Geol. Soc. Malaysia, Bulletin 9, Nov. 1977; pp. 117–122.

Late Mesozoic granitic magmatism in geological structures of the U.S.S.R. North-East

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INTRODUCTION

Geologically composite territory of the Soviet North-East was the site of granite formation on a large scale from Late Jurassic through Cretaceous time. Granitic plutons formed under various tectonic conditions, such as, in the Mesozoic Yana-Kolyma and Chukotsk miogeosynclinal folded systems, in the eugeosynclinal Alazey-Oloy system, and in the Okhotsk-Chukotsk volcanogenic belt; the last developed along the borderline between Mesozoic and Cenozoic folded areas.

In the areas where plutons formed in a miogeosynclinal framework, they consist mainly of granitic and granodioritic complexes that are apparently unrelated to volcanism. Granitic complexes of the eugeosynclinal zone and volcanogenic belt, form gabbro-granitic series which are closely associated with products of volcanic eruptions both in space and time.

Discriminating among the granitic complexes

A number of granitic bodies, the largest in the North-East (up to 7,000 km^2), are peculiar to the Yana-Kolyma folded system. Plutons in the region form chains, or linear belts, which are concordant with the folded and faulted structures that are transverse to the trend of the volcanogenic belt and Cenozoic folded systems. Massifs occur along major deep faults zones, and their greatest masses are confined to the junctions between districts of different geologic origin. Thus, Yana-Kolyma batholithic belt is closely associated with south-western, western and northern borders of the Alazey-Oloy eugeosynclinal system and Yana-Kolyma miogeosynclinal system. Some trains of plutons outline pre-Riphean median massifs.

The overwhelming majority of plutons lie within Inyali-Debin synclinorium which is characterised by composite linear folding and contains the greatest (up to 17 km) thickness of the geosynclinal Verkhoyansk (Permian-Jurassic) complex of sandstone-slate strata. The massifs of the area are linear and concordant with the north-east strike of the folded elements. Separate linear bodies are localized within Paleozoic uplifts.

In rows transverse to the folded structures as well as in zones where Mesozoic rocks fade out and in distrcits of gently dipping non-marine Verkhoyansk beds, the massifs are smaller (up to 600-700 km^2), and not strictly linear.

The plutons are lens-like in section; geophysical data suggest that the thickness of granites probably does not exceed 8-10 km. This applies also to some stock-like bodies and bodies confined to joints. Geological and petrographical data indicate that these plutons are epizonal.

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The granitic elements are Late Jurassic and Early Cretaceous. Potassium-argon absolute ages are widely scattered between 160 and 80 m.y. The age scattering suggests heterogeneity and polygeneity of the plutons, due to metamorphism and complex thermal history, or to addition or loss of parent and daughter isotopes.

Revision of earlier potassium-argon determinations, new radiometric determinations, and recent geological and petrographical studies, enabled the authors to identify a number of granitic complexes related to development of the Yana-Kolyma system,

1. Late Jurassic (155-145 m.y.) complex of biotite granodiorites, adamellites, granites and binary granites with cordierite, andalusite and garnet ("high alumina" complex);
2. Late Jurassic-Early Cretaceous (145-130 m.y.) complex of biotite-hornblende granodiorites;
3. Early Cretaceous (130-120 m.y.) complex of biotite-hornblende granodiorites, granites, and biotite granites;
4. Early Cretaceous (120-110 m.y.) complex of leucocratic granites.

The high-alumina granitic complex is chiefly confined to plutons within the batholithic belt of Inyali-Debin synclinorium. In other parts of the Yana-Kolyma system this complex is not recognized. Within the high-alumina complex are biotite and binary granites containing cordierite, andalusite and garnet. Biotite granodiorite and adamellite are recognized as earlier products. The high-alumina rocks are typified by apatite, zircon, ilmenite and monazite as accessory minerals. The complex, on the whole, is primarily potassic but general alkalinity is somewhat lower than normal.

Small (less than 200 km^2) stocks, dome-like bodies and bodies confined to joints make up the Late Jurassic-Early Cretaceous complex, and form sub-latitudinal rows transverse to zones of linear folding in the southern Yana-Kolyma system. Small intrusions of this complex are found also within batholiths of the high-alumina granites. Within the Jurassic-Cretaceous complex biotite-hornblende granodiorites are dominant and associated with pyroxene-bearing quartz diorites and sparse aplitic granites. Accessory minerals are represented by apatite, zircon, sphene and ilmenite. The rocks are characterised by normal alkalinity and moderate sodium content.

