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PLATE TECTONICS INTERPRETATION OF THE SOUTH TRANSDANUBIAN ULTRAMAFICS

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ABSTRACT

Original rock of the South Transdanubian serpentine was oceanic harzburgite according to chemical composition. In country metamorphic rocks and granites, serpentines lie with steep tectonic contacts. They must have got in this position from above trough obduction. Consequently, these bodies wedge out downwards and do not have any „roots". Serpentines underwent multiphase and partly very strong metamorphism, and their present lizardite—chrysotile composition has been developed probably in last phases. Regional granitization seems to be connected with the obductional origin of the peridotite bodies. Accordingly, the following geological history appears to have taken place: oceanic spreading — about Silurian; island arc development through subduction — about Devonian; collision of Precambrian continent having located on the coast of former ocean, with island arc — Upper Devonian to Lower Carboniferous; postcollisional thermic—isostatic equalization („orogeny") — Lower (and Middle?) Carboniferous. The Upper Carboniferous to Lower Permian molasse is probably a product of the denudation and peneplanation after this „orogeny".

INTRODUCTION

In Southern Transdanubia ultramafics are known near Ófalu on the surface and near Helesfa and Gyód from drilling data *(Fig. 1.)*. The occurrence of serpentine near Ófalu was stated long ago (for review see: SZEDERKÉNYI [1977b]) but it has been investigated in details only through artificial section [SZEDERKÉNYI, 1977c, 1977d; GHONEIM and SZEDERKÉNYI, 1979]. Near Helesfa and Gyód, boreholes drilled by the Mecsek Ore and Mining Company for the control of geomagnetic anomalies, penetrated serpentines [BARABÁS *et al.*, 1964]; their ultramafic origin was established by the first analyses [ERDÉLYI, 1970, 1971, 1974].

1. OUTLINES OF SERPENTINE BODIES

Three South Transdanubian serpentine bodies will be discussed separately first of all on the basis of newest data.

1.1. The Ófalu serpentine body

Near Ófalu serpentine was known in outcrops of about 10×10 m on the eastern slope of Goldgrund valley *(Fig. 2.)* and was traced by geomagnetic measurements not far to the west (JANTSKY, 1979]. According to GHANEM and RAVASZ—BARANYAI [1969] and GHONEIM and SZEDERKÉNYI [1977], country rocks are represented by tuffaceous shale belonging to a volcanogenic-sedimentary sequence of intermediate-basic composition affected by metamorphism in the greenschist-facies. In the natural outcrops, the serpentine body was regarded as a sill [GHANEM and RAVASZ—BARANYAI, 1969; SZEDERKÉNYI, 1974), then as a sill or lavaflow [SZEDERKÉNYI, 1977a].

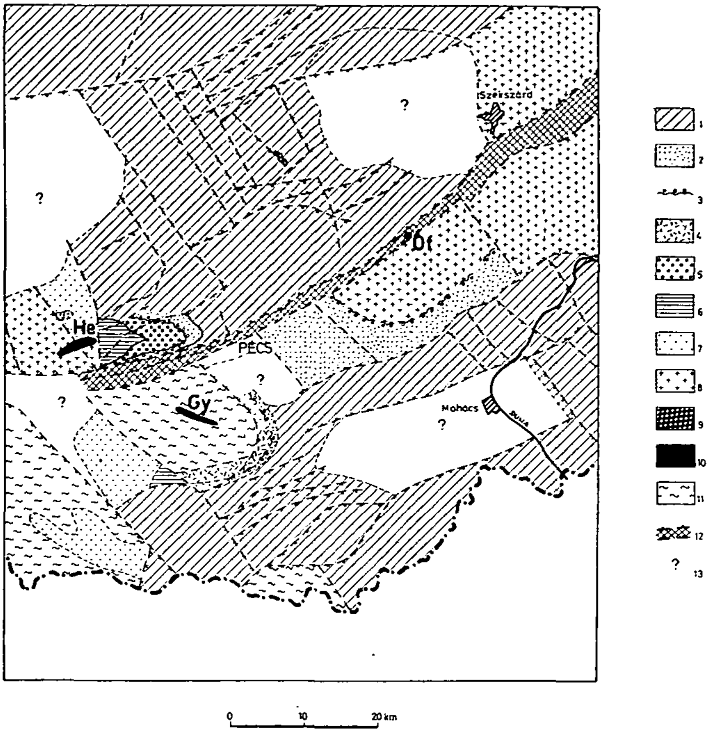

Fig. 1. Position of serpentines within the pre-Cenozoic complexes of Southern Transdanubia

