Πρακτικά	6ου Συνεδρίου		Μάϊος 1992
Δελτ. Ελλ. Γεωλ. Εταιρ.	Τομ.	σελ.	Αθήνα
	XXVIII/2	123-137	1993
Bull. Geol. Soc. Greece	Vol.	pag.	Athens

GEOLOGICAL AND GEOCHEMICAL CRITERIA ON THE CLASSIFICATION OF MESOZOIC VOLCANITES OF THE HELIKON MOUNTAINS, GREECE

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ABSTRACT

During the Upper Jurassic continuous subsidence of the sedimentary basin of the Helikon area resulted in the deposition of thick radiolarian cherts. This evolution was accompanied by a marked volcanic activity which occurred mainly at the base of the radiolarian cherts. Occasionally, volcanics are found as peneconcordant intercalations within the radiolarian cherts. They frequently form pillow-lavas and are closely associated with turbidites and volcanoclastic sequences. They represent submarine basaltic extrusions which show microscopically porphyritic or ophitic textures. By using thickness, lateral extenision, lithologic association and chemistry as criteria for identification, these volcanites can be interpreted as submarine, short-lived, small strato-volcanoes which were active near a probable back-arc basin.

The Helikon volcanic rocks can be easly differentiated from the volcanites of the ophiolitic complex at Exarchos. This complex consists of strongly tectonized serpentinites and gabbroid rocks which exibit distinct features of a high temperature Greenschist metamorphosis and other volcanics of the Exarchos area. The entire complex is probably allochthonous. The time of its emplacement can be dated approximately as post-Kimmeridge according to the underlying sediments.

INTRODUCTION

The Upper Jurassic of the Helikon Mountains is characterized by important volcanic activities. During this time volcanics were produced which consist mainly of loosely packed and partly reworked volcano-detritic rocks. Pillow-like basaltic lavas are often associated with such volcanoclastics.

In this paper samples from four representative outcrops of such volcanics were analysed. They exhibit rather fresh basaltic rocks which are ideal for geochemical analyses.

North of Domvrena pillow-like basalts were sampled, which are enclosed mainly as rootless components in a silicified turbiditic matrix (Samples Th 2, 4, AA 5, 9 taken near the villages of Thisbi (Domvrena) and Agia Anna Point 1, Fig.1). North of Saranti (Point 2, Fig.1) and southeast of Diakopi (Point 3, Fig. 1) pillow-like basaltic layers with a thickness of approx. 10 m were sampled (Sa1, 2, Ma2). Finally a basaltic layer south of Exarchos (Point 4, Fig. 1) was sampled, which showed felsitic differentiates towards the top. In this paper acidic differentiates are excluded from the geochemical analysis,

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because they are of no importance to the magmatotectonic classification of the volcanites. Samples Ex 2 and 790 are basalts which were chosen for geochemical analyses. Figure 1 shows localities for the sampled volcanic rocks.

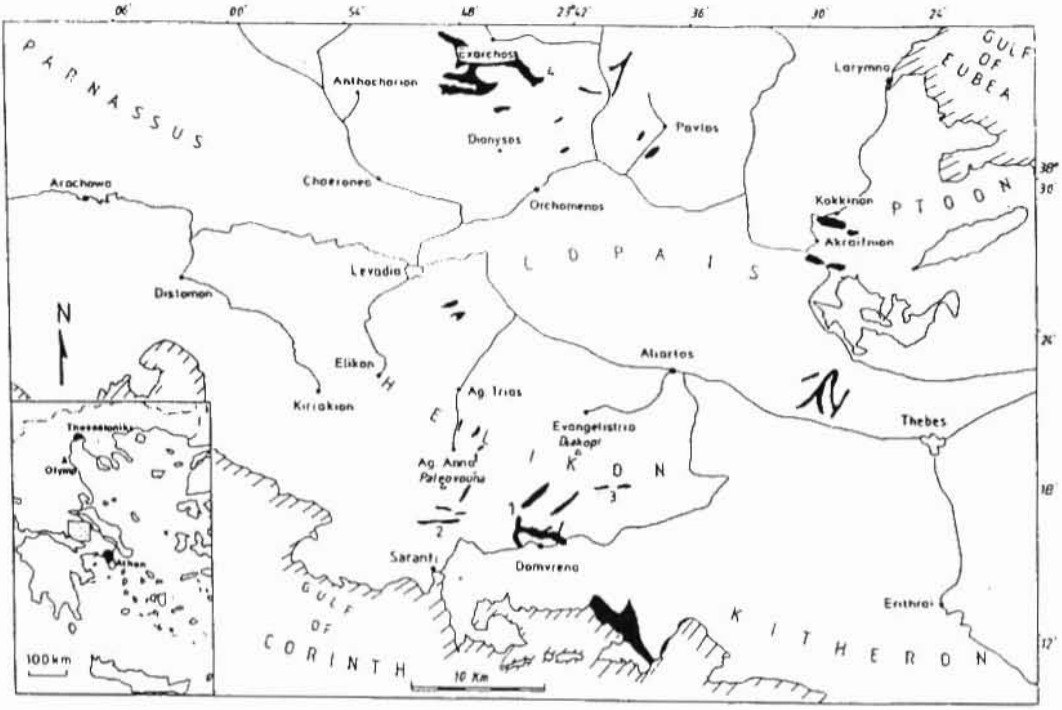

Fig. 1. General map showing the outcrops of Mesozoic volcanics and ophiolites. The Numbers stand for sample locations.

GEOLOGY

Stratigraphic succession in the Helikon

The metamorphic marbles of the Helikon Mountains (Agia Triada, regionally dated as Permian) are overlying thick Triassic and Jurassic carbonates (Domvrena beds, SIMON 1987). Subsidence of the depositional area during the Upper Jurassic was accompanied by submarine volcanism, characterized by volcanoclastics and pillow lavas. Volcanics are often overlain by up to 2 m thick turbidites, followed conformably by radiolarites of Tithonian age (Makariotissa beds, SIMON 1987). Following a hiatus, Cretaceous sediments were deposited with transgressive conglomerates, sand- and mudstones of Aptian to Cenomanian age (Evangelistria beds, KONERTZ 1987). The relatively calm deposition of carbonates in the Upper Cretaceous (Paleovouna beds) was interrupted during the Coniacian. This phase of subaireal exposure led to the formation of bauxites which were topped by carbonates of late Upper Cretaceous. It should be noted that the mountain of Paleovouna has not shown any Upper Jurassic radiolarites so far. According to IGME-IGEY sheets, Amphiklia and Levadhia, the deposition of bauxites occured during the Jurassic. Therefore the stratigraphy of Paleovouna and that of the Parnas-Zone were compared and partly equalized. The upper bauxite horizon, as mentioned before, is overlain by Santonian-Campanian but not Cenomanian which is present in the Parnas-Zone. A complete stratigraphic differentiation of the Mesozoic of the Helikon Mountains was set up by JUX et al. (1987). NE and NW of the Kopais Cretaceous carbonates are conformably overlain by clastic sediments of Lower Tertiary (Akraifnion beds, KONERTZ 1987).

