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Geochemical Characteristics of the Metamorphic Rocks of the Pohorje Mountains

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Abstract

An attempt is made to interpret the origin of the Pohorje metamorphic rocks on the basis of their geochemical features. A total of 187 rock samples was examined chemically and under a polarizing microscope. Taking into consideration the distribution of the major elements and some trace elements seven stratigraphic levels are admitted. Their geochemical patterns and petrogenetic grid are shown by graphical projections, enabling a comparison of the geochemical facies observed with those of preexisting sedimentary deposits and associated igneous rocks. Significant differences between the original parent rocks of the various stratigraphic levels have been found and thereby a restoration of the paleogeographic conditions of the region is given. Some similarities and differences between rocks of the Pohorje and the Saualpe regions have been noted. The problem of the eclogite-amphibolite relation arose. The composition of both metamorphic rocks as well as their distribution in the metamorphic levels indicate that the amphibolite has been derived from the eclogite.

Kratka vsebina

Zaporedje regionalno metamorfoziranih pohorskih kamenin je razdeljeno na sedem enot, ki se med seboj ločijo po stopnji metamorfoze in po kameninskih asociacijah. Na njihov izvor se dá sklepati po tem, kako so v njih porazdeljeni glavni in sledni kemični elementi. V ta namen so v laboratoriju petrografsko-geokemičnega centra v Nancyju kemično analizirali 187 vzorcev iz celotnega sestavljenega profila. Ker gre za izokemično metamorfozo, se kemični sestavi metamorfnih in prvotnih kamenin ne razlikujeta med seboj. Razporeditev geokemičnih parametrov in njihova zveza s petrogenetskimi lastnostmi kamenin sta prikazani grafično. Na ta način je možno neposredno primerjati metamorfne kamenine z izhodnimi sedimentnimi in magmatskimi kameninami. Na drugi strani pa se posamezne petrogenetske enote kemično znatno razlikujejo med seboj; zato je možno sklepati tudi na spremembe v okolju njihovega nastanka.

Posebej je nakazana zveza med amfibolitom in eklogitom; njuni kemični sestavi kažeta, da je amfibolit nastal iz eklogita. Primerjava metasedimentov in metabazitov s Pohorja in Svinške planine kaže na enake prvotne kamenine.

Resumé

Sur la base de 187 analyses (éléments majeurs et Ba, Sr, Co, Cr, Cu, Ni, V) les auteurs définissent les caractères chimiques des principales roches constituant l'ensemble métamorphique paléozoïque de Pohorje (Slovénie, Alpes Orientales). Cette étude confirme le bien-fondé de la division de cet ensemble en 7 unités lithostratigraphiques. Les faciès et tendances géochimiques des formations métamorphiques sont comparés, dans des diagrammes appropriés, aux faciès et tendances des séries sédimentaires et volcaniques. On peut ainsi reconstituer les grands traits des séries antémétamorphiques et esquisser une interprétation paléogéographique. On donne également des éléments de comparaison avec les séries des Saualpe qui ont fait l'objet d'études chimiques récentes. Enfin, à un niveau d'observation plus détaillé, on présente des résultats sur le bilan chimique de la transformation en amphibolites d'éclogites ayant les caractères de métatholeiites de faciès abyssal.

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1. Introduction

Previous to our study, the Pohorje metamorphic rocks had been classified according to field relationships, mineralogical criteria, grade of metamorphism, and the concept of metamorphic facies. Thus the almandine-amphibolite and greenschist facies had been distinguished. Chemical analyses of particular rock samples were carried out only in order to check the mineralogical determination. By the present work, however, the concept of chemistry requiring systematic chemical analyses has been introduced as being the most exact way of deducing the nature of the parent rock, the rank of metamorphism, and the paleogeographic features.

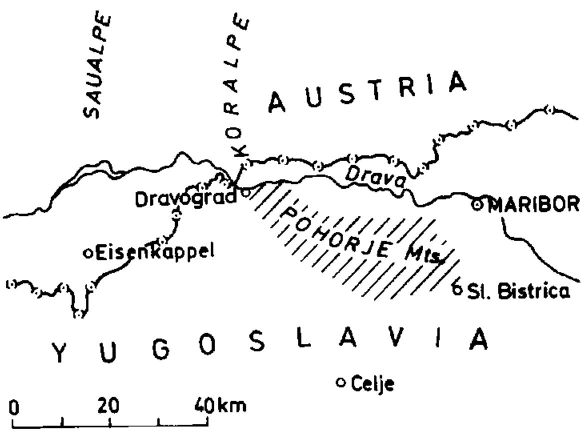


Fig. 1. Location map of the area investigated

2. Geological relations

The inner part of the Pohorje Mountains is made up of a tonalitic laccolith of remarkable dimensions, which is exposed on the top of the massif only (fig. 1). Elsewhere, it is surrounded by a metamorphic cover. Both the core and its cover are penetrated by dacite. The chemical composition of dacite is the same as that of tonalite. Consequently these rocks could have been derived from the same palingenetic magma. As to their age, dacite is placed in the Lower Miocene, whereas the age of tonalite is open to dispute. The contact of these igneous rocks with adjacent metamorphic rocks is distinct.

The Pohorje metamorphic rocks have been produced by a process of regional metamorphism, decreasing in its intensity from the bottom to the top of the rock sequence. According to previous mineralogical examinations (A. **Hinterlechner-Ravnik**, 1971, 1973), no zone associated with sillimanite occurs, which would indicate the highest grade of metamorphism. The great majority of the metamorphic sequence belongs to the almandine-amphibolite facies, characterized by almandine, kyanite, and staurolite crystals, as well as by eclogite lenses. A minor part, however, consists of rocks corresponding to the greenschist facies. The transitional zone between both the almandine-amphibolite, and the greenschist facies, which is well developed in the Saualpe, is much reduced in the Pohorje.

3. Geochemical aspects of the investigation

The application of geochemical analysis to metamorphic rocks proved to be suitable for the recognition of the physical and chemical conditions under which the rock in question originated. It is considered that metamorphism involves no bulk changes in the chemical composition of the parent rock, regardless of the water and carbon dioxide driven out by the metamorphic process. Consequently the geochemical features of a metamorphic unit reflect the pre-existing sedimentary rock succession and the associated igneous rocks. This analytical

Symbols used in geochemical diagrams

The augen gneiss level ○

profile 1: augen gneiss (◒) and related rocks ◒
⊖ profile 2: schist and gneiss
profile 4: augen gneiss (◓) and related rocks ◓
○ amphibolite variety
◬ pegmatitoid gneiss
⛛ ultrabasite
◎ orthoamphibolite

The marble level △

△̄ gneiss and schist
△̲ flaser gneiss
△ amphibolite variety, associated with marble
▲ amphibolite variety, associated with other schists
⟁ pegmatitoid gneiss

The eclogite level □

⊠ schist
◫ gneiss
⬒ flaser gneiss
□ eclogite
⧅ symplektitized eclogite
⧄ amphibolitized eclogite
⊟ amphibolite variety
△ pegmatitoid gneiss
▽ ultrabasite

The ultrabasite level +

∓ schist
± gneiss
\+ amphibolite variety
⊕ eclogite
△ pegmatitoid gneiss
▽ ultrabasite

The diaphthorite level Y

Y	schist and gneiss
ı	andalusite schist
Ɏ	amphibolite variety
⟁	pegmatitoid gneiss
△	pegmatitoid gneiss, associated with andalusite schist
•	rocks of almandine-amphibolite facies as represented only in fig. 11

The greenschist level z

z	acid metavolcanic rock
ẕ	alkali-enriched phyllite and phyllite schist
ẓ	K-enriched phyllite and phyllite schist
z̄	intermediate metavolcanic rock
ƶ	basic metavolcanic rock

The Magdalensberg series level *

*	slate
*̄	Fe-enriched slate
*̲	K-enriched slate
⊛	spilite

The geochemical areas observed in different levels

The augen gneiss level	—·—·—·—
The marble level	—···—···—···—
The eclogite level	— —·— —·— —
The ultrabasite level	························
The greeenschist level	————————
The Magdalensberg series level	— — — — — —
Lodemann's schists in the fig. 11	—ı—ı—ı—ı-

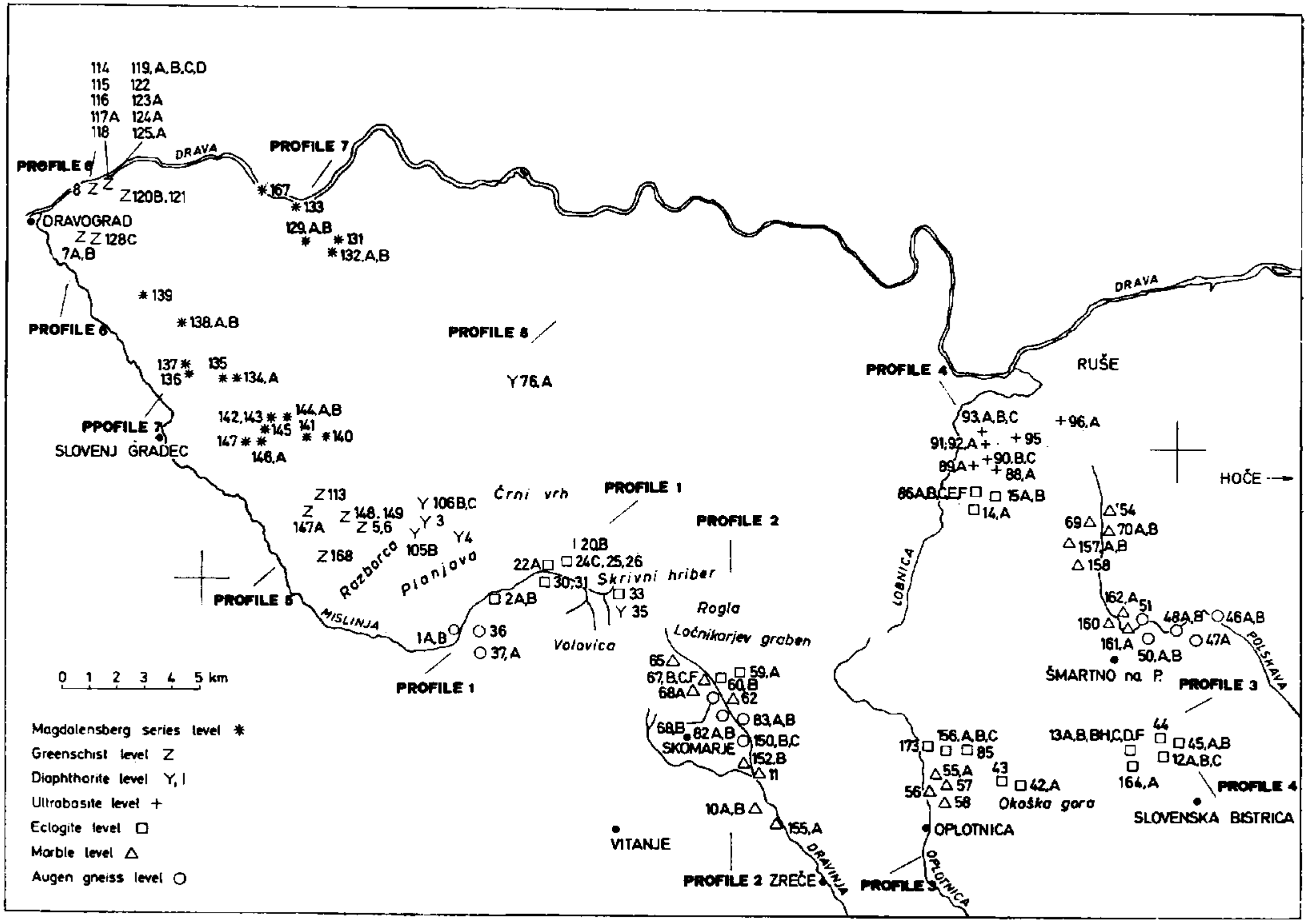


Fig. 2. General location map of the analyzed metamorphic rocks from the Pohorje Mts.

