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Ancient Deep Faults, Their Reactivation and Peculiarities under Different Geodynamic Conditions in Eastern Yakutia (Northeast Russia)

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THEME 10: Metallogenetic Provinces in the Circum-Arctic Region

Summary: The East Siberian palaeo-rift system along the northeastern margin of the Siberian plate in eastern Yakutia is polycyclic; it has been intermittently active from the Proterozoic to Cenozoic. It consists of four trilete systems of deep-reaching fault zones: from south to north, the Sette Daban, Vilyui, Kharaulakh and Nordvik trilete systems, each characterized by three rifts meeting at a triple point. The Devonian - Early Carboniferous rift system was strongly affected by Mesozoic collision, forming the Verkhoyan' fold-and-thrust belt, along which the original rift sediments are now discontinuously exposed.

The Sette Daban region not only displays the best section across the Verkhoyan' Mountains, but also a large variety of structures formed during their polycyclic evolution. The inherited structural history of eastern Yakutia is documented in orogenic cycles. The more or less complete stratigraphic sequence from the Lower Riphean to the Upper Cretaceous, having a total thickness of more than 30 km, is exposed. It can be shown that, during the Proterozoic and Phanerozoic, eastern Yakutia experienced several repeated periods of tectonic activity. Three orogenic cycles can be recognized: Early Proterozoic - Middle Riphean, Late Riphean - Late Silurian, and Devonian - Cretaceous. Each cycle begins with a continental rift, which then develops into a passive continental margin, and is terminated by an orogenic event. In each successive cycle, the ancient deep faults are reactivated and some new major faults are formed.

During the Late Riphean and Devonian rifting, these fault zones were the sites of ultramafic intrusions, basaltic lava effusion, and formation of Ta-Nb-La-Ce and Cu- deposits. During the Mesozoic collision, these zones were affected by greenschist facies 'dislocation' metamorphism and gold mineralization. Under the conditions of an active continental margin, granitic intrusions were formed that are associated with numerous Au, Ag, Pb, Zn, Sn, W, Mo, Bi, Sb and As deposits.

The variety of different types of mineral deposits is supposed to be due to the fact that the deep-reaching fault zones have been repeatedly reactivated under different tectonic conditions. Outside these zones, there was almost no igneous activity, no metamorphism and none of the associated types of mineralization.

INTRODUCTION

Deep-reaching fault zones in the Earth's crust have the following characteristics: 1) They extend downwards from the cover into the crystalline basement. They are often characterised by an elongated zone showing a steep gravity gradient, a sharp bend in gravity isolines, elongated magnetic anomalies or a row of small magnetic anomalies. 2) They are accompanied by igneous activity, 'dislocation' metamorphism and the associated different types of mineral deposits. Deep-reaching fault zones may be interpreted either as faults penetrating the entire crust and controlling the ultramafic and mafic magmatism or as faults within the crust associated with 'dislocation' stress-metamorphism and granitoid magmatism. The faults that penetrate the entire crust formed during periods of crustal extension. In contrast, intracrustal faults were caused by compression during collision. Despite being formed under different geodynamic conditions, the deep-reaching fault zones have some common features. However, the fact that they are associated with sedimentary sequences of a variety of facies laid down in contrasting settings suggests that the faults are long-lived and were reactivated during each successive period of crustal deformation. This can be clearly seen in the South Verkhoyan' Mountains and will be discussed in more detail below.

The South Verkhoyan' Mountains are situated on the southeastern margin of the Siberian plate (Fig.1). They belong to the Verkhoyan' fold belt, which is bounded on the southeast by the Okhotsk-Chukotka volcanic belt. The South Verkhoyan' Mountains of eastern Yakutia have evolved over a time interval of more than 1000 Ma. The outcrops display a sequence of Lower Riphean to Upper Cretaceous with a total thickness of more than 30 km and consisting of volcanic, carbonate and detrital rocks. The strata document a series of orogenic cycles: Early Proterozoic to Middle Riphean, Late Riphean to Late Silurian, and Early Devonian to Cretaceous. Each cycle begins with intracontinental rifting, grades to post-rift downwarping and to the formation of a passive continental margin, but does not attain a spreading stage. The last stage is characterized by an increase in the regional heat flow and orogenic deformation.

Since the Sette Daban region in northeastern Yakutia is well exposed and possesses a more or less complete stratigraphic sequence, it has been studied in order to understand the geological evolution of the entire northeastern margin of the Siberian plate and to try to shed some light on the problems of the Cenozoic continental rifting in the Laptev Sea region.

EARLY PROTEROZOIC-MIDDLE RIPHEAN OROGENIC CYCLE

In the Early Proterozoic period, a palaeo-rift system was created along the present eastern flank of the Siberian plate. The rifting led to the break-up of the East-Siberian palaeocontinent into the Siberian, Kolyma and Okhotsk plates (Fig.1).

