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PRELIMINARLY PETROLOGICAL AND GEOCHEMICAL STUDIES OF THE AREA ÓFALU, MECSEK MOUNTAINS, HUNGARY

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SUMMARY

On the northern frame of Mórágy crystalline mass near Ófalu village a detailed petrological investigation was carried out in the Lower Paleozoic sequence. It is named Ófalu Phyllitoid Group dividing into three formations and seven members of alternating eugeosynclinal volcanic and sedimentary association affected a fairly low grade Abukuma type regional metamorphism produced greenschist as well as greenschist-amphibolite transition facies. The volcanism is represented by andesitic-basalt rocks with associated tuffaceous derivatives and albite-porphyry as well as serpentinized ultramafic sill-like body intruded the geosynclinal complex. According to comparative petrochemical examinations the andesitic-basalt rocks derived from oceanic type tholeiitic volcanism.

INTRODUCTION

Since the first works made by J. BÖCKH [1876] and S. ROTH [1876] several attempts had performed to interpret the crystalline basement rocks of South–East Transdanubia. Until the beginning of the last decade they were first of all descriptive ones without any petrologic considerations. Because of intense covering of the region by younger complexes the investigations have carried out mainly in the Mórágy Mts and its northern margin where the crystalline rocks are outcroping.

Recently a considerable amount of data are available on Cenozoic and recent volcanic suites giving a better understanding of the association between the chemistry of these rocks and their setting in the framework of the plate tectonic theory [DICKINSON, 1968; HART *et al.* 1970; JAKES and WHITE, 1972]. Plate-tectonic interpretations of Mesozoic ophiolite complex have been published from many parts of the world [BAILEY *et al.* BEZZI and PICCARDO, 1971; MOORES and VINE, 1971; BAILEY and BLAKE, 1974, and others]. Paleozoic ophiolites have similar interpretation [BIRD and DEWEY, 1970; FITTON and HUGHES, 1970; HALLBERG and WILLIAMS, 1972; GALE and ROBERTS, 1974, KEAN and STRONG, 1975; LOESCHKE, 1975, 1976a, 1976b, and others].

Known of all these it may be to do a new and up to date petrologic interpretation of Ófalu schists using the axiom that the present provides a key to the past, comparison of new data of recent volcanic suites and older volcanic ones may provide a clue to the origin of these rocks. The present preliminary work of Ófalu schists is intended to be a contribution to identify the petrological and geochemical characteristics of those rocks, particularly the volcanic suite, bearing in mind recent interpıetation placed on other greenstone belts in the plate-tectonic framework then attempt to discuss the volcanic rock series and tectonic setting as a contribution to the question, whether the eugeosynclinal magmatic rocks of Lower Paleozoic of South–East Transdanubia can help to discover plate-tectonic regimes in the rock record of Paleozoic domain.

GEOLOGICAL SETTING AND LITHOSTRATIGRAPHIC CLASSIFICATION OF THE ROCKS

In the southern part of Ófalu village (Eastern Mecsek Mts) there are alternating sequence of eugeosynclinal volcanic and sedimentary associations which have later been regionally metamorphosed ranging from quartz-albite-epidote-biotite subfacies of greenschist facies according to TURNER and VERHOOGEN [1960] up to greenschist-amphibolite transition facies in TURNERS's view [1968]. The rock sequence represents an Abukuma type metamorphism in MIYASHIRO's view [1961].

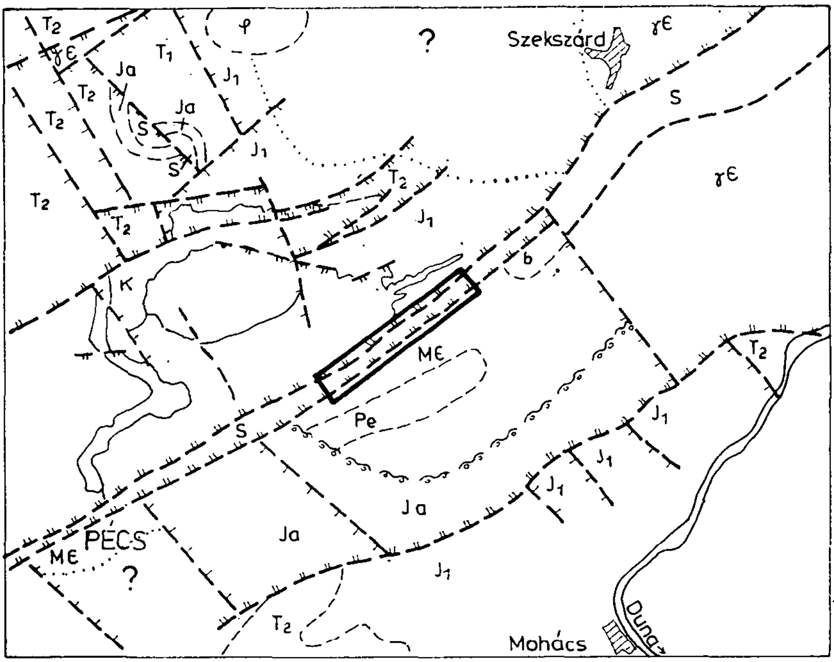

Fig. 1. Site of the Ófalu schists in the groundfloor of South-East Transdanubia.