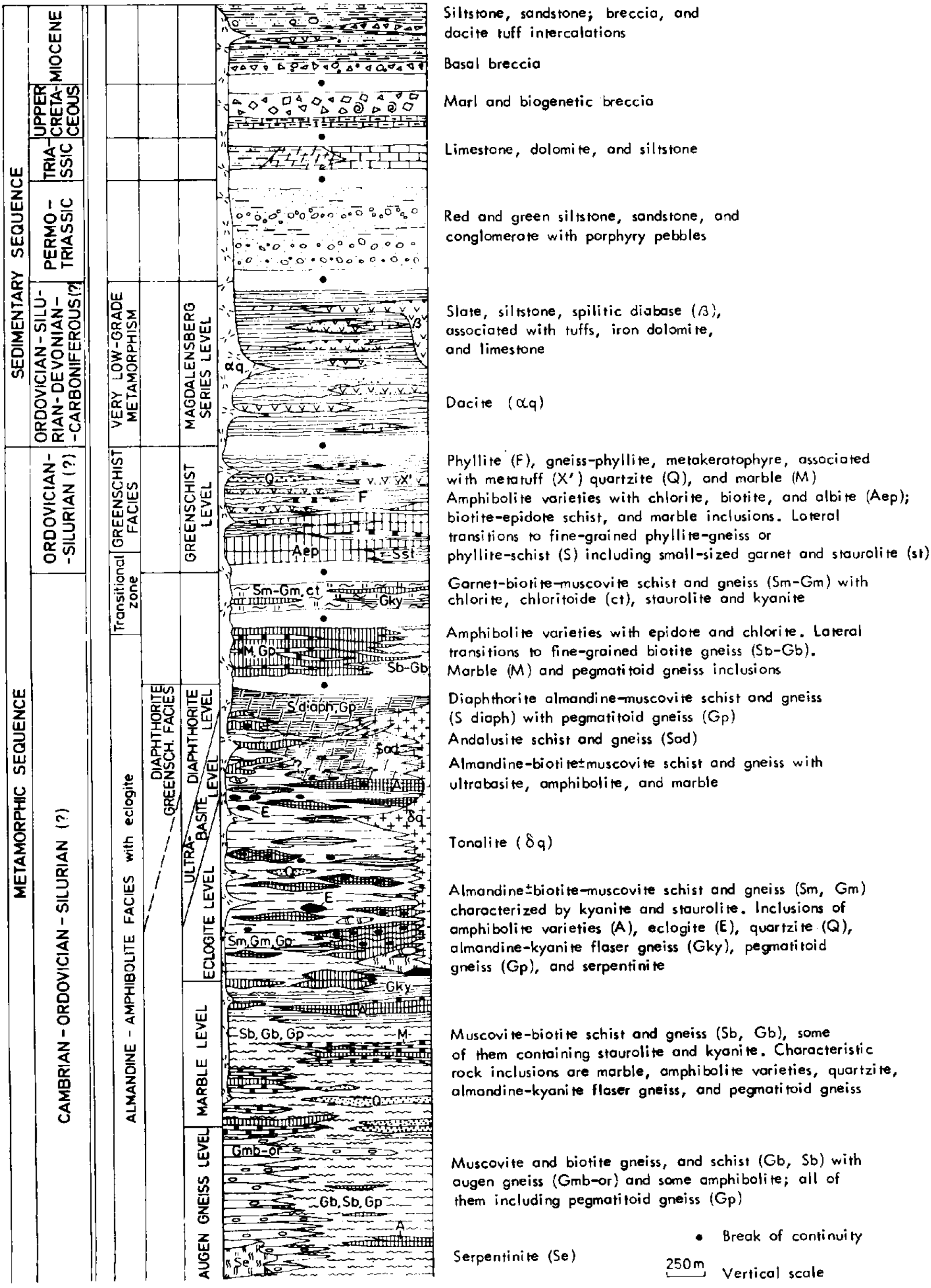


Fig. 3. Columnar section of the Pohorje rock sequence

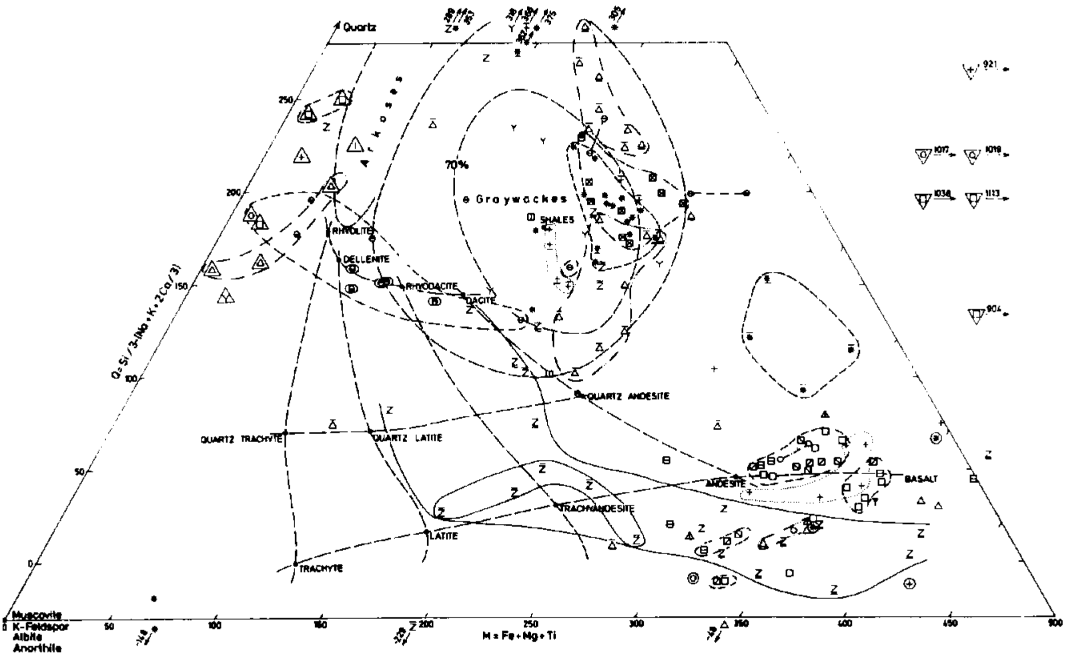


Fig. 4. The Pohorje metamorphic rocks shown by the parameters: [Si/3 — (Na + K + 2 Ca/3)] versus (Fe + Mg + Ti) (after H. de la Roche, 1964 and B. Moine, 1971)

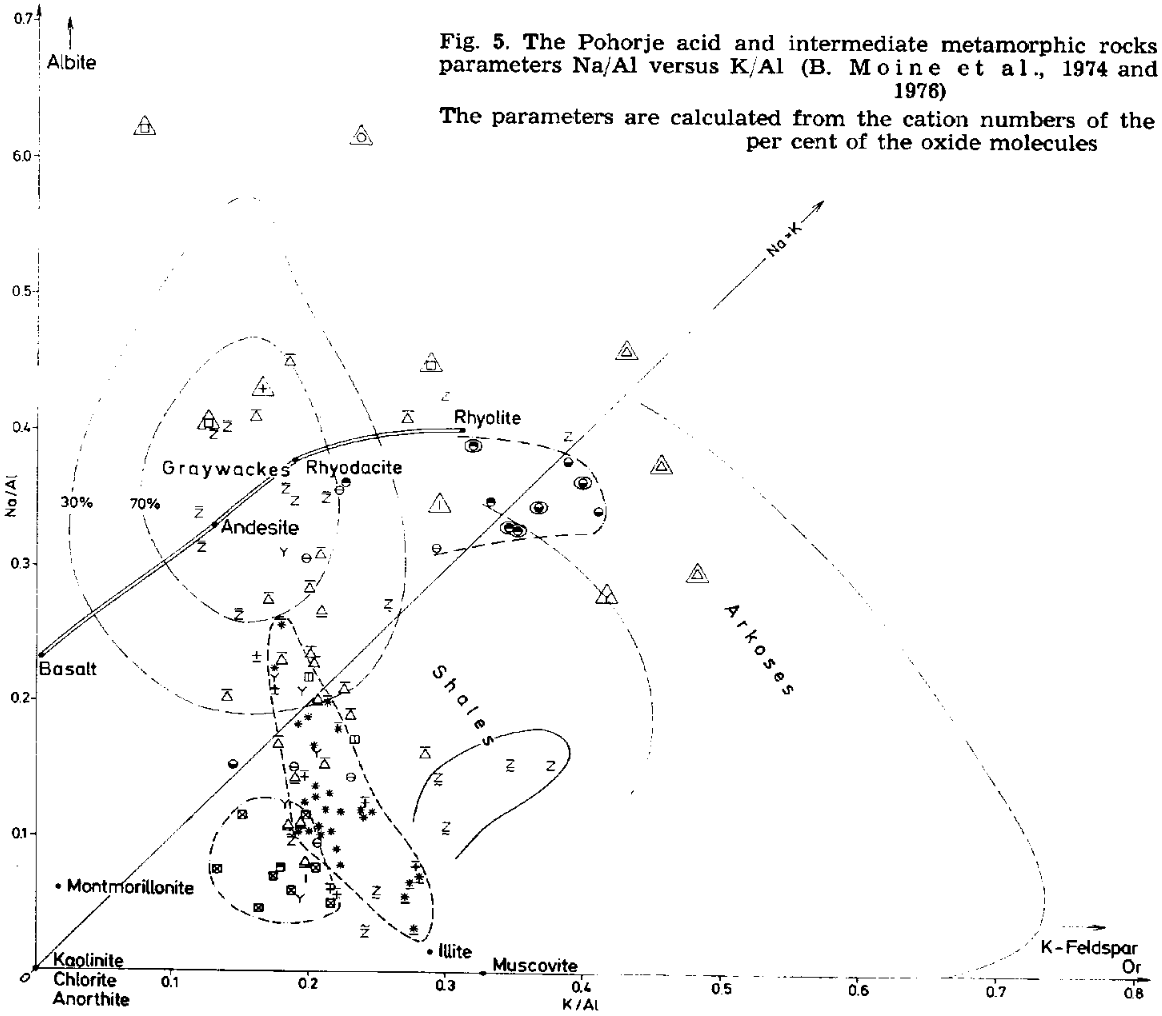
The parameters are calculated from the cation numbers of the corresponding weight per cent of the oxide molecules

method requires a large number of samples which must be taken in accordance with the thickness of the section examined and the characteristic rock associations (B. Moine, 1971). Since the whole metamorphic sequence (fig. 2) as a continuous section does not appear at any one profile, seven partial sections have been properly chosen to illustrate in detail the vertical succession of the characteristic rock associations as well as the lateral variations (fig. 3). The total number of samples taken amounts to 187. They were distributed over the seven selected lithological units from the bottom upwards, as follows: 24, 32, 47, 17, 10, 29, 28 samples, each having a weight of one to three kilograms.

The analyses were carried out at C. R. P. G. in Nancy under the direction of K. Govindaraju following the standard program, developed in this laboratory. The major elements: Al_2O_3, Fe_{tot} as Fe_2O_{3tot}, MgO, CaO, the minor elements: MnO, TiO_2, and the trace elements: Ba, Co, Cr, Cu, Ni, Sr, and V were analyzed by direct-reading emission spectrometry (using an ARL quantometer). The SiO_2 is dosed by atomic absorption, the Na_2O and K_2O by flame photometry (K. Govindaraju, 1973). Automatic computing, automatic graphical calculation, and plotting of the analytical results are reported following the programs, elaborated by the computer group at C. R. P. G. (P. Isnard et al., 1975).

Fig. 5. The Pohorje acid and intermediate metamorphic rocks characterized by the parameters Na/Al versus K/Al (B. Moine et al., 1974 and B. Moine et al., 1976)

The parameters are calculated from the cation numbers of the corresponding weight per cent of the oxide molecules



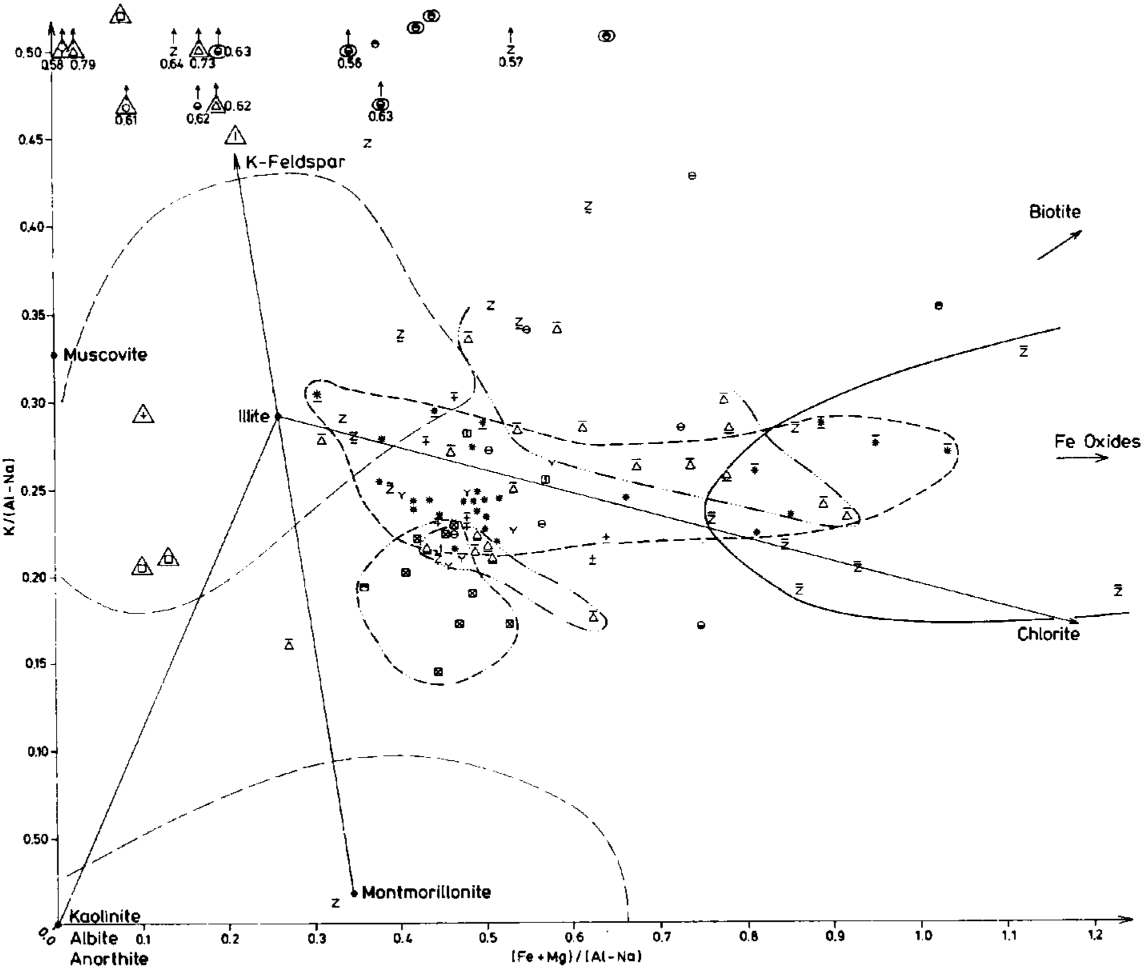


Fig. 6. The Pohorje acid and intermediate rocks defined by the parameters K/(Al-Na) versus (Fe + Mg)/(Al — Na) (after B. Moine et al., 1976)
The parameters are calculated from the cation numbers of the corresponding weight per cent of the oxide molecules

