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Problem of the jadeite rocks, associating with ophiolites

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The importance of jadeite rocks as an indicator of high pressure in the Earth's crust was outlined by Sobolev. Jadeite is characteristic mineral of some glaucophane schist but pure jadeitite occurs only in serpentinite melange. In the Borus mélange (West Sayan) the origin of jadeitites during metasomatic alteration of eclogites was established (Figs. 1—3). Glaucophane schists with jadeitic pyroxenes were found as tectonic sheets at the base of ophiolite nappes or as zonal formations overlained by ophiolite nappes. They are examplified from Ural ophiolitic belts (Fig. 4). The jadeite-bearing glaucophane formation with essential over-pressure during metamosrphism (Fig. 5) may correspond to a specific version of the "contact metamorphism" under ophiolite plate with special fluid over-pressure regime.

The jadeite problem has almost simultaneously been outlined by V. S. Sobolev (1949, 1953, 1960) and H. S. Yoder (1950) in the 50-ies. H. S. Yoder concluded that only specific chemical or kinetic conditions are necessary for the jadeite origin and that "from the pressure one must take away cover of its mystical might". Sobolev suggested to use jadeite as a mineralogical indicator for the high pressures in the earth's crust. For the base of this conclusion Sobolev took the common crystallochemical rule that the change of Al from the fourfold co-ordination (in the albite and nepheline) into the sixfold one (in jadeite) takes place with the pressures increasing. On the basis of the preliminary thermodynamic calculations, he estimated that at T = 600 °C this transition had to occur with the pressure over 7 kbars. Moreover, for the explanation of finding of the jadeite-bearing rocks at the moderate depths, V. S. Sobolev suggested that they were formed under the pressures exceeding the load pressure.

In different years, the author studied the jadeite-bearing rocks in the ultramafics (Dobretsov, 1962, 1963, 1964) and the jadeite-bearing glaucophane schists (Dobretsov, 1974; Dobretsov et al., 1973, 1979). This time the indicator role of jadeite is evidenced in particular, by numerous experimental data (Kushiro, 1966; Currie — Curtis, 1976 et al.), refining the stability field of jadeite-bearing associations. Main difficulties arose in connection with relevant geological-petrological models to explain these high pressures. Just these difficulties led many investigators to the negation of the special role of the high pressure and to attempts to explain the formation of jadeite and glaucophane schists only by the geochemical factors (Marakushev, 1965; 1973; Gresens, 1969 et al.). From these positions, the relation of the jadeitic rocks and glaucophane schists with large overthrusts and the special role of the tectonic factor remained unnoticed or not explained, as it was underlined by authors (Dobretsov, 1963, 1964, 1974).

In the last 10—15 years, in connection with the development of the new global tectonics (or plate tectonics) it became universally recognized that the jadeite-bearing rocks, both the inclusions in the ultrabasites and the glaucophane schists, are indicators of specific tectonic processes such as subduction or obduction of oceanic plate on the active continental margins (Ernst, 1970). They are closely connected with the processes of the tectonic transportation of the ophiolites — sheets of ancient oceanic crust, and they are one of the important instruments of the reconstruction of geodynamic conditions (Dobretsov, 1979).

It became clear that the jadeite bodies in the ultrabasites are connected with definite type zones of serpentinite mélange, fixing abyssal thrusts of the ophiolite sheets. The bodies of jadeitites eclogites, glaucophane schists in such mélange present xenoliths of deep-seated rocks, entrapped in the tectonic transportation of the ophiolites. Probably, hole sheets (of) thickness from 100 m up to 1—2 km) consisting of glaucophane schists in the foot of ophiolite nappes (for example, around the western Pacific) play similar role. Finally, author (Dobretsov, 1979) tried to connect the genesis of California type belts of jadeite-bearing glaucophane schists with the model of multiphase obduction of island arcs rocks on oceanic plate margins. Within continental blocks tectonic zones of abyssal thrust were revealed which contain bodies of mantle eclogites and pyrope peridotites. Well known inclusions of the above-mentioned rocks in Central European crystalline massifs (i. e. Bohemian massif, Granulitegebirge, Sov'i Mts. and others), are receiving such interpretation (Dobretsov, 1982; Dobretsov et al., 1984).

