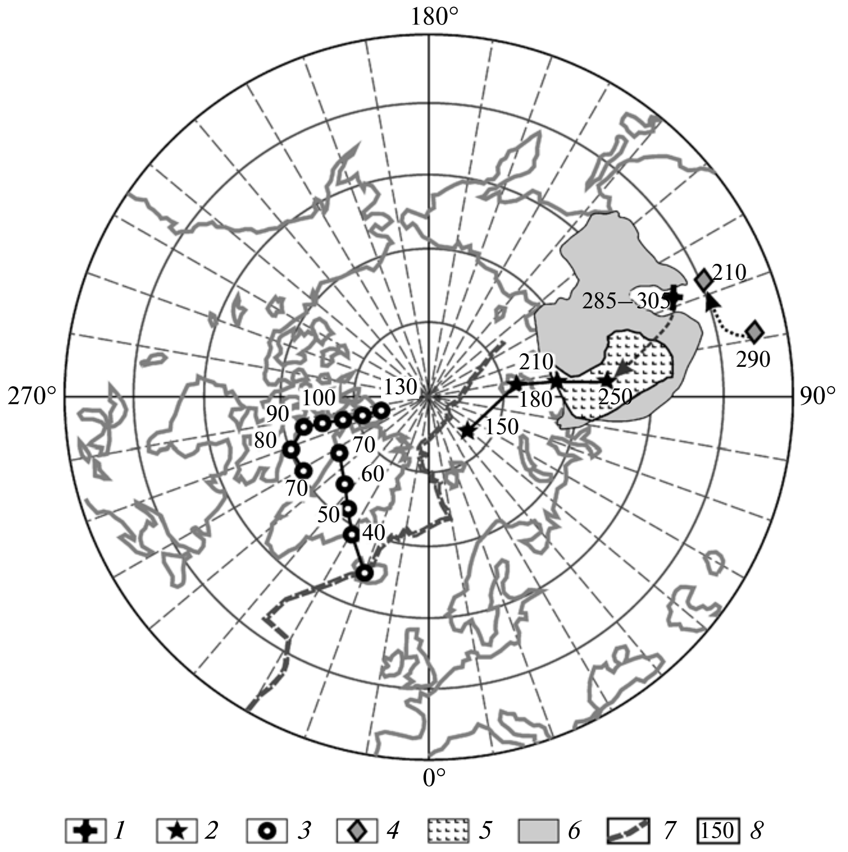

Fig. 3. Scheme of the Iceland hot spot trace in the Arctic basin, after [12]. The Iceland hot spot trace (*1–3*): within the Barguzin–Vitim province [15] (*1*), after the formation of the Siberian traps [13, 14] (*2*), after the formation of the mid-oceanic ridge [12] (*3*); the Mongolian hot spot trace (*4*); traps (*5*); Siberian platform (*6*); mid-oceanic ridge (*7*); age, Ma [12, 14] (*8*).

while the new magmatic activization, involving the Central and Eastern Asia [10] and forming the modern Central-Asian intraplate province (CAIP, Fig. 1), happened after 25 Ma. It should be noted that primitive (PREMA) and enriched (EM2) mantles were the sources of mantle intraplate basalts in the Paleozoic and Mesozoic, whereas Cenozoic basalts formed due to the PREMA and enriched mantle EM1. These data allow us to suggest that the Siberian Craton drifted above the mantle superplume after the breakup of Rodinia. We assume that this was the African superplume according to the ideas [4, 11] that the life duration of the superplume could have been longer and is determined by the activity of various and different-age plumes (or hot spots). To confirm this hypothesis, we carried out paleoreconstructions allowing determination of the location of separate plumes within the LLSVP, active at different times.

A key importance of our reconstructions is the Iceland hot spot, which, as many researchers consider, has retained its position with respect to the absolute geographic coordinates over a long period. Moreover, in accordance to G.S. Kharin, L. Lowver, and R. Muller, and E. Lundin and A. Dore [12–14], Siberian traps owe their origin to the Iceland hot spot. This is shown in Fig. 3 showing the migration of the Iceland hot spot for the last 250 Ma.

The Permian–Triassic paleolatitude of the Siberian traps (62° ± 7°), which is concordant with the modern position of Iceland, does not contradict this theory. Furthermore, this conception agrees with the composition of Siberian traps, basalts of the West-Siberian rift system, and Mesozoic traps of the Arctic basin, the subsequent formation of which is related to the reflection of the Iceland hot spot trace in the lithosphere. The data testify to the isotopic geochemical relationships of the different-age mantle magmatism [15]. Thus, the isotopic compositions of the Iceland hot spot basalts from 250 Ma until the present form a single trend between the compositions of the mantle sources similar to the PREMA and EM2 on the ε_{Nd}–$^{87}Sr/^{86}Sr$ diagram [15].

