PHANEROZOIC GRANITE-CORE DOMES OF THE SIBERIAN NORTHEAST

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ABSTRACT

Plutonism, volcanism, metamorphism, metasomatism, and formation history of the Phanerozoic granitic domes of Northeastern Siberia are described. Paleozoic domes are similar to those of the Northern hemisphere. Mesozoic domes are specific and they are typical only of Circum-Pacific realm.

INTRODUCTION

Granite-metamorphic domes in Northeastern Siberia were found by geological mapping (Fig.1). They are positive geological structures where Phanerozoic granitoid plutons are rimmed by zones of foliated metamorphic rocks. The metamorphic rocks are very similar to Precambrian ones, but in this case the protoliths are Phanerozoic. These domes occur in fold systems and in rigid crustal blocks (massifs) which have pre-late Proterozoic (pre-Riphean) crust of continental type. These domes belong to provinces of Phanerozoic granitoid magmatism.

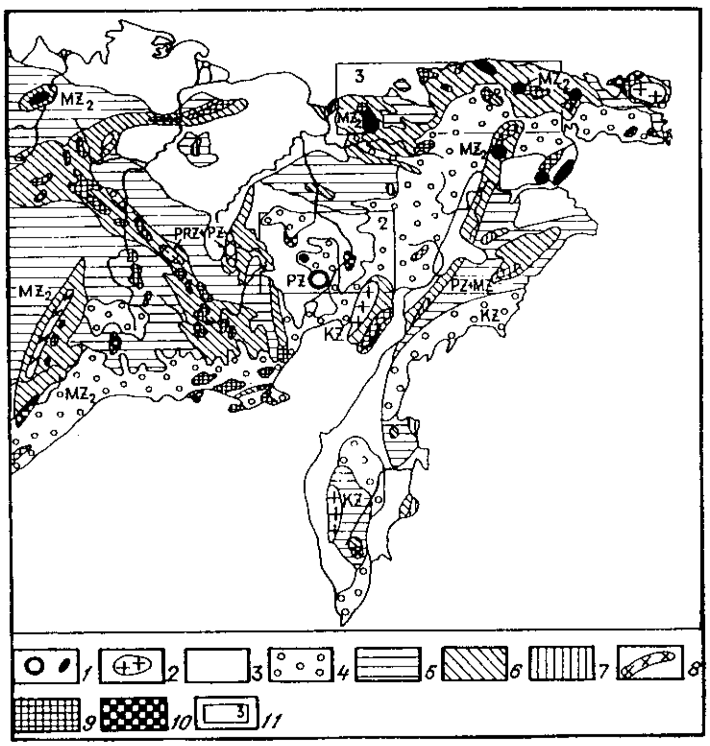

Fig. 1. Metamorphic zonation and setting of granite-metamorphic domes in the Siberian Northeast.
Ages of plutons and metamorphic belts: PRZ + PZ - Proterozoic-to-Paleozoic, PZ - Paleozoic, PZ + MZ - Paleozoic-to-Mesozoic, MZ_2 - late Mesozoic, KZ - Cenozoic.
1 - Paleozoic granite-metamorphic domes (left) and Mesozoic ones (right); 2 - dome having long history of development during the Paleozoic and Mesozoic; 3 - unmetamorphosed cover; 4 - propylitized volcanic rocks (MZ_2 - the Okhotsk-Chukchi volcanic belt); 5 - prehnite-pumpellyite facies; 6 - greenschists; 7 - blueschists and greenschists undivided; 8 - amphibolite facies zone; 9 - granitoid pluton; 10 - pre-Riphean metamorphic rocks belonging to granulite and amphibolite facies; 11 - location of Figures 2 and 3.

We distinguish three groups of domes: (1) Paleozoic; (2) Mesozoic and (3) domes with a long history of development.