The weight per cent of the various oxides obtained from the chemical analysis of a rock has no geological significance. By powdering and analytical preparation, the rock structure is destroyed and the distribution of particular elements in different minerals is not evident either. For the interpretation of the chemical results related to different problems, the reconstitution of the natural relations between chemical and mineral composition must be achieved in several graphical projections.

In the QFM diagram (fig. 4) the parameter Q has been made equal to [Si/3-(Na + K + 2/3 Ca)], whereas M equals (Fe_{tot} + Mg + Ti). Both are plotted

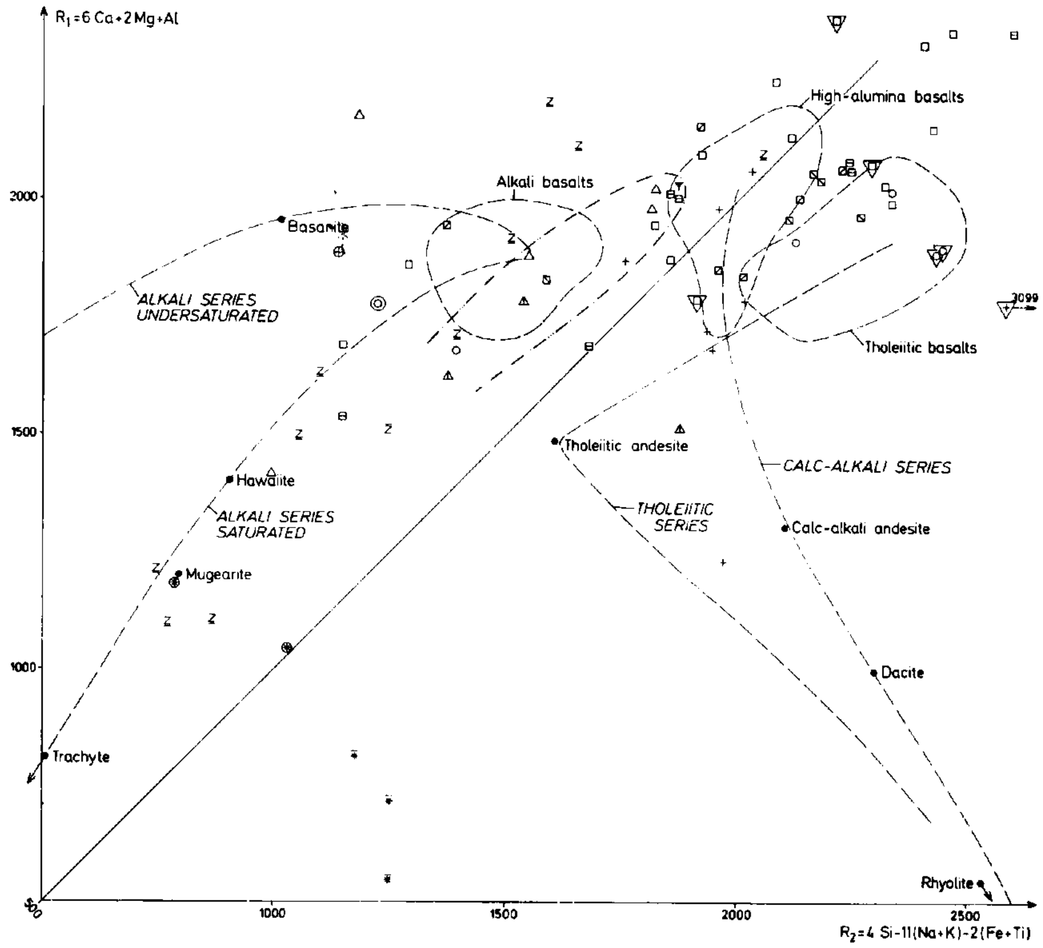


Fig. 7. The Pohorje basic rocks defined by the parameters $R_1 = 6\,Ca + 2\,Mg + Al$ versus $R_2 = 4\,Si - 11\,(Na + K) - 2\,(Fe + Ti)$ (afer H. de la Roche and J. Leterrier, 1973)

The parameters are calculated from the cation numbers of the corresponding weight per cent of the oxide molecules.

in oblique coordinates. These parameters were developed by H. de la Roche (1964). The Q value is found to be 555 for quartz, and nearly zero or zero for feldspars and the essential mafic minerals. The value of the parameter M is zero for quartz, feldspar, pure muscovite, and nearly 555 for the main mafic minerals. The corresponding figure 4 is a part of a triangular diagram, showing the most important rocks, with respect to the proportions of quartz, feldspars, and mafic minerals they contain. In the QFM diagram a grid, corresponding to the parameters of the main igneous and sedimentary rocks, has been plotted for reference. B. Moine (1971) has shown that these parameters are appropriate for distinguishing between graywackes and rocks of granodioritic com-

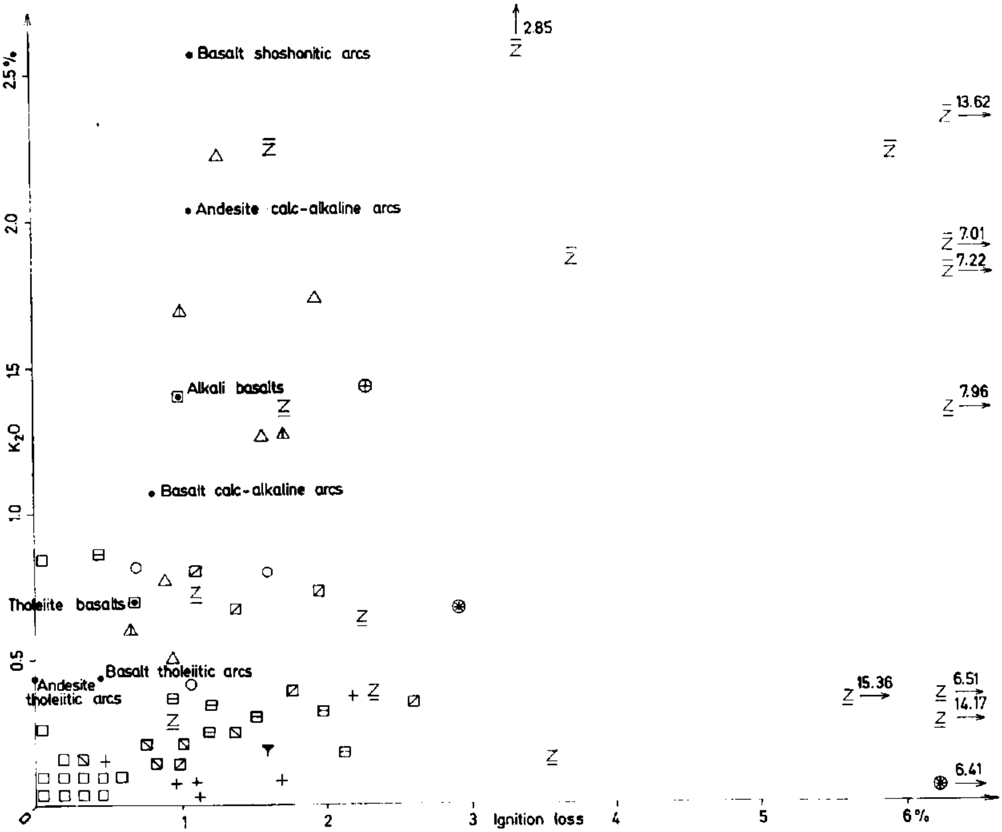


Fig. 8. The K_2O/Ignition loss ratio in the analyzed basic rocks in weight per cent

▣ after V. Manson (1967)

● after P. Jakeš and A. J. R. White (1972)

position. The field of the graywackes is displaced towards quartz and the mafic minerals. Thereby their sedimentary origin is indicated.

For a detailed comparison of the chemical composition of a sedimentary rock to its mineralogical feature the diagram (fig. 5) Na/Al versus K/Al was used (B. Moine et al., 1974, B. Moine et al., 1976). The Na/K ratio was obtained from the relation Na/Al versus K/Al, the aluminium value being constant. The main types of detritic rocks are distributed according to their relative content in albite, K-feldspars, and clay minerals. Quartz and carbonates have no influence.

In detritic rocks, sodium is mainly concentrated in the albite. Subtracting this phase, the difference in the relative proportions of potash feldspar and especially of different clays, like illite, chlorite, montmorillonite, or kaolinite can be obtained. The corresponding parameters (K/Al—Na) versus (Fe + Mg)/

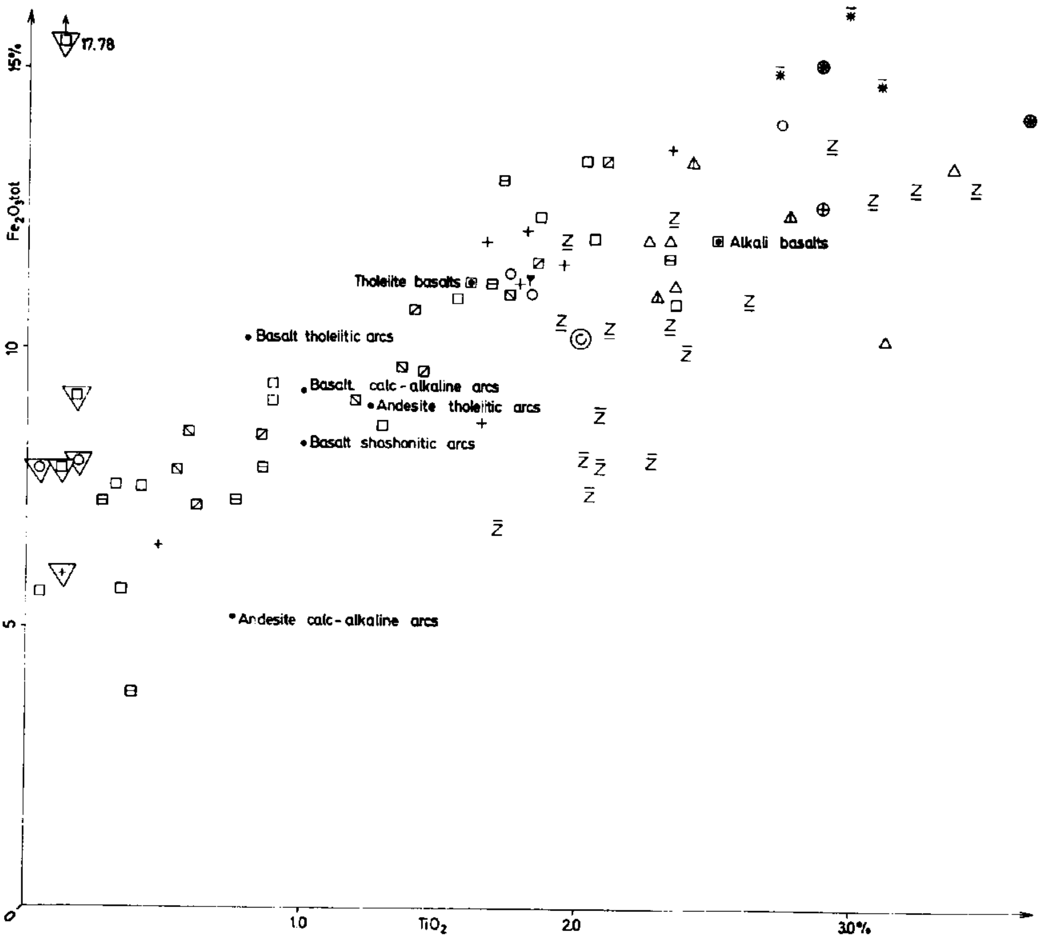


Fig. 9 a. The Fe_2O_{3tot}/TiO_2 ratio in the analyzed basic rocks

▣ after M. Prinz (1967)

• after P. Jakeš and A. J. R. White (1972)

(Al—Na) are plotted in fig. 6 (B. Moine et al., 1976). In this way the clayey composition of shales can be analyzed.