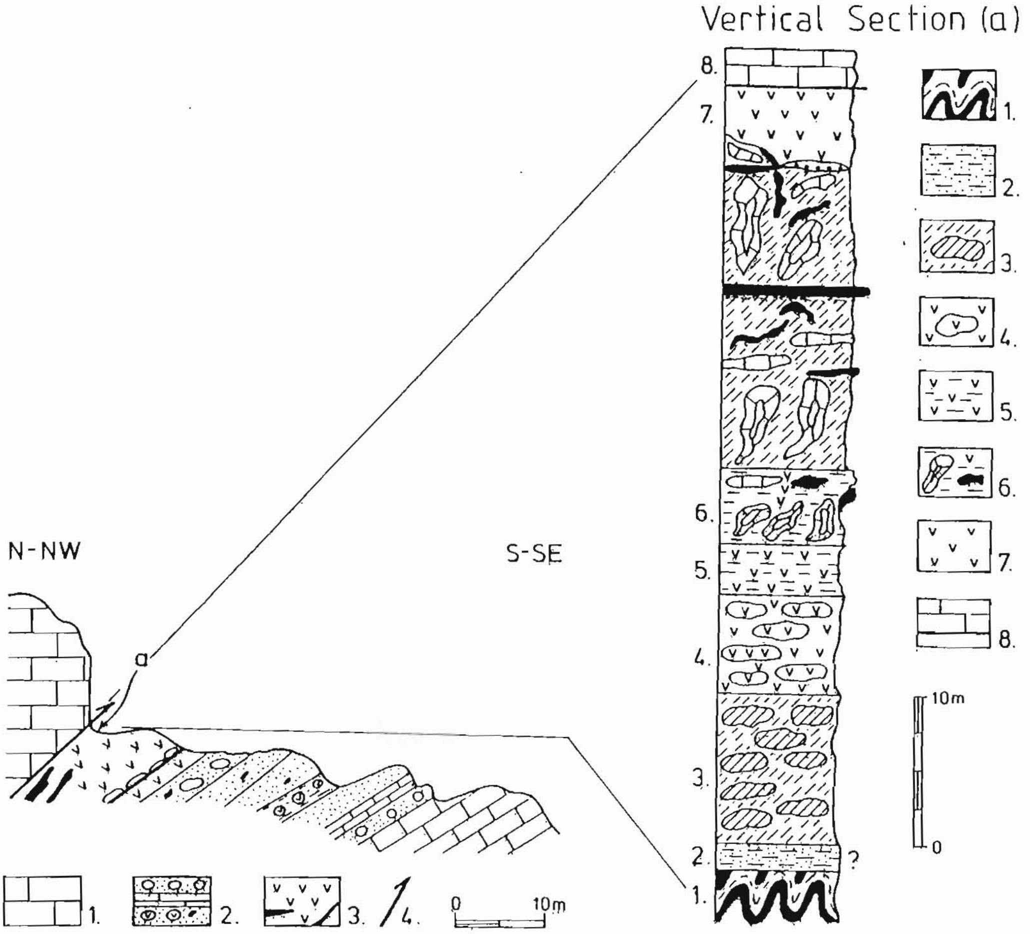

Fig. 2. *Lateral geological section, north of Agia Anna (Thisbi): 1: Domvrena beds, 2: Conglomerates in a carbonate matrix with carbonate layers of Domvrena beds, ultrabasic and chert components, 3: Volcanics, volcanoclastics, ultrabasics and chert components, 4: Fault. Vertical section (a): 1: Folded cherts, 2: Tectonized zone, 3: Clinopyroxenite and gabbro, 4: Serpentinized dunite, 5: Tectonized zone with serpentinite, 6: volcanoclastics with pillow-like volcanics, Domvrena lime (heated) and chert components, 7: Serpentinized dunite, 8: Domvrena beds.*

The transition from the Domvrena to the Makariotissa beds is often characterized by matrix supported conglomerates and grits in a carbonate matrix with volcanic and radiolarian chert components (Point 1, Fig. 1). In such conglomeratic layers thinly developed Domvrena carbonates are intercalated, which point to a conformable transition in both type localities. Basic volcanics as layers or volcanoclastics with giant volcanic components (diameter 2-10 m) occur nearly everywhere with rapidly changing thicknesses of 1-50 m. In Figure 2 such a transition is shown. The basic block components are well preserved in their pillow like form, evidence for an authochthonous or at least parauthochthonous origin. The geologic situation of the lava extrusions south of Exarchos is not exactly identical with the circumstances depicted in Figure 2 because of the following reasons:

1) the Jurassic carbonates are characterized by a lack of continuity and formed bauxites which are overlain by Kimmeridge carbonates.

2) The Exarchos lavas show characteristic hornblende-rich gabbro-xenolites and ultrabasics with boudinage structures dominating. NW of Pavlos dunitic rocks with amphibolitic diverse coronae were formed, which correspond to a considerably higher grade of metamorphosis and tectonization of the magmatic rocks from the enviroments of Exarchos, while the magmatic rocks from S and E of the Kopais were excluded from such an intense metamorphism and tectonization. The stratigraphic situation of these very thick ophiolites from Exarchos cannot be explained satisfyingly because the base has not yet been studied. Characteristic features of the volcanics from Saranti, Makariotissa and also partly from Pavlos and west of Thebes are their layered nature and conformable intercalations of these volcanic beds into the Upper Jurassic sediments. Volcanic components from Thisbi or Agia Anna (Fig. 2) could be interpreted as reworked products from adjacent volcanics during Upper Jurassic times but they are also found in turbiditic rock units. They exhibit closely spaced radial joints which might have been produced by cooling processes after being transported as lava.

PETROGRAPHY – CHEMISTRY OF MINERALS

Microscopically, porphyric and ophitic basalts were identified. The porphyric basalts possess a holocrystalline groundmass consisting of albite-rich plagioclase (partly carbonatized) and diopsidic clinopyroxen within a microophitic texture. The plagioclase ledges reach 0.1 mm in length. The phenocrysts attain up to 1.5 mm and form 5-15% of the entire rock volume. They consist mainly of diopsidic clinopyroxen and little calcite which has probably been replaced the primary anorthite phenocrysts. Apart from a little chlorite and new mineralisations of albite and calcite no further spilitisation indicators could be identified.

Plagioklase (32: Thisbi, 55-67: Exarchos)

	32	55	66	67
NA2O	2,04	4,18	7,92	6,05
K2O	0,05	0,06	0,10	0,55
SIO2	37,94	51,21	63,09	56,52
FEO	3,23	1,05	0,41	0,97
AL2O3	28,45	28,32	22,49	24,39
MNO	0,04	0,03	0,00	0,00
CAO	9,88	12,77	3,48	6,45
MGO	3,68	0,00	0,00	0,10
NIO	0,00	0,00	0,03	0,00
CR2O3	0,08	0,01	0,00	0,00
TIO2	0,00	0,11	0,05	0,04
Summe	85,39	97,74	97,56	95,08

Ab	27,11	37,09	79,88	84,80
Or	0,42	0,32	0,71	3,64
An	72,47	62,59	19,42	35,72

Chlorite (30-42: Thisbi)

	30	31	38	42
NA2O	0,040	0,032	0,049	0,071
K2O	0,007	0,011	0,000	0,035
SIO2	32,654	33,587	32,579	33,989
FEO	16,418	15,790	14,778	14,761
AL2O3	12,534	12,587	12,918	12,708
MNO	0,311	0,198	0,198	0,204
CAO	1,549	1,370	2,318	1,680
MGO	21,210	22,226	20,361	21,638
NIO	0,000	0,000	0,059	0,000
CR2O3	0,000	0,003	0,000	0,000
TIO2	0,000	0,002	0,048	0,050
Summe	84,723	85,806	83,306	85,136