Basic map: according to Kassai, [1980], simplified

Legend:

1 — Mesozoic (simplified)
2 — Upper Permian — Lower Triassic Jakabhegy red sandstone
3 — the Jakabhegy chief conglomerate in discordant overlying
4 — Upper Permian quartz porphyry
5 — Upper Permian sandstone
6 — Lower Permian red sandstone and siltstone
7 — Upper Carboniferous sandstone
8 — granite
9 — Silurian siliceous shale
10 — serpentine: He — Helesfa, Gy — Gyód, Óf — Ófalu
11 — metamorphic rocks
12 — the Mecsekalja dislocation zone
13 — uninvestigated area

Artificial section has confirmed concordant position of the body and its thickness about 10 m but contacts have been proved to be of tectonic type *(Fig. 3)* without any traces of thermal affects [Szederkényi, 1977c, 1977d; Ghoneim and Szederkényi, 1979]. Metamorphism in country rocks has affected also the serpentine body manifesting in shearing of outer zones, in appearance of antigorite in the same zones and in occurrence of reaction rims on chromite grains [Ghoneim and Szederkényi, 1979].

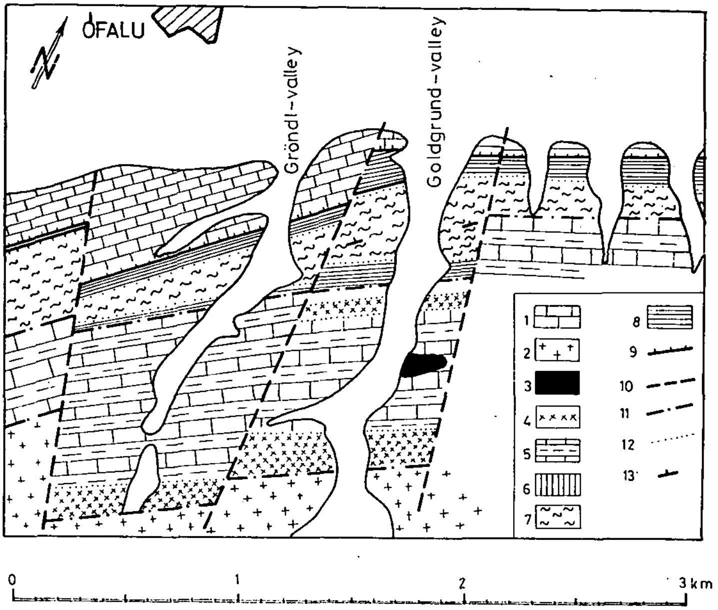

Fig. 2. Geological sketch map of the area Ófalu serpentine

Compiled by Ghoneim [1977] (see in Ghoneim and Szederkényi, [1979])
Legend:
1 — Jurassic limestone
2 — anatectic granite
3 — serpentine and associated rocks
4 — albite porphyry
5 — marble and phyllitic tuff
6 — amphibolite
7 — mica schist
8 — andesitic basalt and its metasomatized varieties
9 — intra-Pannonian overthrusting zone
10 — fault
11 — approximate formation contact
12 — gradational contact
13 — strike and dip

1.2 The Helesfa serpentine body

Near Helesfa serpentine buried by Pannonian sediments was marked by a geomagnetic anomaly of about 5 km long *(Fig. 4)*. The anomaly pattern and two boreholes showed that serpentine was of about 600 m in thickness, of about 150/82 dipping, with sharp contacts of tectonic character and was represented by a wedge-like body in cataclastic-mylonitic granite *(Fig. 5;* see also Szederkényi [1970*)*. The lower tectonic contact was penetrated by the borehole Helesfa—2 in 381,2—289,0 m [Jantsky, 1979]. The bulk of serpentine minerals (lizardite and chrysotile) marks 1T metamorphism but sporadically diaspore occurs [Erdélyi, 19271] probably because of a later thermal effect. Talc-schists [Szederkényi, 1976b; Jantsky, 1979] originated from the serpentine, perhaps are related to the same effect. Serpentines are crossed by aplite-microgranite veins with traces of strong Mg metasomatism [Szederkényi, 1970, 1974; Jantsky, 1979].