PALEOZOIC DOMES

Paleozoic domes are found in the Kedon block of the Omolon massif (Simakov and Shevchenko, 1975, Spetny, 1975, Terekhov et al., 1984). Their history extends back 2.0 Ga when an event of migmatization of Archean basic granulites produced felsic crust (Zhulanova, 1990).The history of these domes is as follows (Fig.2):

(1) In late Proterozoic time there is relative uplift of the Kedon block as evidenced by the changes of thickness of late Proterozoic (Riphean) deposits.

(2) During the Cambrian, the Kedon block becomes a source of arkosic sandstones which are deposited in the neighboring Rassokha block.

(3) At the end of early Ordovician time, an erosional unconformity is present in the areas of the Kedon block close to the granite-metamorphic domes. Felsic tuffs of this age occur as part of the complete sedimentary section

preserved some distance from the domes. The Early/Middle Ordovician unconformity cuts small plutons of porphyritic syenite.

(4) From the early Ordovician to the Middle Devonian, deep-level granitic and syenitic plutons are emplaced in the core of domes. The wall-rocks are mainly pre-Riphean gneisses and schists. Locally the plutons cut the Riphean-to-Ordovician sediments. Part of the Koargichan granitic pluton has a remarkable and unusual texture similar to ductily deformed acidic granulites. Its origin may be from partly melted pre-Riphean metamorphic rocks. We have a Rb/Sr isochron age of 539 Ma for Anmandikan syenitic pluton (Middle or early Cambrian). I think this date is correct and reflects pre-Ordovician remobilization of the oldest metamorphic rocks.

(5) In the middle Paleozoic, centers of acidic volcanism with relatively high alkalinity formed in the domes, and related plutons of the same age were emplaced inside the bodies of early Paleozoic plutons. The youngest volcanic rocks lie unconformably over the early Paleozoic plutons. Middle and early Paleozoic igneous rocks have the same petrochemical features.

(6) Middle Paleozoic post-volcanic hydrothermal metamorphism shows a temperature zonality around the early Paleozoic plutons. This demonstrates that the granite-metamorphic dome continued to be a center of high heat flow.

(7) Post-early Carboniferous (post-volcanic) uplift of the domes is well displayed in the pattern of its periclinal rounding by layered volcanic rocks. This uplift lasted until Permian time. The distribution of transgressive Permian deposits is independent of the arrangement of the Paleozoic domes..