Ilmenite (61-65: Exarchos)

	61	63	64	65
NA2O	0,02	0,01	0,00	0,10
K2O	0,00	0,00	0,00	0,01
SIO2	0,08	0,06	0,06	0,14
FEO	47,51	48,09	47,52	33,18
AL2O3	0,06	0,07	0,05	0,13
MNO	2,00	0,96	1,78	6,10
CAO	0,24	0,22	0,25	0,32
MGO	0,09	0,18	0,08	0,14
NIO	0,00	0,00	0,05	0,00
CR2O3	0,00	0,07	0,04	0,06
TIO2	51,01	50,83	50,27	59,26
Summe	101,01	100,48	100,11	99,44

Tab. 1. Mineral chemistry for plagioclase, chlorite and ilmenite from the Helikon basalts.

Basalts with ophitic textures contain few anorthite phenocrysts (< 2%, 2-3 mm) with $An_{73}Or_{0.4}$ composition. The plagioclase ledges vary between 0.5-2 mm in length and show a composition in the range of $An_{19-63}Or_{0.3-4}$ (Tab. 1). The most common representatives of clinopyroxene in basalts are diopsidic augite and endiopside. The mean composition of such minerals equals the formula $Ca_{44}Mg_{46}Fe_{10}$ (Tab. 2, 56-60). Additionally, slightly increased Cr- or Ni-values occur (0.3-0.7 % Cr_2O_3, about 0.1 % NiO), because the rocks do not contain spinell and it can be presumed that clinopyroxenes acted as Cr- or Ni-carriers. In thin section they are colourless and traversed by ophitic plagioclase ledges. Opaque minerals were identified by microprobe as ilmenites (Tab. 1).

A small basaltic component in an outcrop east of Paleovouna exhibits very few anorthite inclusions and an ophitic groundmass (plagioclase 0.5 mm). Lilac coloured clinopyroxenes exhibit a marked pleochroism from light to dark lilac with a mean composition of Ca_{46} $Mg_{35}Fe_{19}$ beloning to the titanoaugitės due to their high Ti-content (about 3% TiO_2, Tab. 2, 28-41). Their Na_2O-concentrations vary between 0.38-0.57% which are usual values for such alkalic minerals. Titanite agglomerations (< 0.05), finely dispersed, occur in this rock as accessories together with elongated (< 0.2 mm), opaque

(28-41: Thisbi, 56-60: Exarchos)

	28	29	33	34	35	36	37	39	40	41	56	57	58	59	60
NA2O	0,40	0,46	0,51	0,55	0,38	0,47	0,54	0,50	0,57	0,45	0,22	0,24	0,27	0,24	0,33
K2O	0,00	0,03	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,00	0,00
SIO2	47,50	47,02	46,94	45,68	45,42	46,26	47,23	46,03	46,95	46,06	50,66	50,71	49,35	50,00	49,92
FEO	12,94	12,78	12,03	10,18	10,56	10,74	11,09	10,43	12,23	10,20	5,59	5,69	7,74	5,52	7,86
AL2O3	3,13	3,23	3,91	6,06	5,33	4,68	4,04	4,72	3,93	5,64	3,14	2,99	3,56	2,97	3,74
MNO	0,26	0,26	0,23	0,30	0,27	0,19	0,17	0,20	0,25	0,12	0,24	0,15	0,20	0,13	0,14
CAO	20,34	20,00	20,56	21,20	21,03	20,75	20,68	21,28	20,98	21,22	21,04	21,67	20,20	21,24	20,09
MGO	10,79	11,00	11,54	11,23	11,41	11,66	11,90	11,40	11,60	11,67	16,05	16,34	15,07	16,28	15,06
NIO	0,10	0,00	0,04	0,00	0,08	0,00	0,00	0,01	0,01	0,03	0,09	0,07	0,02	0,00	0,08
CR2O3	0,00	0,00	0,03	0,10	0,20	0,17	0,06	0,13	0,03	0,15	0,63	0,65	0,31	0,67	0,30
TIO2	2,80	3,05	3,12	3,25	3,28	3,01	2,70	3,00	2,83	3,04	0,59	0,46	0,94	0,49	0,84
Summe	98,36	97,84	98,92	98,54	97,95	97,83	98,40	97,69	99,38	98,58	98,24	98,98	97,67	97,52	98,37

Wo (Ca)	44,54	43,97	44,61	47,11	46,36	45,60	44,94	46,84	44,77	46,62	43,91	44,26	42,65	43,99	42,48
En (Mg)	32,88	33,65	34,77	34,71	34,99	35,64	35,97	34,89	34,45	35,67	46,60	46,43	44,26	46,89	44,29
Fs (Fe)	22,58	22,38	20,73	18,17	18,65	18,76	19,09	18,26	20,79	17,71	9,50	9,32	13,09	9,12	13,23

Tab. 2. Clinopyroxen chemistry from the Helikon basalts.

minerals which probably represent titanomagnetite. Small, concentric chlorites (Tab. 1) are frequently found in the vicinity of two crossing plagioclase ledges. They represent most probably components of a rest melt or primary olivines which devitrinized to chlorite.

GEOCHEMISTRY

Character and terminology

Chemical analyses from representative lavas of the four outcrops in Tab.3 were performed with XRF and NAA.

The subalkaline character of the rocks is recognizable if plotted in the diagram of WHITEHEAD & GOODFELLOW (1978) TiO_2-SiO_2. The Na_2O+K_2O-SiO_2 diagram of IRVINE & BARAGAR (1971) follows the trend of the treated volcanics and the division line between the alkaline and subalkaline field (Fig. 3). The distribution of basalts in the field of subalkaline rocks is not definite and is probably due to the mobilisation of the alkali metals by alteration processes.

PEARCE & NORRY (1979) used Zr, which is not built into the main phase of basaltic rocks, as an indicator for differentiation of such magmatic sequences. Diagrams of main- and trace elements versus the Zr-concentration reveal a well differentiated rock sequence (Figures 4 & 5). Sample AA5 with the highest Zr-concentration does not fit into the framework and could be interpreted as having been created by a very low melting procedure. This sample has been exluded from the calculation of the regression curve.

From the diagrams well grouped positive correlations of Al_2O_3, TiO_2, FeO and P_2O_5 with correlation coefficients (KK) above 0.8 are conspicious. MnO also shows a positive correlation with a remarkably low KK of 0.64. CaO and K_2O exhibit a relatively well established negative correlation (KK 0.87 and 0.71 respectively). The scatter of values for Na_2O and MgO is probably connected with metamagmatic processes. The well developed parabolic correlation of the SiO_2-values is not definitely connected with magmatic processes. A relation between SiO_2 concentration and hydratisation of the rocks is suspected since most rocks have been transformed autohydrothermally.