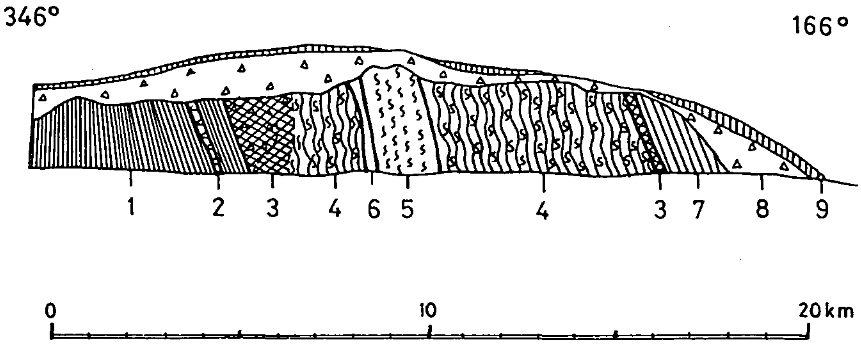

Fig. 3. Profile of the opencast Ófalu serpentine mass, compiled by Ghoneim and Szederkényi, [1979]

Legend:
1 — serizite-phyllite
2 — serizite-phyllite breccia
3 — tectonic zone
4 — sheared serpentine
5 — massive serpentine
6 — chlorite schist
7 — siliceous shale
8 — talus
9 — loess

1.3 The Gyód serpentine body

Near Gyód serpentine buried by Pannonian sediments was marked by a geomagnetic anomaly of about 5 km long *(Fig. 6)*. This anomaly pattern and three boreholes showed that the serpentine body was of about 200 m in thickness, of about SSW 80—82° dipping in approximate concordance with the country gneiss [Szederkényi, 1970, 1974, 1976a, 1977a]. Concerning the type of contact there are no data. *(Fig. 7)*. Clinoenstatite, secondary forsterite and diaspore occurring beside

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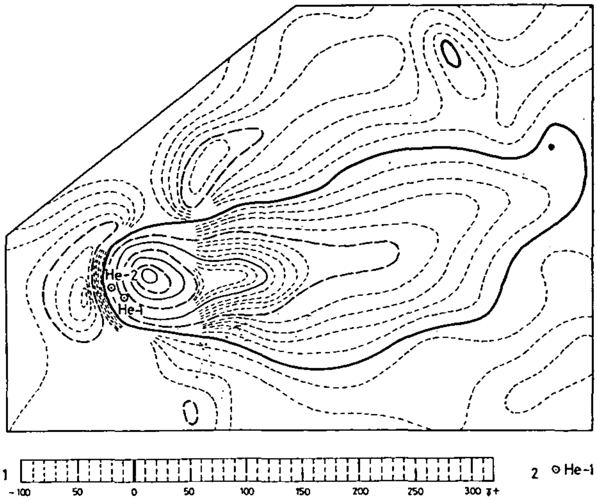
Fig. 4. Geological and geophysical maps of the Helesfa serpentine body

A. Geomagnetic ΔZ-map [Haáz and Komáromy, 1964]
Legend:
1 — scale of vertical component of the geomagnetic field
2 — boreholes on the magnetic anomaly with serial numbers

B. Geological map [Barabás, *et. al.* 1964]
Legend:
1 — topography of the pre-Cenozoic basement
2 — boreholes on the magnetic anomaly with serial numbers
3 — other boreholes
4—11 — rocks on the surface
4 — Lower Cretaceous diabase
5 — Middle Triassic limestone and dolomite
6 — Lower Triassic sandstone, shale, dolomite and anhydrite
7 — Upper Permian red sandstone and conglomerate
8 — Upper Permian variegated sandstone
9 — Lower Permian siltstone
10 — Lower Permian sandstone and conglomerate
11 — granite