The following lithostratigraphic classification can be made in the Ófalu schist sequence respected the rules of the International Subcommission on Stratigraphic Classification [1972] and Hungarian Stratigraphic Committee [1975]:

Group	Formation	Member
Ófalu Phyllitoide Group	Goldgrung Formation	Albite Porphyry Member
		Phyllitic Tuffs Member
		Marble Member
		Amphibolite Member
	Gröndl Formation	Mica Schist Member (highly metasomatized)
		Andesitic Basalt Member (metasomatized)
		Andesitic Basalt Member

This classification is based on petrographic examinations widened by stratigraphic observations.

Andesitic basalts are porphyritic, aphanitic, greyish green coloured rocks. The phenochrysts are plagioclase embedded in a fine grained matrix made of biotite and/or chlorite, few quartz, epidote, sphene, iron oxides and calcite. Plagioclase represents of 30–50% part of the rock; — it has a composition near to peristerite (ranging up to An_{25}).

Chlorite is commonly associated with biotite (together represent about 30% of rock-composition). The analysis of pure chlorite by X-ray diffraction [I. VICZIÁN and M. GHONEIM, 1977] gave a composition close to

$$(Mg_{3,1}\,Fe_{1,5}\,Al_{1,4})\,(Si_{2,6}\,Al_{1,4})\,O_{10}(OH)_8.$$

Biotite is greenish yellow in colour and pleochroic from z=pale brownish yellow or brownish green, x=y greenish yellow. This rock contains some epidote crystalls. The following composition was estimated by electronmicroprobe:

SiO_2	41,4%
Al_2O_3	22,7
FeO	11,7 (total iron)
MgO	0,02
CaO	23,4
	99,2%

Potash feldspars (perthite and orthoclase) are also encountered and they are mainly represents a later origin of potash metasomatism.

Metasomatized andesitic basalts are derived from andesitic basalt by a later metasomatic process which induced potash feldspars and quartz as additional secondary minerals. The essential minerals are highly altered by effect of chloritization, sericitization and kaolinitization. The present rocks are characterized by abundant presence of iron oxides.

Mica schist is used here to denote a regionally metamorphosed and highly metasomatized paste consisting of a mixture of sandy size ($\frac{1}{16}$ mm) quartzo-feldspathic grains and muscovite. Quartz content is abundant, about 20% of the bulk composition. Plagioclase crystalls are predominants suffered a strong cataclasis and alteration. The porphyroclastic "augen" crystal shape rimmed with muscovite, shreds of chlorite and iron oxide are characteristic due to shearing.

Two types of micas are recognized (the white mica and less common mixed layer of chlorite and/or biotite). The white mica was separated and particularly examined by X-ray diffraction. The X-ray studies reveal that the mineral is muscovite in narrower sense having 2 M polytypism with a $\frac{Na}{Na+K}$ of about 4%. The white mica are bended and twisted along the felsic constituents and generally form alignments marking the schistosity planes of the rocks.

Amphibolite microscopically consists of hornblende, plagioclase, chlorite and quartz together with calcite, epidote and iron oxide as accessories. The hornblende is yellowish green in colour and pleochroic from Z=dark green, B=olive green and X=yellowish green. It represents about 30% of the rock constituents. The chemical analysis of hornblende (Table 2) gave a composition close to

$$(Ca_{1.34},\ Na_{0.45},\ K_{0.112})\,(Al_{1.84}Ti_{0.6},\ Fe^{3+}_{1.06},\ Mg_{1.4}/Sr_{1.84},\ Al_{6.09}).\ O_{24}(OH)_{1.49}.$$

Plagioclase represent about 25% of the total volumen of the rock and it has a composition of An_{25-30}. Chlorite (20%) occurs as fibrous aggregates associated with hornblende.

Phyllitic tuffs are fine grained greyish green in colour and have of phyllitic appearance in handspecimens. They consist of oriented fine folias of biotite and chlorite alternating with albite and/or calcareous bands. The volcanic natures of these rocks are represented by abundant presences of albite as the main feldspar mineral, scarcity of quartz crystals and absence of muscovite. Iron oxides are the main accessories.