The compatible elements Cr and Ni (in relation to the primitive mantle) exhibit a markedly negative correlation. A similar behaviour is recognized for most of the Ba-values, although Ba, a Large Ion Lithophile (LIL), was classified as incompatible. The relative incompatibility of Ba may lead (like in a granitic melt) to a compatible behaviour of this element. From ONUMA-diagrams (SCHARBERT, 1983) for the system plagioclase/groundmass of an alkali-olivin basalt, it is deducted that Ba can be built into a plagioclase lattice replacing K, because the distribution coefficient is regarded as the most im-

	Ex2	Th2	Th4	Ex790	Sa1	Sa2	AA5	AA9	Ma2
SiO2	45,37	48,18	38.45	46.82	43,29	38,92	44,31	45.11	47,89
TiO2	1,38	1,31	2.05	1,87	0,60	0,50	2,47	2,11	1.13
Al2O3	14,42	15,44	15,17	16.02	10,73	9.69	15,87	15.96	15,57
Fe2O3	9,39	9,34	11,79	11,57	7,64	7,05	11,17	12,31	8,36
MnO	0,78	0,25	0,23	0,35	0,12	0,15	0,09	0,22	0,14
MgO	8,75	8,99	14,16	5,87	5,95	7,56	4,88	7,21	8.53
CaO	5,37	10,43	9,48	9,07	16,22	20,60	6,26	7,47	8,23
K2O	0,17	0,13	0,02	0,16	1.36	0.85	0.98	0.60	0,39
Na2O	3,84	3,93	1,58	3,58	3,95	3.00	4,37	4,05	4,33
P2O	0,29	0,15	0,28	0,18	0,16	0,14	0,71	0,25	0,13
GV	10,44	2,30	7,72	5,10	10,13	11,73	8,06	5,16	4,90
Summe	100,20	100,45	100,92	100,59	100,15	100,19	99,17	100.46	99,60
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Sc	37,00	35,00	40,00	41,00	32,00	36,00	17,00	36,00	31,00
V	294,00	244,00	290,00	351,00	206,00	175,00	144,00	311,00	,205.00
Cr	226,00	310,00	143,00	61,00	830,00	390,00	22,00	66,00	265,00
Co	36,00	37,00	43,00	44,00	31,00	30,00	21,00	38,00	29,00
Ni	108,00	96,00	59,00	43,00	182,00	97,00	19,00	25,00	141,00
Cu	19,00	13,00	72,00	57,00	25,00	10,00	27,00	57,00	79,00
Zn	51,00	40,00	103,00	101,00	54,00	51,00	115,00	94,00	75,00
Ga	15,00	22,00	15,00	30,00	14,00	12,00	22,00	23,00	15,00
As	-	4,00	-	33,00	11,00	-	-	1,00	-
Rb	3,00	5,00	4,00	4,00	34,00	20,00	33,00	6,00	2,00
Sr	129,00	143,00	1103,00	136,00	87,00	108,00	112,00	213,00	166,00
Y	21,00	28,00	32,00	38,00	15,00	10,00	27,00	35,00	21,00
Zr	83,00	86,00	129,00	108,00	43,00	30,00	283,00	129,00	78,00
Hf	2,50	2,70	3,10	3,10	1,20	0.96	6,60	3,40	2,50
Nb	26,00	2,00	13,00	3,00	4,00	3,00	59,00	12,00	5.00
Ta	2,20	0,20	0,86	0,20	0,30	0,10	4,50	1,00	0.10
Ba	109,00	47,00	56,00	32,00	79,00	97,00	44,00	230,00	37,00
La	20,00	3,60	9,30	5,30	6,70	3,70	41,00	13,00	5,10
Ce	40,00	7,90	22,00	11,00	15,00	9,40	82,00	28,00	15,00
Pr	3,00	1,00	5,00	3,00	1,00	1,00	13,00	4,00	3,00
Nd	13,00	4,00	13,00	18,00	16,00	13,00	51,00	33,00	11,00
Sm	3,70	2,90	4,10	3,90	2,30	1,40	6,70	4,30	2,60
Eu	1,20	1,10	1,70	1,90	0,77	0,57	2,20	1,50	1,10
Gd	11,00	9,00	10,00	9,00	8,00	8,00	14,00	8,00	7,00
Tb	0,50	0,71	1,00	0,86	0,40	0,30	1,10	0,76	0,69
Yb	3,30	3,70	3,30	5,50	1,40	1,50	3,40	3,70	2,50
Lu	0,29	0,40	0,50	0,70	0,13	0,40	0,38	0,32	0,72
Pb	26,00	6,00	4,00	-	5,00	1,00	9,00	1,00	4,00
Cs	0,70	0,70	0,80	0,70	1,90	0,80	0,50	0,70	0,60
Th	3,00	0,60	1,20	0,60	0,83	0,50	7,30	1,30	0,40
U	1,00	3,00	-	6,00	3,00	2,00	4,00	4,00	-

Tab. 3. Analyses from 8 representative basalts samples from Helikon.

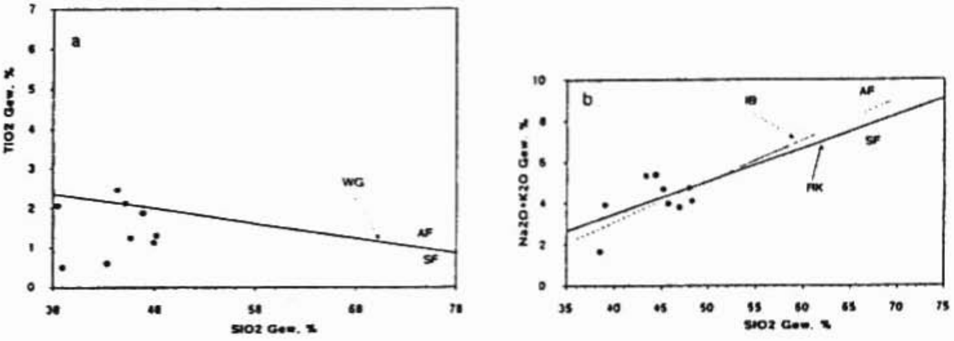

Fig. 3. a: TiO_2–SiO_2–diagram. WG: Fractionation trend after WHITEHEAD & GOODFELLOW (1978). AF: Alkali field , SF: Subalkaline field. b: IB: Fractionation trend after IRVINE & BARAGAR (1971). RK: Regression curve.

