METAMORPHIC FACIES AND SERIES OF FACIES IN THE USSR*)

by

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Abstract

A scheme of facies of regional metamorphism is proposed in which two pressure dependent facies series are recognized. The map of metamorphic facies of the USSR using these facies and facies series is described. The two-pyroxene gneiss facies occurs only in the Archaean shields. The biotite-sillimanite gneisses (amphibolite facies) are widespread on the platforms and in central massifs, but they are scarce in phanerozoic belts. Epidote-amphibolite and greenschist facies occur on the platforms but especially in belts of post-Cambrian age. High pressure metamorphic rocks with eclogites, glaucophane-lawsonite and kyanite-bearing schists and gneisses occur at several places in narrow zones, often connected with deep faults. Two types of metamorphism in mobile belts are recognized, and two types of high pressure zones.

THE PROPOSED SCHEME OF METAMORPHIC FACIES

The proposed scheme of facies of regional metamorphism has been developed from the original ESKOLA scheme (ESKOLA, 1920, 1939) by means of substantial modifications (SOBOLEV, 1964; SOBOLEV et al., 1966; TURNER & VERHOOGEN, 1961).

Particular attention has been drawn to the sharpest possible definition of the facies boundaries by means of the presence or absence of certain minerals and mineral parageneses. Preference is given to equilibria which are only slightly dependent upon the influence of additional factors (in addition to T and P), that is reactions such as polymorphic changes and dehydration which are practically independent of the constitution of the systems and fluid phases.

The proposed scheme is presented in fig. 1***).

Alongside with the traditional names we suggest new names which to our mind correspond better to modern ideas.

As usually, the definition of the facies boundaries is based on parageneses of the most widely distributed rocks – metapelites and metabasites.

The facies are divided by the value of pressure into two distinct series:

*) Report to the working group on the map of metamorphic facies presented at the session in Århus, 13–18. February, 1967. The report is compiled on the basis of the explanatory text to the map of metamorphic facies of the USSR: "The facies of regional metamorphism in the USSR", Novosibirsk, 1966. There is complete list of quoted literature in this paper.

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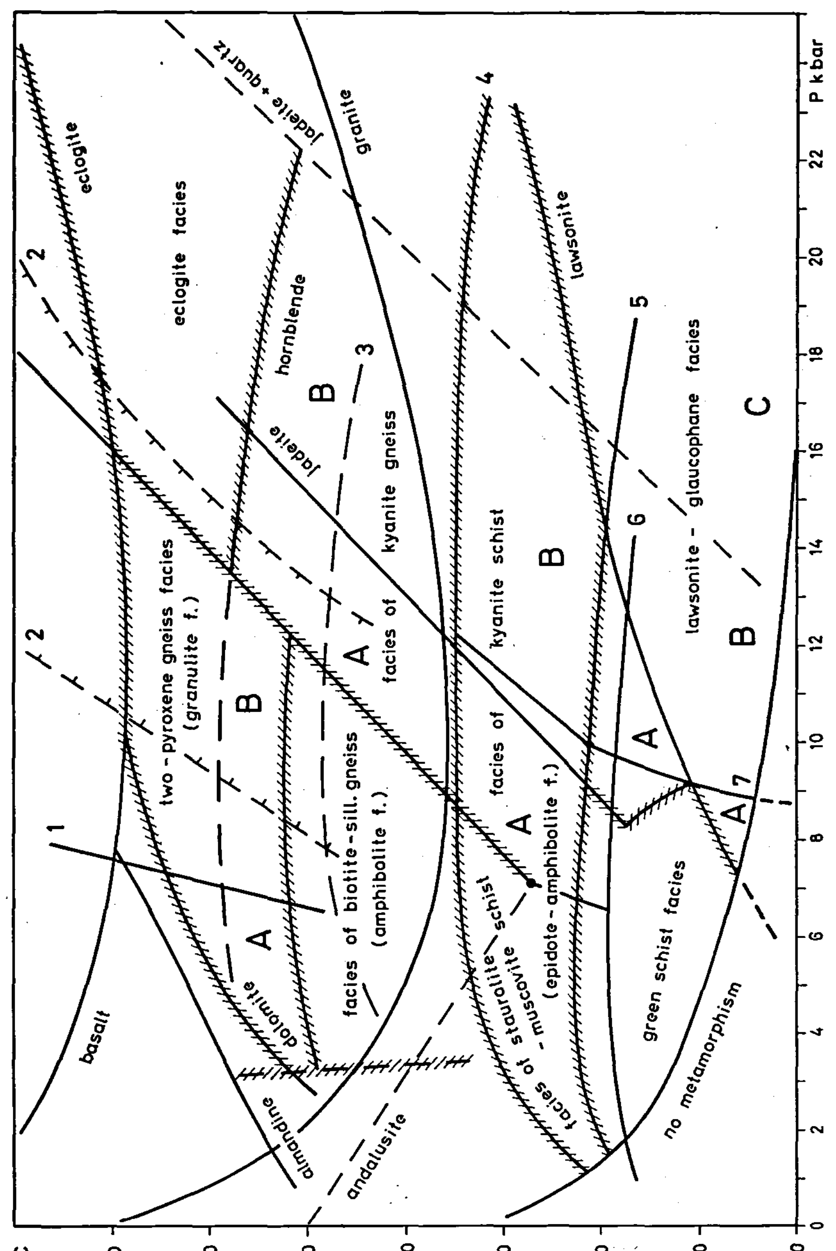
***) In comparison with the previously published scheme (see footnote, *) the proposed scheme of facies and the table of minerals are somewhat modified and extended.