For a detailed study of the basic volcanic rocks the diagram in fig. 7 is shown. Its parameters, $R_1 = 6\,Ca + 2\,Mg + Al$ against $R_2 = 4\,Si - 11\,(Na + K) - 2\,(Fe + Ti)$, were calculated in order to present the projection of Yoder and Tilley's tetrahedron along the critical plane of silica saturation (J. Leterrier, 1972, H. de la Roche and J. Leterrier, 1973). The diagram shows the first bisectrix, which corresponds to the projection of this plane, as well as the areas of tholeiite, hyperaluminous and alkali basalts with their differentiation trends.

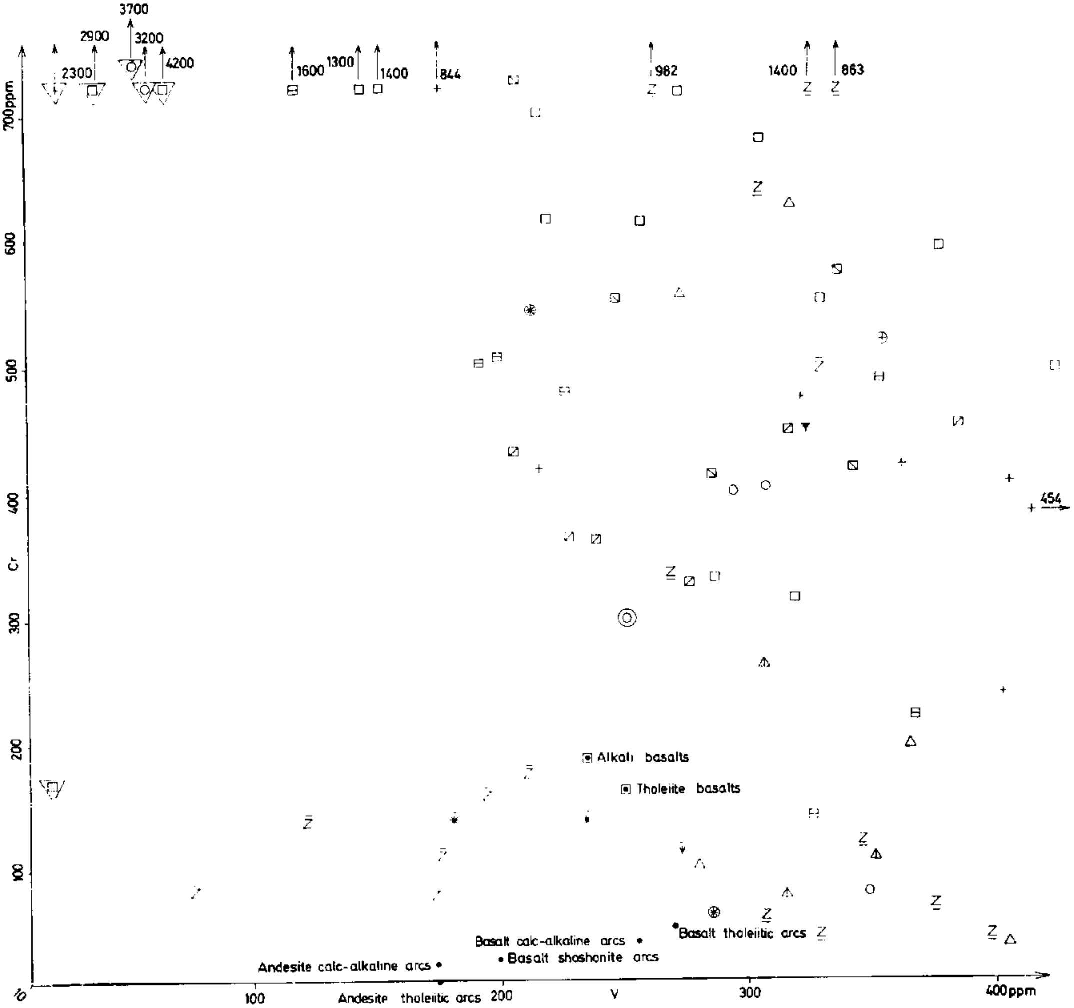


Fig. 9 b. The Cr/V ratio in the analyzed basic rocks

▣ after M. Prinz (1967)

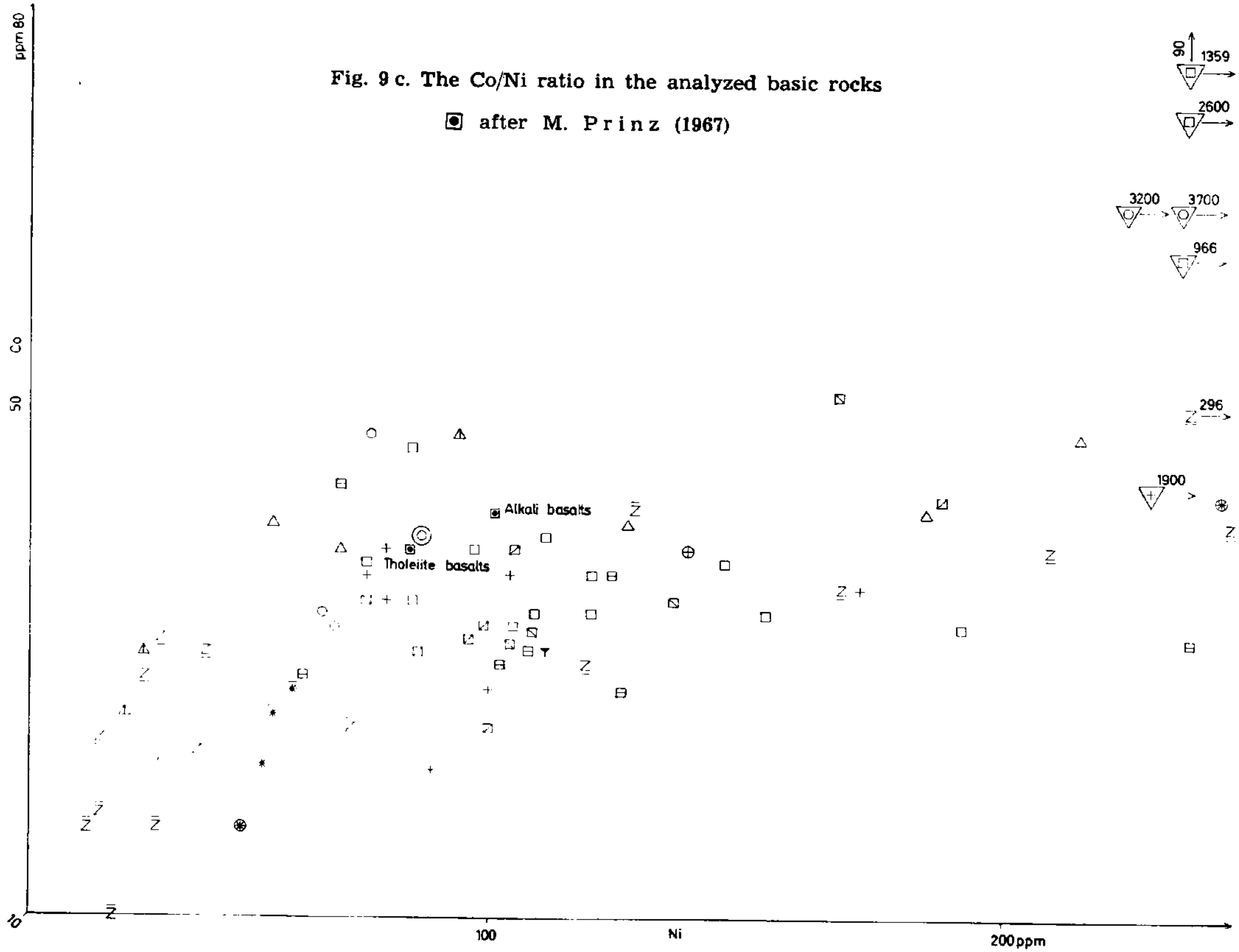
● after P. Jakeš and A. J. R. White (1972)

The basic rocks could be distinguished also by a comparison of the K_2O variation with the ignition loss (fig. 8). The trace elements of the metabasites are shown by the ratios Fe_2O_{3tot}/TiO_2, Cr/V, Co/Ni and Ba/Sr (figs. 9 a, 9 b, 9 c, and 9 d).

The (Al/3-K) versus (Al/3-Na) diagram (fig. 10 a) was proposed by H. de la Roche (1968). It is based on a different geochemical behaviour of aluminium and alkali metals occurring in igneous and sedimentary rocks. From the

Fig. 9 c. The Co/Ni ratio in the analyzed basic rocks

▣ after M. Prinz (1967)