The Early Cretaceous complex of granodiorite and granite is confined to the southern and northeastern quarters of the Yana-Kolyma system, and where it forms sub-meridional and northeasterly trending rows of plutons. The rocks belonging to the complex also include the large batholithic bodies of the Inyali-Debin synclinorium. Early phasesof the complex are represented by biotite-hornblende granodiorites and granites, and later ones by biotite and leucocratic granites. Sphene, orthite, apatite, zircon and ilmenite are accessory minerals. The rocks generally contain more potassium than sodium, and they reveal alkalinity higher than normal.

The complex of leucocratic granites is found mainly in the south-eastern Yana-Kolyma system in the zone of gently sloping beds as well as in the depression that separates Paleozoic rocks from the pre-Riphean Omolon massif. In places, the complex also includes bodies belonging to the Early Cretaceous complex of granodiorites-granites. Plutons there are not very large (50-200 km^2), being mainly stocks and small intrusions confined to joints. The leucocratic biotite granites there, contain apatite, zircon, orthite, xenotime, magnetite and ilmenite. The rocks belong to the potassic series.

The Yana-Kolyma system is, therefore, characterized mainly by granitic complexes, which do not reveal any links with volcanic activity. Most of the plutons are heterogenous and polygenetic.

The Chukotsk folded system, which differs from the Yana-Kolyma system because of its folded-block structure, absence of zones of strained linear folding and the limited (3 to 5 km) thickness of its geosynclinal assemblage includes granitic bodies which have a number of peculiarities. The plutons are strictly restricted to fault zones having north-western and north-eastern strikes. The intrusions are grouped in places in intersecting rows 150 to 300 km long. No clear association of plutons with certain folded structures exists as they occur both in synclinal depressions and in anticlinal uplifts. Within the latter granitic outcrops are of substantial size (up to 1500 km^2.)

Intrusions are localized in anticlinal uplifts within Paleozoic terruginous and carbonate strata and in geosynclinal depressions in Permian-Triassic sandstone and slate strata. Granites are also common in the pre-Riphean Eskimo massif.

Geological observations and geophysical data suggest stratiform plutons. The greatest thickness of granites occurring in central parts of the plutons, is estimated at 4 to 5 km. Such massifs are epizonal, but it is also possible that those located in uplifts (epi-mesozonal massifs) may extend to greater depths.

An Early Cretaceous age for those granites is indicated in a number of places where they break upward through Valanginian deposits, and are in some places overlapped by post-Aptian volcanic rocks belonging to the Okhotsk-Chukotsk belt. Some potassium-argon determinations obtained recently for biotite and whole-rock samples yield 130 to 120 m.y. ages and for the overlapping volcanic rocks, 110-100 m.y. ages. The results agree well with the stratigraphic relationships.

Plutons are composite in most cases. A number of phases have similar intrusion ages, these include biotite-hornblende, pyroxene-bearing quartz diorites, biotite-hornblende granodiorites, biotite and biotite-hornblende granites, and leucocratic and binary granites. Granodiorites and granites are dominant. Apatite-sphene-orthite-zircon-ilmenite assemblage of accessory minerals is characteristic of every rock type. The granites are typically potassic rocks.

Therefore, Chukoka, in contrast to the Yana-Kolyma system, is characterized by a single Early Cretaceous granitic complex. It may be correlated with granodiorite-granite complex of the Yana-Kolyma system, and similarly, its plutons were not attended by volcanic eruptions.

In the Alazey-Oloy eugeosynclinal system, Late Mesozoic granites are considerably less abundant, and having been little studied, only broad generalizations are possible. Plutons of epizonal origin are concentrated in the south-east sectors of the system and along the major northwesterly-trending Oloy-Berezovsk fault. Of the two Lower Cretaceous granitic complexes identified here, one forms large (up to 800 km^2) batholithic bodies, elongated northwesterly, parallel with folded structures. These massifs are localized within Upper Jurassic sedimentary and dominantly andesitic volcanic strata, and consist of biotite-hornblende granodiorites and granites, and some subalkaline granites· These are predominantly potassium-sodium rocks which yield K-Ar ages of 109 to 113 m.y.