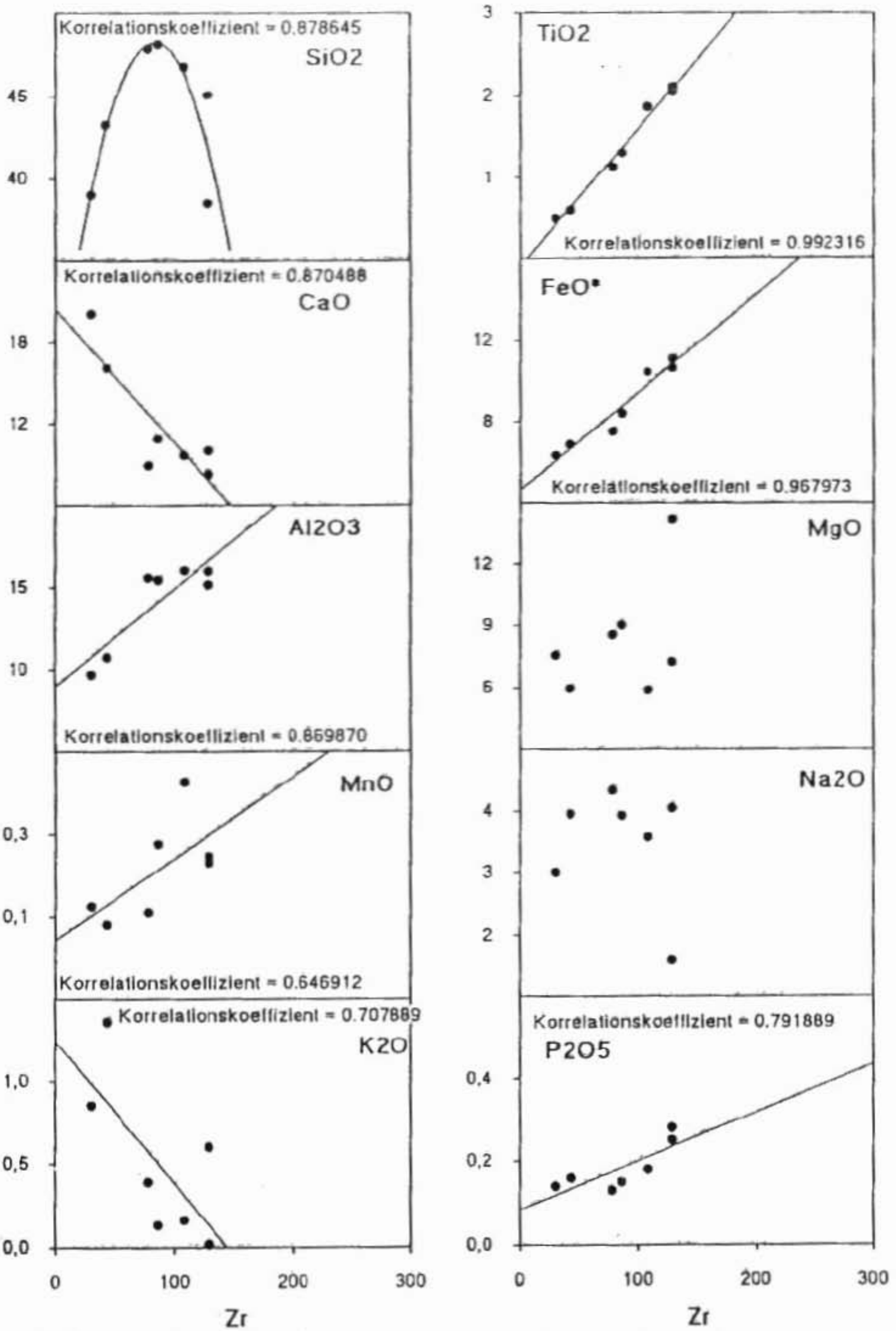

Fig. 4. *Variation of major elements (wt %) with Zr (ppm) for the volcanics from Helikon.*

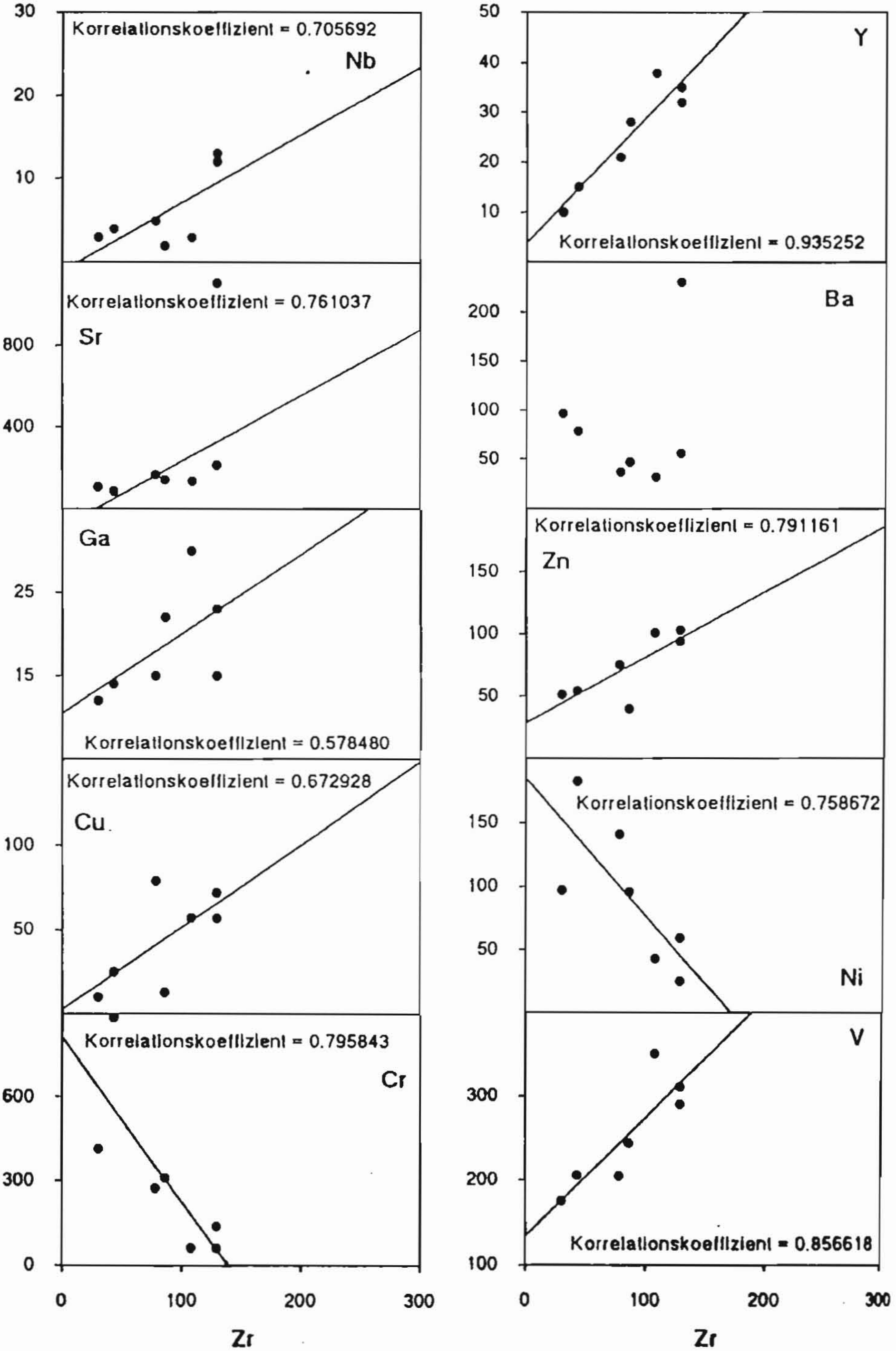

Fig. 5. *Variation of trace elements (ppm) with Zr (ppm) for the volcanics from Helikon.*