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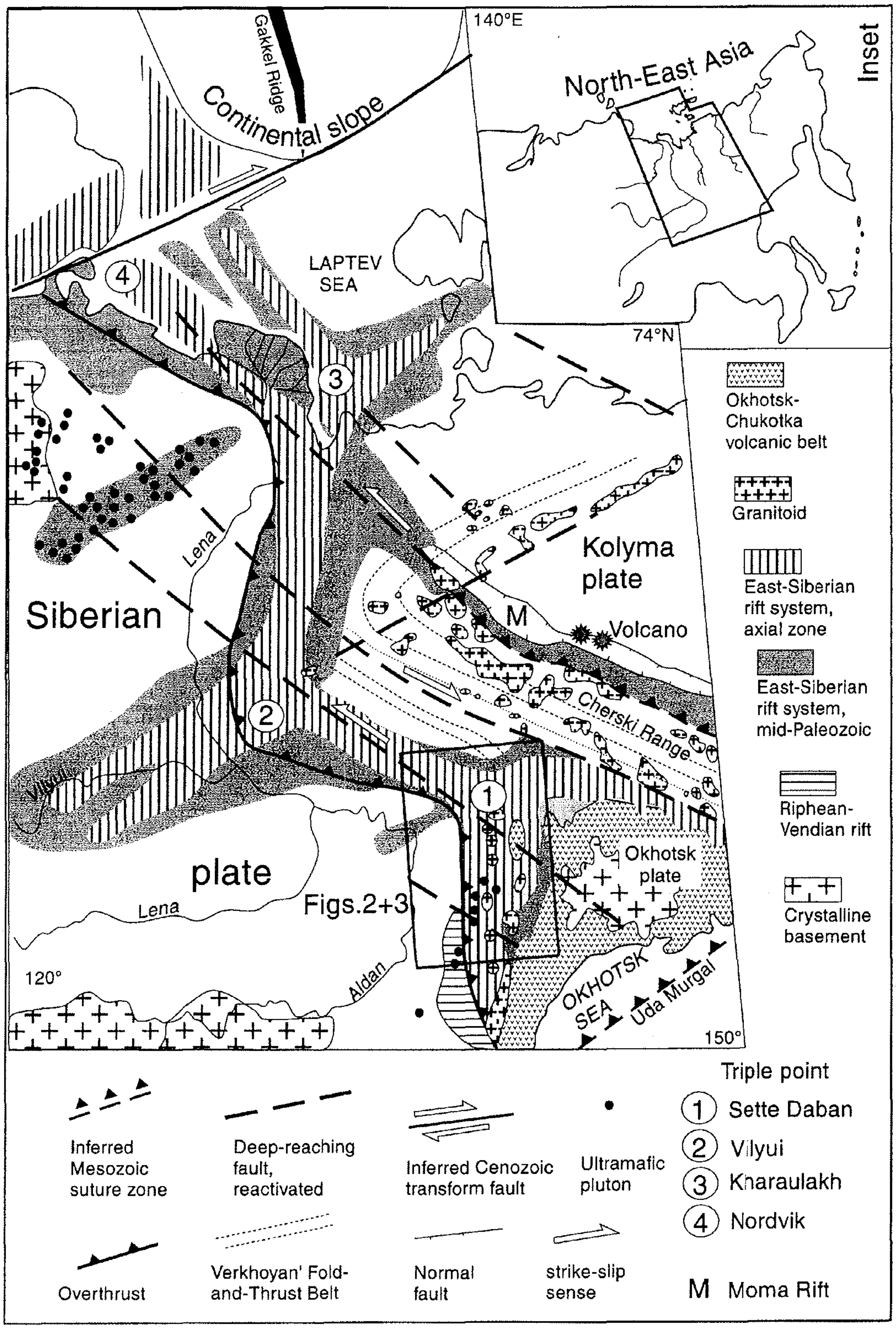

Fig. 1: Structure of the East Siberian palaeo-rift system in Devonian and Early Carboniferous time and its evolution in Mesozoic and Cenozoic times. Trilete systems of major fault zones (numbers in circles): (1) Sette Daban; (2) Vilyui; (3) Kharaulakh; (4) Nordvik. M - Moma Graben.

The following features are characteristic for the Early Proterozoic rifting:

1) intercalated basalts within Lower Proterozoic variegated coarse clastic and minor carbonate sediments in a graben in the southern part of the South Verkhoyan' Mountains and a pluton of ultramafic alkaline rocks with platinum mineralization;
2) formation of a N–S trending basin filled with Lower to Middle Riphean detrital and carbonate sediments 5–6 km thick;
3) updoming between Middle and Late Riphean and weak folding (regional unconformity beneath Upper Riphean).

LATE RIPHEAN-LATE SILURIAN OROGENIC CYCLE

Continental rifting (Late Riphean-Vendian)

In the Late Riphean period the formation of a palaeo-rift again began within the East Siberian palaeocontinent. Variegated continental sediments with intercalated basalts of the same age have been identified in all palaeo-rifts on the eastern margin of the Siberian plate.