The other Lower Cretaceous granitic complex forms bodies confined to joints with a sub-meridional strike, and have outcrop areas of 200 to 400 km^2. The massifs break upward through Upper Jurassic and Hauterivian strata. Potassium-argon ages are scattered from 130 to 100 m.y. Granosyenites, quartz syenites and granites prevail in this complex, but they were preceded by gabbros, syenite diorites and monzonites. The rocks have higher than normal alkalinity, with potassium slightly greater than sodium.

In the Alazey-Oloy zone as a whole the characteristic granodiorites and granites have higher than normal alkalinity where associated with gabbros. Relationships with volcanic formations is not yet understood.

Within the Okhotsk-Chukotsk volcanogenic belt the intrusions are localized in volcanic covers of various composition; recent geological data suggest that they might have been formed during Albian through Cenomanian time. Complexes of gabbros, grandoiorites and granites are closely related in space and time, and are apparently genetically related. They form single and multi-phased plutons which reveal some mineralogical and petrochemical affinities, enabling one to group these complexes into gabbro-granitic series. The gabbro-granitic series are thought to be related to the process of formation of the volcanogenic belt.

A post-Aptian (110-100 m.y.) gabbro-granitic series is in the volcanic belt's exter nal zone which is superimposed on Mesozoic structures and on ancient rigid massifs. Most of the rocks overlying the plutons are volcanic accumulations of andesite-basalt, andesite, dacite and liparite composition. The plutons commonly extend transversely across Mesozoic structures and ancient massifs, and they form well defined rows that transect the belt's structures. Plutons are localized within the limits of greater uplifts, and in places they form the enclosing framework for volcanic-tectonic depressions. Intrusions are rare in volcanic plateaus.

The plutons range widely from tens of square kilometres to 1,500 km^2. Their shapes in profile are thought to be dome-like or bed-like. All are typical sub-surface bodies.

Petrographical analysis of the intrusive series shows fairly normal composition for gabbro, gabbro-diorite, diorite, quartz diorite, granodiorite, adamellite and granite which made up successive intrusive phases during formation of the massifs. Rock proportions for individual may vary: granodiorites and adamellites are, however, predominant. Granites are characterised by biotite and amphibole with orthoclase. Gabbro is commonly leucocratic and substantially hornblendic, with quartz and potassium feldspar being minor but normally present. Accessory minerals are represented by apatite, zircon, sphene and magnetite.

In the west the demarcation between the volcanogenic belt's internal and external zones coincides with the junction of Mesozoic and Cenozoic folded areas, but in the east the internal belt is immediately linked to Cenozoic strata with no apparent disconformities. Albian-Cenomanian (110-95 m.y.) gabbro-granitic series of intrusions in the internal zone break upward through a notedly marine series of sedimentary and siliceous volcanic rocks of Jurassic and Early Cretaceous age, as well as through subareal basalts, andesite-basalts and andesites. The youngest of the intruded volcanogenic formations were dated as Albian-Cenomanian.

The intrusions form distinct linear rows concordant with the general strike of the volcanogenic belt's structures. In some places they are en echelon. The plutons commonly have outcrop areas of more than 1000 km^2 and many are laccolith-like in profile. They appear to be epizonal.

The following rock sequence may be recognized in the multi-phase plutons: gabbro-diorite-quartz diorite-tonalite-plagiogranite-leucocratic granite, with tonalite and diorite being dominant. The gabbroic rocks contain considerable hornblende. Accessory minerals comprise apatite, magnetite, zircon, and, rarely, sphene. All rocks belong to the sodic type.

The gabbro-granitic series is closely associated with volcanics in space and time. Andesite-ignimbrite-gabbro-granodiorite-granitic volcano-plutonic association is identified within the belt's external zone, with acid and moderately acid rocks being widely developed. The internal zone is characterized by a basalt-andesite-diorite-tonalitic association, with episodic occurrences of acid rocks. Paragenetic relationships may be established between the volcanic and plutonic members of these associations, namely, the plutons were intruded after the accumulation of volcanic rocks.