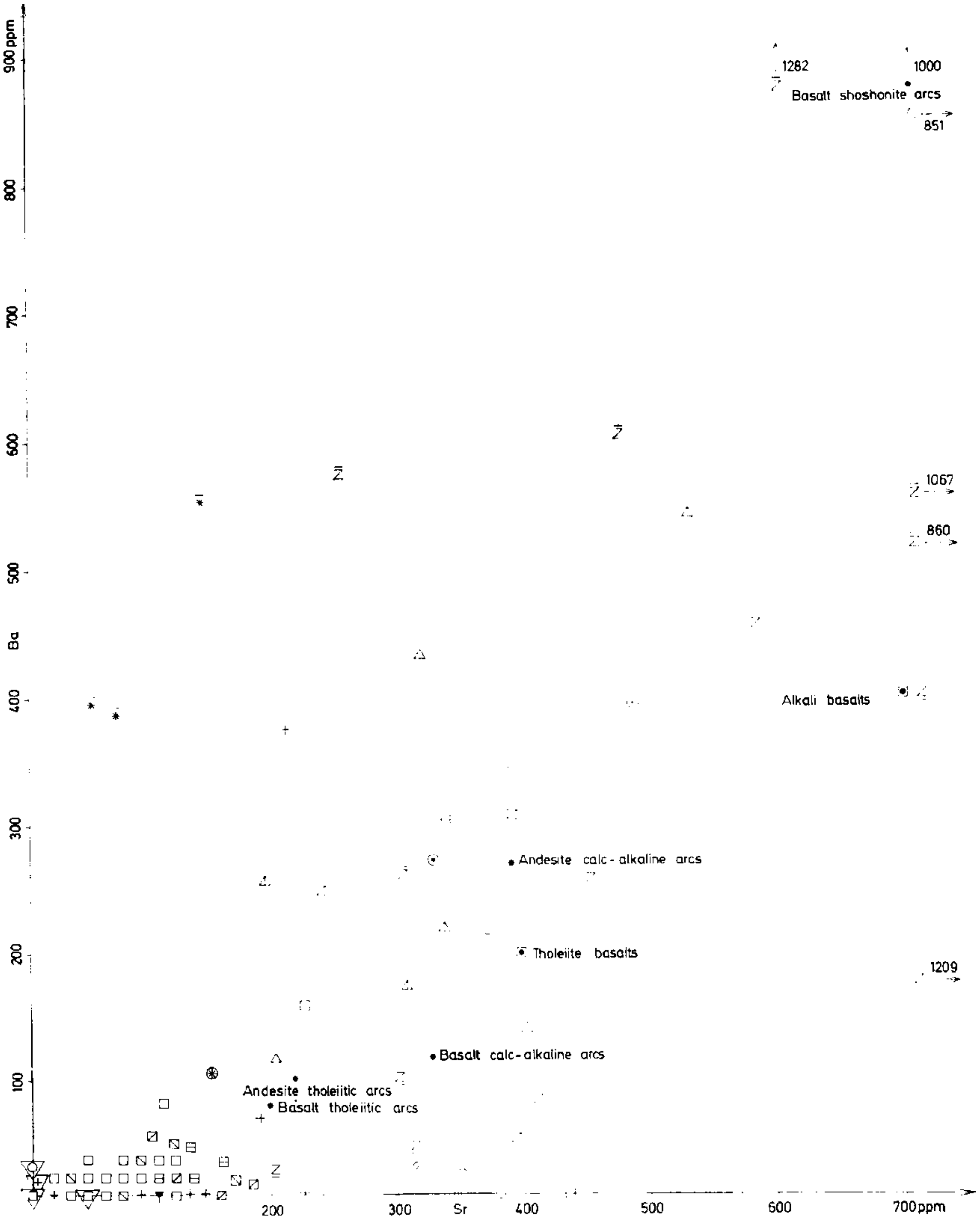
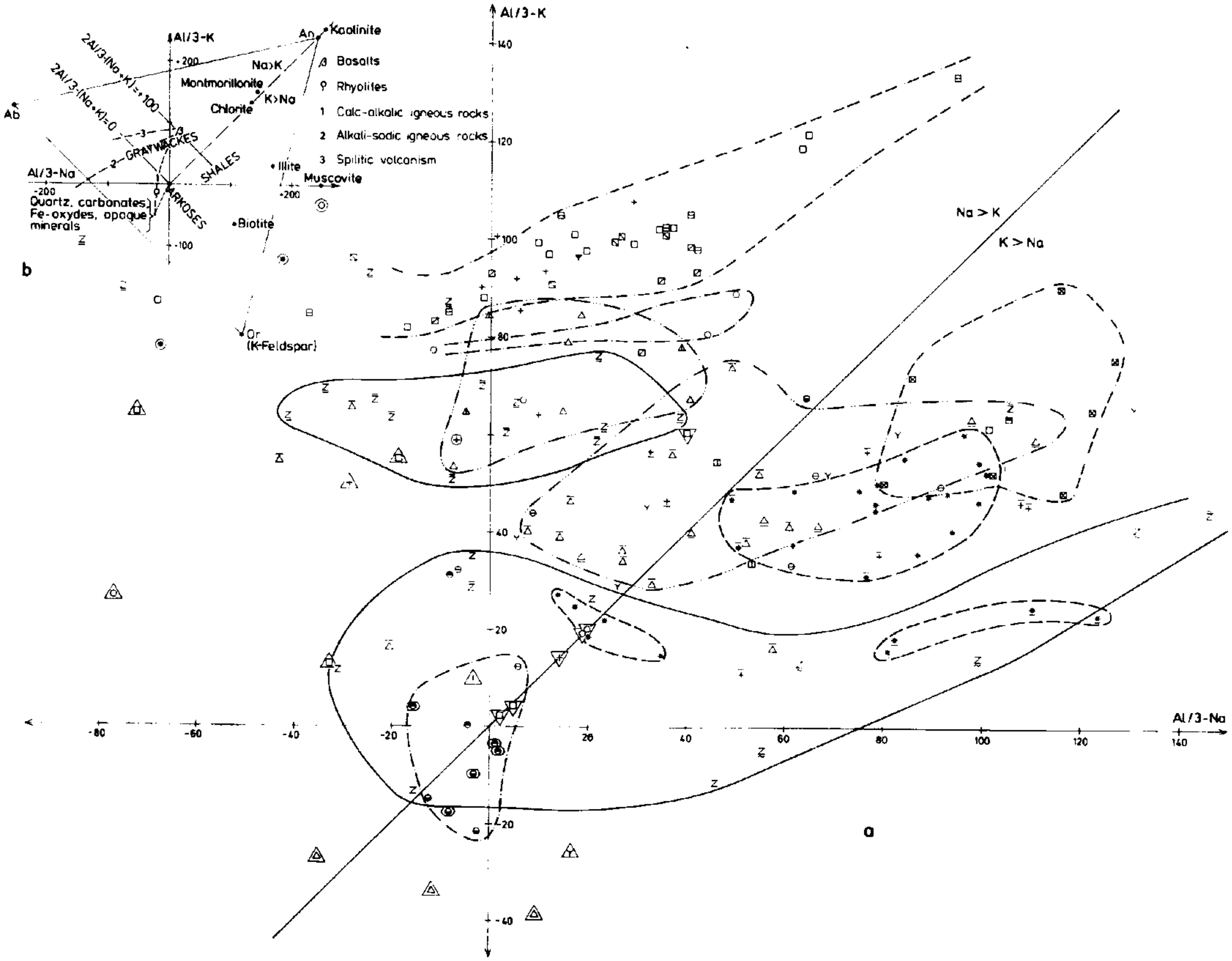


Fig. 9 d. The Ba/Sr ratio in the analyzed basic rocks

▣ after M. Prinz (1967)

● after P. Jakeš and A. J. R. White (1972)


Al/3-K
Al/3-Na
Na > K
K > Na
a
b
An
Kaolinite
Ab
Na>K
K>Na
Montmorillonite
Chlorite
Illite
Muscovite
Biotite
Or (K-Feldspar)
2Al/3-(Na+K)=+100
2Al/3-(Na+K)=0
GRAYWACKES
SHALES
ARKOSES
Quartz, carbonates, Fe-oxydes, opaque minerals
β Basalts
ρ Rhyolites
1 Calc-alkalic igneous rocks
2 Alkali-sodic igneous rocks
3 Spilitic volcanism
+200
-200
+100
-100
140
120
100
80
40
20
-20
-40
-60
-80

distribution of the rock forming minerals a clear distinction between the fields of the rock groups can be recognized. A chemical difference between the graywacke and pelite is also indicated. The K-feldspar, anorthite, and albite are located at the poles of a quasi-equilateral triangle as it is evident from the figure 10 b. The clay minerals having K > Na are distributed on the right hand side of the diagram. Quartz, carbonate and Fe-oxides are located in the centre. The influence of all the minerals contained in a rock is thus reflected in diagram 10 a.

The chemical analyses of representative rocks constituting each metamorphic level are assembled in the tables 1 to 7.

4. Petrology and geochemistry of the lithostratigraphic units

4.1. *The augen gneiss level*

The rocks of the deepest metamorphic level are visible at the surface in two areas, those of Oplotnica—Mislinja and Šmartno, simply because they have been displaced by tectonic movements. Consequently the thickness of the level varies from 600 to 1000 meters. The level was sampled at three profiles varying in petrological composition.

The augen gneiss level is the only metamorphic level in the Pohorje Mts. which is characterized by acid rhyolitic and rhyodacitic volcanism indicated by the chemical composition of augen gneiss and associated fine-grained gneiss varieties. About 40 per cent of the rocks occurring along the Mislinja brook (profile 1) and the Polskava brook (profile 4) show an augen structure. Along the Dravinja river (profile 2), biotite-muscovite schist and gneiss prevail. They originated from immature shale and graywacke. Only in this profile do some thin amphibolite intercalations occur. They appear to be derived from basalt.

The acid meta-volcanic rocks of both the Mislinja and the Šmartno areas show somewhat different geochemical properties. In the Mislinja area, the biotite-muscovite augen gneiss is interlayered with muscovite gneiss of aplitic character. The latter indicates a composition close to rhyolite (figs. 4, 5, and 10 a). The augen gneiss, which contains less quartz and more iron shows, however, a tendency towards dellenite. Some immature arkoses may geochemically resemble acid igneous rocks. As the analyzed samples do not show any sedimentary trend, they are considered to be of volcanic origin.

The biotite augen gneiss and biotite gneiss from the Šmartno area have a rhyodacitic composition. There exists a transition to the geochemical properties of the biotite-muscovite augen gneiss from the Mislinja area (fig. 4). But the Šmartno biotite augen gneiss is more melanocratic due to a higher (Fe + Mg)-content.

Fig. 10 a. The Pohorje metamorphic rocks represented by the parameters (Al/3 — K) versus (Al/3 — Na)

Fig. 10 b. The main igneous and sedimentary areas and tendencies presented as functions of the different behaviour of K, Na, and Al (after H. de la Roche, 1968 and B. Moine, 1974)

The parameters are calculated from the cation numbers of the corresponding weight per cent of the oxide molecules

Two different samples of interlayered fine-grained biotite gneiss were analyzed. One of them corresponds geochemically to rhyodacite (sample 50 B), having fine grains of K-feldspar in the matrix. The other one containing more biotite, shows a sedimentary tendency towards graywacke, like the rocks from the second profile of this level (sample 46 A). Its lower quartz content and a higher (Fe + Mg)-content can be clearly seen in the QFM diagram.

The muscovite schist associated with augen gneiss along profiles 1 and 4, is less developed (sample 36). It belongs to the range between graywacke and shale (figs. 10 a and 5). The high value of Na/K ratio indicates the relatively high albite content of the original sedimentary rock and therefore its low maturity.

The muscovite-biotite schist and gneiss from profile 2 correspond to the broad field of graywackes and shales (figs. 4 and 5). Regarding the schists, this is in agreement with the mineralogy of analyzed gneisses which are richer in plagioclase. The gneiss samples are descended from graywackes with some arkosic tendency. On the other hand, the schist samples are derived from not very mature shales. Their feldspar content is low (fig. 4). The geochemical field between illite and chlorite (fig. 6) corresponds to the clayey constituent of samples. The gneiss samples examined by the same parameters exhibit an increased content in K-feldspar.

Only in profile two of the level do there occur interstratified garnet-amphibole schist and amphibolite, representing original basic volcanic rocks (figs. 4,

Table 1. **Chemical analyses of the rock samples taken from the augen gneiss level**

Sample	SiO_2	Al_2O_3	Fe_2O_{3tot}	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	I.L.	Total
1A	72.01	14.37	1.69	.04	.45	.86	2.99	5.44	.25	.94	99.04
1B	69.58	14.75	3.20	.06	.95	1.79	3.09	5.00	.62	.87	99.91
50	68.14	14.87	4.19	.07	1.19	2.48	2.98	4.74	.71	.63	100.00
50B	70.30	14.17	3.31	.06	.99	2.18	3.01	4.34	.55	.53	99.44
68	69.03	14.55	4.35	.08	1.85	1.94	3.15	2.96	.54	.19	99.64
82A	58.00	19.91	9.51	.14	3.16	.41	1.18	3.79	1.20	2.88	100.18
82B	76.19	13.94	.60	.04	.07	.23	5.22	3.03	.00	.69	100.01
83A	48.22	14.90	11.13	.19	6.63	12.01	1.64	.79	1.80	1.61	98.92
150	47.45	14.43	14.02	.23	5.72	10.36	3.29	.81	2.73	.71	99.75

Sample 1 A: muscovite gneiss of aplitic character close to rhyolite
Sample 1 B: biotite-muscovite augen gneiss close to dellenite
Sample 50: biotite augen gneiss close to rhyodacite
Sample 50 B: biotite gneiss geochemically corresponding to augen gneiss of rhyodacitic composition
Sample 68: biotite-muscovite gneiss of aplitic character derived from a graywacke
Sample 82 A: muscovite schist derived from a shale
Sample 82 B: aplitoid gneiss
Sample 83 A: garnet amphibolite close to tholeiitic basalt
Sample 150: amphibolite close to alkali basalt

7, 8, and 10 a). The amphibolite varieties (samples 83 A and 83 B) have a composition close to tholeiitic basalt. The amphibolite (sample 150) abounds in alkali, especially in Na, and is closer to alkali basalt (fig. 7). The same feature may develop, however, through metasomatism and spilitization.

In Šmartno augen gneiss small synmetamorphic serpentinite and some harzburgite inclusions have been observed (samples 48 A and 48 B). Amphibolite with a partly preserved magmatic texture (sample 47 A) also occurs together with the ultrabasite. This rock is chemically related to alkali basalt showing a sodic tendency (fig. 7).

The rocks of the augen gneiss level reflect a clastic sedimentation associated with acid volcanism in an eugeosyncline.

4.2. The marble level

The marble level occurs in two separated areas in the southern and eastern part of the massif, clearly exposed between the Oplotniščica and Dravinja brooks, and north of Šmartno, towards Ruše. The rock sequence is about 900 to 1000 meters thick. It was sampled along three profiles.

The prevailing metasediments are biotite ± muscovite schist and gneiss (52 per cent) and flaser gneiss with ± almandine ± kyanite (15 per cent). Amphibolite varieties represent an important group (10 to 30 per cent).

Thin layered marble is a common rock only in this metamorphic level. It is more abundant in the southern part of the massif, where it represents up to 30 per cent of the horizon, than in the northern part. The MgO-content of 23 analyzed samples, taken from Zreče marble, amounts to 20 per cent, which corresponds to dolomite. Accessory minerals in the marble, originating from siliceous and argillaceous admixtures, are represented by quartz and calcium-bearing silicates, as also some ore minerals and graphite.

Quartzite makes up 5 to 10 per cent of the level. Usually, it contains accessory silicates of corresponding metamorphic degree, derived from argillaceous admixture, and also some graphite.

The samples of schist and gneiss intercalated with flaser gneiss are evaluated together, as there is little geochemical difference between them. Twenty-one samples were analyzed. They are considered to originate from graywackes and shales, displaying a large variation of sodium and potassium (figs. 5 and 10 a). Their (Fe + Mg)-content is high and fairly constant, notwithstanding the fact that the ratio between aluminium and alkalies, as well as between sodium and potassium, varies considerably (figs. 4 and 5). The metasediments remain very fine-grained, in spite of their high metamorphic degree. Their graywacke composition shown in the different diagrams might, therefore, correspond to rather immature shales, whose albite component has not yet been disintegrated during weathering.