In the South Verkhoyan' Mountains, a N–S trending rift trough 250-300 km wide (Fig. 2) formed in this period; it was filled with carbonate and detrital sediments up to 5 km thick containing a Cu and Pb-Zn mineralization. The succession contains dolerite-trachydolerite sills totaling more than 1 km in thickness. U-Pb dating of baddeleyite occurring in sills yielded ages of 974 to 1005 Ma (RAINGIRG et al. 1998).

At the end of Late Riphean time, basaltic and trachybasaltic lavas were erupted in the central part of the trough. The basalts attain a maximum thickness of 1400 m. In the Sette Daban palaeo-rift, the basalt lava flows and then the dolerite sills in the Upper Riphean succession gradually disappear laterally towards the adjacent Kyllakh and Yudoma uplift zones (Fig. 2). The sedimentary formations in the rift thin out towards the palaeo-uplifts at the rift margins. Volcano-plutonic complexes of ultramafic alkali rocks and carbonatites associated with Ta, Nb, REE (La, Ce) and Y deposits and apatite occur in the palaeo-rift. U-Pb dating of REE minerals suggest an age of 600-650 Ma.

The Late Riphean fault zones were obliterated by subsequent folding. However, deep faults are assumed to have been active in the central part of the Late Riphean rift and were associated with intense basalt and ultramafic magmatism. Furthermore, the occurrence of faults is confirmed by rapid lateral facies changes and rapid lateral increases in thickness of successions within parallel fault-bounded zones in the rift.

In Vendian time the trough was filled with variegated detrital and carbonate sediments 1.5-2.1 km thick containing Ge, Pb and Zn mineralization of the Mississippian type.

Passive continental margin (Early Cambrian–Middle Ordovician)

Subsequent to Late Riphean rifting, intense downwarping of the Earth's crust took place. During the Early Cambrian the South Verkhoyan' mountains were part of a deep-water basin and the adjacent uplifts were shelf zones. The basin was filled with carbonate-clay-chert sediments overlain by detrital carbonate turbidites up to 6 km thick.

Shallow continental regime (Late Ordovician–Late Silurian)

During Middle to Late Ordovician the conditions of a passive margin changed to a continental regime, evidenced by the occurrence of a Middle Ordovician variegated succession of limestone, marl, dolomite, and gypsum.

At the site of the South Verkhoyan' Mountains was a shallow bay in a marine basin, in which reef limestone 1.5-2.5 km thick accumulated. Intercalations of alkali (potassium) trachyte tuff are widespread and phonolite lavas occur in the upper part of the sequence.

At the end of Silurian period, updoming, weak folding, and peneplanation occurred. A weathering crust 20–450 m thick formed on the Ordovician-Silurian peneplain in Late Silurian time and evaporites accumulated in lagoons.

DEVONIAN-CRETACEOUS OROGENIC CYCLE

Continental rifting

The Late Silurian updoming was fragmented by faults in Late Silurian and Early Devonian times, thus beginning the mid-Palaeozoic continental rifting (LEVASHOV 1977). During this period the East Siberian palaeo-rift system was regenerated once again along the north-northeastern side of the Siberian platform, reactivating Late Riphean rift troughs (Fig. 1). The East Siberian palaeo-rift system consists of four trilete systems (MITCHELL & GARSON 1981, p. 43) of deep-reaching fault zones: from south to north Sette Daban, Vilyui, Kharaulakh and Nordvik. Each branch of a trilete system is a single rift zone up to 400 km wide consisting of several smaller parallel grabens and horsts 40–70 km wide. The structure of one of the well exposed branches of the Sette Daban trilete system was studied in the Sette Daban range (Fig. 2).

The northwestern and southern branches of the Sette Daban trilete system crop out in the South Verkhoyan' Mountains. The northeastern branch is covered by Carboniferous and Permian detrital sediments. However, in Late Triassic to Early Jurassic times a synsedimentary graben formed in these sediments in which intense contemporaneous basalt eruption occurred. Furthermore, the Mesozoic structural trends follow the „trilete" trend of the Middle Palaeozoic rift zones.

The Sette Daban palaeo-rift comprises several deep faults: Burkhala, eastern Sette Daban, Menkyule, Allakh-Yun' and Minor. Grabens associated with these faults contain volcanogenic, detrital and carbonate sediments (SAGIR 1997).