The third, gabbro-granitic series of a probably Post-Cenomanian age (90-80 m.y.) was insignificantly developed in the belt, although recorded in both external and internal parts of the belt. They are small (50-100 km^2) and have a stock-like form in profile. They are characteristically epizonal bodies. The rocks of the series form separate plutons in some cases, yet, more often, they form later phases within massifs of earlier gabbro-granitic series. Rocks typical of the series, are gabbro, syenite-diorite, granosyenite, granite and alkaline granite. The rocks are subtsantially hornblendic and pyrozene-bearing. Arfvedsonite, aegirine and riebeckite are typical of the alkaline granites. Granites feature higher than normal alkalinity with sodium dominant over tassium. They do not reveal any relation to volcanism. It seems possible that activity in the volcanogenic belt was terminated with the series.

CONCLUSIONS

The general characterization of Late Mesozoic granitic magmatism (summarized in Table 1) leads to the following conclusions.

Miogeosynclinal structures of the Soviet North-East are characterised by moderately sodium, potassium-sodium and potassium granodiorite-granitic and granitic associations. 'High alumina' granites occur exclusively in the zones of strained linear folding where the thickness of geosynclinal complex is at its maximum. Differences in tectonic evolution and geological structure of the North-eastern miogeosynclinal systems seems to have brought more prolonged and more versatile magmatism in the Yana-Kolyma system than in the Chukotsk system.

Granodiorite-granitic and granitic complexes show no definite relation to volcanism and they are not preceded by earlier-phase gabbros and diorites. Judging from their mineral composition, the granodiorites may have formed under moderately aqueous, relatively low-temperature conditions (ilmenite series of Ishihara, 1975).

Granites of the eugeosynclinal zone and volcanogenic belt are closely associated in space and time with gabbro and diorite complexes, and they form a single gabbro-granitic series. Gabbro and diorite complexes are paragenetically linked with the products of volcanic eruptions. The granites were derived from low aqueous, high temperature melts (magnetite series of Ishihara, 1975).

TABLE 1

PECULIARITIES OF LATE MESOZOIC GRANITOIDS IN THE STRUCTURES OF THE NORTH-EAST U.S.S.R.

Tectonic position / Main features	Miogeosynclinal system		Eugeosynclinal system	Okhotsk-Chukotsk belt	
	Yana-Kolyma	Chukotsk	Alazey-Oloy	external zone	internal zone
Characteristic rock types	adamellites, granites, leucocratic granites	granodiorites granites	granodiorites	quartz diorites, granodiorites	tonalites, plagiogranites
Attending rocks	granodiorites	quartz diorites, leucocratic granites	gabbros, diorites, syenite-diorites, granosyenites	gabbros diorites, leucocratic granites	gabbros, diorites
Sizes of the massifs	up to 7000 sq. km.	100–2000 sq. km.	50–1000 sq. km.	100–2000 sq. km.	
Shapes of the bodies	beds	stocks, sills		beds, stocks, domes	
Mineral parageneses of typical rocks	biotite, microcline, andesine-oligoclase quartz, hornblende (rarely), cordierite, andalusite	hornblende, andesine, biotite, quartz, orthoclase	hornblende, biotite, andesine, orthoclase, quartz	pyroxene, hornblende, biotite, andesine-oligoclase, quartz, orthoclase	
Accessory minerals	apatite, zircon, ilmenite, sillimanite, monazite	apatite, zircon, ilmenite, sphene orthite	apatite, sphene, orthite, magnetite	apatite, zircon, magnetite, sphene, orthite	
Chemism of typical rocks	SiO_2=68–73% $K_2O > Na_2O$	SiO_2=68–74% $K_2O \gg Na_2O$	SiO_2=64–68% $K_2O \approx Na_2O$	SiO_2=62–69% $K_2O \approx Na_2O$	SiO_2=62–66% $Na_2O > K_2O$
Relation to volcanic processes	Absent		Possible	Close time-spatial	

Since the depth of formation of plutons was of the same order throughout the different zones, it seems valid that the peculiarities of granitic magmatism were determined by the levels of melt generation. Granites of the miogeosynclinalz ones are thought to have crustal origins, whereas those in both the eugeosynclinal zone and volcanogenic belt are thought to have mantle sources.

REFERENCE

ISHIHARA, S., 1975. Magnetite series and ilmenite series granitic rocks. *Record Proc. 13th Pacfiic Science Congress, p,* 403.