The schists of profile 4 show a large dispersion in their alkali and aluminium contents. Flaser gneiss with almandine ± kyanite shows the same feature. If containing kyanite, it represents the most mature and Al-rich rock of the level (samples 56, 70 A and 157 A in fig. 5). Without taking into consideration such samples, the geochemical variability of the schists of this level would be much reduced (fig. 10 a).

The greatest degree of deviation from the general geochemical properties of schists is shown by a light biotite-muscovite gneiss (sample 161). Its (Fe + Mg)-content is very low (fig. 4). An unusual geochemical feature is shown by a fine-grained biotite gneiss (sample 155). This is an intermediate rock, poor in silica and rich in feldspar, which could have been derived from a rhyodacitic tuff (fig. 4).

Some schists contain a large amount of opaque minerals. Their high Fe-content, related to a somewhat increased Ca- and Mg-content, as well as a lower SiO_2 value, indicate a basic tuffitic admixture (samples 55 A and 157).

Metabasites are interlayered with marble and biotite schist. Eight samples were analyzed. They showed a transitional character between basalt and andesite (figs. 4 and 10 a). Their silica content is relatively low, and alkali content high. In spite of some possible alkali variation during metamorphism, they probably originated from alkali basalt and partly from hyperaluminous basalt (fig. 7). Some metabasites show a tendency towards ultrabasite, as is proved by their high Cr- and Ni-content (samples 10 A and 160, figs. 9 b and 9 c). The amount of TiO_2 is usually high in all samples. But it is a little lower in amphibolite variety, which is related to marble (fig. 9 a).

Although metabasites associated with marble contain an increased Mg-content they are not of metasomatic but of magmatic origin. This is proved by their high Cr- and Ni-value, too. Alike the metabasites interlayered with marble are characterized by a relatively high MgO/Fe_2O_{3tot} ratio compared with those interlayered with schist. Only a small decrease in Fe_2O_3-content and thereby a small increase of the MgO/Fe_2O_{3tot} ratio could be related to metasomatic evolution, because a thin Fe-aureole is observed in the Zreče marble associated with amphibole schist.

Table 2. **Chemical analyses of the rock samples taken from the marble level**

Sample	SiO_2	Al_2O_3	Fe_2O_{3tot}	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	I.L.	Total
10A	46.44	13.72	11.88	.16	9.10	11.70	2.29	.50	2.29	.95	99.03
54	65.27	17.28	7.49	.09	2.32	.51	1.61	3.37	1.14	1.28	100.36
62	61.15	16.23	7.19	.08	3.19	3.60	3.05	3.10	1.06	.84	99.49
67F	59.37	15.91	8.34	.07	3.54	4.46	1.95	3.01	1.05	.86	98.56
68A	48.87	15.38	10.93	.19	5.54	9.72	3.27	1.69	2.29	1.03	98.91
70A	56.12	22.44	9.94	.08	3.10	.14	1.10	4.12	1.38	1.60	100.02
152	44.77	15.93	11.13	.18	7.63	11.05	1.96	1.73	2.34	1.94	98.66

Sample 10 A: garnet amphibolite variety derived from a metabasite with an ultrabasic tendency
Sample 54: biotite-muscovite gneiss derived from a shale
Sample 62: biotite gneiss derived from a graywacke
Sample 67 F: flaser gneiss without kyanite
Sample 68 A: amphibolite derived from an alkali basalt
Sample 70 A: almandine-kyanite flaser gneiss derived from a shale
Sample 152: amphibolite variety derived from an alkali basalt

The rock assemblage of the marble level, intertongued with pelitic sediments, dolomite, quartz sandstone and alkalic basites, proves the existence of a confined basin.

4.3. The eclogite level

The eclogite level extends itself along the southern slopes of the Pohorje Mts. from Slovenska Bistrica over Rogla to Mislinja brook. On the northern slopes it is exposed from Hočko Pohorje to the Lobnica brook and thins out westwards. The level is about 1000 meters thick. Four sections have been sampled in the southern and northern part of the massif.

The metasediments from different profiles of this level can be discussed together, as they show the same geochemical features. Eleven samples of the almandine-biotite-muscovite schist were analyzed. They show fairly high contents in aluminium and K/Na ratio compared with other metapelites from Pohorje (figs. 10 a and 5). It could be derived from a very mature shale. The small variations of the low Na/Al ratio are related to the plagioclase content. Gneiss derived from graywacke occurs to a smaller extent. The analyzed sample of an almandine flaser gneiss contains kyanite aggregates and resembles the other metapelites from the geochemical point of view, like the flaser gneiss of the marble level. Illite-montmorillonite clay, containing some chlorite, was probably the original material that yielded muscovite schists (fig. 6).

Metabasites are the most frequent inclusions of the rock sequence. They consist of amphibolite varieties and rare small eclogite lenses. Some eclogite lenses were found in the underlying marble level too; one outcrop of eclogite occurs in the overlying ultrabasite level south of Ruše. Eclogite is usually rather amphibolitized but no sharp boundary between unaltered and altered rock occurs. The analyzed metabasite samples consist of eclogite (12 samples), symplektitized eclogite (five samples), amphibolitized eclogite (six samples) and layered amphibolite varieties (seven samples). All these rocks show similar geochemical features as regards their QFM parameters. They correspond to the range between basalt and andesite, showing small differences in silica content. The Al-content is high and the K-content low (fig. 10 a). The low potassium value is a characteristic of tholeiite basalt of oceanic association. It is encountered in some eclogite hyperaluminous varieties, too (fig. 7). But the Al-high basites did not necessarily derive from hyperaluminous basalts. The basalt tholeiite area is even enlarged towards the hyperaluminous field, as is the case for numerous oceanic tholeiites.

Some eclogite varieties are close to alkali basalt due to the high contents of TiO_2 and Na_2O. Therefore they could be a product of the spilitization.

The K_2O-content of the metabasites of this level is generally very low. In eclogites is may drop even to less than 0.1 per cent. It increases to 0.4 per cent in amphibolitized eclogites and in some amphibolite varieties. A rough comparison was made between the K_2O variation and ignition loss related mainly to H_2O (fig. 8). This comparison shows that the retrogressive evolution from eclogite to amphibolite took place by the addition of H_2O and probably also by a small addition of K_2O ranging from 0.2 to 0.3 per cent. It would be interesting to control this observation with a detailed examination. The data are in accordance with the observed amphibolitization of doleritic and gabbroidic rocks (M. Piboule, personal communication).

A low K_2O value is a characteristic of the amphibolite of the ultrabasite level, too. The metabasites of all other levels show a very high K_2O-content. Consequently their origin from basic rocks rich in potassium is assumed. Nevertheless, some K_2O was probably introduced by metamorphism.

Other differences observed between the eclogite and amphibolite varieties are:

— an increased CaO/SiO_2 ratio, with some very high values in eclogite,

— an increased Fe_2O_{3tot}/TiO_2 ratio and very low TiO_2 values in eclogite (fig. 9 a),

— increased Cr/V and MgO/Fe_2O_{3tot} ratios in eclogite compared with amphibolite (fig. 9 b),

— an increased Ni-content in the rocks with very high Cr and MgO values (fig. 9 c),

— a very low Ba/Sr ratio is still lower in eclogite than in amphibolite (fig. 9 d).

Magmatic differentiation is indicated by the rather high variation of MgO/Fe_2O_{3tot} ratios. The highest ratios, with MgO-contents of 9 to 10 per cent,

Table 3. **Chemical analyses of the rock samples taken from the eclogite level**

Sample	SiO_2	Al_2O_3	Fe_2O_{3tot}	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	I.L.	Total
12B	48,02	18.79	5.69	.12	10,08	13.55	1.80	.06	.35	.40	98.86
13A	50.50	15.92	8,65	.17	8.65	11,62	2.15	.10	1.29	.57	99.62
13B	49.60	16.03	7,84	.18	9.51	11.81	2,47	.25	.55	1.37	99.61
13C	49.51	17.43	7.20	.14	8.74	11,40	2.26	.73	.62	1.96	99.99
13D	49.61	16.64	7.27	.13	9.14	11.90	2.27	.30	.28	1.51	99.05
14	54,82	22.97	9.67	.18	2.51	.95	1.05	2,82	1,22	2.46	98.65
14A	61.46	20.90	7,02	.12	1.87	.69	.96	3.43	.92	2,15	99.52
31	56.32	20,11	9.01	.18	2.81	2.89	1.41	2.80	1,02	2.95	99.50
156C	49.59	14.16	10.89	.15	6.67	10.05	4.99	.26	2.33	.01	99.10
164	37.16	.76	7.87	.10	37.55	.81	.00	.03	.12	13,68	98.08
173	53,94	20,73	9.10	.19	2.66	2.32	2.76	3.81	1,07	2.57	99.15

Sample 12 B: eclogite with kyanite and primary amphibole
Sample 13 A: zoisite eclogite
Sample 13 B: symplektitized kyanite-zoisite eclogite
Sample 13 C: amphibolitized eclogite
Sample 13 D: amphibolite
Sample 14: muscovite schist derived from a shale
Sample 14 A: kyanite flaser gneiss
Sample 31: almandine-muscovite schist derived from a shale
Sample 156 C: eclogite variety rich in sodium
Sample 164: serpentinite
Sample 173: muscovite-biotite gneiss derived from a graywacke

correspond to eclogite hyperaluminous varieties. Only eclogite with a high MgO and Al_2O_3 value contains kyanite crystals (D. Coffrant and M. Piboule, 1975). In eclogite, Cr often amounts to 600 ppm; it may exceed even 1000 ppm. The higher Cr-contents did not result from a contamination during pulverisation, as they follow the higher MgO value.

In the eclogite level there also occur the synmetamorphic serpentinized dunite with harzburgite, and a small body of Mg-rich garnet pyroxenite as well. They contain very large quantities of the trace elements, like Ni, Co, and Cr.

The very mature oceanic shale associated with tholeiite basalt is characteristic for the eclogite level. Infrequently marble and quartzite occur.

4.4. The ultrabasite level

Along the northern slopes of the Pohorje Mts. the eclogite horizon iz overlain by biotite-muscovite schist and gneiss, containing metabasites. To a minor extent, marble, kyanite flaser gneiss, and synmetamorphic lenses of ultrabasite occur. The level was sampled only in one profile.

Metasediments are the most common rocks of the ultrabasite level. Five schist samples and two gneiss samples were analyzed. In respect of the QFM parameters, they correspond to the wide range of graywackes and shales (fig. 4). Some schists show a quarzite trend. The variation of the Na/Al and K/Al ratios results from the different degrees of maturity of the original sediments (fig. 5). Their main part was quite mature. Schists of this level have intermediate properties between the schists of the eclogite level and all other Pohorje schists. Their clayey constituent represents a mixture of preponderant illite with chlorite (fig. 6).

Geochemically well-grouped metabasites occur as amphibolite varieties. The original rocks were mainly basalts (six samples); only one sample shows andesitic properties (fig. 4). The metabasites of this level resemble the metabasites of the eclogite level, being characterized by a very low K_2O-content (fig. 8). Therefore it can be said that they probably correspond to oceanic tholeiites, too, comprising some hyperaluminous varieties as well (fig. 7). The Fe_2O_{3tot}/TiO_2, Cr/V, Ni/Co, and MgO/Fe_2O_{3tot} ratios are high but lower than in eclogite (figs.

Table 4. **Chemical analyses of the rock samples taken from the ultrabasite level**

Sample	SiO_2	Al_2O_3	Fe_2O_{3tot}	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	I.L.	Total
90B	57.90	20.28	8.77	.13	2.74	1.35	.71	4.10	.94	3.61	100.53
90C	43.73	13.64	12.55	.18	9.16	10.82	2.98	1.43	2.88	2.30	99.67
91	60.95	16.75	8.11	.09	2.20	4.68	2.38	2.48	1.25	1.29	100.18
93	48.21	14.40	11.93	.20	8.12	12.06	2.57	.03	1.65	1.13	100.30

Sample 90 B: muscovite-biotite schist derived from a shale
Sample 90 C: symplektitized and amphibolitized eclogite rich in sodium
Sample 91: biotite-muscovite gneiss derived from a graywacke
Sample 93: amphibolite variety derived from a tholeiite basalt

9 a, 9 b, and 9 c). The TiO_2-content exceeds 1.5 per cent, whereas the average Cr-content amounts to about 420 ppm. The Ba/Sr ratio is very low, like that in the eclogite (fig. 9 d).

The only symplektitized biotite eclogite (sample 90 C) represents an exception in this level and corresponds to an alkali basalt, similar to some NaO_2- and TiO_2-rich eclogite varieties of the eclogite level (Fig. 7). The geochemical parameters of these rocks, as well their Fe_2O_{3tot}/TiO_2 and Cr/V ratios, may be compared. Their Ba/Sr ratio is higher than in other eclogites.