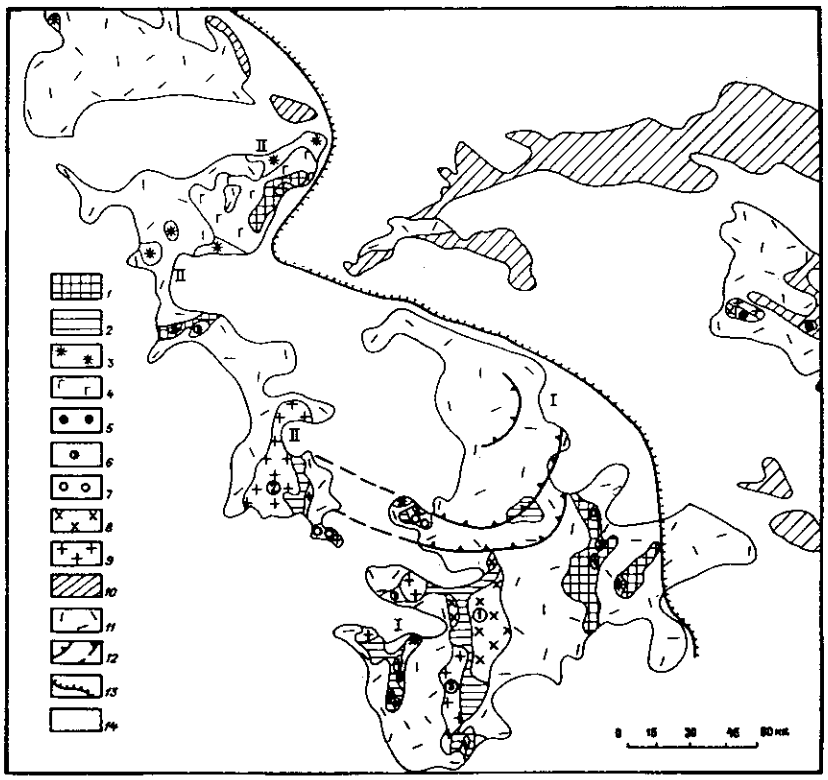

Fig. 2. Paleozoic granite-metamorphic domes at the Omolon massif.
For location see Fig. 1.
Pre-Riphean basement of the massif: 1 -basic metamorphic rocks with or without minor migmatites, sparse isolated granitoid plutons, 2 - the same undergone penetrating migmatization during the early Proterozoic; Riphean, Vend and Cambrian represented with: 3 - carbonate and terrigenous facies, 4 - basic volcanic ones including mafite-ultramafite layered intrusions; Lower and Middle Ordovician: 5 - carbonate and terrigeneous deposits forming thick sequences without unconformity, 6 - the same rocks together with conglomerate, a sequence of lesser thickness, 7 - the same sequence with an unconformity between Middle and Lower Ordovician; early Paleozoic plutons: 8 - mainly syenitic, 9 - mainly granitic; Devonian and Lower Carboniferous: 10 - carbonate and terrigeneous deposits and in places minor volcanic rocks, 11 - mainly terrestrial volcanic deposits (the Kedon sequence); 12 - fault system rimming the Upper Kedon volcanic-tectonic depression; 13 - limit of transgressions during Devonian-to-early Carboniferous time; 14 - Upper Paleozoic, Mesozoic and Cenozoic. Numbers in circles: 1 - the Anmandikan Pluton, 2 - the Koargichan Pluton, 3 - the Abkit Pluton.

The area of the Paleozoic domes in the Kedon block contrasts with neighboring Rassokha block where the upper and middle crust consists of more heavy rocks and where, during Riphean-to-Cambrian time, basic volcanism took place. Domes are absent in the Rassokha block.

The geologic setting and general appearance of the early Paleozoic plutons (mostly quartz-monzonites and monzogranites) are similar to Proterozoic plutons of the East Siberian craton. For this reason the first investigators of the Omolon massif thought that their ages were also the same. It is true that the granite-metamorphic domes of the Omolon massif and of the East Siberian shield have similar places in the sequence of geological events which affected the Archean crystalline crust of both areas, but the ages of these plutons are different. This is an important distinction between the history of the Siberian plate and the fold-belt.

Shields and massifs in Western Europe and in Mongolia show similar magmatic histories. In general the history of Paleozoic domes of Siberian Northeast is similar to the granite series of H.H. Read (1949).

LATE MESOZOIC DOMES

First, we will describe the domes from the intracratonal part of the Mesozoic belt of the Siberian Northeast, particularly the numerous domes in the Chukchi fold system. Then we will discuss some peculiarities of domes located in the Koni-Taigonos fold system on the margin of Precambrian continental crust.

In the Chukchi fold system, Cretaceous granite-metamorphic domes expose the Paleozoic basement complex through its thick Triassic sedimentary cover (Fig.3). These basement folds are complicated by normal faults. The strikes of the basement folds obliquely crosscut the uniform northwest strike of the Triassic basin. On the west of the Chukchi fold system, the Alarmaut uplift is one of these basement folds. Its position coincides with the boundary of the Jura-Cretaceous Rauchua basin. In the central part of the fold system, the Velitkenay uplift obliquely crosses the Triassic basin from its north margin to the basin axis.

