ISSN 1028-334X, Doklady Earth Sciences, 2006, Vol. 410, No. 7, pp. 1048–1052. © Pleiades Publishing, Inc., 2006.
Original Russian Text © N.P. Laverov, V.I. Kovalenko, V.V. Yarmolyuk, O.A. Bogatikov, V.V. Akinin, A.G. Gurbanov, A.N. Evdokimov, E.A. Kudryashova, M.M. Pevzner, V.V. Ponomareva, V.G. Sakhno, 2006, published in Doklady Akademii Nauk, 2006, Vol. 410, No. 4, pp. 498–502.

GEOLOGY

Recent Volcanism of Northern Eurasia: Regionalization and Formation Settings

Academician of the RAS **N. P. Laverov**[a], Academician of the RAS **V. I. Kovalenko**[a], Corresponding Member of the RAS **V. V. Yarmolyuk**[a], Academician of the RAS **O. A. Bogatikov**[a], **V. V. Akinin**[b], **A. G. Gurbanov**[a], **A. N. Evdokimov**[c], **E. A. Kudryashova**[a], **M. M. Pevzner**[d], **V. V. Ponomareva**[d], and Corresponding Member of the RAS **V. G. Sakhno**[e]

Received June 20, 2006

DOI: 10.1134/S1028334X06070105

In the framework of studies under the "Variations of Environment and Climate: Natural Disasters" program of the Presidium of the Russian Academy of Sciences, we compiled the map of recent volcanism of northern Eurasia on the GIS basis and outlined volcanic regions with different compositions of igneous rocks, evolution of volcanism, and geological conditions of its development. A series of thematic maps (maps of topography, neotectonics, recent faults, and distribution of earthquake sources) represented by separate sheets served as a structural base of the GIS layout. The projection of volcanic areas on these maps allowed us to analyze relations of volcanic events with a large number of independent indicators of recent endogenic activity and, as a result, to assess the most essential regularities in the manifestation of neovolcanism in northern Eurasia.

The map shown in the figure demonstrates the distribution of active volcanic regions in the orographic system of Eurasia. The volcanic areas reveal systematic relations to young mountainous regions, i.e., to the zones of neotectonic activity. These zones of different geodynamic patterns make up the periphery of the Eurasian Plate.

The areas of volcanic activity are distributed nonuniformly throughout marginal mountainous systems of the Eurasian Plate. They are combined into regions that are generally separated in space. Moreover, they differ from one another in tectonic control, composition of igneous rocks, their age, and general trends of volcanic evolution. Based on these specific features, the following types of volcanic regions are recognized in northern Eurasia: (a) mid-ocean ridges (MOR), (b) island arcs, (c) continental collision zones, (d) within-plate zones, including those related to the mantle hot spots, continental rifts, and transcontinental belts.

The MOR-type region is represented by volcanic manifestations of the ~1800-km-long Gakkel Ridge. This ridge is the northern segment of global MOR system with a slow spreading rate (1.0–1.3 cm/yr). However, the structure of the Gakkel Ridge is typical of MOR. The linear volcanic edifices extend along the axial rift valley, and E-MORB-type basalts are predominant among igneous rocks [1]. Manifestations of Late Cenozoic alkali basalt volcanism along the continental framing of the newly formed oceanic lithosphere (New Siberian, Novaya Zemlya, and Spitsbergen islands) probably mark a boundary of rifting in the Arctic Basin.

Volcanic regions of island arcs formed above subduction zones are represented by the Kuril, Kamchatka, and other volcanic arcs of eastern Asia. The recent stage of their evolution embraces the last 3 Ma [2]. These regions are characterized by extremely active and diverse volcanism. Volcanic eruptions occur here virtually every year. It is not surprising that the present-day topography of volcanic arcs is largely controlled by volcanoes formed over the last 40–50 ka. Morphological types of volcanic edifices include lava plateaus and volcanic plains, shield volcanoes, and calderas. Such structures are typically represented by large conic stra-

[a] *Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Russian Academy of Sciences, Staromonetnyi per. 35, Moscow, 119017 Russia*
e-mail: vik@igem.ru
[b] *Northeastern Complex Research Institute, Far East Division, Russian Academy of Sciences, Portovaya ul. 16, Magadan, 685000 Russia*
[c] *All-Russia Research Institute of Geology and Mineral Resources of the World Ocean, Angliiskii pr. 1, St. Petersburg, 190121 Russia*
[d] *Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 119017 Russia*
[e] *Far East Geological Institute, Far East Division, Russian Academy of Sciences, pr. Stoletiya Vladivostoka 159, Vladivostok, 690022 Russia*