Table I.

Characteristics of facies of metamorphism based on the more significant minerals and mineral associations

Facies	Critical	Forbidden	Common (+ typical rare minerals)
	Facies of intermediate pressures (B series) forbidden: Ky, Jd, Laws, Gar (>50% pyrope)		
(Granulitic) B_1 Two-Pyroxene gneisses	Hyp_{50} + Di + Q Hyp_{60} + Gar + Or Hyp_{45} + Cor + Or Hyp + Gar + Cor + Or Hyp_{20} + Q Hyp + Di + Pl + Or Gar + Sill + Cor + Her	Orthoromb.amph., Cum. Mu + Q Staur, Mu, Ep, And, Ky, Bi_{40}, Hb+Cc+Q, +Q+Or+Pl>20 Hb+Gar+Bi+Q For+An.	(± Gar) Gar+Sill+Q+Or (± Cor), Hyp +Or+Pl+Q Di+Pl+Cc+Q; typical rares: Cod+Or, En+ Sapp; Under high pressure: Hyp+Di+Gar+ Pl, Sill+Hyp (in B_2 too)
(Amphibolitic) B_2 Biotite-Sillimanite gneisses	Bi + Sill + Or + Q (And + Or) Gar + Spl + Staur + Sill	Chloritoid, Fe–Ep, Staur + Q, Ep + Pl_{50} Trem – Actin. in Al-rich rocks Dol+Q	Bi, different amphiboles, Cor, Gar, Sill, And, diff. Pl, Or, Sill (And) + Gar + Cor.
(Epidote-Amphibolitic) B_3 Staurolite-Muscovite schists	Staur + Q + Sill (And), (Staur + Q) Mu + Q + Sill, (Mu + Q + Alm + Bi) Hb + Bi + Ep + Pl_{10-30} + Q	Sill (And + Or) Fe and Fe–Mg Chlorites Cor (rare), Wo	Different amphiboles, Gar, Ep, Staur, And, Chloritoid, Pl>25 Bi+Mu+Q; Sill under high press.
Greenschist facies B_4	Chl+Cc+Q, Dol+Q, Pyrophyllite+Q Mu+Chl+Stilpnom+Ab+Q Mu+Chl+Ep+Ab+Q Mu+Chl+Act+Ab+Q	Staur, Cor, Sill, And, Alm, Pl>10 Al–amphibole, Bi (rare)	Different chlorites, Trem, Act, Talc, Mu+Talc, Mu+Q, Ep.
		High pressure facies (C series)	
Lawsonite-Glaucophane C_4	Laws, Arag, Jd+Q, Glauc + Ca-Al miner (Ep, Pump, Laws, Zo)		The same as in B_4, +Ky, Phengite, Mg-pumpell, Glauc, Chl, Aeg–Jd.
Kyanite schist C_3	Glauc+Gar, Ky + Staur + Q, Ky+Mu+Q	Sill, And, Cor+Gar.	The same as in B_3 facies
Kyanite gneisses and Amphibolites C_2	Ky+Or, Basic Pl+Ky, Gar+Carintin + Omph, Ky+Gedr+Gar.		The same as in B_2 facies
Eclogite C_1	Gar>50, Gar+Omph+Rutile.	Hyp+Pl, Sill, Cor, Staur, Amphiboles, Pl?	Gar+Di, Jd, Ol+Gar+Di+Opx, Gar+Di+ Ky, Gar+Di+Cod