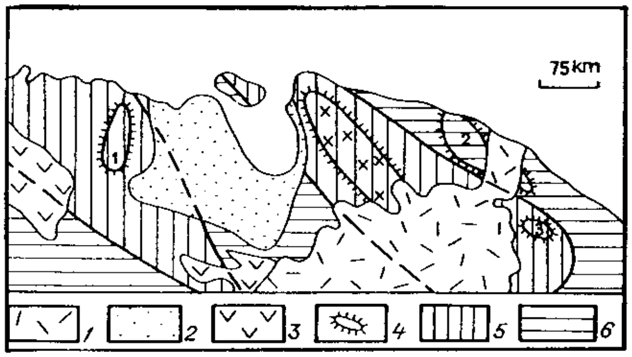

Fig. 3. Late Mesozoic granite-metamorphic domes in the Chukchi mesozoides. For location see Fig. 1.
1 - the Okhotsk-Chukchi volcanic belt; late Mesozoic basins: 2 - with mainly terrigeneous sediments, 3 - with mainly volcanic rocks; 4 - granite-metamorphic domes (crosses where not eroded): 1 - the Alarmaut Dome, 2 - the Velitkenay-Koekvun Dome system; late Triassic basins: 5 - deep, and 6 - shallow shelf seas.

Metasedimentary rocks and Triassic metadiabases with subhorizontal attitudes occur in the central part of the domes. Here the Cretaceous granitoid plutons are recumbent, tongue-shaped (cf. Hutchison, 1970). Minor folds, as well as shear zones, are most characteristic of the flanks of domes. Boudinage and other rock-flow features in the core of the dome define a zone of ductile deformation with flat schistosity. Its border with the belt of brittle deformations in the upper part of the Triassic complex is diffuse due to the difference in mechanical properties of gabbro-diabase sills and layered terrigeneous deposits. A buried row of domes found by geophysical research strikes from the eastern edge of the Rauchua basin near Pevek city to the northern border of the Okhotsk-Chukchi volcanic belt. Triassic sedimentary rocks lie recumbent upon these domes but they are strongly flattened. Upper Triassic shells of *Monotis ochotica* are compressed up to ten times.

Deeper level recumbent plutons consist of intermediate and acidic rocks, and shallower, younger ones are granitic. Features of deep level emplacement are shown by the older rocks. They are coarser (5-to-8 mm) than the plutons cross-cutting the Triassic complex (3-5 mm, except for phenocrysts). Porphyritic texture is absent in the deep level rocks. No chilled margins exist even in the thinnest sheets. Rocks with different mineral percentages often have sharp contacts, but there is no evidence of their being a different age. That is the peculiarity of deep-level rocks. Comagmatic rock suites intruding the Triassic complex have different generations of cross-cutting emplacement even of single composition.

Unusual ocellar sphene-bearing biotite quartz-diorite is found among the deep-level rocks. This texture is one of best examples of liquid silicate immiscibility in a rock origin (Gelman, 1962). It is possible that this physicochemical phenomenon is more characteristic of deep level magmatism than people usually think. Immiscible magmatic melts may be separated during their intrusion into upper structural levels. Ocellar sphene-bearing biotite quartz-diorites similar to the example from Chukotka are described from several deep-level plutons in Europe and were found recently by J. M. Amato and E. L. Miller (personal communication) in the core of the Kigluaik dome in Alaska. This quartz-diorite is not the only unusual igneous rock present in the cores of domes. There is also meladiorite, characterized by large but very thin biotite plates. Meladiorite of this type is found in the Alarmaut dome, as xenoliths in a lamprophyric dike in the buried dome near Pevek city, and among deep-level rocks in the Indigirka Alazea Interfluve. In the summer of 1994, J.Toro and I found this type of meladiorite in the dome on the Chukchi Peninsula.

The general characteristic of relatively deep level emplacement of plutons in dome cores is their connection with coeval regional metamorphic rocks of amphibolite facies, not with hornfelses. Migmatites also surround these plutons. In the Alarmaut dome there are very small bodies of fist or walnut-sized anatectic cordierite-phyric granite. Arteritic dikes extend from recumbent migmatite boies, and are several meters thick. Therefore, anatexis is present but is not of great geological significance on the exposed portion of the dome.

Metamorphic zonation is, in general, the successive change from garnet amphibolite facies to epidote amphibolite and then to greenschist facies. The rock association related to peak metamorphism is the following: silica undersaturated tremolite marble and impure marble, and diopside-tremolite schist; silica saturated garnet gedritite, garnet amphibolite, gedrite-hornblende amphibolite, clinopyroxene- hornblende schist, grossular-gedenbergite skarn (Fig. 4). They are mainly isochemical metamorphic derivatives from limestones and dolomitic limestones, layered marls, pelitic rocks and gabbro-diabase. The variety of mineral paragenesis depends mainly on the variation in lime content in the protoliths.