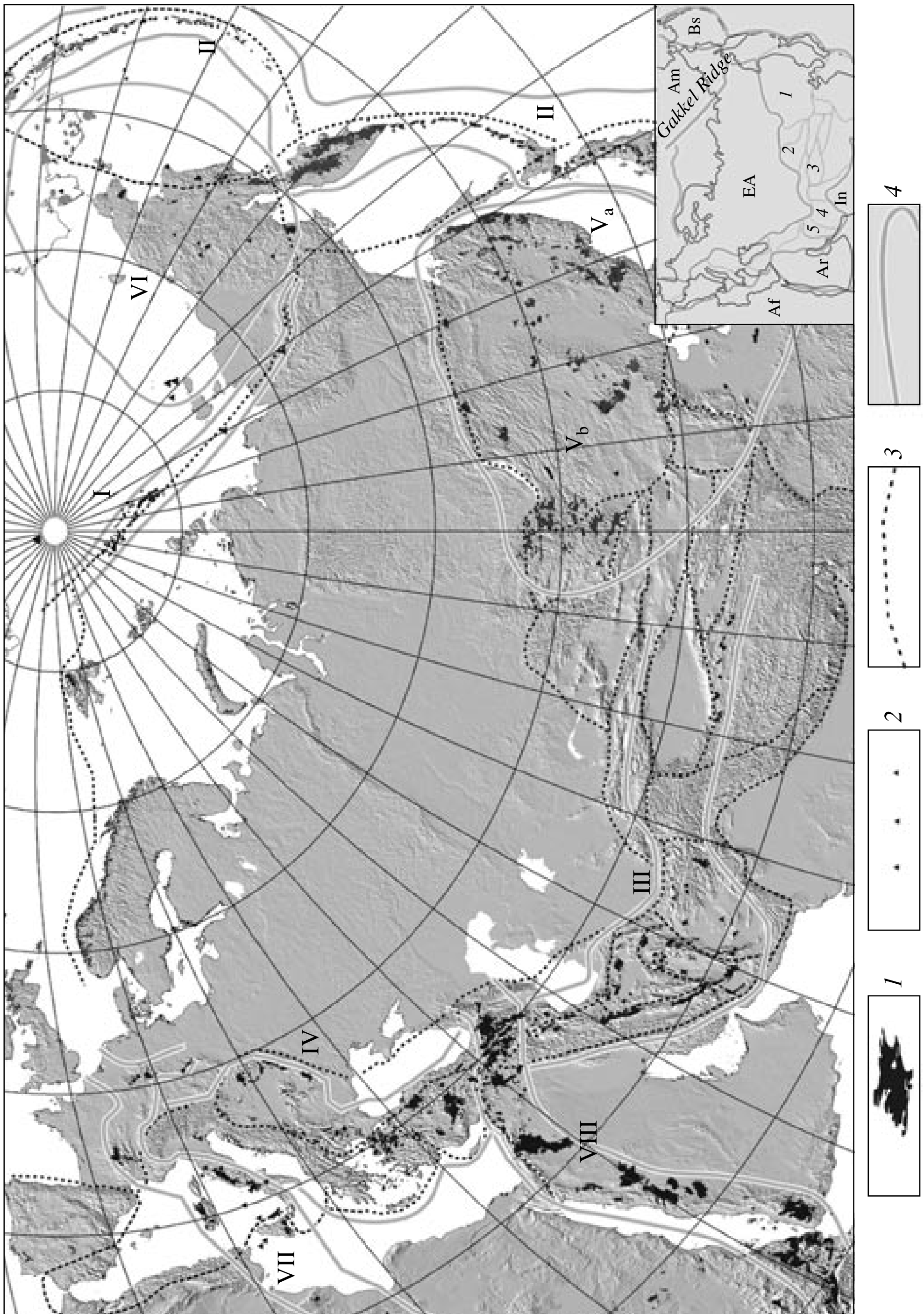

Fig. 1. Map of recent volcanism in northern Eurasia. (*1*) Lava field, (*2*) volcano, (*3*) microplate boundary, (*4*) boundary of volcanic regions. (I–VIII) Volcanic regions: (I) Gakkel Mid-Ocean Ridge; (II) Kamchatka, Kuril, Aleutian, and other island arcs; (III, IV) Tethyan (collisional) belt: (III) Asian branch, (IV) Anatolian–Balkan branch; (V, VI) within-plate provinces: (V) eastern and central Asia: subprovinces: (Va) Primorye, (Vb) Central Asia; (VI) Northeast Russia; (VII, VIII) transcontinental rift belts: (VII) Central African–Central European, (VIII) East African–Transcaucasus.