A



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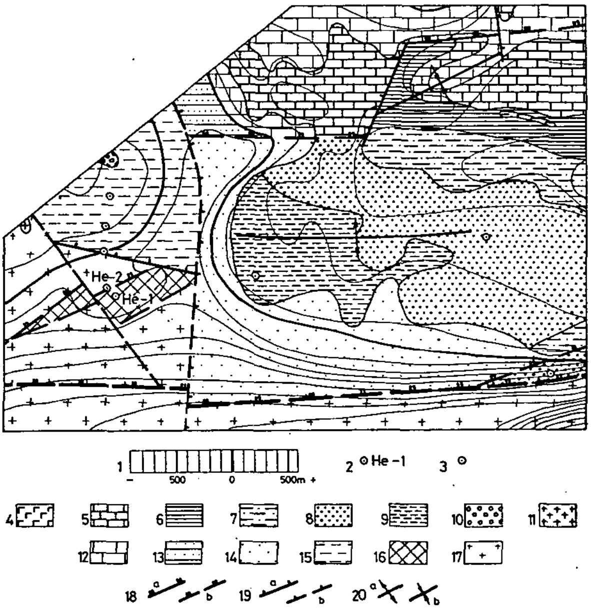

12—17 — rocks buried by Neogene sediments
12 — Middle and Upper Triassic
13 — Permian and Lower Triassic
14 — Permian
15 — Lower Permian
15 — serpentine
17 — granite
18 — reverse fault: a — on surface, b — buried
19 — normal fault: a — on surface, b — buried
20 — fold axis: a — anticlinal, b — synclinal

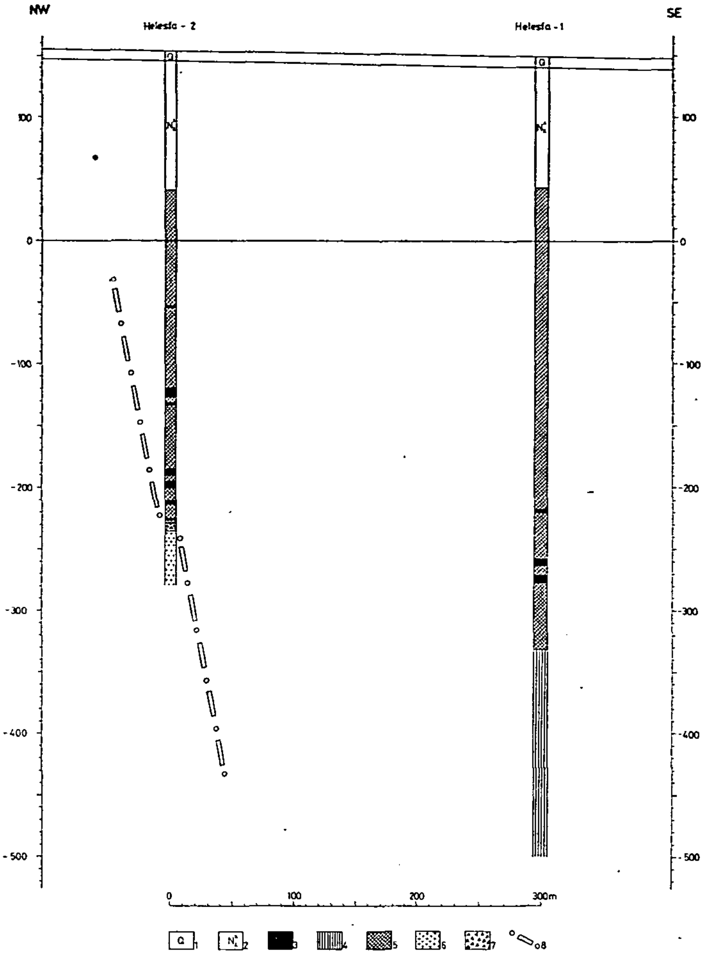

Fig. 5. Position of the Helesfa boreholes in vertical section
Source of columns: Jantsky [1979] (simplified)
Horizontal distances: from the map scale 1:100.000 *(Fig. 4-B)*

Legend:
1 — Quaternary sediments
2 — Middle Pliocene sediments
3 — aplite-microgranite vein
4 — talc schist
5 — serpentine
6 — cataclastic-mylonitic granite
7 — tectonic breccia
8 — assumed contact of the serpentine body

the dominant lizardite and chrysotile gives evidence of a strong later thermal affect [Erdélyi, 1971]. Serpentines are crossed by aplite-microgranite veins with a strong Mg metasomatism [Szederkényi, 1970, 1974; Jantsky, 1979].