The sample 88 A taken from a small pyroxenite lens is an ultrabasite and has an exceptionally high Cr- and Ni-content.

4.5. The diaphthorite level

Retrogressively altered rocks occur along an important tectonic line bordering the northern part of the Pohorje Mts. They are, however, more frequent in the southern Pohorje area. The thickness of the level amounts to 500 meters. The primary cover of the diaphthorite level has been completely removed. In the southern Pohorje this level is underlain by the eclogite level, while in the northern Pohorje by the ultrabasite level. Similar geochemical features of the rocks building up the ultrabasite and the diaphthorite levels indicate their equivalence.

The rock sequence of this level is uniform. It consists of black-gray diaphthorite almandine schist and gneiss. At the deepest part of the level marble and amphibolite occur. The latter might belong to the eclogite level, as it is underlain by insignificant diaphthorite schist only.

The Pohorje tonalite pluton has thermically influenced only the retrogressively altered schists. Therefore, along their border, andalusite-almandine schist and gneiss may occur. As andalusite schist originates from diaphthorite schist, their similar geochemical properties will be described together.

Six rock samples were taken from two profiles. The main rock group consists of schist and gneiss showing a normal sedimentary character. Therefore no significant chemical changes seem to be related with retrogressive metamorphism. The diaphthorite schists are characterized by a constant CaO-content

Table 5. **Chemical analyses of the rock samples taken from the diaphthorite level**

Sample	SiO_2	Al_2O_3	Fe_2O_{3tot}	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	I.L.	Total
20	59.48	20.17	8.60	.15	2.25	1.08	.85	3.70	.70	2.31	99.29
3	46.80	15.22	11.15	.20	8.86	12.01	2.51	.18	1.82	1.60	100.35
4	70.79	13.07	4.37	.09	1.86	2.70	2.48	2.19	.80	1.57	99.92
35	58.11	20.34	8.29	.16	2.42	1.95	1.54	3.42	.74	3.34	100.31

Sample 20 B: andalusite-biotite-muscovite schist derived from a shale
Sample 3: amphibolite variety derived from a tholeiitic basalt
Sample 4: diaphthorite almandine gneiss derived from a graywacke
Sample 35: diaphthorite schist derived from a shale

of about 2 per cent, whereas the amount of silica varies considerably. The quartz-rich schist and gneiss contain more sodium and are more abundant in plagioclase. Therefore, they show a tendency from shale to graywacke, which is proved by the Na/Al versus the K/Al ratio (fig. 5). The metasediments of the diaphthorite level are geochemically close to those of the ultrabasite and greenschist levels. On the other hand, they differ quite a lot from the mature schist in the eclogite level.

The analyzed metabasite sample was taken from the bottom of the diaphthorite level. It is geochemically similar to the basites of the eclogite level. The amount of CaO contained is relatively high and the amount of K_2O is very low (fig. 8). Like the former rocks, it probably originates from oceanic tholeiite basalt, despite its plotting in the hyperaluminous basalt field (fig. 7).

The rock association lying between the diaphthorite and greenschist levels could hardly have been identified in the Pohorje Mountains, whereas it is well developed north of the river Drava.

4.1.—4.5. Inclusions of pegmatoid and aplitoid gneisses

A part of the Pohorje metamorphic rock sequence crystallized under the conditions of the almandine-amphibolite facies. It is characterized by inclusions of pegmatoid and aplitoid gneisses. Both represent metamorphosed acid igneous rocks derived from a hypothetical magma differentiates. They may occur along all rock varieties. Usually they are foliated like the surrounding rock; infrequently the later is cut accross by them. The thickness of their sheets varies from several decimeters to some meters. Their main constituent is quartz, the remainder being orthoclase-microcline, albite or oligoclase, and some muscovite. No mafic minerals are found in them.

Nine samples from different levels were examined. They represent the most leucocratic rocks of the Pohorje Mts., showing deviations in all the fundamental diagrams (figs. 4, 5, 6, and 10 a). Their potash and sodium contents vary widely. Consequently a leucogranitic and leucogranodioritic character prevails. Leucogranodioritic rocks showing a pronounced sodic character are similar to the genetically unrelated quartz keratophyre occuring only in the greenschist level. The pegmatoid and aplitoid gneisses, being nearly Fe- and Mg-free, show a particular geochemical feature as opposed to all other rocks.

4.6. The greenschist level

Greenschists occur to a lesser extent along the northern and southern borders of the Pohorje Mts. Only southeast of Dravograd is the level well developed to a thickness of about 1000 meters. There the majority of samples were taken along the profile 6. Only a few of them are from profile 5, north of Mislinja.

In the lower part of the sequence, amphibolite and amphibole schist occur (30 per cent). They are associated with biotite and epidote schist (20 per cent). Phyllite schist is of interest due to its idiomorphic small pink garnet and staurolite crystals (10 per cent). The stratigraphic position of this fine-grained staurolite schist is not clear. In the uppermost part of the level, phyllite and gneiss phyllite prevail (30 per cent), mainly with a carbonate admixture. Its characteristic are inclusions of metakeratophyre and its tuff (6 per cent). Infrequently small inclusions of marble, quartzite, and graphite phyllite may occur. These different rock groups of the sequence show a corresponding geochemical diversity.

Metabasites and their metatuffs, composed of amphibole, chlorite, biotite, and albite-oligoclase, have an alkalic character, being rich in sodium, and some of them in potassium, too (fig. 7). They are represented by ten samples. In sample 114, a high K_2O-content and Ba/Sr ratio coincide with the average value for alkali basalts. The geochemical position of the alkali basalt breccia (sample 149), which shows a trend towards ultrabasite, is due to its calcite cement unusual in the various diagrams. Samples 119 A and 119 C are close to ultrabasite, too, having a small content of aluminium, silica, and alkali, but a high MgO-content. All the other varieties are spilites, as is clearly indicated in fig. 10 a. They originate from primary basalt and andesite, or from their respective tuffs. Their Na_2O-content varies from 3 to 6 per cent. One sample is a carbonate phyllite with a tuffaceous spilitic admixture.

The trace elements vary widely in these basic rocks. In varieties close to ultrabasite, the Ni-, Cr-, and V-content are very high. Their K_2O-content ranges from 0.16 to 0.37 per cent, and their Ba-content from 30 to 100 ppm. In the spilitic rocks, too, the K_2O-content and the Ba/Sr ratio vary widely. Their TiO_2- and V-content are very high and their Ni- and Cr-content very low (figs. 8, 9 a, 9 b, 9 c, and 9 d).

The metavolcanic rocks forming the middle and upper part of the greenschist sequence are represented by seven analyzed phyllite schists, containing different proportions of albite, chlorite, biotite, epidote, and quartz. Their original mineralogy was studied first by means of the parameters [Si/3—(Na + K + 2 Ca/3)] versus [K—(Na + Ca)], and (Fe_{tot} + Mg + Ti) versus [K — (Na + Ca)] (H. de la Roche, 1964). The acid and basic igneous rocks are clearly distinguished by these parameters. The rocks of transitional composition are dispersed between them. The same results from the analyzed samples (diagrams are not attached). This group of rocks could have been derived from graywacke according to their aluminium and alkali relation (fig. 10 a). But this is not in agreement with their low silica and high TiO_2-, Cr-, and Ni-content (figs. 4, 8 a, 8 b, and 8 c). Regarding the QFM parameters, they belong to transitional igneous rocks, and are displaced from the graywacke field. Their removed position may result, partly, from a sedimentary carbonate contamination.

The very high K_2O-content, related at a given SiO_2 percentage to Ba and Sr, is characteristic for different rocks of shoshonitic association of the island-arcs (P. Jakeš and A. J. R. White, 1972). As the potassium content in analyzed intermediate volcanic rocks is high, their Ba- and Sr-content are increased, but nevertheless they are still low. On the other hand different data indicate the complexity of the Ba and Sr variation (P. Jakeš and A. J. R. White, 1972; H. Puchelt. In: K. H. Wedepohl, 1972, Ba 56-E-5).

In the upper greenschist level, there occur metakeratophyre and its tuff, as represented by gneiss phyllite, including albite and occasionally orthoclase. With increasing depth, five samples were analyzed; one of them, however, appears to be rather deep among the metabasites. These rocks are geochemically

Table 6. **Chemical analyses of the rock samples taken from the greenschist level**

Sample	SiO_2	Al_2O_3	Fe_2O_{3tot}	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	I.L.	Total
5	52.06	24.46	9.13	.17	2.61	.02	.42	5.45	.85	4.54	99.71
7A	76.87	12.45	1.25	.01	.23	.00	3.01	4.45	.00	.86	99.13
114	45.25	15.96	12.96	.27	6.27	10.14	2.55	1.33	3.44	1.74	99.91
115	50.29	16.24	12.92	.21	4.24	5.35	5.63	.76	3.21	1.11	99.96
119A	42.44	11.33	10.82	.20	9.98	12.99	2.14	.37	2.32	6.51	99.15
120B	45.77	15.30	9.93	.15	5.03	8.92	3.00	1.86	2.39	7.22	99.57
121	62.09	17.76	6.21	.08	2.01	1.95	2.95	4.21	.85	2.12	100.23
128	55.32	15.92	7.29	.05	2.87	3.48	1.50	5.11	.88	6.68	99.10
128C	52.97	17.00	8.01	.13	3.34	6.46	3,69	2.85	2.02	3.35	99.82

Sample 5: phyllite schist derived from a shale
Sample 7 A: phyllite metakeratophyre originating from a rhyolite
Sample 114: chlorite-amphibole-epidote schist derived from an alkali basalt
Sample 115: epidote-biotite-amphibole schist derived from a spilite
Sample 119 A: chlorite-amphibole schist derived from a basalt with an ultrabasic tendency
Sample 120 B: chlorite-albite phyllitic metatuff derived from a trachybasalt
Sample 121: phyllite metakeratophyre derived from a quartz trachyte
Sample 128: phyllite acid metatuff with sedimentary admixture
Sample 128 C: albite-chlorite schist derived from a trachyandesite

very dispersed with respect to their quartz content (fig. 4). They are also alkali rich, and sodium usually prevails over potassium, proving their albitic character. The original rocks were rhyolite and quartz trachyte. Sample 7 B is poor in sodium, but rich in potassium. Therefore, its origin from a shale with a tuffaceous admixture can be supposed (fig. 5). It reveals a progressive geochemical relation to those phyllite schist and phyllite which show a more aluminous character. Four such samples were analyzed. They displayed a widely varying quartz content (fig. 4) and a high potassium content. Their geochemical properties are transitional, between shales and arkoses (fig. 5), and probably correspond to a tuff, having a high sedimentary admixture. Two samples of phyllite schist, with fine garnet and staurolite, taken from the lowest part of the greenschist level, are even more rich in aluminium and potassium. It therefore follows that they do not contain any volcanic admixture.

The greenschists which overlie a stratigraphic-metamorphic hiatus differ essentially from the rock assemblages of all other levels. They originate from basic, intermediate and acid volcanic rocks intercalated by some metapelites.

4.7. The Magdalensberg level

The slightly metamorphosed Magdalensberg series is well developed in the northwestern part of the Pohorje Mts. to a thickness of 1000 meters. It also occurs along their southern border, where it follows a fault between Zreče and Vitanje. Two profiles were sampled.

It is worthwhile to note that Devonian fossils were determined from the upper part of the greenschist level in Saualpe. As in the overlying Magdalensberg series Silurian age was proved, the greenschist level was supposed to be a metamorphosed stratigraphic duplication (J. Neugebauer, 1970). In the Pohorje Mts., however, neither have fossils been found, nor could a geochemical correlation of the greenschists with the Magdalensberg series be determined.

The sequence is composed of prevailing slates and siltstones including some diabase, its tuff, and some carbonate rocks. Slates and siltstones are mainly derivatives of Al-rich illitic clay containing some chlorite (15 samples). In the dark grayish-red slate in the upper part of the Magdalensberg series the not very frequent enrichment of Fe-content is related with TiO_2, and is usually associated with a somewhat increased Na_2O-content (figs. 4, 5, 6, and 9 a). The slate adjacent to volcanic rocks in the upper part of the series shows a dispersion with respect to the Na/Al against K/Al relation, too (fig. 5). An increased Na-content of the slate is related at the same time to its higher SiO_2-content. Therefore the apparent immaturity of sediments caused by the increased Na-content originating from a volcanic contamination, has not been conditioned by weathering during sedimentation.

Among the slates of the Magdalensberg series only a few are enriched in potassium (four samples). With regard to aluminium and alkali ratio, they correspond to some rocks in the greenschist level (four samples, figs. 5 and 10 a). The general characteristic of greenschists is a high Na-content, indicating volcanic contamination. This trend, however, is less marked in the Magdalensberg series. It should be mentioned that the groups compared here refer to a stratigraphic interval of considerable thickness in their respective levels.