The marble outcrops measure from 150 to 200 m in thickness. It is light yellow to greyish white in colour and highly massive and brittle rock. Under the microscope the rock consists of mosaic aggregates made of calcite and quartz interrupted by muscovite and limonite. Garnet and diopside are encountered in some specimens.

Albite porphyry commonly intrudes Goldgrund Formation rather than Gröndl Formation, and it is not easily distinguished in the field. The rock is hemicrystalline and exhibits porphyritic texture. It consists of granoblastic albite phenochrysts enclosed in matrix made of chlorite, sericite, quartz and sometimes calcite. Opaque minerals are widely distributed within the groundmass. As it is indicated by X-ray, the quartz represents not more than 5% of the bulk composition of the rock. Chlorite forms the main matrix component.

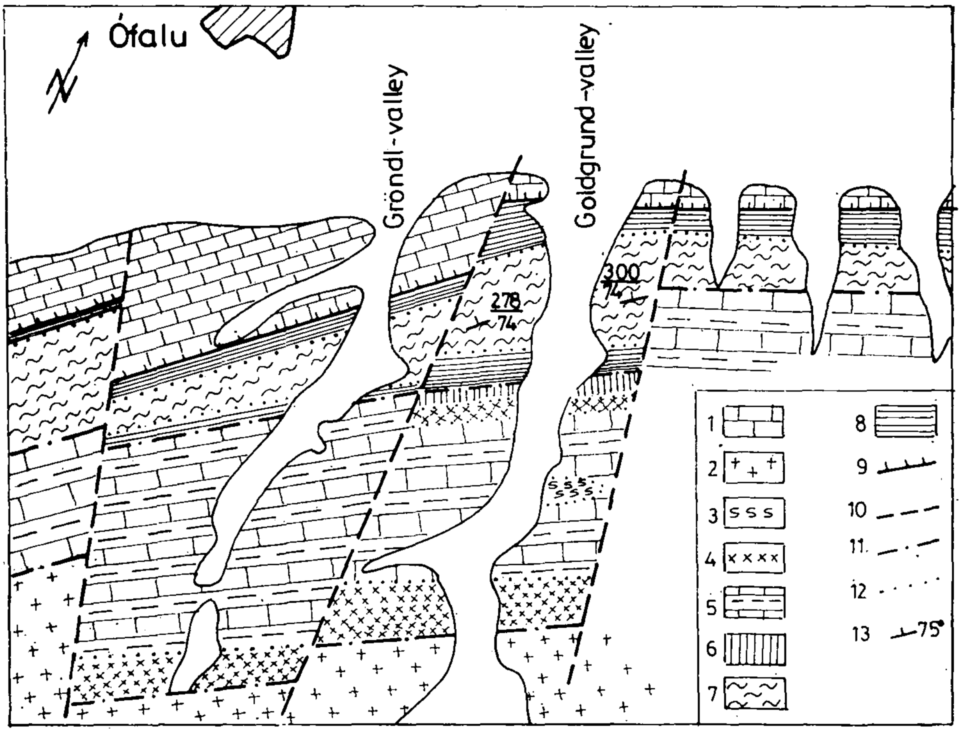

Fig. 2. Geological sketch map of the area Ófalu schists, by M. Ghoneim, 1977. Scale: 1:25 000. Legend: *1.* Jurassic limestone, *2.* anatectic granite, *3.* serpentinite and associated rocks, *4.* albite porphyry, *5.* marble and phyllitic tuffs, *6.* amphibolite, *7.* mica schist, *8.* andesitic basalt and its metasomatized varieties, *9.* Intra-Pannonian overthrusting zone, *10.* faults, *11.* approximate formation contact, *12.* gradational contact, *13.* strike and dip.

The serpentinite and associated varieties wasintruded into the geosyncline in form of sill-like body [GHANEM, R. BARANYAI, 1969] in strict conformity with the regional strikes of the recipient metasediments. Under the microscope the rocks consists of fine aggregates of serpentine minerals together with carbonates, chromite and magnetite. It has a "mesh" texture. Most of the rock specimens contain chromite grains, the rims of which are intensely altered into iron-rich chromite surrounding the original chromite crystals.

PETROCHEMISTRY

As it was mentioned the Ófalu Group under consideration represents Pre-Devonian sequence of metamorphosed eugeosynclinal volcanic and sedimentary rocks. In such a case it is always more difficult to discuss the petrochemistry of the metavolcanic rocks as that of originally magmatic ones, since these rocks take up water during devitrification and metasomatism and change their bulk composition especially those which affected by a later K-metasomatism.

To have highly estimated chemical data as well as acceptable petrochemical characters, the following precaution are taken into consideration:

1. The samples for chemical analysis, were selected to have no secondary potash feldspars as a result of K-metasomatism and minimum alteration. This selection was made by microscope and then checked by X-ray.
2. The most convenient way to identify the present volcanic rock suite is to use elements that show clear chemical differences between the different magma types and are also not affected by secondary alteration processes.