* The index shows the iron content in minerals in % $\left(\frac{Fe}{Fe + Mg} \cdot 100\right)$
or the anorthite content in plagioclase (%An)



T °C
1000
900
800
700
600
500
400
300
P kbar
0
2
4
6
8
10
12
14
16
18
20
22
basalt
eclogite
eclogite facies
hornblende
granite
jadeite + quartz
jadeite
two - pyroxene gneiss facies
(granulite f.)
facies of biotite - sill. gneiss
(amphibolite f.)
facies of
kyanite gneiss
facies of
kyanite schist
facies of staurolite - muscovite schist
(epidote - amphibolite f.)
lawsonite
lawsonite - glaucophane facies
green schist facies
no metamorphism
almandine
dolomite
andalusite
A
B
C
1
2
3
4
5
6
7

Fig. 1.

ABBREVIATIONS USED IN TABLE I

Act.	=	Actinolite	Her.	=	Hercynite
Ab.	=	Albite	Hyp.	=	Hypersthene
Alm.	=	Almandine	Hb.	=	Hornblende
Amph.	=	Amphibole	Jd.	=	Jadeite
And.	=	Andalusite	Ky.	=	Kyanite
An.	=	Anorthite	Laws.	=	Lawsonite
Arag.	=	Aragonite	Mu.	=	Muscovite
Bi.	=	Biotite	Omph.	=	Omphacite
Cc.	=	Calcite	Opx.	=	Orthopyroxene
Chl.	=	Chlorite	Pl.	=	Plagioclase
Cor.	=	Cordierite	Or.	=	Potassium feldspar
Cod.	=	Corundum	Pump.	=	Pumpellyite
Cum.	=	Cummingtonite	Q.	=	Quartz
Di.	=	Diopside	Sapp.	=	Sapphirine
Dol.	=	Dolomite	Sill.	=	Sillimanite
En.	=	Enstatite	Spl.	=	Spinel
Ep.	=	Epidote	Staur.	=	Staurolite
For.	=	Forsterite	Stilpnom.	=	Stilpnomelane
Gar.	=	Garnet	Trem.	=	Tremolite
Gedr.	=	Gedrite	Wo.	=	Wollastonite
Glauc.	=	Glaucophane	Zo.	=	Zoisite

the intermediate-pressure facies series and the high-pressure facies series. The boundary between the series is defined by the equilibrium curve of kyanite in the high-temperature zone and of lawsonite in the low-temperature zone, and also by the curve of complete eclogitization of basaltic rocks. The two former curves were previously considered to be close to the equilibrium curves of jadeite and pyrope. Each series is divided into four facies according to the temperature of metamorphism. Most distinct is the boundary between the high-temperature and low-temperature facies which corresponds to the equilibrium curve of muscovite + quartz. Other boundaries are presented in the proposed scheme. The characteristic parageneses are presented in the table I.

THE MAP OF METAMORPHIC FACIES OF THE U.S.S.R.

The map at a scale of 1:7.500.000 is based on a cartographic map at the scale of 1:5.000.000. When compiling the map it was in many cases

Fig. 1.
P-T scheme of metamorphic facies.
A, B, C subdivision of facies according to pressure.
1 forsterite + anorthite ⇌ clinopyroxene + orthopyroxene + spinel.
2–2 interval of basalt-eclogite transition.
3 line of stability of orthorhombic amphibole (and pyroxene + quartz).
4 line of stability of muscovite + quartz.
5 *lower limit of stability of hornblende, almandine and staurolite + quartz.*
6 line of stability of pyrophyllite.
7 glaucophane + lawsonite (or epidote).

Remark: All boundary curves are drawn assuming an approximate value of the partial pressure of water of 0.2–0.4 for the high temperature facies and up to 0.8 for the low temperature facies.