The Burkhala (No. 1 in Fig. 2) fault controlled the position of the Dzhalkan graben, which is 45–50 km wide and contains 3500 m of deposits of which 1500 m are basalts. The basalts and trachybasalts contain native copper mineralization of the Lake Superior type (USA); the overlying variegated detrital sediments also contain stratabound deposits of copper-bearing sandstones (White Pine type). The Dzhalkan graben is bounded and complicated by synsedimentary normal faults with a displacement of 1-5 km (SAGIR et al. 2000). A dyke swarm of dolerites and trachydolerites was intruded in the graben and on the adjacent horsts. It can be traced over a distance of 300 km. The frequency of dykes cutting Cambrian and Ordovician sediments normally ranges around 1-15 dykes/km2 but locally attains 50-200 dykes/km2. The dykes vary in thickness from 0.5 to 20 m, on average 2–3 m.

The eastern Sette Daban fault controlled the formation of the synsedimentary Eastern Khandyga graben, which is 70-80 km wide (2 in Fig. 2). The graben is composed of several blocks

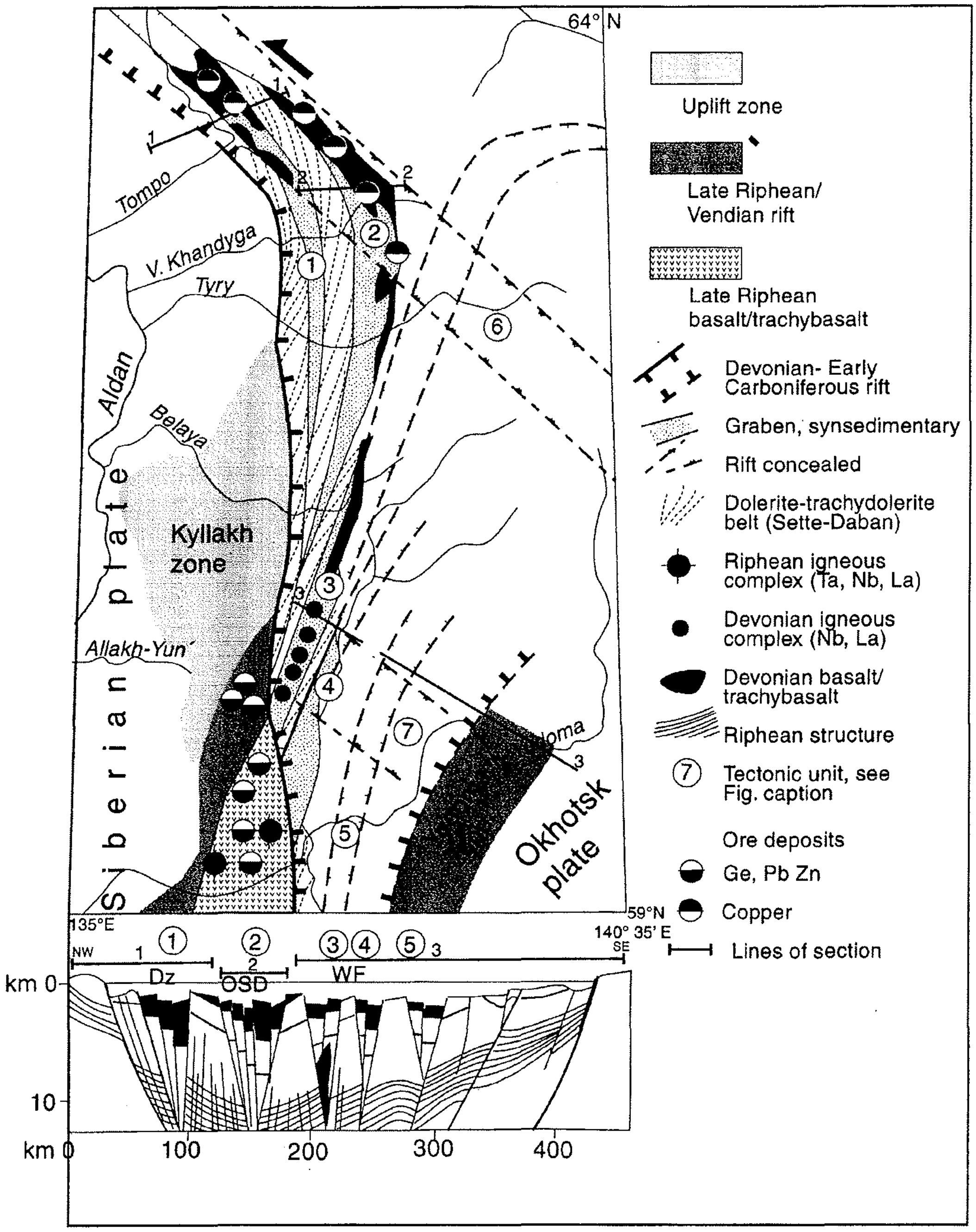

Fig. 2: Structure and metallogeny of the Sette Daban trilete system in the South Verkhoyan' region in Late Riphean to Vendian and Devonian to Early Carboniferous times. Numbers in circles denote faults that controlled the mafic and ultramafic igneous activity: (1) Burkhala, (2) East Sette Daban, (3) Menkyule, (4) Allakh-Yun', (5) Minor, (6) Tompo-Okhotsk, (7) Mendzhel.

bordered by synsedimentary normal faults with displacements of 0.8-4.5 km. The thickness of the rift fill attains 2500-3000 m, of which only 300-400 m consist of basalt to trachybasalt lavas. Variegated clastic and carbonate rocks above and below the lavas contain intercalations of copper-bearing sandstone and evaporites. Dyke swarms of dolerites and trachydolerites in the graben and on the adjacent raised blocks can be traced for a distance of up to 200 km. The dyke frequency in the area is 1-3 dykes/km2 but locally reaches 10-50 dykes/km2.