Elements that have undergone little change during such alteration include Ti, Zr, Y, Nb and Sr [CANN, 1970, PEARCE and CANN, 1971] using such "immobile elements" it has been demonstrated that the different magmatypes can be geochemically separated and characterized in altered rocks [FLOYD, 1976].

The major and trace element analysis for 12 selected rock samples of the metavolcanites of the Ófalu Group are represented in Table 1a. The cation mesonorms for these analyses are comprised in Table 1b. In such rocks it is obvious that the calculation reflects the alteration of these rocks which will be discussed later with special care. The number and origin of the samples is the following:

Sa–5	Andesitic basalt (from Goldgrund valley)
203 and 204	andesitic basalt (extreme eastern tributary near Ófalu village)
13	andesitic basalt, (Goldgrund valley, GHANEM and R. BARANYAI 1969)
99	calcareous phyllitic tuff (Gröndl valley)
401753	Albite porphyry (Goldgrund valley)
94	calcareous phyllitic tuff (Gröndl valley)
2	albite porphyry (Grönd valley, GHANEM and R. BARANYAI, 1969)
Sc. 17	Amphibolite (Goldgrund valley)
126	Amphibolite (Studer valley, GHANEM and R. BARANYAI, 1969)
226	Amphibolite (Bátaapáti village)
88/1	Amphibolite (Bátaapáti, JANTSKY B., 1974)
330, 331, 321	Ocean floor type basaltic rocks of Lower Paleozoic Grimeli Formation of the Stavenes Group, Norway. (GRALE, 1975)

TABLE 1A

Major and trace element analyses (wt%) for rocks of Ófalu Group compared with ocean floor-type basaltic rocks of Lower Paleozoic Grimeli Formation of Stavenes Group, Norway [GALE, 1975]

	Sample No.														
	Sa—5	203	204	13	99	401753	94	2	Sc- 17	126	226	88/1	330	331	321
SiO_2	53,12	50,40	52,01	45,50	52,29	64,54	48,01	50,24	49,47	51,64	49,97	49,96	48,00	49,70	49,60
TiO_2	1,26	2,03	1,59	1,59	2,25	1,00	2,45	2,51	1,81	2,44	2,38	1,50	1,92	1,38	2,31
Al_2O_3	18,65	16,59	16,23	18,79	16,06	15,40	13,32	14,87	12,90	13,97	15,19	13,30	13,60	15,20	13,10
Fe_2O_3	2,01	2,83	2,54	3,76	5,36	1,23	1,00	2,40	3,01	3,34	4,13	3,80	13,60^{+}	9,70^{+}	13,90^{+}
FeO	4,46	4,05	3,20	5,35	1,31	3,41	7,66	7,98	10,32	8,10	8,25	6,63			
MnO	0,06	0,10	0,08	0,12	0,15	0,06	0,13	0,21	0,17	0,18	0,22	0,18	0,21	0,17	0,27
MgO	4,71	6,58	4,51	6,81	1,53	2,62	5,46	6,18	7,85	5,80	4,79	6,25	6,900	9,00	6,50
CaO	2,40	5,57	5,18	6,12	6,97	1,79	7,91	6,24	6,55	7,53	9,55	10,02	11,6	10,90	11,20
Na_2O	4,80	4,11	4,80	2,92	7,20	4,08	2,10	3,94	2,38	4,26	2,82	3,96	2,96	3,10	3,00
K_2O	3,09	3,30	3,75	2,50	0,42	2,61	1,38	0,62	0,95	0,52	0,33	0,75	0,14	0,09	0,14
$-H_2O$	0,41	1,14	0,02	0,11	0,04	0,06	0,05	0,11	0,22	0,09	0,27	2,02	1,50^{++}	2,34^{++}	1,76^{++}
$+H_2O$	3,31	2,33	2,94	4,91	1,48	2,47	4,57	3,01	3,32	1,99	2,24	0,14			
CO_2	0,52	0,98	1,96	0,92	4,47	1,01	5,40	0,27	0,59	0,03	0,11	1,62	—	—	—
P_2O_5	0,90	0,80	0,90	0,29	0,47	0,16	0,39	0,48	0,18	0,23	0,45	0,15	0,11	0,07	0,13
Cr_2O_3	0,00	0,01	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	—	—	—
Total	99,98	99,80	99,67	99,69	99,24	100,4	99,83	100,0	99,73	100,1	100,7	100,3	99,74	101,6	101,9