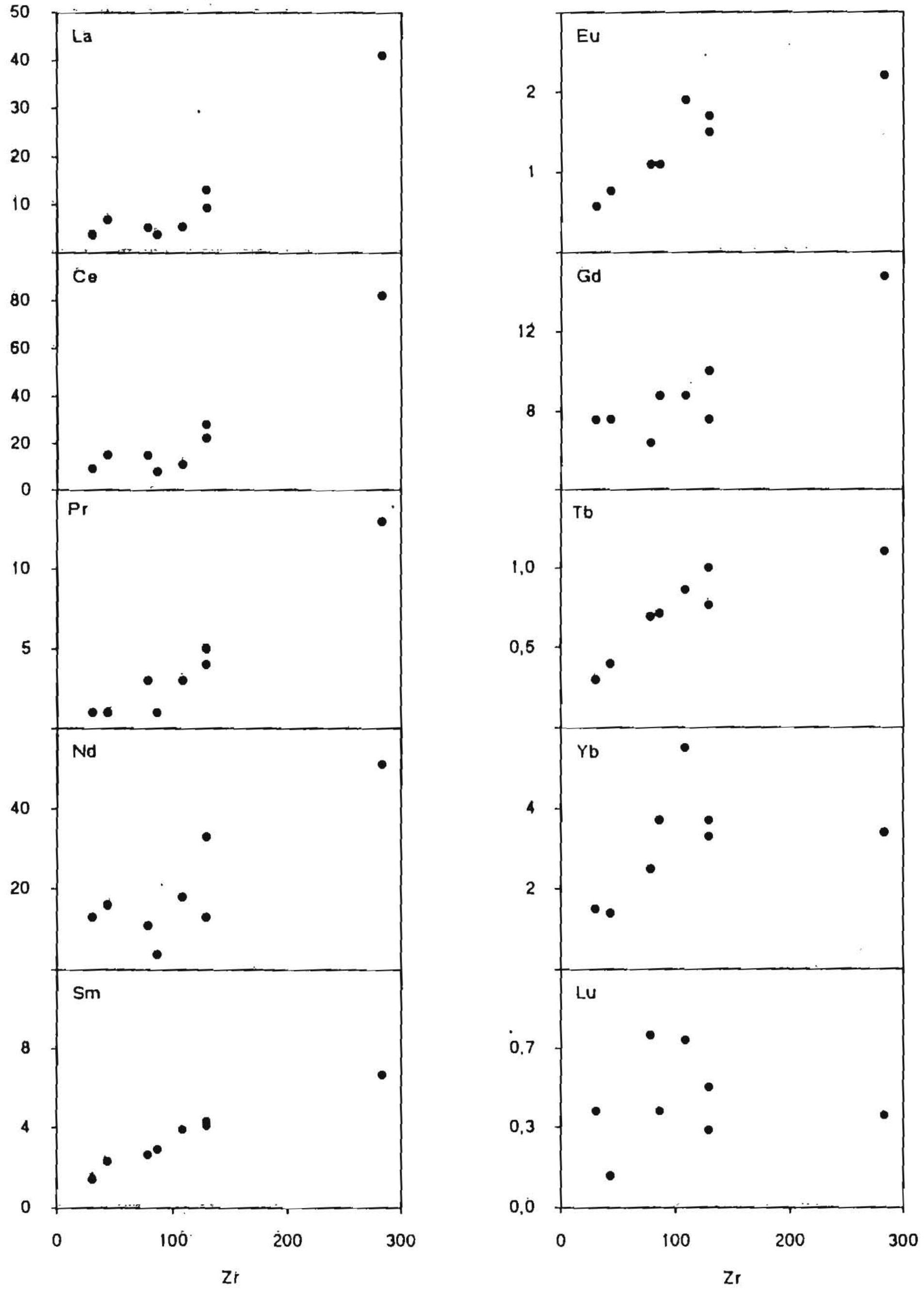

Fig. 6. Variation of REE (ppm) with Zr (ppm) for the volcanics from Helikon.

portant parameter for incorporation of trace elements in silicate lattices. Other incompatible or moderatly incompatible elements such as Nb and Y show, as expected, a well established positive correlation. The elements V and Zn which are regarded as incompatible, exhibit a positive correlation, acting therefore in relation to the other elements as incompatible. This behaviour may be correlated with a lack of magnetite (as spinell phase) in primitive basaltic magmas and with a low degree of melting, the more so since the incorporation of V into clinopyroxenes has probably been prevented by the incorporation of Cr.

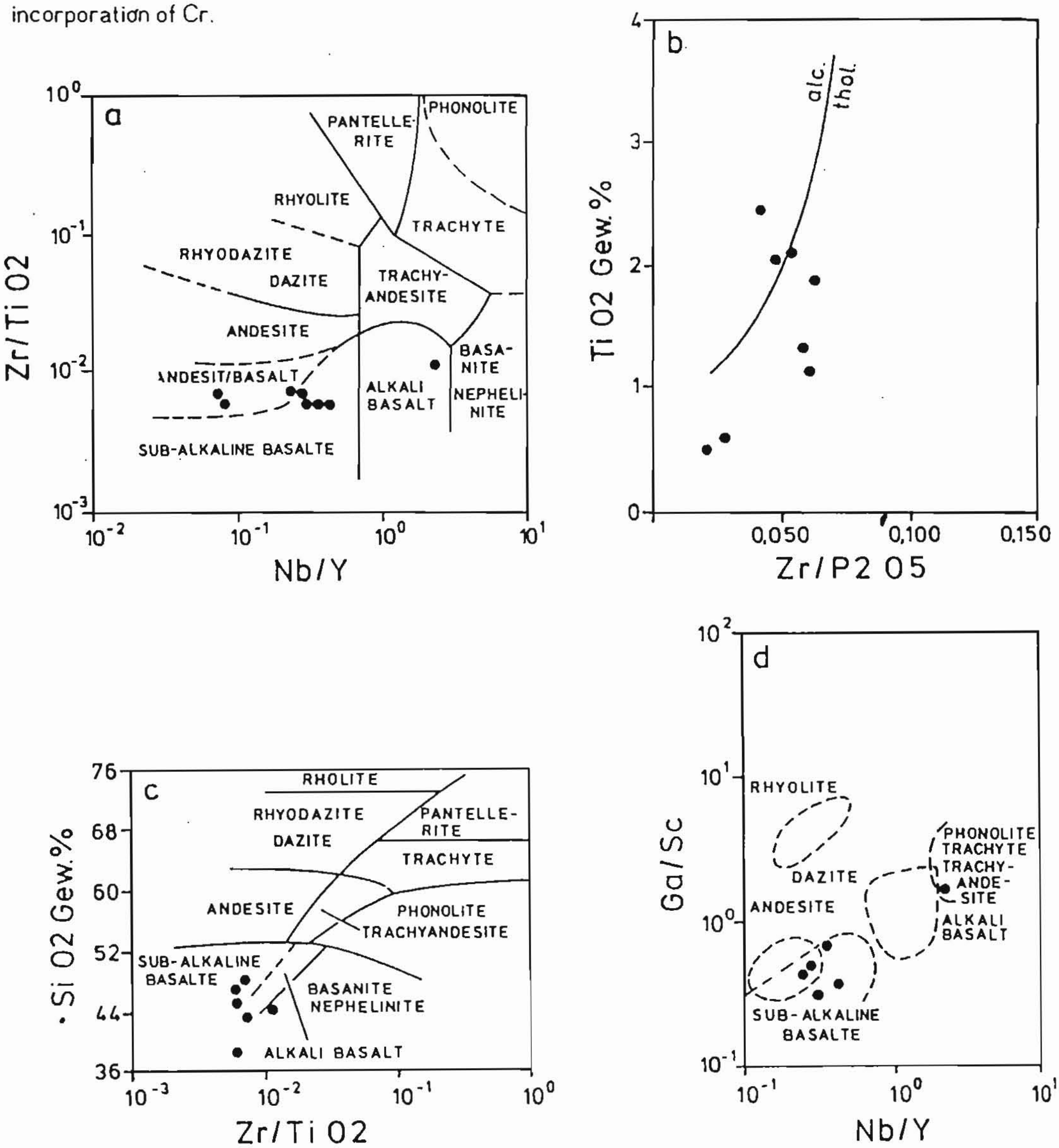

Fig. 7. Nomenclature and character diagrams. a, b and d: The majority of the volcanics from Helikon plot in to the field of sub-alkaline basalts (adapted from WINCHESTER & FLOYD; 1977). b: The majority of the volcanics from Helikon plot into the tholeiitic field (adapted from WINCHESTER & FLOYD; (1976).