Let us consider the evidences of these relations on the example of some jadeite-bearing complexes, studied by the author, and first of all those of them which are closely connected with the ophiolites. All the considered examples are related to the Urals — Mongolian folded system where the ophiolites and associated jadeite and glaucophane rocks are Riphean or Early Paleozoic in age (Dobretsov, 1974).

In the West Sayan Mts. two such ophiolite zones are known (Fig. 1) — (1) the Borus one, with jadeite-bearing rocks and eclogites in the serpentinite mélange, and (2) the Kurtushibin zone where a large ophiolite nappe is underlain by a mélange zone with eclogites inclusions as well as an independent sheet of jadeite bearing glaucophane schists.

The Borus zone is of complex imbricate structure. The zones of the serpentinite mélange of two types (Dobretsov, Tatarinov, 1983) were distinguished at the foot of large sheets. Jadeite rocks bodies described here previously (Dobretsov, 1963; Yudin, 1963) are associated, as it has been established, only with the mélange of the 1st type underlying the upper ultrabasite sheet with signs of the

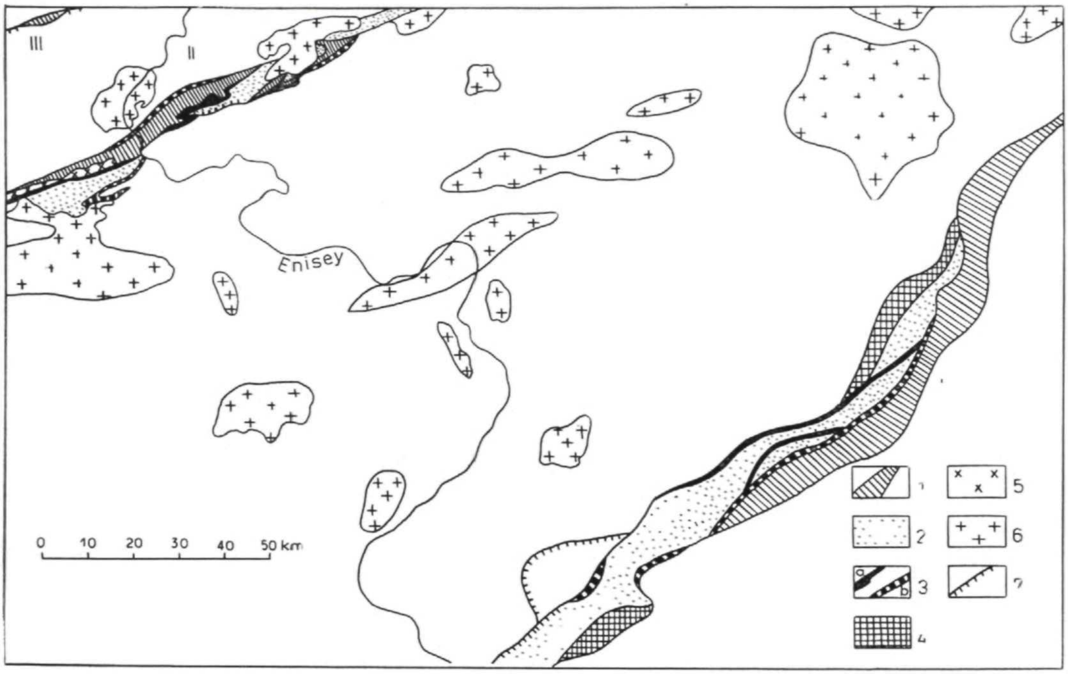

Fig. 1. Ophiolite belts of West Sayan (I Kurtushibin, II — Borus, III — North Sayan). 1 — ophiolites (ultramafics, gabbro, diabases), 2 — basalts and sediments, including olistostrom, 3 — I type melange with inclusions of eclogites, jadeite rocks and glaucophane schists (a), II type melange (b), 4 — glaucophane schists, 5 — diorite-plagiogranites, 6 — Paleozoic granites, 7 — overthrusts (without melange)