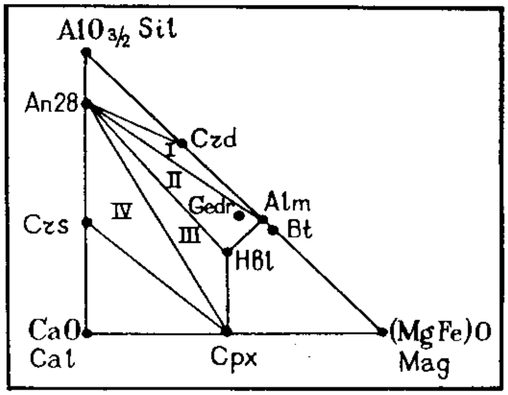

Fig. 4. Paragenesis related to peak metamorphism in the Alarmaut Dome (mol.%).
I - garnet gedritite, II - garnet amphibolite and two-amphibole amphibolite, III - pyroxene-hornblende schist, IV - grossular-hedenbergite skarn. *Alm* - pyrope-almandine, *An28* - plagioclase of 28 anorthite %, *Bt* - biotite, *Cal* - calcite, *Cpx* - clinopyroxene, *Crd* - cordierite, *Crs* - grossular, *Gedr* - gedrite, *Hbl* - hornblende, *Mag* - magnetite.

The origin of the rare grossular-gedenbergite skarn and the two-amphibole amphibolite is bimetasomatic. The skarn is found as metaconcretions among gedrite metapelites. Garnet gedritite is transformed to two-amphibole amphibolite in a rim 3-4 mm thick at its contact with the metaconcretion. The lime necessary for the crystallization of hornblende comes from calcareous concretions. The silica, alumina, and magnesia in the calcareous concretions come from gedritite. We must remember that gedrite- and hornblende-bearing amphibolite belongs to the peak of metamorphism, not the latest reactions. That metamorphic rock similar to garnet amphibolite corresponds to lime concentrations intermediate between such of gedritite and clinopyroxene-hornblende schist.

The mineral paragenesis of gedritite is of critical significance in the determination of the thermodynamic conditions of peak metamorphism. It is: garnet (Almandine 72, Pyrope 21, Grossular 7) - gedrite (ferromagnesium ratio F=0.62, alumina=17.65, sodium=0.62%) - biotite (F=0.54, alumina=17.41, potassium=6.57%) - cordierite (F=0.2-0.4) - anorthite 28 - quartz (Gelman, 1961). Aluminum may be present in the orthoamphibole crystal lattice according to two kinds of isomorphism. The first is tschermakitic: (Mg,Fe)Si -> $(Al,Fe)^{VI}$ Al^{IV}. The second is edenitic: 2(Mg,Fe) -> Na Al^{VI}. Considerable amount of Al^{VI} and a high content of Na are essential.

Gedrite with these properties was found first in the Alarmaut dome (Gelman, 1961), then in other domes in Northeastern Siberia (Gelman et al.,1980), and also in the North American Cordilleras (Ernst, 1988, Greenwood et al., 1991, Stoddard and Miller, 1990). These properties of gedrite indicate high pressure about of 5 kb during dome formation. That is much more than the possible lithostatic pressure. Instead, this high pressure is caused by high hydraulic magma pressure. The assemblage of metamorphic rocks containing high-magnesium gedrite and moderate-magnesium garnet, without cordierite, but together with kyanite described by A. Hietanen (1959) near the Idaho Batholith, is formed at still more high pressure (over 6.5 kb). High-ferrous gedrite in schistose hornfels from the Kitakami Mountains, Japan, (Seki and Yamasaki, 1957) defines the shallowest gedritite facies (less than 4 kb). Therefore our granite-metamorphic domes represent the upper part of Mesozoic regional metamorphism. At the Alarmaut dome, temperature of peak metamorphism is 680 degrees, according to the garnet-biotite geothermometer.