The Menkyule fault zone (3 in Fig. 2) controlled the location of the Belaya graben, which is more than 50 km wide (Sagir et al. 2000). The variegated rift fill attains a thickness of 650-1800 m, of which trachybasalts make up only 100 m. The displacements along the synsedimentary normal faults range from 0.7 to 3.5 km. A dyke swarm of alkali picrite, dolerite and trachydolerite more than 150 km long occurs in the graben.

Volcanic and plutonic rocks of alkali-ultramafic composition with deposits of Nb, La and Ce and apatite are associated with the graben. Ring and fault diatremes and lamproites are associated with these ultramafic plutons. The diatremes cut Ordovician to Silurian rocks. The age of the lamproites is around the Frasnian-Famennian boundary. Observations in river alluvium revealed the presence of indicator minerals for diamonds (chrome spinel, picro-ilmenite, moissanite, garnet, chromite etc.). They suggest that primary diamondiferous deposits may exist in Middle Palaeozoic rocks in the catchment area. The mineralogical and petrographic characteristics of the lamproites in the Belaya graben are similar to those of the diamondiferous lamproites of the Kimberley province in Western Australia (JAQUES et al. 1986).

The Allakh-Yun' fault (4 in Fig. 2) controls the location and development of the Allakh-Yun' graben, which is 25-30 km wide. The thickness of the clastic and carbonate succession reaches 500-3000 m. Basalt lava flows are absent. Only several dolerite dykes and lamproite diatremes are present. A few diamonds (up to 3 karats) have been found in river beds; however, their relationship with primary diamondiferous rocks *in situ* has not yet been studied. The Allakh-Yun' graben was thrust onto the Belaya graben during the Mesozoic collision (Late Jurassic to Early Cretaceous). These two units were formerly thought to be a single unit (SAGIR 1997).

The Minor fault (5 in Fig. 2) was identified in Middle Carboniferous to Lower Permian siliciclastic rocks in the central part of the South Verkhoyan' Mountains. A belt of metamorphic rocks runs along the fault for a distance of 300 km. The Middle Palaeozoic Gorbi graben is located at the southern end of the fault. The graben is over 25 km wide, the Devonian rocks (Frasnian–Famennian) in the graben are 150-300 m thick, and the displacement along the synsedimentary faults ranges from 0.1 to 1.0 km. The Devonian sediments thicken towards the north. This suggests that the main zone of the Middle Palaeozoic graben is concealed by Carboniferous to Permian rocks.

During the Devonian–Early Carboniferous, basaltic volcanic activity and accumulation of rift sediments took place only in the grabens mentioned above. On the adjacent raised blocks (horsts), Devonian rocks are either totally absent or are much thinner (100-200 m). Synsedimentary folding occurred in the rift during this period.

The rocks within the grabens are polycyclic. In Sette Daban five tectono-magmatic cycles have been identified: Early Devonian (to Emsian), Early (Late Emsian) to Middle Devonian, Frasnian, Famennian, and Early Carboniferous. Each cycle can be subdivided into regular episodes:

1) intrusion of dolerite and trachydolerite dykes, effusion of basaltic and trachybasaltic lava flows (each 20-400 m thick), erosion of the basalts from horsts in the rift zone and from the rift shoulders and accumulation of variegated, copper-bearing, carbonate and detrital rocks (50-500 m thick) in fluvial, lacustrine, lagoonal and coastal environments;
2) waning of the tectono-magmatic activity, downwarping of the Earth's crust and accumulation of shallow-water carbonates (100-500 m thick); and
3) increase of the deep-seated heat flow, uplift of the Earth's crust, and beginning of continental conditions. This was then followed by another cycle.

Comparable cyclicity has been identified in the Vilyui and the Kharaulakh trilete systems (LEVASHOV 1977).

The Sette Daban and Vilyui trilete systems are linked by the Tompo-Okhotsk deep fault zone, which is inferred to be a transform fault of Middle Palaeozoic age (Fig 1).