most continuous transportation. The strip of serpentinite schists with jadeite bodies in the middle part of the Kantegir river valley is an example of the mélange of the 1st type. It dips at 35—40° under the main ultrabasite body of the Borus range. The schistosity in the serpentinites is of the same orientation. The jadeitite and apojadeite-albitite bodies are of rounded shape and contain (1) relics of early high-temperature margins, torn off during the tectonic transportation, and (2) irregularly-developed low-temperature fringes, illustrating late reactions of the albitized jadeitites with the surrounding serpentinites. Both in the margins and in the body (itself) several stages can be outlined in the transformation of the primary coarse-grained jadeitites and the margins with diopside-jadeite and hornblende into the low-temperature associations with albite, analcime, late (frequently aegirine or jureite-bearing) diopside-jadeite, actinolite, mica, chlorite. Not long ago in a mélange zone in the south — western part of the Borus belt eclogite bodies were found (Fig. 2), which change into diopside-jadeite margin in the marginal part and are surrounded with small jadeitite bodies representing, seemingly, outer zone of the same those. These immediately observed transitions prove that the jadeite rocks were formed during the metasomatism of the eclogites and are isofacial with them. In the central part of the Borus range jadeite-bearing albitite bodies were observed (with jadeite, aegirine-augite and quartz), which had originated at the ex-

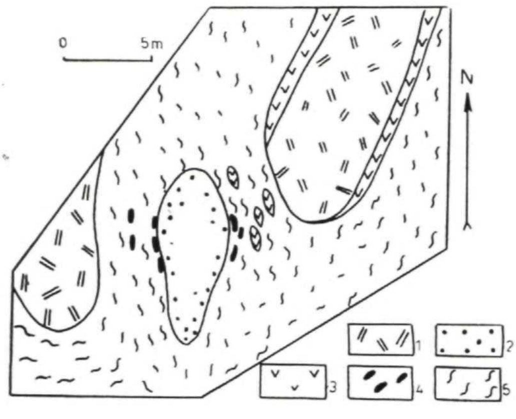

Fig. 2. The inclusions of eclogites and jadeitic rocks in the Borus melange. 1 — mica and albite-mica rocks; 2 — eclogites, 3 — garnet amphibolites, 4 — jadeite rocks, 5 — serpentinite schists

pense of acid dikes during one of the stages of the tectonic movements and the following metasomatism. The intrusion of the dikes, their metasomatism, the associations of the rocks, their relation with the serpentinites allow to distinguish at least 4 stages of tectogenetic processes and of regressive transformation of the abyssal xenoliths (table 1).

At all stages of the metasomatism mineral facies of higher alkality are characteristic with apo-eclogictic jadeitites (possibly, with nepheline admixture) at the expense of the eclogites (stage 1), aegirine-bearing or jureite-bearing jadeite, Na-amphibole, cancrinite (stage 2), aegirine-augite or chloromelanite, Na-amphibole, analcite, natrolite, schizolite (the stages 3 and 4). Rocks of normal alkalinity (eclogites, garnet amphibolites, epidote albitites, actinolitites etc.) coexist side by side with them.

The interaction with the magnesian medium of the filtrating solutions of normal alkalinity is contributed to the alkalies increasing as it was established previously (Dobretsov, 1964). Probably, solutions were generated from the buried sea waters and added from the continental "enclosing rock" at the stages II—IV. the K_2O and K_2O increasing, similar to the alkaline facies of the magnesian skarns (after Zharikov), took an additional effect in the last case. The higher pressure influenced only the specific mineral composition of the metasomatites as well as the higher solubility of Na-Al, Na-Cr, Na-Fe minerals (jadeite, juriite, aegirine, Na-amphibole, albite). For that reason, as well as, probably, because of the somewhat different composition of the solutions, in the mélange of the 2nd type, alkaline metasomatites are not typical, and slightly modified rocks (metagabbro, metabasalts, schists) and Ca-metasomatites (rodingites, nephrites) predominate being characterized also by very low potential of CO_2. It corresponds to the brucite appearance in the serpentinite mass of the 2nd type mélange in comparision to carbonates, usual in the mélange of the 1st type.

The variation of the conditions of the rock transformation specified the diversity of the mineral composition in the metasomatites and the combination of several stages in the same body. It is related not alone to the change of the secondary minerals (cancrinite, analcime, various Na-amphiboles, zeolites, rare sulphides and arsenides) but first of all to the variation of the jadeite pyroxene composition. As is seen from Fig. 3, the compositions of the pyroxenes include practically all the fields of the $NaAlSi_2O_6$ — $Na(Cr, Fe^{+3})Si_2O_6$ — — $Ca(Mg, Fe)Si_2O_6$ system. For the stage I the pyroxenes of the series jadeite-diopside-jadeite-omphacite are typical, being characterized by the small content of NaFe- and NaCr-components and some immiscibility between jadeite and diopside-jadeite. This immiscibility is due to the different structure of ordered diopside-jadeite (P/n unlike C/2n in jadeite) and