The parameters of metamorphism change in space and time. Garnet gedritite grades up into biotite-sillimanite and biotite-andalusite schists. Shear zones containing these rocks extend into the Triassic complex. Andalusite schists border weakly metamorphosed sedimentary rocks containing blastic minerals of greenschist facies. Also, minor domes composed of low grade metamorphic rocks with similar mineral paragenesis and zonality are superimposed upon the buried dome near the settlement of Maiskii. These interesting structures contain gold deposits. Garnet-gedrite paragenesis changes into biotite-sillimanite with the emplacement of potassium granite. The pressure of metamorphism decreases and chemical activity of potassium increases. Temperature also increases on the contacts with plutons.

As we have seen there is no evidence of dome formation in the pre-Mesozoic and early Mesozoic development of the Chukchi fold system. The beginning of dome formation is coeval with the earliest deposits in the late Jurassic-early Cretaceous basins. These early deposits are of Oxfordian and Kimmeridgian age. They are quartz-plagioclase sandstones with rare microcline and garnet. Similar sandstones were also deposited during Beriasian to Valanginian time. The two are separated by Volgian polymictic and volcanogenic sandstones, siltstones, tuffites and tuffs. I think that all of these sediments are volcanogenic. The beginning of dome formation was accompanied by volcanic eruptions.

Middle Cretaceous volcanic formations related to the Okhotsk-Chukchi volcanic belt lie on the eroded surface of granites and metamorphic rocks of the core of the Velitkenay dome. It is remarkable that petrochemical features of mid-Cretaceous volcanics and older plutonic rocks are the same, but the geological structure of the volcanic belt is independent of the metamorphic domes. The entire history of the domes is restricted to the Oxfordian to the Albian. This conclusion agrees with the available K/Ar ages.

How long did the general metamorphic episode last? Let us turn again to the narrow zones of two-amphibole amphibolite between garnet gedritite and grossular-gedenbergite skarn. The diagram of paragenesis vs. composition (Fig. 4) shows that the coexistence of Ca-bearing amphibole and gedrite becomes impossible when the relative concentration of CaO decreases to less than 2.5 times the concentration along the grossular to clinopyroxene tie-line. Using a diffusion equation we conclude that 3 or 4 mm of change of that critical concentration from the border of the concretion requires no more than a few hundreds or tens of years. This conclusion agrees with available experimental data (Zaraisky, 1993). In our case, bimetasomatism is ended due to the dramatic decrease of temperature by 150 degrees. Assuming a geothermal gradient at the time of peak metamorphism of 100 degrees/km, this decrease in temperature may be due to rapid uplift of the dome by 1 or 1.5 km, or to the return of the geothermal gradient to a normal gradient of 20-30 degrees/km, or to a combination of both events. The short duration of late Mesozoic doming is striking.

late Mesozoic domes in the Koni-Taigonos fold system occur at faults. Zolotogor'e and Tanurer domes, as well as the Allakh-Yun metamorphic zone, are situated at rifts that cross to the margin of the old continent. South Taigonos, Magadan and several other domes belong to faults proximal to the Taigonos island arc, which developed near the continental margin at least from the late Paleozoic to the Neocomian (Belyy et al., 1989). At first approximation we see the biggest shear zone, however more careful mapping shows the longitudinal metamorphic zonation. Strongly metamorphosed rocks related to garnet amphibolite facies are adjacent to granitoid plutons having different features of deep level emplacement. The metamorphic zonation is similar to that in the domes of the Chukchi fold system. The general geological situation here explains the high pressure metamorphism by magmatic loading, not just hydraulic pressure of magma (similar to the North Cascades crystalline core, after Miller et al. 1993, and to the southeast Coast Plutonic Complex, after Brown and Walker, 1993).