The analyses of Hungarian samples made by M. EMSZT

	Sa—5	203	204	13	99	401753	94	2	Sc- 17	126	226	88/1	330	331	321
Zr	1000	1800	650	1150	250	120	200	180	200	145	250	—	151	99	185
Sr	2000	3900	2000	5700	165	230	250	128	130	280	260	—	164	135	128
Rb	31	20	28	N. D.	14	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.	—	0	0	2
Zn	75	95	55	67	48	55	250	120	90	65	3200	—	98	60	112
Ni	70	70	N. D.	N. D.	45	38	50	N. D.	65	N. D.	N. D.	—	61	113	56

Trace element analysis (in ppm) by X-ray fluorescence method made by G. RISCHÁK

N. D. = Not detected

$^{+}$ = Total Fe content in Fe_2O_3

$^{++}$ = Total H_2O content

— = Not analyzed

TABLE 1B

Cation mesonorms of the rocks of Ófalu Group

Sample No. / Miner.	Sa—5	203	204	13	99	401753	94	2	Sc. 17	126	226	88/1
Q	12,00	7,70	7,23	6,39	9,96	29,27	20,70	2,93	7,88	8,63	5,08	5,16
Ab	44,00	37,30	43,50	27,35	63,95	37,50	19,85	37,05	22,50	39,20	26,40	36,00
An	—	9,65	1,40	17,95	—	—	—	18,65	—	7,75	5,94	0,80
Or	2,88	0,48	9,33	—	—	12,30	—	—	—	—	2,05	4,50
Bi	25,31	30,65	21,00	25,64	3,93	8,62	13,58	6,08	9,47	5,04	—	—
Ho	—	—	—	—	—	—	—	—	34,00	26,19	46,80	40,36
Hyp	—	—	—	7,48	1,26	—	17,70	24,18	12,48	0,10	—	—
Ap	1,90	1,62	1,93	0,61	0,88	0,33	0,93	0,93	0,48	0,48	1,16	0,29
Sph	1,77	4,20	3,36	3,48	2,01	0,99	2,10	5,43	4,02	5,22	5,22	3,21
Cal	1,37	2,46	5,06	1,22	11,24	2,60	13,90	0,70	1,32	0,08	0,34	4,16
Mt	2,13	2,94	3,20	4,05	3,00	1,31	1,05	2,61	3,33	7,14	4,51	4,05
Rut	0,41	—	—	—	0,87	0,37	—	—	—	—	—	—
Cor	8,23	2,99	4,32	5,68	4,10	6,64	9,59	1,37	4,37	—	3,17	—
Hem	—	—	—	—	1,70	—	—	—	—	—	—	—
Total:	100	99,99	100,3	99,85	99,90	99,93	99,40	99,93	99,85	99,83	100,7	99,03

Major element analysis of hornblende separated from amphibolite rocks, Goldgrund Valley, Ófalu

TABLE 2

SiO_2	45,97%
TiO_2	4,24
Al_2O_3	11,71
Fe_2O_3	5,98
FeO	9,46
MnO	0,20
MgO	7,58
CaO	8,34
Na_2O	1,62
K_2O	0,69
$-H_2O$	0,12
$+H_2O$	3,16
CO_2	0,44
P_2O_5	0,09
Total:	99,60%

Analyzed by M. EMSZT.

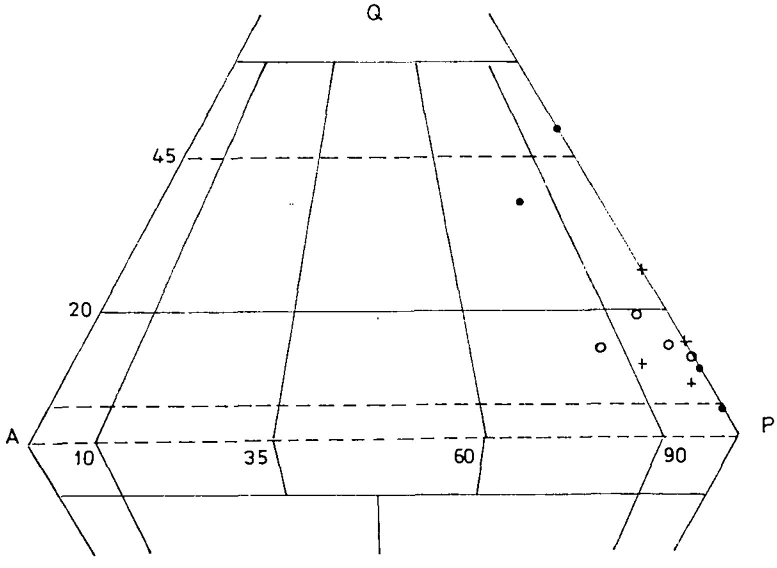

Fig. 3. Distribution of the Ófalu metavolcanics in the QAPF diagram [STRECKEISEN, 1967]
O andesitic basalt
+ amphibolite
• albite porphyry

The cation mesonorms are represented on QAPF diagram [STRECKEISEN, 1967]. This figure nicely reveals that the metavolcanics of the Ófalu Group were originally andesitic basalt and plot mainly in the basalt field of QAPF diagram (some analysis were plotted outside these fields probably due to secondary alteration).