Stages of the jadeitites transformation

Table 1

Stage	Facies:	Main mineral:	Valuation: T °C:	Valuation: P, kbars:	Tectonics:
I	Eclogitic	C/s jd + di — jd ± hrb, phl; omph + gr + hrb + rut.	600	10	Abyssal thrusts (subductions?)
II	Garnet-glaucophane and epidote-amphibolite	Aeg — di — jd, Cr — jd + ab + mc ± Na — amph, can; Na — hrb + gr + pl ± ± ep, sph.	550	8—10	1st stage moderate-abyssal trusts (obduction?) Intrusion of acid dykes
III	Green schist (and transitional)	Ab + Aeg — aug + + Anc + mc ± Na — — amph, schizolite; Ab + Ep + Na — — act + mc + sph	a) 400 b) 400	8—10 3—6	Main stage of mélange. Near-surface thrusts, main serpentinization.
IV	Low-temperature metasomatites	Ab + Aeg — jd + Na — — amph + anc ± ± natrolite, ± qz, Ab + anc, Ab + chl + carb	200—300	3—8	Repeated thrusts (mélange of the IInd type) The interaction with enclosing rocks.

Adopted abbreviations in the table and the text: Ab — albite, act — actinolite, aeg — aegirine, amph — amphibole, aug — augite, anc — analcite, gr — garnet, di — diopside, di-jd — diopside-jadeite, jd — jadeite, can — cancrinite, qz — quartz, omph — omphacite, pl — plagioclase, hrb — hornblende, rut — rutile, mc — white mica, sph — sphene, phl — phlogopite, ep — epidote.

depends on the high T, P, the kinetics of the crystallization, the NaFe and NaCr content (Dobretsov, 1962; Dobretsov et al., 1971; Carpenter, 1981). This immiscibility may disappear with increasing of temperature and Fe^{+3} — Cr content. At the first stage the oxygen potential and the interchange with the ultrabasites (the Cr supply) were not intensive. They sharply increase at the stage 2 where bright green pyroxenes of jadeitejurite or more rare aegirine-jadeite series appear in the bodies margins and veins. The latter are more typical for the stages III and IV whereas Cr enters mostly into Cr-chlorites or more rarely into Cr-bearing garnets and amphiboles. Similar regularities, as the formation of a wide range of aegirine-jadeite pyroxenes, are typical also for jadeite-bearing glaucophane schists (Essene, Fyfe, 1967; Dobretsov, 1974).

Temperature and pressure estimations presented in the table I and the Fig. 5, are made on the basis of mineral pairs such as gr-amph, gr-cpx, amph-cpx (Perchuk, 1970), data of jadeite-diopside-albite-quartz system (Kushiro, 1969; Currie, Curtis, 1976), and composition of white mica associating with albite and other Fe-Mg minerals (Dobretsov et al., 1976).

All the valuations of the rock generation and transformation in the 1st type mélange zones correspond to the oceanic geotherme. Most likely it means that all the stages of the abyssal thrusts occurred in the oceanic or intermediate environments, and the continental crust in which now the Borus ophiolite belt is situated, appeared only at the final stages due to thickening of the crust. Because of these stages (III and IV) in the 1st type mélange we observe the combination of the low and high pressure associations.

Rocks with glaucophane (stage III) and with aegirine-jadeite pyroxenes, analcite and zeolites including the association jad + anc + qz (the stage IV) are especially typical. One can suggest that the rocks with these associations are included at the stages III and IV from the underlying glaucophane schist zone, formed at the stages I—II. It is favourable from the availability of the jadeite-bearing glaucophane schist zone, at the foot of the ophiolite sheets of the related Kurtushibin belt (Fig. I). Here the 1st type mélange and glaucophane schist zones are also combined. In this mélange zone underlying the lowest sheet in the central part of the belt, inclusions of eclogites, garnet amphibolites, glaucophane schists are present, missing here "in situ". The mélange zones were not established at the periphery of the belt but large sheets of glaucophane schists are present here. A lawsonite-glaucophane and intermediate zone with jadeite-bearing rocks was mapped in the south Urbun area. (Petrologia. . ., 1979).