The NW–SE trending Tompo-Okhotsk fault zone (6 in Fig. 2) is a sinistral strike-slip fault zone 50-70 km wide. Within this zone there are several major normal faults downthrown to the northeast. The fault-controlled basaltic volcanic activity was particularly intense along the fault zone. The total thickness of the basalt lavas increases from 300 m to 900-1400 m in a northwesterly direction. The most intense basalt magmatism therefore appears to have occurred in the central part of the East Siberian paleorift system, between the Sette Daban, Vilyui and Kharaulakh trilete systems. In the Dzhalkan and East Khandyga grabens, NW–SE trending synsedimentary normal faults were active with a throw up to 1.5 km.

In the southeastern part of the Tompo-Okhotsk transform fault within the Kukhtuy crystalline basement of the Okhotsk plate (Fig. 1), Devonian (Frasnian–Famennian) continental successions are known. In total, the sinistral displacement in this 50-70 km wide Tompo-Okhotsk transform fault zone is equivalent to the amount of opening of the palaeo-rift.

In the NW-SE-trending Mendzhel zone (7 in Fig. 2), which is about 30 km wide, there are numerous faults with a sinistral strike-slip and a normal component (downthrow of 2-3 km). These faults controlled the positions of the alkali ultramafic plutons in the Belaya graben. Andesitic, dacitic and rhyolitic tuffs and lavas of Devonian age are known in the southeastern part of the Okhotsk plate.

Passive continental margin (Middle Carboniferous-Middle Jurassic)

After the Devonian-Early Carboniferous rifting, the northeastern part of Yakutia again experienced subsidence and became a passive continental margin between the Siberian, Okhotsk and Kolyma continental plates. During the Late Palaeozoic, the south Verkhoyan' Mountains were part of a deep-water basin between the Siberian and Okhotsk plates. Here, Visean-Middle Carboniferous sediments rest transgressively on the entire rift structure and mark the beginning of the Verkhoyansk siliciclastic sequence, which is 12-18 km thick. At the base, the siliciclastic and carbonate succession is composed of an olistostrome (Visean) and deep-water distal turbidites (Middle Carboniferous and Lower Permian), and in the middle and upper parts it consists of silty-sandy shelf sediments (Upper Permian and Lower Triassic–Middle Jurassic) in which coastal and deltaic sediments are present.

Collision (Late Jurassic-Aptian)

In Late Jurassic time, collision began in the South Verkhoyan' Mountains due to the collision of continent and island arc in the Uda–Murgal zone (GUSEV et al. 1985). Similarly, collision occurred along the southwestern margin of Kolyma plate in the Cherski Range.

This event caused the closing of the Verkhoyan' basin and initiated Mesozoic folding in the South Verkhoyan' region. The intense compression caused tight folding and thrusting of the sedimentary sequences associated with strike-slip faulting. The most intense folding occurred in Middle Palaeozoic rift zones (in palaeograbens). The Mesozoic structures were formed along mid Paleozoic normal faults (Fig. 3). In the reac-