Legend for the inset. Lithospheric plates: (EA) Eurasian, (Af) African, (Ar) Arabian, (In) Indian, (Am) North American, (Bs) Bering Sea. Microplates: (*1*) Amur, (*2*) Junggar, (*3*) Tarim, (*4*) Afghan Median Mass, (*5*) Luth Median Mass.

tovolcanoes (e.g., Klyuchevsky, Avachinsky, and Kronotsky) composed of hundreds of cubic kilometers of erupted volcanic material. Some volcanoes differ in the periodicity of volcanic eruptions. At the Klyuchevsky Volcano, the quiet periods do not last more than a few years, whereas the quiescence periods of other volcanoes span hundreds of years. The absence of volcanic activity for more than 3.0–3.5 ka indicates the extinction of the volcanic center [2]. Andesites are typical of volcanic products of such regions, although they can include the entire range of composition (from basalts to rhyolites) and facies affiliation (lavas, tuffs, and ignimbrites).

Volcanic regions of continental collision zones are related to the Alpine–Himalayan Orogenic Belt that arose in the zone of collision between the Eurasian Plate, on the one hand, and Arabian–African and Indian plates, on the other. The orogenic belt is controlled by the belt of microplates and is characterized by neovolcanic activity of variable intensity over the entire belt extending from central Tibet in the east to the Iberian Peninsula in the west. We subdivide this collisional volcanic (Tethyan) belt into the Asian and Anatolian–European branches.

The *Asian branch* (figure) includes the volcanic regions related to the part of the collision belt that currently occurs within the Asian continent. This branch formed above the collision zone of Arabian and Indian plates and their subsequent subduction beneath the Eurasian Plate. Volcanic areas in this region are often controlled by boundaries of microplates (rigid median masses within the collision belt), which are distinguished by zones of intense orogeny. The evolution of these volcanic regions is divided into several stages. The recent history of volcanism is governed by processes of the late orogenic stage that began mainly in the Pliocene [3, 4]. These processes promoted the formation of large lava plateaus, shield volcanoes, and stratovolcanoes that are grouped into volcanic chains conformable with the strike of mountain ridges. The volcanic rocks vary from basalt to rhyolite in composition. The large volcanoes (Damavand, Saghand, Bazman, and others) are high (>1000 m above the basement) and mainly composed of intermediate and acid lavas, tuffs, and ignimbrites. The volcanoes of this type are characterized by episodic activity. Studies in the Caucasus [2] have shown that the quiescence periods may span from a few thousand to a few tens of thousands of years. The appearance of calderas indicates the catastrophic character of eruptions. Such volcanoes are typical of convergent boundaries of lithospheric plates and are combined with alkaline rocks characteristic of within-plate volcanism. For example, centers of carbonatitic and phonolitic–basanitic volcanism were established in the Afghan Median Mass. Fragments of lava plateau composed of basalts and alkali basalts are known in the Luth Massif [3, 5, 6]. Occurrences of subalkali basalts are also found along the framing of many stratovolcanoes.

The *Anatolian–Balkan branch* of collisional volcanic belt extends along the northern continental framing of the Mediterranean Sea and is characterized by relations to subduction zones. The volcanic activity proceeded here during most of the Cenozoic. The Pliocene–Pleistocene volcanic events related to recent orogeny are attributed to the neovolcanic stage. The most intense neovolcanic activity is typical of the Anatolian segment, which incorporate large stratovolcanoes and lava highlands (e.g., Erciyes, Melendiz, and Hasan), and the Carpathian–Dinarian volcanic region [2, 7, 8]. Andesites, dacites, and rhyolites, which are prevalent among igneous rocks, make up stratovolcanoes and pyroclastic fields together with alkaline rocks (tephrites, phonolites, and subalkali basalts) that occur as small lava plateaus and isolated domes and necks. It is suggested that the combination of diverse magmatism is caused by increasing backarc rifting behind subduction zones [8, 9]. The intensification of rifting in this part of the Tethys since the late Miocene could be provided by the interaction of regional assemblage of plates with the Atlantic plate that gave rise to the formation of deepwater basins of the Mediterranean, Black, and South Caspian seas [9]. The modern volcanic activity in this region is related to the Aegean and Liparian volcanic arcs with a number of central volcanoes, including the well-known Santorini Volcano dominated by andesites, dacites, rhyolites, and their pyroclastic facies.