In the Polar Urals, a combination of glaucophane schists and 1st type mélange zones were recognized along the Main Urals thrust, dividing the myogeosynclinal belt of the western slope of the Urals and the ophiolite eugeosynclinal belt (Fig. 4).

In the massif Ray-Iz (Petrologia . . ., 1979; Kazak, 1980) at the foot of a large sheet-like ultrabasite body of more than 3 km in the thickness a mélange zone of the thickness over 100 m was recognized. Peridotites, pyrope pyroxenites, eclogites, jadeite rocks, vesuvianite, glaucophanites and other rodingites are present as inclu-

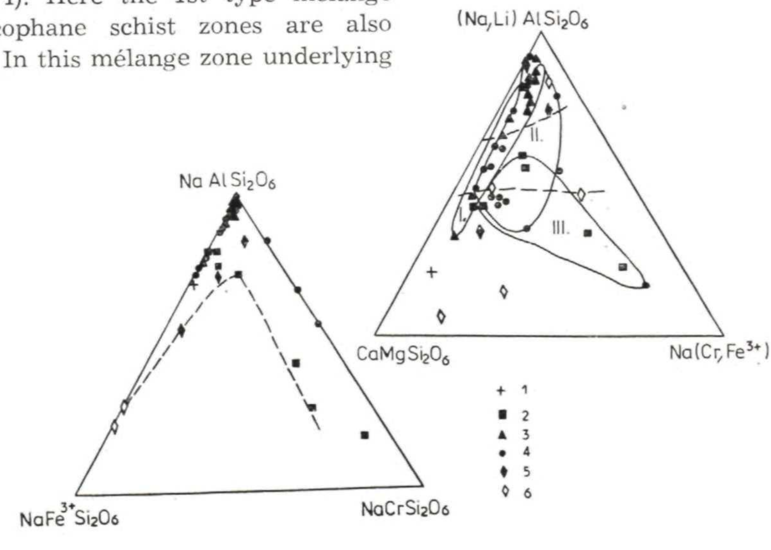

Fig. 3. Composition of jadeitic pyroxenes of the Borus melange Rocks: 1 — eclogites, 2 — jadeitic margins, 3 — jadeitites of 1st stage, 4 — jadeitic rocks and rims of 2nd stage, 5 — albites and (6) metasomatic rocks of 3rd stage (see Table 1)

sions in the mélange. 200 m-thickness separate sheets of glaucophane schists (below) and chloromelanite rocks are present above the mélange zone.

In the ophiolite massif Voikar-Synya glaucophane-jadeite rocks situated to the south the latter (Fig. 4A) are present at the foot of its western overturned part. Glaucophane and garnet-chloromelanite (eclogitic) rocks are formed at the cost of diabases and gabbros of an ophiolitic section including a change of anogabbroic blastomylonites (Petrology . . ., 1979; Lennykh et al., 1976). These rocks are tectonically boudinaged during the latest movements. The mélange zone with the inclusions of jadeitities, albitites garnet amphibolites is distinguished to the east, inside the ultrabasites of this massif. This zone and the jadeitites themselves are very similar to the above-discussed mélange zone of the 1st type of the Borus belt (Dobretsov, 1964, 1974).

The Salatin zone (Kozak, 1980) represents essentially a mélange-olistostrome zone. The serpentinite mélange bodies measuring from hundreds of meters up to 25 km^2 are included into the rock mass of the graphitic schists and quartzites. The ophiolites, dunites-harzburgites, gabbro-diabases bodies as well as these of eclogites, eclogite-like rocks, jadeitites, nephrites, rodingites are included in the serpentinite mélange but the glaucophane schists are absent. From the west this zone limits the green-stone rock masses of the Tagil synclinorium with dunite-pyroxenite-gabbroic bodies of the so-called platinum-bearing formation. Their attribution to the ophiolites is disputable but the bodies in the Salatim zone represent certainly the members of an ophiolitic as-