The volcanic rocks are intercalated with marl, rich in calcite content (samples 138 and 138 A). Some samples contain dolomite admixture (samples 129, 132 A, and 132 B).

The spilitized diabase conglomerate and tuff have been analyzed from the Pohorje area (fig. 10 a). Both have a very high TiO_2-content, which could be an indication of their alkali basalt origin. In conglomerate the Cr-content is very low (63 ppm), whereas in the tuff it is very high (542 ppm). Similar differences have been observed in the metabasites of the greenschist level.

After C. K. W. Lodemann (1970), and J. Loeschke (1973, 1975) the pelitic sediments of the Magdalensberg series from Saualpe and Eisenkappel originate from shale and show an incipient degree of metamorphism. The included spilitic rocks show a wide range of Ca-, K-, and Na-content. Small ultrabasic bodies were also found. The tuffite associated with diabase has a high Fe- and Mg-content. According to J. Loeschke (1975) the spilites appear to originate from alkali olivine basalts resulting from submarine eruptions. This way is indicated by a comparison of the Ti-, Zr-, and Cr-analyses made of the spilite samples and the recent basalts occurring in subcontinental and mid-oceanic ridges.

Recently, J. A. Winchester and P. A. Floyd (1976) proved that Loeschke's spilites belong to alkali basalt not only in view of their high TiO_2-content, but also by the relations TiO_2 versus Zr/P_2O_5 and TiO_2 versus Y/Nb. In this way the alkali basalt is clearly distinguished from the tholeiitic basalt.

Table 7. **Chemical analyses of the samples taken from the Magdalensberg level**

Sample	SiO_2	Al_2O_3	Fe_2O_{3tot}	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	I.L.	Total
129A	50.56	19.00	14.77	.11	2.24	.60	2.32	3.64	3.09	3.38	99.71
129B	45.36	14.78	15.05	.12	6.85	3.85	4.32	.05	2.88	6.41	99.67
131	79.18	8.28	3.53	.17	1.71	1.26	.95	1.51	.48	3.39	100.46
134	62.73	18.90	6.47	.01	2.15	.08	1.39	3.71	.74	3.58	99.76
138A	49.44	9.05	2.71	.24	1.18	18.15	1.41	1.50	.16	15.79	99.63

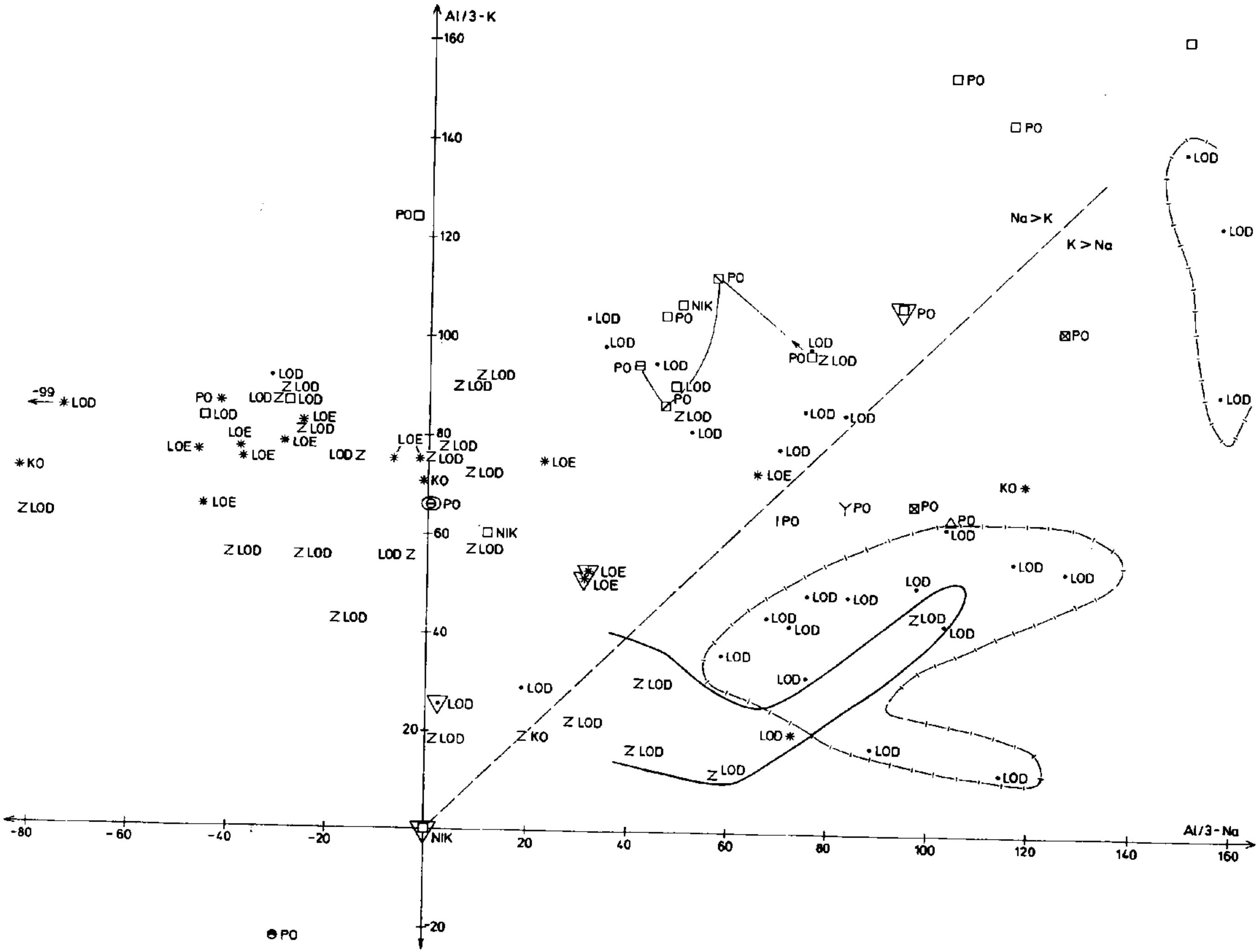
Sample 129 A: Fe-enriched slate
Sample 129 B: spilite tuff
Sample 131: SiO_2-enriched slate
Sample 134: slate
Sample 138 A: slate with increased carbonate and Na-content

5. Geochemical features of the Pohorje and Saualpe Mountains

From the petrological point of view the metamorphic rock sequence of the Pohorje Mts. resembles that of the Saualpe. In both areas the rocks of the Magdalensberg series and of the greenschist and almandine-amphibolite facies without a sillimanite zone are developed. Some differences occur in details only. Thus, for instance, augen gneiss and diaphthoritic rocks are not known at all in Saualpe. The thickness of the Saualpe sequence amounts to 7000 m (C. K. W. Lodemann, 1970).

The main constituents of 50 samples taken from the Saualpe, as well as their trace elements, and the corresponding Niggli parameters point to magmatic and sedimentary equivalents of the metamorphic rocks. The first group comprises metabasites from weakly metamorphic diabase to eclogite. In the second one, there are metapelites from slate to schist and gneiss. Although Lodemann found a conservative metamorphism, he presumes some homogenization. All metabasites including eclogite, are derived from gabbroid magma. Metasediments originated from a rather homogenous claystone and siltstone, and less frequently from graywacke. A carbonate admixture was uncommon in sedimentary rocks. The rocks of a higher metamorphic rank show a smaller distribution of the basic oxides, than the rocks of a lower metamorphic rank having a similar composition. For this reason a migration of elements in an interval of several hundreds of meters, and a tendency to chemical homogenization with the increasing grade of metamorphism was supposed. The repeated geochemical comparison of metabasites showed with progressive regional metamorphism only a slight decrease in TiO_2, Al_2O_3, FeO, K_2O and H_2O, and a significant increase in Na_2O. But an introduction of Na-content to the metamorphic rocks of the Saualpe cannot be generally applied to other metamorphic areas (C. K. W. Lodeman, 1973).

Lodemann's chemical analyses are presented in relation to the parameters (Al/3-K) versus (Al/3-Na) (fig. 11) and compared with the Pohorje analyses (fig. 10 a). In the figure 11, also some former Pohorje rock analyses (V. V.



Al/3-K
160
140
120
100
80
60
40
20
-20
-80
-60
-40
-20
20
40
60
80
100
120
140
160
Al/3-Na
Na > K
K > Na
-99
PO
PO
PO
PO
PO
NIK
NIK
NIK
KO
KO
KO
Z KO
LOD
LOE
Z LOD
LOD Z
LOD Z
PO
Y PO
I PO

Nikitin, 1942, NIK) and unpublished data from the Pohorje (PO) and Kobansko area (KO) are attached. It was not possible to compare the individual levels of the Pohorje with those of the Saualpe, as Lodemann's analyses are classified into three groups characterized by the degree of metamorphism. As regards maturity and aluminium content, some varieties of almandine flaser gneiss from the Saualpe exceed the correesponding Pohorje gneiss. In the Saualpe, a slight trend towards graywacke was observed.

The metabasites of almandine-amphibolite facies are represented by amphibolite and eclogite. The analyses certainly point to oceanic tholeiite as in the case of the Pohorje metabasites of the eclogite and ultrabasite levels.

Neither in the Saualpe, nor in the Pohorje Mts. is the development of greenschists uniform. They cover a wide range of the rocks consisting of shales, and volcanic rocks of acidic, basic, and intermediate composition.

The slate of the Magdalensberg series originates from shale. The included diabase has a spilitic character. Ultrabasic tendency is uncommon. The data about these rocks in fig. 11 were taken mainly after Loeschke (J. Loeschke and J. Rolser, 1971, and J. Loeschke, 1973). His research refers to the Magdalensberg series from the Eisenkappel surroundings, where it appears to be typically developed.

Eclogite is a characteristic metamorphic rock of the Pohorje and Saualpe Mts. Regarding the equilibrium conditions of included accessory mineral assemblage kyanite-zoisite, eclogite crystallization was experimentally determined at 620°—650°C and more than 9 kbar (B. Storre and K.-H. Nitsch, 1973 and H. G. F. Winkler, 1974). Recent investigation of the distribution of elements among eclogite co-existing mineral pairs yields even more detailed temperature and pressure ranges for the formation of this rock. For this reason, in the Saualpe, eclogite crystallized at 500°—660°C and 5.5—9 kbar (V. Richter, 1973, p. 27). As the Pohorje eclogite contains the mentioned minerals, the above cited P—T conditions are considered to be favourable for its formation.

6. Conclusions

The purpose of the geochemical investigation of the Pohorje metamorphic rocks has been to deduce their origin from their chemical features, and therefrom to reveal the paleogeographic conditions.

The investigation proved that seven volcano-sedimentary metamorphic levels can be distinguished, some of them having peculiar inclusions and different grades of metamorphism. It results from our research work that the original rock sequence has been much disturbed by tectonic. By the geochemical study the rhyodacitic character of augen gneiss and the intermediate volcanic

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Fig. 11. The metamorphic rocks from the Saualpe (C. K. W. Lodemann, 1970 and 1973, LOD) and the rocks of the Magdalensberg series from the Eisenkappel environment (J. Loeschke and J. Rolser, 1971, J. Loeschke, 1973, LOE) characterized by the parameters (Al/3 — K) versus (Al/3 — Na)
The parameters are calculated from the cation numbers of the corresponding weight per cent of the oxide molecules

origin of some greenschists was ascertained. Such an interpretation would be impossible from textural and mineralogical points of view only.

From the geochemical features of the original volcano-sedimentary sequence either normal or tectonic contacts of the levels were determined. By the acidic metavolcanites enclosed in the augen gneiss level a preexisting sialic basement is indicated. The same could be deduced from the alcalic metabasites of the marble level. Dolomitic marble and quartzite show a more confined sedimentary basin. Their connection with immature sediments points to marginal parts of the basin. The rock association of the augen gneiss and marble level indicates, therefore, an eugeosynclinal environment.

The metabasites of the eclogite level show the properties of the abyssal tholeiite. They are associated with metapelites of high maturity. This rock unit could be considered as equivalent in time of formation to the underlying augen gneiss and marble levels. In this case the eclogite unit should be interpreted as a thrust sheet. By the ultrabasite level the ocean origin is proved even if there ophiolite is out of the question.

The rock units mentioned above appear to be of the preorogenic origin. They have been developed in an early geosynclinal stage. The greenschist level is characterized by the basic and intermediate volcanics of alkalic and potassic nature showing shoshonitic tendency. On the top acidic igneous rocks occur. Such a characteristic corresponds well enough to the volcanism of the orogenic phases along a continental margin.

The Magdalensberg series differs widely from the underlying rock units. That is why it could not be considered as a simple repetition tectonic of the greenschists. Moreover the two rock units are partly synchronous, but the origin of the Magdalensberg series is quite different as regards the paleogeographic conditions.

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