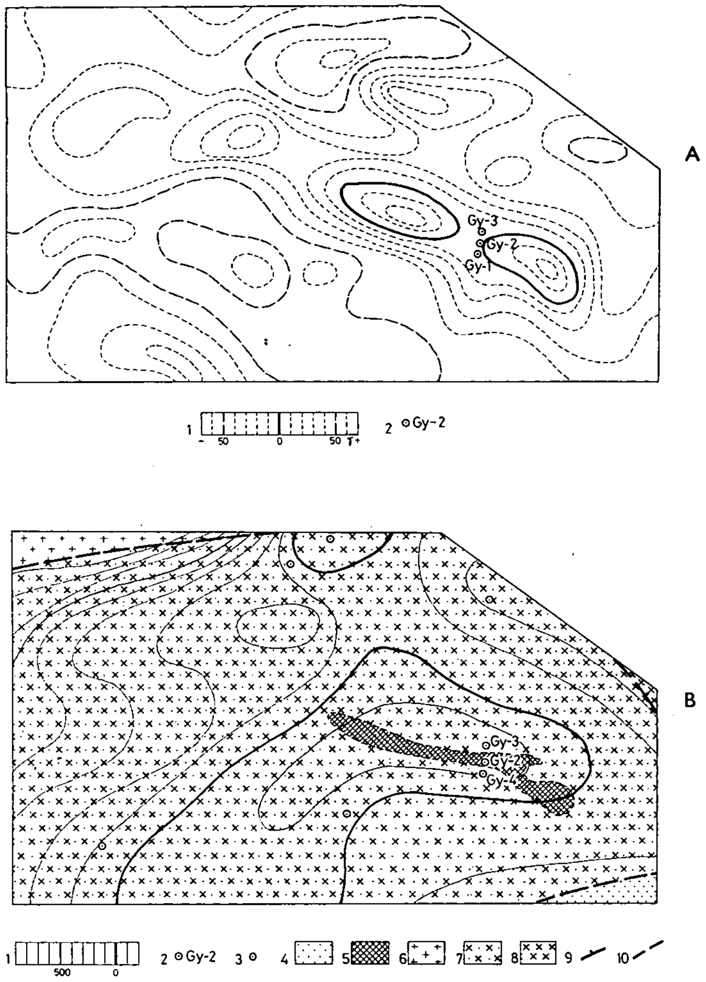

Fig. 6. Geological and geophysical maps of the Gyód serpentine body
A. Geomagnetic ΔZ-map (Haáz and Komáromy, 1964]
Legend:
1 — scale of vertical component of the geomagnetic field
2 — boreholes on the magnetic anomaly with serial numbers

B. Geological map (Barabás *et. al.*, 1964]
Legend:
1 — topography of the pre-Cenozoic basement
2 — boreholes on the magnetic anomaly with serial numbers
3 — other boreholes
4 — 8 — rocks buried by Neogene sediments
4 — Permian
5 — serpentine
6 — granite
7 — metamoprhis rocks and Upper carboniferous sandstone and sericite schist
8 — metamoprhic rocks
9 — normal fault
10 — fault of unclear type

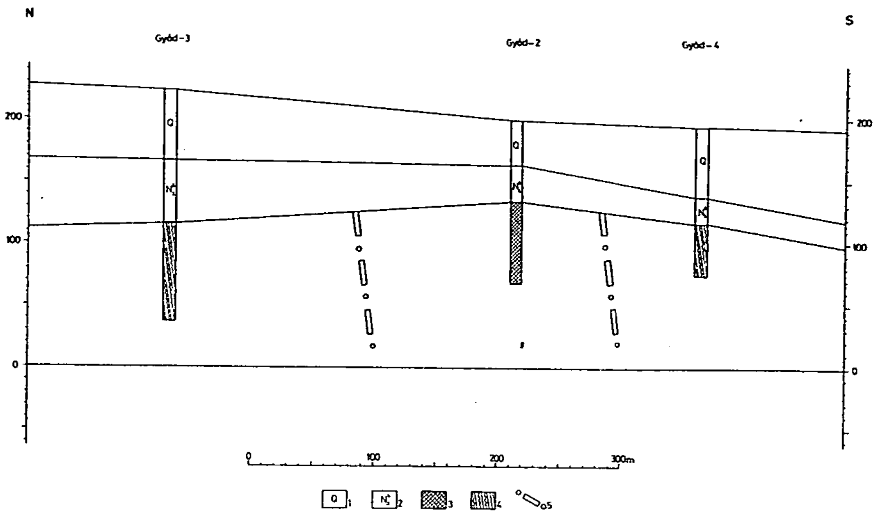

Fig. 7. Position of the Gyód boreholes in vertical section

Source of columns: JANTSKY [1979] (simplified)
Horizontal distances — from SZEDERKÉNYI [1976a] and from the map scale 1:100.000 [BARABÁS *et al.* 1964]