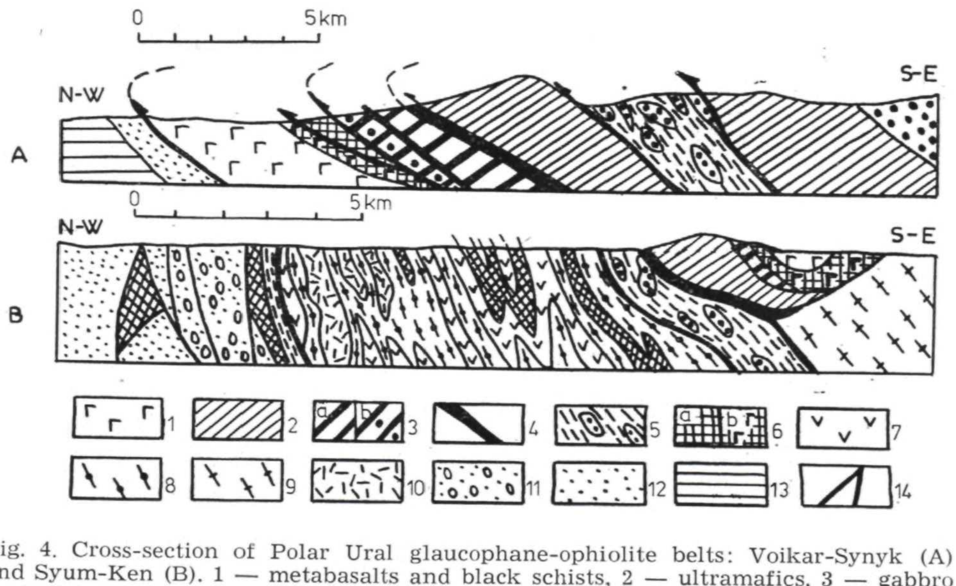

Fig. 4. Cross-section of Polar Ural glaucophane-ophiolite belts: Voikar-Synyk (A) and Syum-Ken (B). 1 — metabasalts and black schists, 2 — ultramafics, 3 — gabbro and diabases (a) and glaucophanized gabbro (b), 4 — serpentinitic melange, 5 — melange (at Fig. A) and blastomylonites (at Fig. B) with inclusions of metaperidotite, eclogite and jadeite rocks, 6 — glaucophane metadiabases (a) and glaucophane-lawsonite metabasalt, 7 — amphibolites with rare glaucophane, 8 — mica schists, 9 — gneisses with amphibolite and eclogite bodies, 10 — granito-gneiss olistoliths, 11 — metaconglomerates, 12 — metasandstones and quartzites, 13 — nonmetamorphosed Paleozoic sediments, 14 — faults

sociation. The mélange-olistostrome zone is evidently underlain by a zone of the glaucophane schists 2,5 km wide which changes little by little into the metavolcanogene green schists to the west.

In all above-described cases in the mélange were mainly present the more abyssal rocks (eclogites, jadeitites, garnet amphibolites), than the underlying glaucophane schists but those and others, as we saw in the example of the Borus belt, are united by the common oceanic geotherme and evidently characterize the different depth sections (and in some cases, and the different formation stages) of the common zone of the overthrusts characterizing a multistage obduction.

This multistage is the most brightly discovered in the zones of the California type with the jadeite-bearing glaucophane schists. The Maksyutov complex in the South Urals is an example of such types of zones. Here the situation is other than in the above-described cases (Dobretsov, 1974; Lennykh, 1977). Evidently, the Maksyutov complex presents a fragment of the more ancient basement, moved upon together with the underlying plates of the