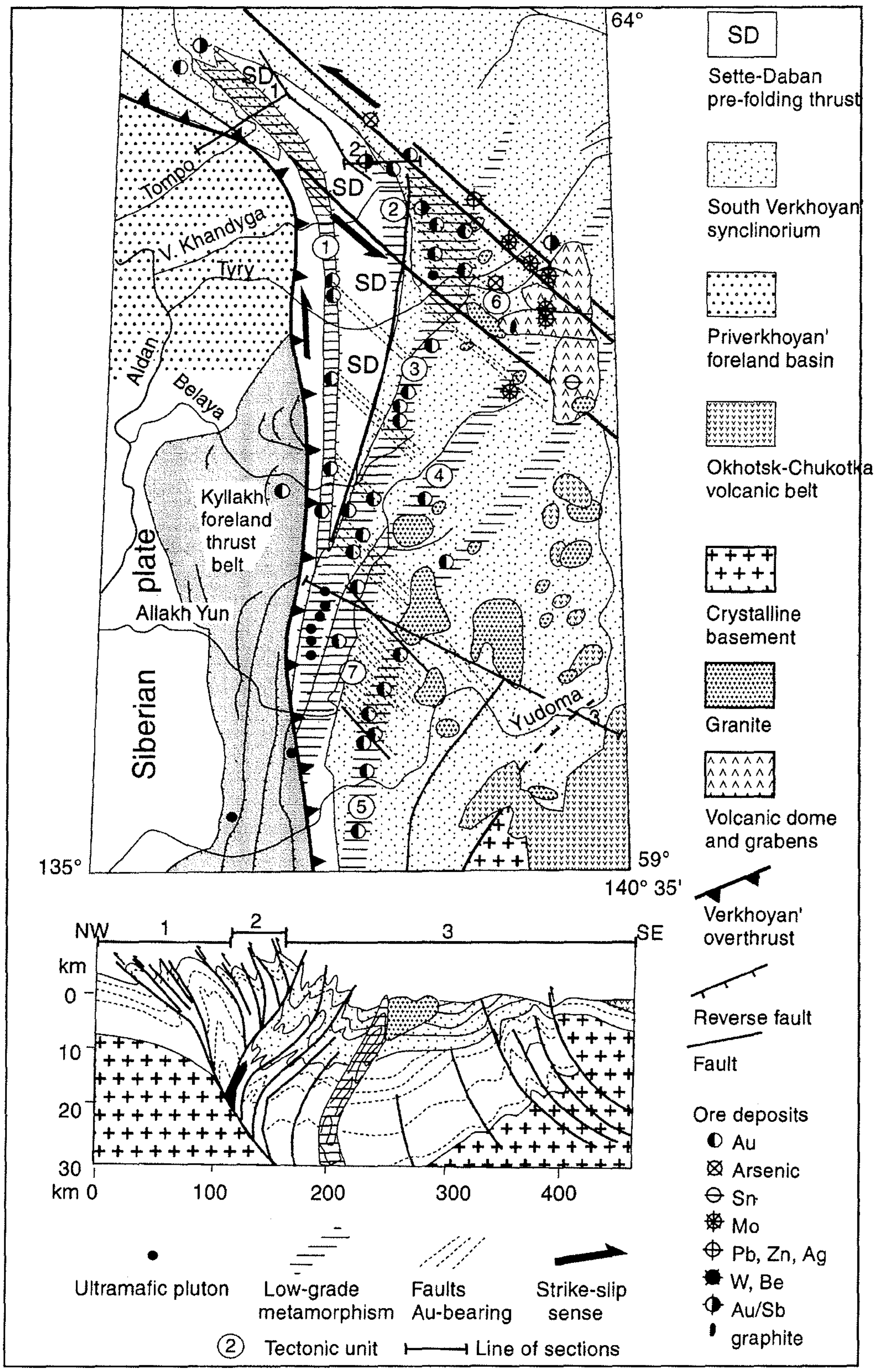

Fig. 3: Structure and metallogeny of the South Verkhoyan' mountains in the Late Jurassic to Late Cretaceous periods. Numbers in circles denote faults that controlled the mafic and ultramafic igneous activity (see also Fig.2)

tivated zones of the ancient deep faults, the Lower Proterozoic to Permian sedimentary rocks were metamorphosed (KOKIN & ANDRIANOV 1989), the metamorphic grade increasing downwards.

Metamorphism in the area of the Burkhala and eastern Sette Daban faults is of sericite-chlorite subfacies. In the vicinity of the Menkyule and Allakh-Yun' faults, the 'dislocation' metamorphism reached the chlorite-biotite subfacies in the Lower to Middle Palaeozoic clastic and carbonate rocks and sericite-chlorite subfacies in Middle Carboniferous to Lower Permian rocks of the Verkhoyan' Mountains. In the Minor fault, metamorphism ranges between the sericite-chlorite, chlorite-biotite and epidote-actinolite and even staurolite subfacies. The metamorphic zone is 10-25 km wide and can be traced along the ancient deep faults for a distance of more than 200 km. Locally the 'dislocation' metamorphism is so intense that gneiss structures with possible plastic flow occur (Tompo-Okhotsk and Mendzhel faults). At some distance from the deep faults, the sediments have suffered only epigenetic alteration.

Metasomatism and mineralization also took place at the junctions of N-S to NW-SE-trending metamorphic belts. Middle Palaeozoic dolerite to trachydolerite dykes in the Burkhala, East Sette Daban and Menkyule fault zones experienced beresitization (pyrite-rich), albitization and silicification, with which gold mineralization is sometimes associated. Linear zones of gold-bearing dolerite dykes can be traced for a distance of several tens of kilometers. Numerous gold placer deposits formed during erosion of these dykes. In the metamorphic zones within the Middle Carboniferous-Lower Permian mudstones and siltstones, graphite and SiO2 metasomatism was accompanied by gold mineralization. Gold mineralization is associated with metamorphic rocks over a distance of several tens to hundreds of kilometres, either as primary ore or as placer. In this case, the main primary deposits are localized at the junctions of the ancient deep faults.

NW-SE and NE-SW-trending dyke swarms of lamprophyres and diorite porphyries occur at the intersection of the metamorphic belts associated with the Minor and Mendzhel' faults. Furthermore, anatectic granite plutons occur along the Minor and Allakh-Yun' faults and are associated with the meta–morphism along the deep faults. The low-grade metamorphic rocks are affected by contact metamorphism. The rocks contain deposits of Au, W, Mo and other metals.

A stock of ankerite-dolomite carbonatite containing REE and Au mineralization occurs in Lower Permian metamorphic rocks at the junction of the Menkyule and Tompo–Okhotsk deep seated faults. The metamorphic rocks are overprinted by contact metamorphism.

At the end of the Aptian, the area of the South Verkhoyan' Mountains again underwent folding. A mountainous region formed along the present eastern margin of the Siberian plate. It consists of three main structures (Fig. 3): the Sette Daban fold-and-thrust uplift, the South Verkhoyan' synclinorium and the Kyllakh fold-and-thrust belt of the Siberian platform. All these structures were formed by northwestward compression. This oblique compression in relation to the north-south trending margin of the Siberian platform caused considerable (5-20 km) sinistral strike-slip movement along the main faults that control the structural pattern of the area.