Legend:
1 — Quaternary sediments
2 — Middle Pliocene sediments
3 — serpentine
4 — migmatic amphibolite
5 — assumed contacts of the serpentine body

1.4 Summary

Main geological peculiarities of three serpentine bodies are practically identical. They are steep dipping sheet- or lens-like bodies with tectonic contacts concordant with the schistosity. Serpentinization took place at comparatively low temperature according to dominance of lizardite and chrysotile. Serpentine was affected by thermal influences of variegated intensity.

2. ORIGINAL ROCKS OF SERPENTINES

Original rocks of the Helesfa and the Gyód serpentine were considered by ERDÉLYI [1970, 1971] to be peridotite. According to his opinion, magnetite (5—6% of rock) originated from olivine through its serpentinization. SZEDERKÉNYI [1974, 1976a, 1977a] qualified the same rocks to be pyroxenite on the basis of their characteristic "mush" structure and of occurrence of clinoenstatite in the Gyód serpentine. Later he considered original rock of the Ófalu serpentine with the same "mush" structure to be peridotite [GHONEIM and SZEDERKÉNYI, 1979], therefore structural criteria seem to be uncertain. According to ERDÉLYI [1971], clinoenstatite occurs on the cleavage planes and is originated only through a strong thermal influence. According to DEER *et al.* [1963], clinoenstatite does not occur in rocks. According to DOBRETSOV *et al.* [1980], clinoenstatite is known from two points on the whole Earth

(Papua and Mariana) and in specific rocks (marianites) only. Therefore clinoenstatite is not a suitable basis for the diagnostic of pyroxenites and ERDÉLYI' s opinion on the peridotite origin of the Helesfa and Gyód serpentines seems to be more convictive. On the basis of the petrochemistry and the Ni—Cr contents, GHONEIM and SZEDERKÉNYI [1979] considered original rock of the Ófalu serpentine to be Alpine type peridotite with MgO/SiO_2 ratio near to that in lherzolites.

Several investigations including statistic evaluation of 3500 ultramafic analyses from 160 regions of the Earth [ABRAMOVICH and KLUSHIN, 1978] show that chemical composition of dunites and peridotites remains statistically unchanged during serpentinization except for increase of the water content and the Fe_2O_3/FeO ratio. Therefore serpentine analyses calculated on the water-free basis are expected to reflect composition of the original ultramafics realistically. The South Transdanubian serpentines, however, contain CO_2 beside H_2O, in the largest amount near Ófalu (Table 1). Relationship between the CO_2 and other rock-components has been examined in the Ófalu serpentine. Good correlation occurs with the SiO_2, MgO and CaO contents *(Fig. 8)*. On the plots SiO_2 against CO_2 and MgO *versus* CO_2, two groups with independent correlations are delineated. Differences in the CaO—CO_2 correlation between these two groups are insignificant (Table 2). Other components do not show any coherence with the CO_2.