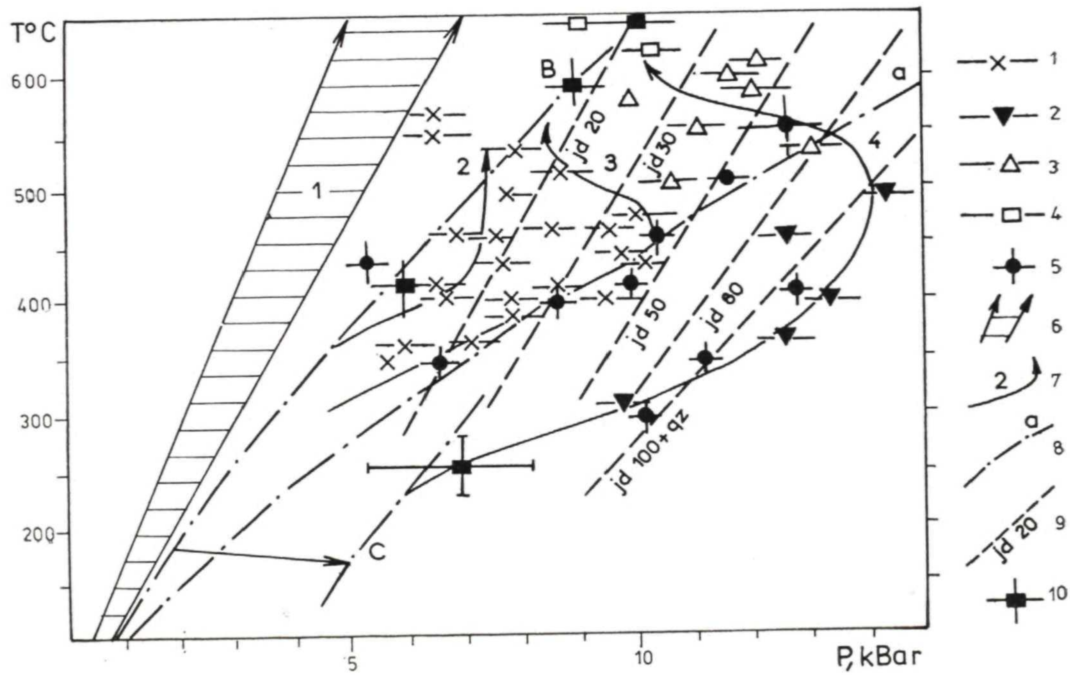

Fig. 5. P-T conditions of the formation of jadeite rocks, glaucophane schists and eclogites. 1—4 — average and limit origin conditions of glaucophane complexes (1), quartz-jadeite-bearing rocks (2), eclogites from glaucophane schists (3), eclogites from gneiss (4), 5 — some estimations from Alps, California, New Caledonia, Oregon with use of the oxygen isotope determinations (Brown, O'Neil, 1982; Dobretsov, 1974), 6 — interval of the usual greenschist and prehnite-pumpellyite metamorphism, 7 — curves of P-T evolution of the different types of metamorphism (2 — glaucophane-greenschist, 3 — lawsonite-glaucophane, 4 — jadeite-glaucophane), 8 — geothermes of the Precambrian shields (a), oceans (b) and geothermes in the subducted plates with fluid over-pressure (c), 9 — isolines of jadeite content in pyroxenes with albite and quartz, 10 — P-T conditions of rocks from the Borus melange

ophiolites to the east, to the green stone rock masses of the Magnitogorsk synclinorium and overlapped by the nappe of the green schists of the Suvanyak complex (species-the Lower Paleozoic ?). This plate is similar to the complex Seziya-Lanza in the Alps on his tectonic position, the composition of the rocks (the predominance of the acid rocks including the greywackes and arkoses) and on the maximum pressures obtained in the complexes of the glaucophane schist type. They are fixed on the mineral associations of the type 1) jad 90—100 + qz + alm + paragonite + + sch; 2) laws + alm + omph; 3) jad 80—100 + qz + glauc + sch. The association I is the most interesting in which the analyzed jadeite is very clear in the centre and is enriched in aegirine and diopsid (up to 10—15 %) only in the margins during diaphthoresis. These associations and the peculiarities of the composition of the minerals in the eclogites correspond to T = 500—550 °C, P = 14—15 kbars (Dobretsov, Sobolev, 1975; Dobretsov, 1974).

Combination of the California type jadeite-bearing glaucophane schist mélange and blastomylonite zone at the foot of ophiolite nappe can be seen at the northern part of Polar Ural near ultramafic Syum-Keu (fig. 4 B). Here from the SE to NW the following complexes are exposed: 1) basalts and metabasalts with lawsonite and glaucophane; 2) ophiolites plate (diabase, gabbro, ultramafic), 3) mélange; 4) blastomylonite zone with inclusions of eclogites and glaucophanites; 5) the jadeite-bearing glaucophane schist complex similar to Maksutov one; 6) metamorphosed olistostrom with olistolith of altered granites.

The lines of evolution of P-T conditions of glaucophane schists and jadeite rocks are drawn at Fig. 5. The line 2 (fig. 5) corresponding to glaucophane green schist metamorphism and jadeite rocks in ultramafics is close to the oceanic geotherme with the small surplus of pressure. The line 3 corresponding to lawsonite-glaucophane metamorphic rocks (with jadeite pyroxenes and quartz) is characterized by the essential overpressure. The line 4 with maximal overpressure corresponds to the eclogite-glaucophane complex of Californian type, containing jadeite-quartz association. The nature of this overpressure was explained by the combined tectonic model (Dobretsov, 1979, 1981).

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