The rare earth elements (REE) show positive correlations in response to Zr (Fig. 6). With Nd and Lu an extreme scatter of values was recognized which may be referred to an inaccuracy in analytical methodology (NAA).

Nomenclature diagrams of WINCHESTER & FLOYD (1977) definitely allow a definition of the majority of basalts as subalkaline basalts. The tholeiitic character of these rocks is documented by the presence of immobile elements like Ti, Zr and P in the diagrams of WINCHESTER & FLOYD (1976) (Fig. 7).

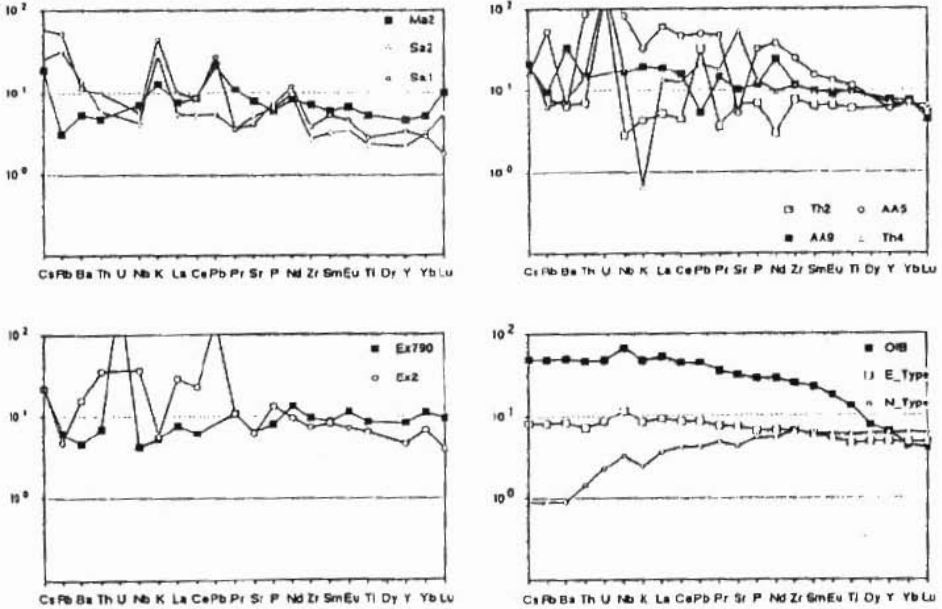

Fig. 8. Primitive mantle-normalized trace element adundance patterns for the volcanics from Helikon. Normalisation values for "primitive mantle" and OIB, E-Type and N-Type patterns from SUN & McDONOUGH (1989).

Magmatotectonic classification

For the classification of lavas according to magmatotectonic events, mantle-normalisation (SUN & DOUNOUGH, 1989), MORB-normalisation (PEARCE, 1982) and several X/Y-diagrams were applied (Fig. 10).

Mantle-normalisation diagrams show, inspite of many "anomalies" which are referred partly to the mobility of the respective elements, a distinct trend for samples Ma2, Sa2, and Sa1 which are more comparable to the MORB type than to the OIB. Samples Ex2 and Ex790 follow a shallow gradient for the elements Lu-Pb. Concentrations of incompatible elements (left area of the diagram, Sr-Rb) exhibit as slight enrichment in comparison to the samples from Saranti and Makariotissa.

Sample Th4 shows similar trends as Th2 from Yb to P, but from P to La an increase of the values is indicated. La and Nb are placed in the normal field for MORB concentrations. The negative K-anomaly is referred in principal to fractionation processes, like the formation of feldspar and hornblende accummulates because the sample does rarely produce metamagmatic conversion products (Fig. 8).

Samples AA5 and AA9 (especially AA5) show a distinctly different trend than the rest of the basalts. This trend is better comparable with the OIB (Fig. 8). Samples Th2, Th4 and AA9 belong to the same outcrop and constitute probably a rock series. This definite enrichment of the LIL-elements in most of the alkaline rocks (Samples: Th2, Th4, AA5 and AA9) in contrast to the other rocks can be regarded as a contamination indicator of primary magma sources by crustal material.

PEARCE (1982) has normalised different destructive and constructive plate margin basalts against the N-Type (Aula-Fartak trench). In such spider diagramms he defined minor differences between

MORB and IAT chemistry. Trends from the mantle-normalisation diagrams for the analysed rocks were reconfirmed by the MORB-normalisation diagrams (Fig. 9). The MORB character of the analysed basalts (except AA5 and AA9) is underlined by these diagrams. The basalts are similar to the E-Type (SUN & DONOUGH, 1989) or the transitional Type after PEARCE (1982). Diagrams a,b,c and d (Fig. 10) clearly show that the majority of the analysed basalts are attached to the OFB. The elements used here are compatible as well as incompatible, their mobility against metamagmatic processes is neglectable and as such they reflect true magmatic conditions. Diagrams e) and f) exhibit, with an increasing scatter of values, more similarities with the trend of abyssal basalts. This is in accordance with the depositional environment during the Upper Jurassic.

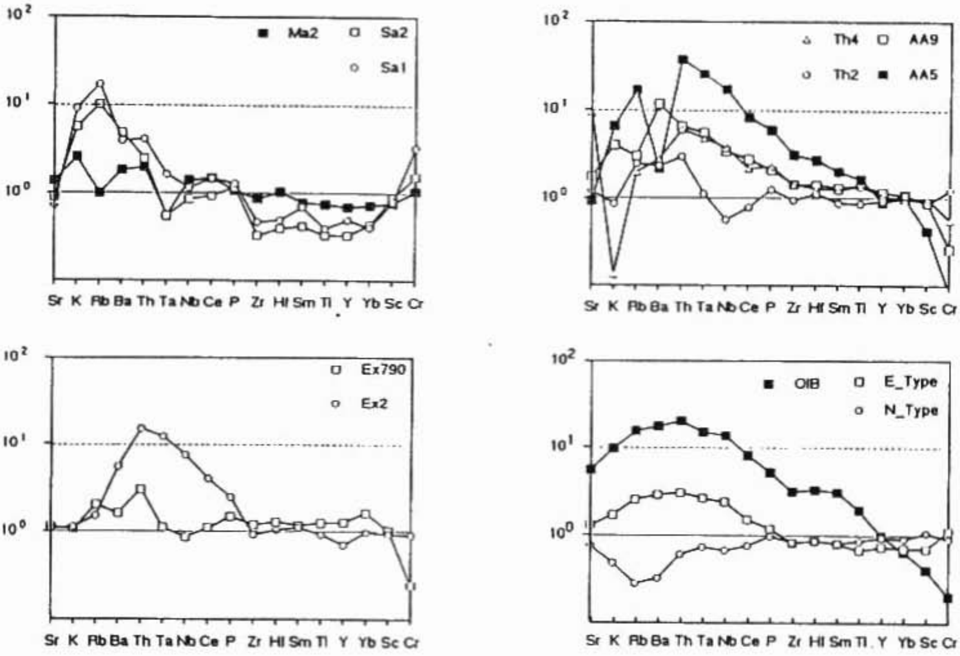

Fig. 9. MORB-normalized trace element abudance patterns for the volcanics from Helikon. Normalisation values for "MORB" from PEARCE (1982). OIB, E-Type and N-type patterns from SUN & McDONOUGH (1989)