The time interval of doming may be estimated as Jurassic to Aptian, the beginning of the Okhotsk-Chukchi volcanic belt origin. So, the late Mesozoic doming on the continental margin is the same geological event as that in the intracontinental environment. The distinctive feature is the mafic-to-ultramafic magmatism. Such rocks are absent in the intracontinental domes of the Chukchi fold system, but they are very characteristic of the Koni-Taigonos fold system. Emplacement of mafic rocks is mainly premetamorphic, but postmetamorphic gabbro and pyroxenite are present in Zolotogor'e dome, for example. Also, granitoids in the cores of domes are different in so far as they belong to different petrographic provinces. Granitoids are more sodium-rich in the Koni-Taigonos fold system and more potassium-rich in the Chukchi one. So, late Mesozoic doming as structure transformation and rock metamorphism shows surprising indifference to basic magmatism and to the compositions of transmagmatic fluids on which granitoid petrochemistry depends.

A COMPARISON OF PALEOZOIC AND MESOZOIC DOMES, AND THE GIANT DOMES WITH LONG HISTORY OF DEVELOPMENT

Paleozoic and late Mesozoic granite-cored metamorphic domes have similar histories, but there is one profound geological difference. The durations of doming are estimated at about 350 m.y. for the Paleozoic and about 30 m.y. for the Mesozoic. Paleozoic doming is related to the global division of plates and mobile belts while late Mesozoic doming is a specific Pacifician event.

It is very interesting that there are different connections between dome history and closed volcanism. Middle Paleozoic volcanism studied on the Omolon massif was connected not only to petrochemical features of synmetamorphic plutonism, but in geostructural sense, to domes eroded before volcanic explosions. Owing to the stability of the pattern of late Mesozoic petrographical zonality in Northeast Asia, postdoming volcanism in the

Okhotsk-Chukchi volcanic belt shows some such relations, but no structural connection between mid-Cretaceous volcanism and pre-Aptian domes.

We have fewer reasons to see connection between Cenozoic (mainly Miocene) rifting on the Northern inshore of the Sea of Okhotsk and late Mesozoic doming, although Cretaceous granites exposed in places of relative elevation between rift troughs and destroyed domes show a tendency to uplift during the Cenozoic. In the Cordillera, the late Mesozoic doming continued rifting beginning in early Cenozoic time, and the relation between doming and rifting is closer. Possible doming is mainly a crustal event as well, while rifting has a deep nature, and their relation is not linear.

The domes with a long Paleozoic-to-Mesozoic history of development are interesting in view of the above geological differences between Paleozoic and late Mesozoic domes. The East Chukchi (Koolen) and the Taigonos are domes having this long development. Both are giant, their characteristic size is about 50 to 80 km. Their cores consist of Lower Precambrian crystalline rocks. The core of the East Chukchi dome is bordered by steeply dipping shear zones of Upper Precambrian and lower to mid Paleozoic sedimentary rocks. Farther situated Ordovician and Silurian deposits are unmetamorphosed. Another structure is possible in the Taigonos dome, where the Precambrian core has a root, but on its margins it is squeezed on the Paleozoic and lower Mesozoic rocks. Paleozoic and lower Mesozoic rocks are metamorphosed in shear zones to garnet amphibolite facies. Compositions and tectonic setting of granite plutons as well as volcanics are different too in these domes. Hower in both of these domes, we don't see an accidental superposition of late Mesozoic doming on Paleozoic doming.

Geological evidence shows a tendency towards uplift in the entire history of the East Chukchi dome, from the Ordovician to the Cretaceous. Post-Archean regional metamorphism and plutonism took place during the Devonian and then during the Cretaceous. The Taigonos dome developed at least during the Permian and the Triassic, when development of Paleozoic domes was finished and development of late Mesozoic domes had not begun. I.L.Zhulanova (1990) proves that metamorphism in the Inchik shear zone on the southeastern site of that dome is of pre-Aptian age. The giant domes are a special case. I hope that joint investigations of the East Chukchi dome beginning in 1994 by Stanford University, California, and Northeastern Research Institute, Magadan, Russia, will produce new data to help resolve related problems.

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