Regions of within-plate volcanism. The most sizable is the *within-plate volcanic province of eastern and central Asia* that embraces a number of spatially separated, structurally unrelated, and autonomously developing volcanic areas (regions) that evolved at least during the last 30 Ma [10]. Their formation is related to mantle plumes (hot spots) located above the asthenospheric projections at the base of some regions (e.g., South Baikal, Hangay, and Udokan) [10, 11]. The Primorye and Central Asian subprovinces are recognized in terms of specific features of the structure of volcanic areas and composition of igneous rocks. The Primorye subprovince is characterized by a system of NE-trending grabens that extend along the continental margin and control the linear (riftogenic) type of localization of volcanic fields. Tholeiitic, subalkali, and alkali basalts are predominant. Trachyrhyolites, comendites, and pantellerites are associated with basaltic rocks forming lava domes and extrusions. The rocks mentioned above are typical of bimodal volcanic associations in the Circum-Japan Sea alkaline igneous province [12]. The pantelleritic Paektusan Volcano at the North Korea–Northeast China border is the largest manifestation of this association. The last catastrophic eruption of this volcano happened a few hundred years ago.

The volcanic regions of the Central Asian subprovince are concentrated between the Siberian and Sinian platforms. They are superimposed onto different structural zones of this territory and largely confined to the boundaries of the Amur microplate. The graben (rift) systems (e.g., the Baikal Graben) are conjugated with the volcanic regions. However, in general, the volcanic activity was unrelated to processes of graben formation and mainly confined to areas located beyond the rift basins [10]. Large lava plateaus, up to $n \times 10^3$ km^3 in volume, which formed as a result of fissure eruption of highly mobile basic melts, shield volcanoes, and numerous valley flows related to single effusions, are typical of volcanic regions in this subprovince. Melanephelinites, basanites, trachybasalts, and basaltic trachyandesites are the most abundant volcanic products. Numerous pulses of volcanic activity are recorded in the geological history. In some regions, the frequency of eruptions increased with time. The historical eruptions known in the Eastern Sayan, Hangay Range, and the Lesser Hinggan Range testify to the active volcanic state of the territory [10].

The *Northeastern within-plate volcanic province* is characterized by small manifestations of the late Miocene–Holocene volcanism, which produced isolated lava flows; cinder cones; melanephelinitic, basanitic, and basaltic plugs and dikes, including historical eruptions (Anyui volcanoes). Some of these volcanic manifestations are controlled by plate boundaries with a high present-day seismicity, including the Moma Graben located at the extension of the Gakkel Ridge. Other manifestations are unrelated to the plate boundaries. These neovolcanic manifestations are scattered in the territory of Alaska and the Chukchi Peninsula, where the coeval rifting is also notable. However, the rifts are confined to a narrow zone of the Bering Strait. They are absent near the areas of the Late Cenozoic volcanic activity.

The *transcontinental near-meridional rift belts* represented by the Central African–Central European (CACE) and East African–Transcaucasus (EATC) belts are identified as a special group of within-plate volcanic regions. These structural units are characterized by crosscutting relations with boundaries of the Eurasian, African, and Arabian lithospheric plates, and in particular, with the Tethyan collisional volcanic belt [3, 13]. The CACE Belt is traced by the Late Cenozoic volcanic fields and grabens of continental Europe (grabens and volcanic districts of the Central European Rift System, e.g., the Rhine Graben) and the Mediterranean (Pantelleria, Sardinia, and the Roman Province). In the south, the volcanic belt extends to northwestern Africa (Tibesti, Jebel Kurush, Air, and Ahaggar) and reaches the Gulf of Guinea.

The EATC Belt extends from the Fore-Caucasus (Mineral'ny Vody district) to Tanzania. In the Alpine Fold System, this belt is recorded in volcanic fields of the Transcaucasus Uplift, where more than one-half of the late orogenic volcanics of the Mediterranean Belt were accumulated from the Late Miocene to Holocene [3]. In the south, the EATC Belt is traced by volcanic fields and grabens of the Levant system and the Red Sea in the Arabian Shield area. Further, this belt passes into structures of the East African Rift System.