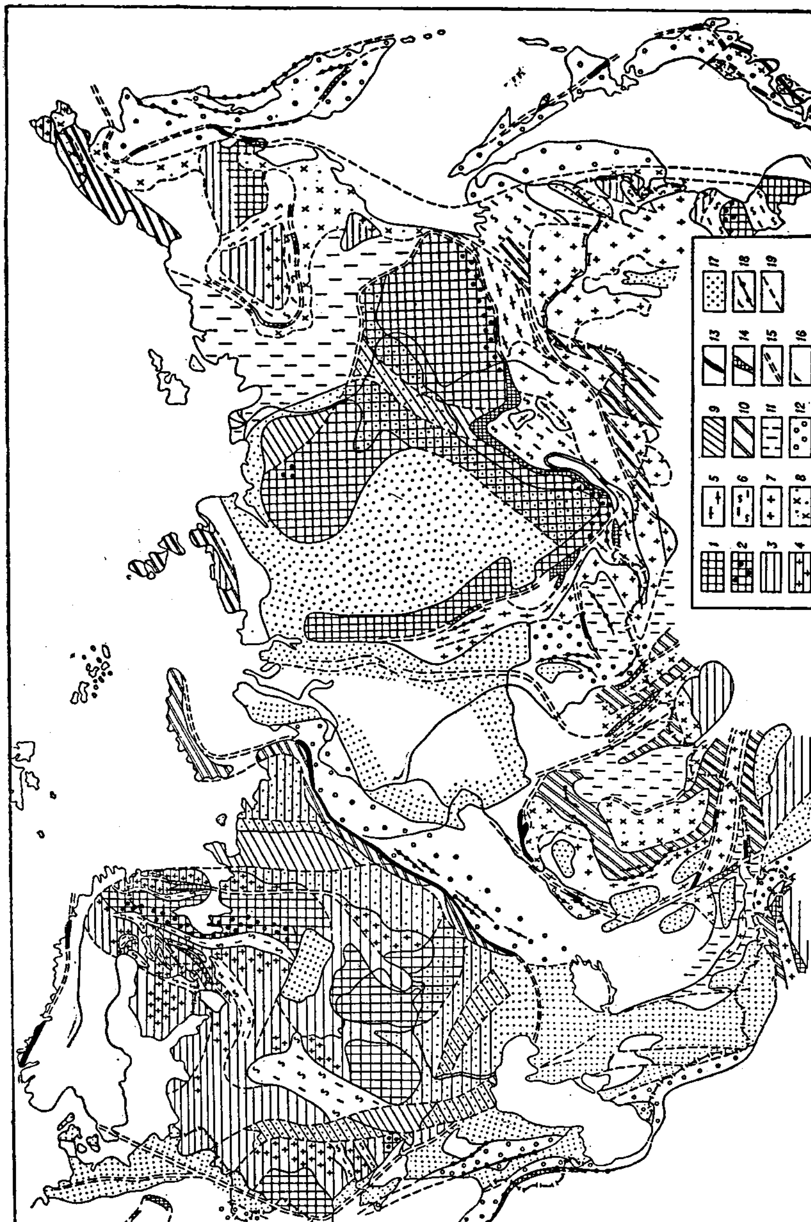


Fig. 2.

difficult to distinguish individual facies, but possible to show the sum of two individual adjacent facies, as it is indicated in the legend to the map. This difficulty is partly due to the shortage of knowledge – it has for instance not yet been possible to distinguish the facies of the platforms. In all cases the highest degree of metamorphism established by means of the parageneses, has as far as possible been indicated in the map, since it is impossible to show different stages of diaphthoresis in the scale of the map. In the provinces covered by unmetamorphosed sediments the facies of the underlying basement rocks are shown where possible. Age divisions are shown with symbols. This is not so much the age of metamorphism as that of the substratum rocks determined stratigraphically, and that of the figures of absolute age determination (for the Precambrian). In the areas of non-divided Precambrian rocks and for the metamorphic rocks which are supposed to underlie a sedimentary cover the age is not indicated.

Additionally, some geological features (granitoids, ultramafics, faults, the depth of the Moho discontinuity, etc.) have been indicated which may help in correlation and interpretation of the features displayed in the map.

Fig. 2.
Provinces of preferential development and presumed shallow occurrence of regional metamorphic complexes:

1 – facies I and I + II
2 – same, high pressure (eclogitic, locally kyanite-carrying rocks)
3 – facies II
4 – same, with migmatites and migmatite-plutonic rocks
5 – facies II + III
6 – facies III + IV (Precambrian)
7 – provinces with predominantly granitic rocks + areas of facies I and IV, separated by an unconformity
8 – same, overlain by slightly metamorphosed rocks cut by granites (complex 7, less eroded)
9 – facies IV in trench-like structures (aulacogens)
10 – facies IV, in folded belts
11 – facies IV, presumably occurring at the base of thick folded sequences
12 – facies IV, III, and II, in zones and islands, often in association with granitic rocks

High pressure zones:
13 – Type I with rocks of facies V and VI
14 – Type II, chiefly facies VI, often with granitic rocks
15 – probable continuation of high pressure zones.
Other symbols:
16 – provinces of unknown type metamorphic rocks
17 – provinces of thick non-folded and non-metamorphosed deposits (on the 2.500 m isopach for the platforms, and 1,500–2,000 m for other provinces)
18 – principal ultrabasic belts
19 – principal faults.