Then the next step in this work is to identify the type of basalt included in the Ófalu Group by help of MIYASHIRO system.

MIYASHIRO [1975a, and b] had classified the volcanic rock series of the Earth into two main groups: alkalic and nonalkalic ones. The latter may by subdivided into tholeiitic (Th) and calc-alcalic (CA) series. For the distinction between alkalic and nonalkalic series, the HARKER's-type variation diagram with SiO_2 content on the abscissa [HARKER, 1909] was adapted particularly by MACDONALD and KATSURA [1964] and then MIYASHIRO [1975a].

Illustrating of Na_2O+K_2O versus SiO_2 with KUNO's boundary *(Fig. 4)* reveals that Ófalu metavolcanics contain representatives of both alkalic and tholeiitic basalt magma series. The metavolcanic rocks of the Gröndl Formation are represented in the alkali field, while the metavolcanic members of the Goldgrund Formation are mainly in the tholeiitic basalt field of division.

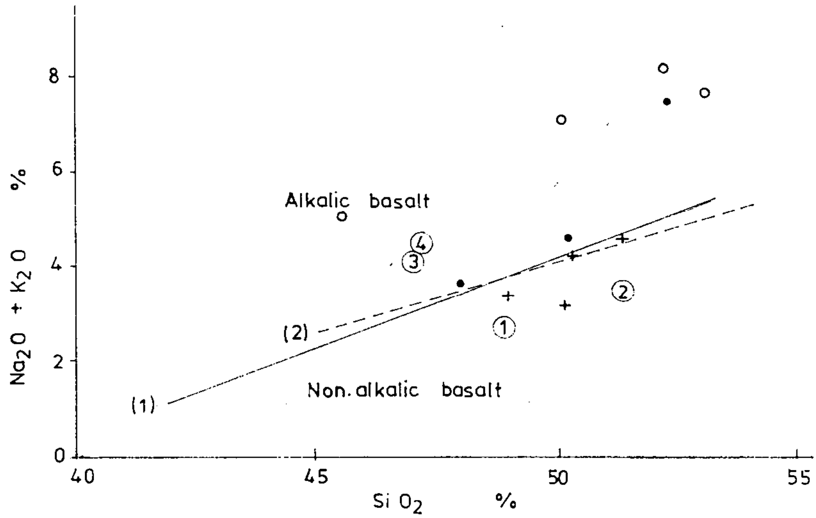

Fig. 4. Alkali-Silica variation diagram. The curve (1) means the boundary between the alkalic and tholeiitic basalt in Hawaii [MACDONALD and KATSURA, 1964] and curve (2) gives the boundary between alkalic and nonalkalic volcanic rocks in Japan [KUNO, 1966]. Symbols:
O andesitic basalt from Ófalu
+ amphibolite from Ófalu
• albite porphyry from Ófalu
1 oceanic tholeiitic basalt [MANSON, 1967]
2 continental tholeiitic basalt [MANSON, 1967]
3 oceanic alkalic basalt [MANSON, 1967]
4 continental alkalic basalt [MANSON, 1967]

In fact this plot is not entirely reliable in this context. The unreliable nature, particularly of the alkalic series is due to variable migration of akalics during metamorphism as well as the role of secondary alteration and interaction with foreign material, the latter will be discussed in another proceeding work.

The chemical data of the metavolcanics of the Goldgrund valley are presented in standard AFM diagram *Fig. 5.* The data plot firmly within the tholeiitic field of composition defined by IRVINE and BARAGER [1971].

For graphical distinction between tholeiitic and calc-alkaline series of basalt, MIYASHIRO [1973 and 1975b] had proposed the use of variation diagram based on variation of SiO_2, TiO_2, FeO wt. percent (where FeO means total iron as FeO) with advancing fractional crystallization (the latter is indicated by FeO/MgO ratio). From *Fig. 6a, b, c,* it can be seen that the metavolcanic rocks of the Goldgrund Formation tend to plot well within the fields of the tholeiitic rock series.