All these arguments indicate that if the Iceland hot spot appeared no less than 250 Ma ago then the northern boundary of the African LLSVP controlled by this spot existed in the same period. T. Torsvik et al. [11] found the earlier stage of the LLSVP development showing that the large Skagerrak intrusive province, covering the huge territory of Great Britain, the North

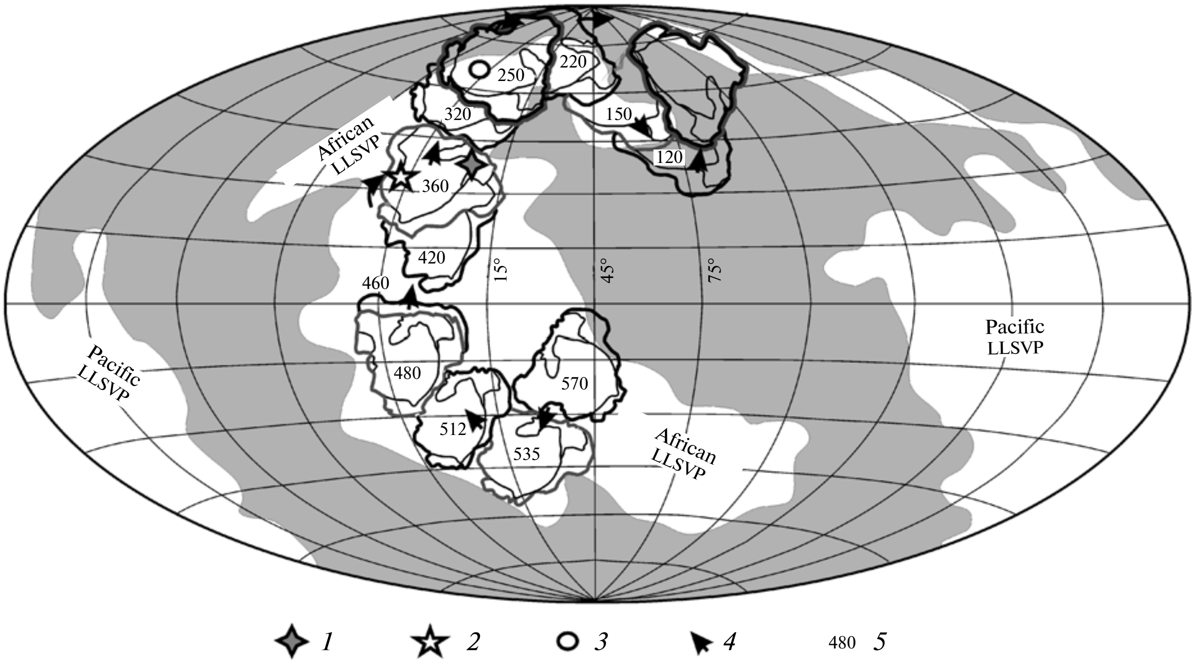

Fig. 4. Paleogeographic reconstruction of the Siberian Craton from 570 to 0 Ma, after [15], relating its movement above the African LLSVP. Mantle plumes (*1–3*): Altai–Sayan (*1*), Vilyui (*2*), Iceland (Siberian trap) (*3*); direction of the continental movement (*4*); age, Ma, of one or another continental position (*5*).

Sea, Germany, Norway, and Sweden with the center located in the Skagerrak graben (North Sea), existed 297 ± 4 Ma ago. Its center was situated in the marginal part of the African LLSVP, near its equatorial zone. In compliance with this, the African LLSVP has been in existence for a minimum of 300 Ma, its contours are similar to the modern boundaries, and it can be supposed that the African superplume that destroyed Pangea had boundaries close to contemporary ones. The stability of the Iceland hot spot for the last 250 Ma may serve as a longitudinal control of the movement of Siberia in the Phanerozoic. Correspondingly, the longitudinal positions of the African hot spot (330°–70° E) are the limits of the movement of Siberia in the Phanerozoic, whereas its latitudinal dislocations were considerably larger, which follows from summarizing V.A. Kravchinskii [15].

Figure 4 illustrates the displacement of the Siberian Craton and is based on the idea of the constant geographical position of the Iceland hot spot, stability of the longitudinal position of the African LLSVP on the Earth's surface, and the latitudinal location of separate hot spots manifested within the Siberian Craton in the Phanerozoic.