I: Granulite facies (Two-pyroxene gneiss f.)
II: Amphibolite facies.
III: Epidote-amphibolite facies.
IV: Greenschist facies.
V: Lawsonite-glaucophane facies.
VI: Kyanite schist and gneiss facies.

DISTRIBUTION OF FACIES AND SERIES OF FACIES IN THE TERRITORY OF THE U.S.S.R. (Fig. 2)

In the territory of the USSR the rocks of the two-pyroxene gneiss facies (granulite-facies) are exposed only in the areas of the Archean shields (Ukrainian, Baltic, Anabar (RABKIN, 1959) and Aldan) or in smaller structures of similar type (the Sharyz-halgay block in the southern Pribaikalia (SHAFEEV, 1964), the Yenisey Range, the Omolon Massif in the North-East, and the Korean shield). According to geophysical data and drilling the rocks of this facies lying underneath a sedimentary cover either continue the outcrops of a shield or are associated with buried large positive structures such as the Tartarian Arch on the Russian Platform. This facies is on the Russian Platform confined to the marginal parts adjacent to large major faults.

On both the Russian and Siberian Platforms the eclogitic and other rocks, which characterise the PT region of the two-pyroxene gneiss facies transitional to the eclogite facies, are situated in the "near-suture" zones. This is characteristic for the Aldan shield, the Sharyzhalgay block, the northeastern margin of the Sino-Korean Massif and for the province of Belomorian rocks of the Baltic shield. The latter is, however, distinguished by a closely spaced alternation of rocks of the two-pyroxene gneiss facies (including "drusites" and eclogitic rocks) with rocks of the kyanite gneiss facies and with lower-temperature muscovite-carrying parageneses. The Belomorian formation is shown in the map with the special colour for non-divided facies of intermediate and high pressures.

In the provinces of the two-pyroxene gneiss facies larger "synorogenic" granitic intrusions and their contemporaneous metamorphism are absent. Strong granitisation (migmatites, migmatite-plutons, etc.) is concentrated towards the areas of development of the lower-temperature rocks of the biotite-sillimanite gneiss facies. The provinces of the two-pyroxene gneiss facies also display specific tectonic features.

The rocks of the *biotite-sillimanite gneiss facies* (amphibolite facies) are in the USSR confined predominantly to platforms or central massifs. They are either closely connected with the Archean rocks of the two-pyroxene gneiss facies or they form independent younger structures, being closely associated with migmatites and, often, with the rocks of lower-temperature facies. This is typical for the Baltic shield, Ukrainia and in general for the Russian Platform. The formations dominating in the Proterozoic folded provinces in Siberia (Stanovoy Range, Khamar-Daban, etc.) are essentially analogous to the biotite-sillimanite gneiss facies; in a number of cases they certainly were formed as a result of progressive metamorphism. For instance, in the Slyudyanka area deposits of the same age show metamorphic zonation from the biotite-sillimanite gneiss facies to the lower-temperature facies.

In the Paleozoic and younger folded provinces the biotite-sillimanite gneiss facies is subordinate. In provinces adjacent to the Siberian and Chinese Platforms the rocks of this facies are exposed in the central massifs and in isolated tectonic blocks (the Okhotsk, Amolon, Bureya, Tarim Dzhungari, Ulutau-Kokchetav and smaller massifs) where they are overlain with a marked unconformity by unmetamorphosed or greenschist facies rocks. The rocks metamorphosed at biotite-sillimanite gneiss facies conditions have usually undergone an intensive diaphthoresis and are probably relics or projections of an ancient Precambrian basement. The huge masses of younger granitic rocks, which often accompany them, could, in a number of cases, be regarded as products of fusion of the ancient basement. In folded belts of the Ural type (the Urals (VOROBYOVA et al., 1962), Caucasus, Kamchatka (LEBEDEV & BONDARENKO, 1962), and Japan (MIYASHIRO, 1961)) the rocks of the biotite-sillimanite gneiss facies are rarely involved in zoned complexes; actually, there is in the terrritory of the USSR no reliable evidence to substantiate metamorphism at the physical-chemical conditions of this facies during Paleozoic or later times.

The muscovite gneiss and schist facies (epidote-amphibolite facies) and the greenschist facies are spatially closely connected. They occur on platforms within the superimposed troughs (mainly Riphean) such as the Karelian, Saxaganian and Timan belt on the Russian Platform; in the Proterozoic complexes of the foothills of the East Sayan and Yenisey Range; or in the basements of younger aulacogens, such as the Dnepr-Donets and Vilyuy. However, the rocks of these facies are most characteristic and widely distributed within the folded provinces, especially in those of post-Cambrian age.