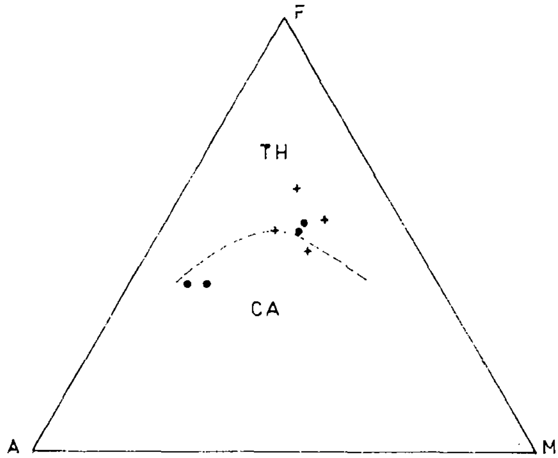

Fig. 5. A=(Na_2O+K_2O); F=(FeO, total Fe); M=(MgO) variation diagram. The field boundary separating tholeiitic (above) from calc-alkalic composition. After IRVINE and BARAGER [1971]. Symbols:
+ amphibolite
· albite porphyry

TECTONIC IMPLICATION OF THE ÓFALU THOLEIITIC BASALT

There is close relationship between volcanic rock series and tectonic setting of theirs. MIYASHIRO [1975a, b] reported about the abundance of the volcanic series on the Earth. Regarding the tholeiitic series they are predominant in midoceanic ridges and other plateau basalts, and they are the most abundant volcanic rocks on the Earth. Although tholeiitic basalts are mainly originated at the oceanic ridges, the continental basalts of tholeiitic nature cover large areas.

PEARCE and CANN [1973] compiled a large number of analytical data of oceanic and continental tholeiites. By means of a TiO_2—P_2O_5—K_2O diagram were able to discriminate the two types. The tholeiitic rocks of Ófalu Group are plot in this discrimination diagram well inside the field of oceanic tholeiites *(Fig. 7).*

A method using the trace elements Ti, Zr, Y, Sr and Nb as discriminants in distinguishing the tectonic environment of generation of basic volcanics has recently been outlined [PEARCE and CANN, 1971, 1973, GALE and ROBERTS, 1974, and FLOYD, 1976]. The elements Ti, Zr, Y and Nb do not appear to be mobile under conditions of greenschist facies metamorphism, whereas Sr can slightly affected by secondary processes. The different tectonic environments of magma generation can be determined by Ti—Zr and Ti—Zr—Sr plots.

The application of this method to the tholeiite basalt of the Ófalu (Group *Fig. 8* and *9* confirm the presence of ocean-floor basalt, since they plot mainly within the field C in *Fig. 8* and near to the field A of *Fig. 9.* The latter behaviour had been recorded for the ocean-floor basalt from the Lower Paleozoic Grimeli Formation of the Stavenes Group, Norway, by GALE [1975] (Table 1 and *Fig. 9*).