The neovolcanic activity is notable within both transcontinental rift belts, in particular, at their intersection with the Tethyan Belt. The neovolcanic activity in the CACE is recorded in historical eruptions of Etna and Vesuvius. In the EATC, they are recorded as eruptions of the Tendurek, Nemrut, Elbrus, and Kazbek volcanoes [3]. Alkaline igneous associations and volcanic rocks of elevated alkalinity are typical of both rift belts. At the same time, the calc-alkaline andesites, dacites, and rhyolites are widespread at the intersections of these belts with the Tethys collisional belt. Such a combination of alkaline and calc-alkaline igneous rocks is explained by the thermal and compositional influence of mantle diapirs (sources of alkaline or within-plate magmatism) on the crust of the foldbelt. This influence promoted the formation of anatectic and hybrid (rhyolitic and dacitic, in particular) melts and thus stipulated the specific character of magmatism at the intersection of rift and fold belts.

CONCLUSIONS

(1) We have compiled the first map of recent volcanism in northern Eurasia that exhibits the systematic distribution of regions with volcanic activity during the last 10–15 Ma in this part of the Earth. The entire periphery of the Eurasian Plate mostly occupied by Russia is volcanically active.

(2) The volcanic activity is related to the active geodynamic continental zones recorded by mountain systems and belts. The volcanic activity is nonuniformly developed, and volcanic centers are grouped into autonomously evolving volcanic regions.

(3) We have typified the volcanic regions on the basis of their geodynamic setting and identified the regions related to the following settings: (a) mid-ocean ridges, (b) island arcs, (c) continental collision zones, and (d) within-plate structures.

(4) The regions show various patterns of neovolcanic activity. The island arcs are distinguished by the highest activity with predominance of basaltic and andesitic volcanism. Andesitic–dacitic volcanism, which produced large stratovolcanoes and ash flow (ignimbrite) fields, is typical of regions of the collisional type. The within-plate volcanic regions stand out by fissure eruptions of highly mobile basic lavas and rather long-term ($n \times 10^3$–$n \times 10^4$ yr) intervals between pulses of volcanic activity.

REFERENCES

1. M. Edwards, G. L. Kurras, and M. Tolstoy, Nature **409**, 808 (2001).
2. *Recent and Present-Day Volcanism in the Territory of Russia*, Ed. by N. P. Laverov (Nauka, Moscow, 2005) [in Russian].

3. E. E. Milanovsky and N. V. Koronovsky, *Orogenic Volcanism and Tectonics of the Alpine Belt of Eurasia* (Nedra, Moscow, 1973) [in Russian].
4. O. Spieas, G. Lensch, and A. Mihm, in *Geodynamic Project in Iran* (Geol. Surv. Iran, 1983), Final Rept., No. 51, pp. 247–263.
5. B. Ya. Vikhert, G. K. Eremenko, V. M. Chmyrev, and D. Abdulla, Izv. Akad. Nauk SSSR, Ser. Geol., No. 9, 29 (1979).
6. A. N. Demin, V. I. Slavin, Yu. M. Dovgal, et al., Izv. Vyssh. Uchebn. Zaved., Geol. Razved., No. 2, 74 (1972).
7. C. Szabo, S. Harangi, and L. Csontos, Tectonophysics **208**, 243 (1992).
8. Y. Yilmaz, J. Volcanol. Geotherm. Res. **44**, 69 (1990).
9. L. P. Zonenshain, M. I. Kuz'min, and V. M. Moralev, *Global Tectonics, Magmatism, and Metallogeny* (Nedra, Moscow, 1976) [in Russian].
10. V. V. Yarmolyuk, V. I. Kovalenko, and V. G. Ivanov, Geotektonika **29** (5), 41 (1995).
11. Yu. A. Zorin, E. V. Balk, M. R. Novoselova, and E. Kh. Turutanov, Fizika Zemli **24** (7), 32 (1988).
12. *The Geological Development of the Japanese Islands*, Ed. by M. Masao, G. Masao, and H. Mitsuo (Tsukiji Shokan, Tokyo, 1965; Mir, Moscow, 1968).
13. V. V. Yarmolyuk, O. A. Bogatikov, and V. I. Kovalenko, Dokl. Earth Sci. **395**, 183 (2004) [Dokl. Akad. Nauk **395**, 91 (2004)].