They occur in two types of regional development. The first is represented by the extended monofacial areas of one-time-metamorphosed rocks as, for instance, the Riphean greenschist sequences of the Altay-Sayan province and Kazakhstan. The second type is represented by zoned complexes, that is series of metamorphic rocks of the same age displaying transition from unmetamorphosed rocks to the facies of muscovite gneisses (epidote-amphibolite facies) or, rarely, to the facies of biotite-sillimanite gneisses. In many cases these rocks are spatially connected with granitic intrusions. Such metamorphism is often called "plutono metamorphism" and "regional-contact metamorphism".

In the USSR the zoned complexes or series of facies are confined mainly to the Uralian type of folded belts irrespective of their age. They are known from the Caledonian and Hercynian formations in the Urals and Cornyy Altay and from the Meso-Cenozoic formations of Kamchatka, Sakhalin and Caucasus. The zoned complexes are found mainly in the eugeosynclinal belts and are often associated with abundant basalt and ultramafics and with thin layers of granite. The zoned complexes (series of facies) known from these structures represent both intermediate and high pressure formations.

THE REGIONAL DISTRIBUTION OF THE HIGH-PRESSURE FACIES

The most outstanding feature of the proposed maps is the distinction of all presumed high-pressure rocks. The high-pressure facies and series of facies from relatively small areas represented in the majority of cases by narrow but fairly extended zones adjacent to marginal faults on the boundary between large provinces of different stability. These zones are often interpreted as deep fault zones.

Two types of high-pressure zones can be distinguished:

1. The zones of jadeite-lawsonite-glaucophane rocks, eclogite bodies and subordinate kyanite rocks within greenschists. These zones are rich in ultramafic rocks but are practically devoid of granitic rocks. The following examples may be mentioned: the Main Uralian Fault zones in the South and Polar Urals (KEYLMAN, 1963; LODOCHNIKOV, 1941; UDOVKINA, 1963), the Talov-Mainsk zone in Koryakiya (DOBRETSOV & PONOMAREVA, 1965; KAYGORODTSEV, 1961), the Sanbagawa and Kamuikotan in Japan (MIYASHIRO, 1961), as well as smaller zones— the Borus massif in West Sayan (DOBRETSOV, 1964), and the Itmurund and Chara in Kazakhstan. These zones are characterized by a "mottled" distribution of metamorphism which is associated with deep fault zones: there is a zonal arrangement characterized by an increase of the degree of metamorphism which is associated with deep fault zones: there is a zonal arrangement characterized by an increase of the degree of metamorphism towards the axial part of the zone.

Similar to this type of metamorphic zones is the Kokchetav-Ulutau-Makbal Arc (EFIMOV, 1964; TRUSOVA, 1956) with exposures in all three localities of the eclogite gneiss complex together with kyanite- and glaucophane-bearing rocks and other types of high-pressure rocks which are the higher temperature types corresponding to the rocks of the above mentioned zones. Data has been obtained which indicates that this zone continues towards the Aktyuz Region and farther to the east.

The high-pressure zones of the first-named type, though of considerable extension, are very narrow and are associated entirely with deep fault zones. This is substantiated by a rapid transition of the metamorphic formations into slightly metamorphosed rocks away from the fault.

The deep fault zones of the first type constitute as a rule, the boundaries between miogeosynclinal and eugeosynclinal provinces, that is between large volumes of the earth crust characterized by different types of deep structure.

2. The second type of zones is characterized by the development of kyanite schists, or sometimes eclogitic rocks, associated with migmatites or granitic bodies (generally of two-mica type) which often contain kyanite-bearing pegmatites. This type includes an almost uninterrupted belt along the southern fringe of the Siberian Platform (from the Yenisey Range, through the Biryusa Block and the Priolkhonye, to the Mama Field and farther on towards the southern fringe of the Aldan shield); the Irtysh zone of crushing (KHOZEVA, 1964; KHOZEVA, 1966a, 1966b); the zone of the Keyvi suite in Kola, and other zones which have not yet been studied in greater detail and which are indicated on the map only because kyanite is known from these regions (the South Pribaykalye and the Patomo-Vitim Highland). It is at the moment impossible to determine their true shape and size.

It must be emphasized that the facies of kyanite schists and gneisses is sufficiently studied. It cannot be excluded that this type of high-pressure rocks is more widely distributed than is shown on the map. It appears that this facies could possibly be found along the northern and southern boundaries of the Stanovoy folded belt where kyanite has been found locally. On the whole, the high-pressure zones of the second type are much broader across the strike (in places not less than 50–100 km) than those of the first type.