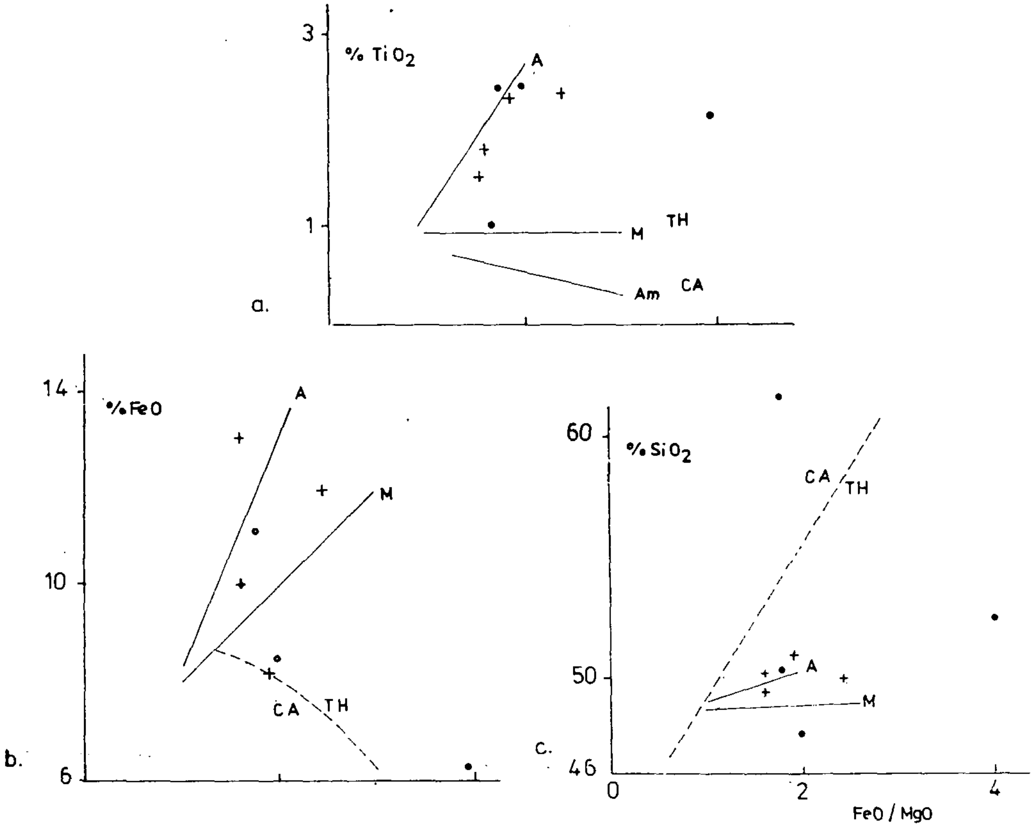

Fig. 6. TiO_2—FeO/MgO and SiO_2—FeO/MgO variation diagrams. The field boundaries separating the tholeiitic (TH) and calc-alkaline (CA), and the trend line for abyssal tholeiites (A), Macauley Island arc tholeiite series (M) and the Amagi calc-alkaline series (Am), after MIYASHIRO [1975b]. Symbols:

+ amphibolite
• albite porphyry

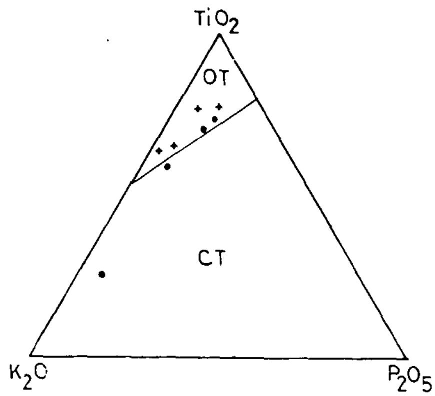

Fig. 7. TiO_2—K_2O—P_2O_5 discrimination diagram with the field boundary of the ocean tholeiite (OT) and continental tholeiite (CT) [PEARCE and CANN, 1973]. Symbols:

+ amphibolite from Ófalu
• albite porphyry from Ófalu

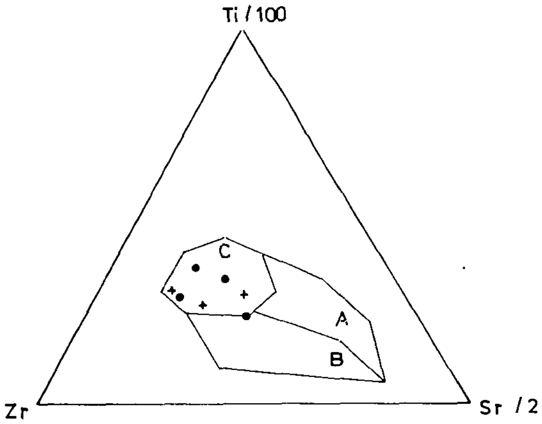

Fig. 8. Ti—Zr—Sr discriminant diagram for distinguishing ocean floor type basalts (field C), low K content tholeiites (field A) and calc-alkaline basalts (field B). After PEARCE and CANN, 1973. Symbols:

+ amphibolite from Ófalu
· albite porphyry from Ófalu

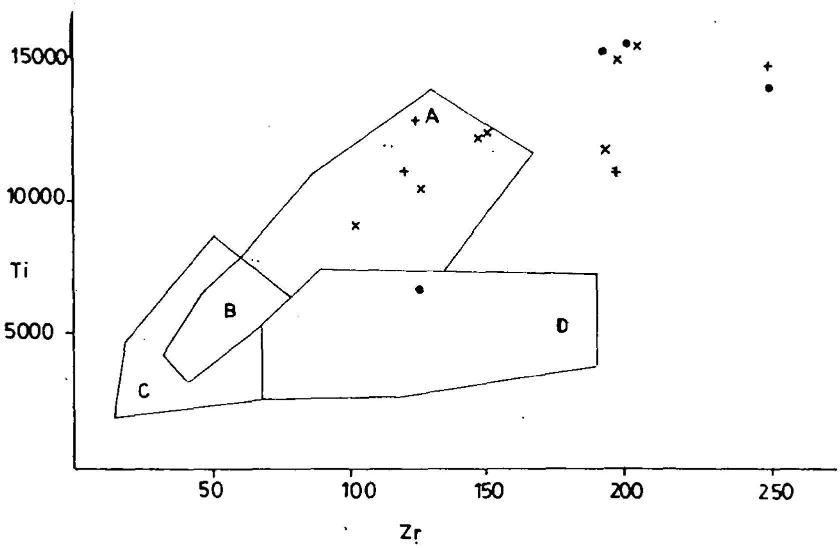

Fig. 9. Ti—Zr plot of Field A=ocean-floor basalts, Field B=ocean-floor basalt and low K content tholeiites of island arcs, Field D=calc-alkaline basalts and andesites. Symbols:

× ocean-floor basalt from Lower Paleozoic Grimeli Formation of Stavenes Group, Norway
+ amphibolite from Ófalu
· albite porphyry from Ófalu

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