Active continental margin (Albian-Late Cretaceous).

Formation of an active continental margin and the Okhotsk-Chukotka volcanic belt began in the Albian in the Okhotsk plate (GUSEV et al. 1985). Cretaceous volcanic rocks (Albian) rest unconformably on a peneplain consisting of folded Permian to Jurassic rocks. In this period the South Verkhoyan' Mountains were behind the active Okhotsk-Chukotka continental margin. Ancient deep faults in the South Verkhoyan' Mountains were reactivated. The most intense reactivation of the faults accompanied by plutonic and volcanic activity is known from the Tompo-Okhotsk deep-reaching fault at the junctions with the Minor, Allakh-Yun' and Menkyule faults.

In the Tompo-Okhotsk deep fault zone, volcanic craters and NW-SE-trending volcano-tectonic depressions (grabens) formed in 10-15 km wide zones over a distance of 50-100 km. The volcanic craters range in size between 15x20 to 30x40 km. Together, they represent a „volcano-tectonic" complex consisting of andesitic, dacitic and rhyolitic lava flows, ignimbrites and tuffs. Dykes, subvolcanic rocks and granitoid massifs caused greisening, argillitization and silification. Volcanic/plutonic complexes associated with deposits of Sn, W, Mo, Au, Te, Bi, As, Sb, Pb, Zn, Ag, Hg, U and other metals (Fig.3), are found particularly at the junctions of NW-SE and NE-SW-trending, deep faults.

The ancient deep faults within the entire northeastern Yakutia were reactivated (Fig.1) during this period and the ore deposits of eastern Yakutia were formed, particularly here.

CENOZOIC PERIOD

In Cenozoic times the territory of eastern Yakutia experienced extension in the rift system of the Laptev Sea (DRACHEV 1995) due to the spreading within the Eurasian basin. The rift zones (grabens) of the Laptev Sea succeed the Mid- Palaeozoic deep faults of the Kharaulakh trilete system. The Moma graben (M in Fig. 1) also follows a Mid-Palaeozoic transform fault (Fig.1) of the East Siberian palaeo-rift. It represents an intramontane basin filled with Oligocene coarse-grained clastic rocks 300 m thick (GUSEV et al. 1985). Basaltic and rhyolitic volcanics in the Moma graben suggest that this graben may result from reactivation of an ancient deep fault in Miocene-Pliocene time.

It is possible therefore that the Cenozoic period represents the initial rifting phase of a new orogenic cycle in eastern Yakutia

CONCLUSIONS

The following conclusions can be drawn:

• Eastern Yakutia is characterized by polycyclic reactivation of ancient, deep-reaching tectonic structures. The geological history of the region can be subdivided into a regular succession of tectonic cycles: Early Proterozoic to Middle Riphean, Late Riphean to Silurian, Devonian to Cretaceous, and the Cenozoic cycles. Each cycle begins with intracontinental rifting, which grades into the formation of a passive continental margin; the spreading stage is never reached, and the cycle ends with increasing heat flow and compressive deformation.

• The formation of the East Siberian palaeo-rift system comprises a combination of four trilete systems of deep faults: from south to north the Sette Daban, Vilyui, Kharaulakh and Nordvik trilete systems.

• Deep faults have been formed or reactivated during periods of crustal tectono-magmatic activity. This suggests that these faults were long-lived tectonic structures and were reactivated during each new period of tectonic activity.

• In each geodynamic setting, the deep-reaching fault zones were associated with a characteristic type of magmatism and mineralization. During continental rifting, they were associated with ultramafic and mafic igneous activity as well as deposits of Ta, Nb, Ce, La, Cu, Ge, Pb, Zn and Pt. During the period in which the continental margin was active, the deep faults controlled the intrusion of granitoids and the formation of associated ore deposits of Au, W, Mo, Ag, Sb, As, Hg, Pb, Zn, Sn, Te, Bi and graphite (KOKIN & SAGIR 1999). In the collision period, low-grade metamorphism took place with which Au deposits were associated. The frequent reactivation of the deep faults caused ore deposits of different age, type and composition to be associated in the same tectonic zone. Outside these deep-reaching fault zones, igneous activity, metamorphism and related mineralization are absent.

• In the Cenozoic period, the grabens of the Laptev Sea rift system were formed along ancient deep faults belonging to the Kharaulakh trilete system.

• The history of eastern Yakutia has been dominated by polycylic rifting, which began in Early Proterozoic and continues today. Evidence for it is the very similar trace and major element composition of the ultramafic alkali rocks and basalts of different ages in the South Verkhoyan' mountains and in the entire East-Siberian palaeo-rift system.

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