The deep fault zones of the second type have apparently been initiated within a thick sialic crust at the boundaries of large stable blocks or platforms.

The very high pressures which occurred within these two types of metamorphism have affected rocks of different compositions and under different conditions of metasomatism. Therefore Na-Mg metasomatism is characteristic for the first type, whereas Si-Al metasomatism is associated with the second type of the high pressure zones.

The high pressure zones are as the folded belts in general, characterized by steep geothermal gradients $\frac{(\delta T)}{(\delta H)}$ during metamorphism. The depth of formation of the majority of kyanite-, glaucophane- and jadeite-bearing rocks could not be very great (not exceeding 10–15 km) which may be inferred from the thickness of the overlying sequences and from the steepness of the geothermal gradient. The latter may be estimated from the low and intermediate temperature of formation of these rocks. The assumption that these rocks were formed at a considerable depth and consequently were metamorphosed under conditions of a very low geothermal gradient seems unfounded. For the same reason it appears to be reasonable to assume that the relative PT-gradient $\frac{(\delta P)}{(\delta T)}$ was higher during metamorphism of high-pressure type than in other provinces, and that the pressure was due not only to the weight of the overlying rocks but also to other factors, primarily of a tectonic nature.

It should also be noted that the high-temperature facies of the high-pressure series (eclogite and especially kyanite gneisses) display a number of peculiarities and therefore cannot be kept within the above mentioned characteristic first of all for the Precambrian "blocks" such as the Belomorian of the Baltic shield, the South-West Pamir and possibly some Baykalian blocks of the Sayan-Stanovoy belt. These rocks are not confined to a restricted zone but are developed on a fairly large territory. In many cases zones of lower temperature facies of the high pressure series are fringing these "blocks". It is very unlikely that the blocks were metamorphosed at a depth greater than 40–60 km. Considerable regions may therefore have been exposed to overpressures up to 10 kbar.

Without touching the eclogite problem it should be mentioned that in all cases eclogites form isolated bodies but never areas; they are indicated on the map by out-of-scale symbols. The eclogite bodies often differ from the surrounding rocks with regard to facies of metamorphism. This concerns

Table II.

The age of some metamorphic formations of the U.S.S.R.

Areas	Metamorphic facies	The age of substratum according to geological data	Absolute ages (million years)	Remarks
1. Anabar massif	Two-pyroxene gneiss f.	Archean	1) 2100–2500 2) 1800–1900 Diaphthoresis	
2. Aldan shield	Two-pyroxene gneiss f. + biotite-sillimanite gneiss f. (the Aldanian Complex)	Archean	1) 2800–3200 2) 2100–2500 Diaphthoresis	
3. Ukrainia	a) Two-pyroxene gneiss f. (The Bug complex)	Archean	2100–2700	
	b) biotite-sillimanite gneiss f. (different formations)	Archean – Lower Proterozoic	1) 2800–3200 2) 1800–2100	
	c) staurolite-muscovite f. + greenschist f. (Saxaganian)	Proterozoic	1800–2300	
4. Karelia and Kola peninsula	a) Two-pyroxene gneiss f. (a part of the Belomorian series)	Archean? Proterozoic?	1900–2700	Diaphthoresis and rejuvenation
	b) Biotite-sillimanite gneiss f. (the Kola series)	Archean	2600–3000	
	c) Biotite-sillimanite gneiss f. staurolite-muscovite f. (the Ladoga series)	Proterozoic	1800–1900	
	d) Kyanite schists (the Keyvi suite)	Proterozoic	1900–2700	
5. The Sayan-Stanovoy Province	Biotite-sillimanite gneiss f. (The Stanovoy Complex)	Upper Archean or Lower Proterozoic	1) 2000–2100 2) about 1800 Diaphthoresis	