Evidence of the Early Paleozoic movements of Siberia through the mantle plumes [15] include the numerous Neoproterozoic and Cambrian OIB complexes typical of oceanic plateaus or island arcs. Based on paleomagnetic data, such complexes of the Dzhida ophiolite zone were formed at 15°–20° S. These results point to the position of the Siberian Craton under the influence of the African LLSVP in the period of 570 Ma.

Traces of interaction between the Siberian Craton and individual Altai–Sayan, Vilyui, Mongolian, and Iceland plumes were identified in the continental structure. The maximal longitudinal movements of Siberia in the Paleozoic were about 7 cm/yr. It is important that, not accepting the longitudinal limits, these dislocations should have been significantly larger [15], which is unlikely with the present estimations of lithospheric plate movements.

The earliest mantle plume manifested in the Siberian Craton exerted the development of the Altai–Sayan Caledonides in the Ordovician–Silurian [15]. In the Early Devonian, after accretion with Siberia, this plume (40° ± 15° N, ~360° E) continued to govern the formation of the structure and magmatism of the southwestern continental margin where the triple graben system of the Altai–Sayan rift area formed. By the Middle Devonian, going on to localize above the Altai–Sayan hot spot and owing to the rotation, Siberia overlapped the Vilyui hot spot (35° ± 15° N, ~340° E). Its influence on the lithosphere led to the formation of the triple graben system of the Vilyui rift system and continental breakup in its eastern (modern coordinates) part [9]. As is seen from Fig. 4, the migrating Siberian Craton went above the Altai–Sayan and Vilyui hot spots, traces of which are lost after the complete continental movement. The Iceland and Mongolian hot spots responsible for some igneous areas in Central Asia [15] affected Siberia more protractedly.

The northward movement of Siberia in the Carboniferous led to the collision and overlapping of the Iceland hot spot by the south (in modern coordinates) Transbaikal active continental margin [10, 15]. The interaction of the plume with structures of the margin at 310–280 Ma stimulated formation of the Barguzin–Vitim zonal igneous areal with a batholith (Angaro–Vitim) core and peripheral rifting zones [10, 15]. Such a specific plume activity was determined by the interaction between the plume and the crust of the active continental margin bringing about its anatexis under the mantle effect [15]. The clockwise rotation of Siberia in the Permian caused the magmatic migration from the Barguzin–Vitim areal to the Siberian trap province.

Contemporary with the Barguzin–Vitim areal, a new intraplate igneous areal appeared in South Mongolia where the Gobi–Tien Shan and Main Mongolian lineament rift zone formed (310–285 Ma) due to the Mongolian hot spot [15]. The rotation of Siberia in the Permian and Early Mesozoic dislocated the Iceland hot spot under the Siberian traps and determined the magmatic migration above the Mongolian hot spot through Central Mongolia to Transbaikalia. This migration formed the Khangai (270–250 Ma) and East-Mongolian–Transbaikalia (220–190 Ma) zonal igneous areals similar in structure to the Barguzin–Vitim areal [15].

In the Mesozoic, Siberia moved from the Iceland hot spot, which is recorded by the magmatic trace formed in the Mesozoic Arctic basin [13]. The reconstructions [15] showed that ~180 Ma ago Siberia moved from the African LLSVP and no intraplate magmatic activity was manifested from 190 to 160 Ma.

The activization of intraplate processes in the southern frame of the Siberian platform in the Late Mesozoic and Cenozoic was related to a series of long-lived mantle hot spots [9] that retain their stable geographic position for more than 140 Ma [15]. These hot spots are drawn toward the accumulation of mantle plumes [4] at the southwestern margin of the Pacific Ocean, which is probably one of the branches of the Pacific superplume. Hence, it can be suggested that, by the beginning of the Late Mesozoic, Siberia had significantly shifted eastward and was subjected to the influence of the Pacific plume. Such a fast latitudinal movement of the Siberian Craton was likely due to the opening of the Atlantic and Indian oceans at this time.

Thus, this study shows that intraplate activity within the Siberian Craton in the Phanerozoic followed from its migration over the hot spots' agglomeration, which can be compared to the African superplume and corresponding LLSVP. The continuity of the intraplate activity in the limits of this superplume allows us to suggest its age identity to be antipodal to the Rodinian superplume. Consequently, it can be concluded that this superplume has been in existence, at the very least, no less than 1 Ga. Considering the similarity of Rodinian and Pacific superplumes, the superplumes are the most long-lived deep-seated structures of the Earth. Their relationship to the formation of the supercontinent probably reflects the antiphased activity caused by the thermostating effect and energy accumulation by superplumes during the overlapping by supercontinents [3]. It should be noted that during analysis of evolution and formation of modern continents, it is necessary to consider both the processes related to the plate boundaries and the activity of superplumes determining the intraplate magmatism inside the plates.

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