CONCLUSIONS

A determination of the geotectonic framework of the Upper Jurassic Helikon basin only by the means of geochemical data is difficult because the original chemistry has been altered by spilitisation and weathering processes.

The analysed volcanics are submarine effusives which produced for their majority pillow-like structures. They are closely connected with turbidites and radiolarites and rest either on cherts or on a transitionary sequence, which consists mainly of matrix supported conglomerates and thinly bedded carbonates. Oceanic conditions in the basin were only established in the Upper Jurassic with the deposition of radiolarites. The alkali-basalt components of the rock series Th2, 4, AA5 and 9 can be used as an indicator of oceanized crust, if an extremely low degree of melting is assumed for the alkalinity of these rocks. The evaluation of diagrams from fresh and spilitisized basalts shows more of a constructive than destructive character for the evolution of the analysed basalts.

The tectonic origin of these basalts is still an open question which cannot be answered from such few data. The results achieved so far permit the assumption for the development of an ocean during the

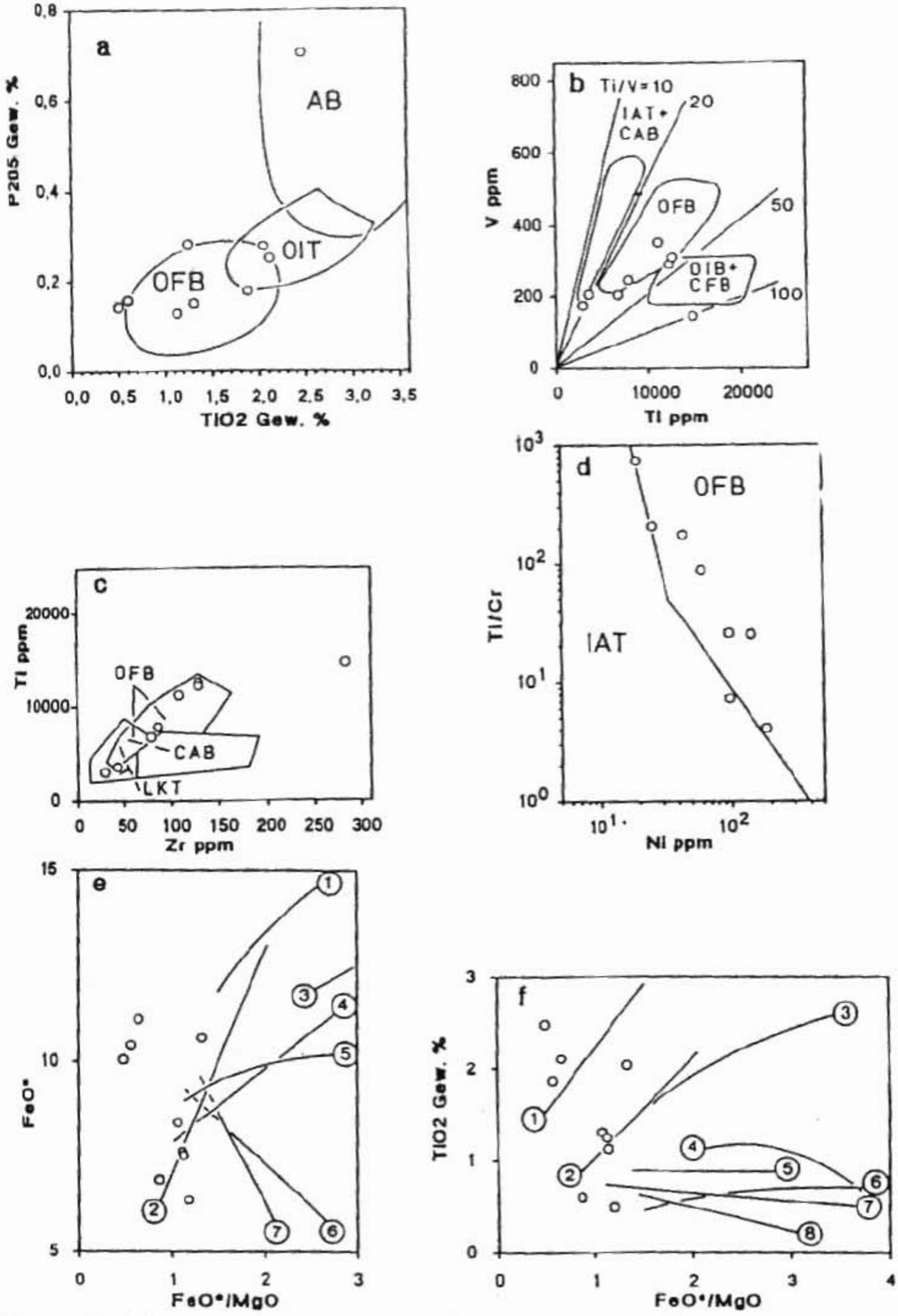

Fig. 10. Magmatotectonic discrimination diagrams for distinguishing between constructive and destructive plate margin settings. a: P_2O_5–TiO_2 diagram (RIDLEY et al. 1974). 2 5 2 b: V–Ti diagram (SHERVAIS, 1982) c: Ti–Zr diagram (PEARCE & CANN, 1973). d: Ti/Cr – Ni diagram (BECCALUVA et al. 1979). e, f: FeO–FeO*/MgO and TiO_2–FeO*/MgO diagrams (MIYASHIRO, 1974, 1975). (1) fractionation trends of Skaegaard and Kilauea basalts respectively, (2) abyssal tholeiites, (3,8) island arc tholeiites.*

Upper Jurassic which did not produce a typical ophiolitic structure but layers of volcanics, usually as OFB. These layers characterize the existence of short-lived strato-volcanoes and are rather categorized into a back-arc basin than into a typical oceanic basin. The ophiolites in the north (near Exarchos) are most probably differentiated from the volcanics of the Helikon, since they do not only contain plutonic rocks (peridotites, gabbros, pyroxenites) but exhibit acidic differentiates within their volcanic suites which do not fit into an oceanized crust model. Additional results on the geochemistry of clinopyroxenes in spilites and isotope studies on fresh basalts may delineate a more precise geotectonic environment in the near future.

Acknowledgement: I am deeply indebted to my friend and collegue Thomas Kreuser for translation and argumentation advice. The Deutsche Forschungsgemeinschaft (DFG) has financed part of the analytical work which is highly appreciated.

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