6. South West Pamir	Kyanite gneiss f. (The Vakhan series)	Precambrian? Paleozoic?	150–2100	repeated diaphthoresis?
7. Kazakhstan Kokchetav massif	a) Eclogite f. b) Biotite-sillimanite gneiss f. c) Greenschist f.	Archean or Lower Proterozoic Proterozoic	1) 900–1200 2) 500– 750 450– 600	Several stages of diaphthoresis
8. Kirghiz Range, Tyan-Shan	1) Eclogites 2) Biotite-sillimanite gneiss f. + muscovite gneiss and schist f.	Pre-Riphean	500– 700	Age of diaphthoresis
	3) Greenschist f.	Riphean	300– 640	
9. Southern Ural	1) Eclogite f.	Lower Riphean?	370– 450	Several stages of diaphthoresis including pseudomorphoses after lawsonite
	2) Lawsonite-glaucophane f. (the Maksylltov complex) 3) Kyanite schist f. (the Ufalean complex) 4) Greenschist f.	Proterozoic or Riphean from Ordovician to Upper Riphean in different zones	1) 900–1200 2) 280– 360 280– 400	Diaphthoresis last periods of metamorphism
10. Karpatian, Rakhov massif	1) Biotite-sillimanite gneiss f. + staurolite-muscovite schist f.	Precambrian	700± 60	after hornblende and biotite
	2) Greenschist diaphthoresis	Hercynian or Upper Jurassic-Lower Cretaceous	240– 280 up to 100	two stages of diaphthoresis
11. North-West Kamchatka	Lawsonite-glaucophane f.	Lower-Middle Paleozoic	300– 350 and 150– 230	metamorphism and diaphthoresis
12. Sakhalin	Lawsonite-glaucophane f. + greenschist f.	Upper Paleozoic	60– 170	possibly, absolute age – diaphthoresis

primarily temperature but not pressure, i.e. eclogites are localized in high-pressure zones together with other high pressure rocks. The eclogites from the kimberlites of Yakutia (SOBOLEV & SOBOLEV, 1964) including the diamond-carrying kimberlites may be regarded as a special case and are doubtless xenoliths originating from the upper mantle.

METAMORPHISM AND THE CRUST OF THE EARTH

The problem of the nature of the lower part of the crust of the earth and of the Mohorovicic discontinuity underneath the continents should be considered next. The so-called "basaltic" layer may be represented generally by rocks belonging to the facies of two-pyroxene gneisses from which the granitic component has been removed as a result of partial fusion and a rise of the fluid phase to higher levels of the crust (SOBOLEV et al., 1967). The Moho discontinuity may at some places under the continents represent the boundary from basic to ultrabasic rock in such a way that the two-pyroxene gneiss facies (spinel-pyroxenite and -peridotite) remain. In this case the boundary of the eclogite facies is situated below the Moho discontinuity, hence the facies of the diamond bearing eclogites belongs to still greater depths. In other places the Moho discontinuity corresponds to the transition from the two-pyroxene gneiss facies to the eclogite facies without any change in the chemical composition of the rocks. These conclusions have been founded on studies of xenoliths from kimberlites, which enabled us to produce a schematic section through the crust and upper mantle underlying the northern part of the Siberian Platform (SOBOLEV & SOBOLEV, 1964).

It might be suggested that in the earth crust under the fold belts in the zones of development of eclogite the Moho discontinuity may coincide with the eclogite transition. But in contradistinction to the platforms these provinces, as a rule, have undergone later alterations, so that at great depths the process of repeated metamorphism (regressive with respect to pressure) is fully completed. Therefore the boundary of the eclogite facies may be displaced into the depths of the mantle.

In conclusion it may be stated that the "basement" under the platforms is composed of the two-pyroxene gneiss facies, and that the facies of high pressure (in particular the zones of high pressure in fold belts) are most special. Therefore these facies should be especially considered when preparing a world map of metamorphism.

THE AGE OF METAMORPHISM

The dating of the main stage of metamorphism is very difficult. Most of the absolute ages obtained by the K-Ar-method indicate the age of the latest processes of diaphthoresis. For this reason the age of the series of metamorphic rocks, in particular those from the young fold belts, is often questionable. The following are the preliminary results for some of the facies.

All occurrences of the two-pyroxene gneiss facies and the majority of the biotite-sillimanite gneiss facies (amphibolite facies) belong to the Archean basements of the Russian and Siberian Platforms (TUGARINOV & VOYTKEVICH, 1966). The latter facies is the formation representing the lowest known temperature for the Archean of the USSR. In the post-Archean the picture of distribution of facies is more colourful, though the low-temperature facies prevail. Since the Paleozoic fold belts occupy most of the territory of the USSR the rocks of the greenschist facies, which occur generally in the basement of geosynclines, are mainly of upper Proterozoic-Cambrian age.

Until recently the "jadeite-glaucophane type of metamorphism" has been considered a specific phenomenon of the post-Paleozoic metamorphism. However, the data from the Soviet Union shows this idea to be untenable. Many rocks of the lawsonite-glaucophane facies in the Urals, West Sayan and Kazakhstan were formed in the lower Paleozoic or even in the late Precambrian (?).

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