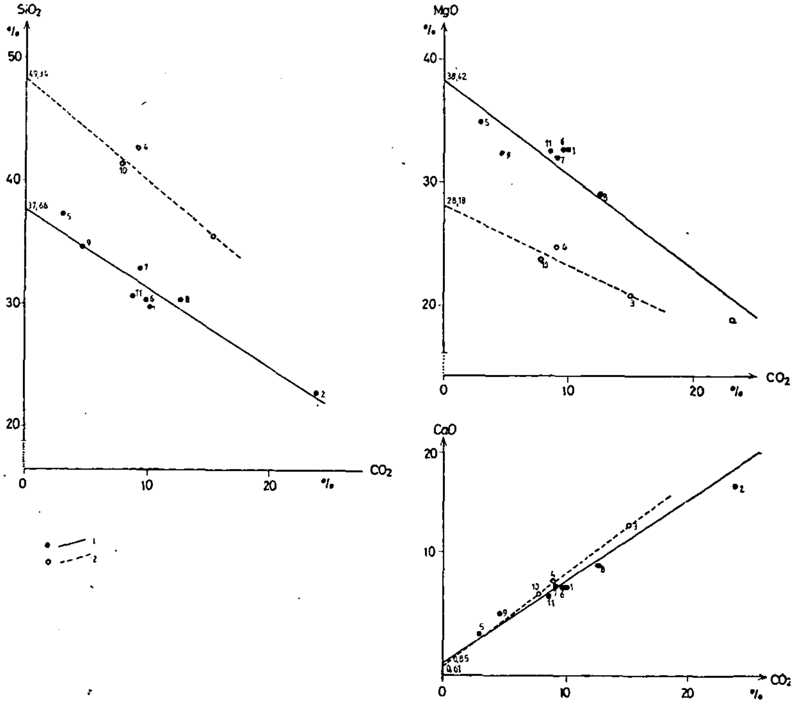

Fig. 8. Correlation between the CO_2 and the SiO_2, MgO and CaO in the Ófalu serpentine
Source of data: Table 1

Legend:
1 — sample and regression line of I group
2 — sample and regression line of II group

TABLE 2

Regression coefficients of linear correlations between CO_2 and main components of serpentines

	Ófalu—I (8)	Ófalu—II (3)	Helesfa (5)	Gyód (4)	Perkupa (5)
SiO_2	0.92	0.87	0.78	0.02	0.80
Al_2O_3	0.12	0.99	0.17	0.01	0.18
Fe_2O_3	0.01	0.30	0.16	0.26	0.80
FeO	0.21	0.33	0.03	1.00	0.91
MnO	0.41	0.99	0.01	1.00	0.06
MgO	0.90	0.84	0.52	0.97	0.90
CaO	0.98	1.00	0.30	0.93	0.06
Na_2O	0.02	0.99	0.43	0.02	0.97
K_2O	0.00	0.98	0.04	0.28	0.03

Source of data: Table 1
in brackets: numbers of employed data (*i.e.* of CO_2 determinations)

TABLE 3

Average serpentine composition in volatile-free form

	Ófalu—I [8]	Ófalu—II [3]		Helesfa [6]	Gyód [3]	Perkupa [5]	Pyrox.	Perid.	Lherz. [69]	Harzb. [71]
SiO_2	42.85^+	55.85^+	53.72^+	45.05	43.75	44.64	50.78	43.90	45.7	45.0
TiO_2	0.01	0.00	0.00	0.01	0.00	0.00	0.53	0.82	0.2	0.1
Al_2O_3	2.24	1.35	4.42^+	2.03	2.45	2.21	4.12	4.02	3.7	1.7
Cr_2O_3	—	—	—	—	—	0.43	—	—	0.3	0.3
Fe_2O_3	7.57	7.67	7.38	6.72	6.28	5.19	2.45	2.53	5.1	6.8
FeO	2.24	2.16	2.08	2.41	0.59^+	0.82^+	7.41	9.92	3.6	2.2
MnO	0.16	0.11	0.37^+	0.13	0.09	0.14	0.13	0.21	0.1	0.1
MgO	43.72^+	31.90^+	30.68^+	43.21	46.51^+	46.01^+	21.83	34.29	38.4	42.6
CaO	0.97^+	0.69^+	0.66^+	0.31	0.18^+	0.50	12.07	3.49	2.3	0.7
Na_2O	0.11	0.08	0.25^+	0.07	0.06	0.04^+	0.45	0.56	0.3	0.2
K_2O	0.03	0.11	0.36^+	0.07	0.08	0.01	0.21	0.25	0.1	0.1
P_2P_5	0.09	0.08	0.08	0.01	0.01	0.00	—	—	—	—

$+$— calculated from the correlation with CO_2
in brackets: number of data
source of Hungarian data: Table 1
Pyrox. — NOCKOLDS' pyroxenite average [HUANG. 1962]
Perid. — NOCKOLDS' peridotite average [HUANG. 1962]
Lherz. — oceanic lherzolite average [KASHINTSEV *et. al.*, 1979]
Harzb. — oceanic harzburgite average [KASHINTSEV *et. al.*, 1979]

Since the SiO_2, MgO and CaO vary to a large extent with the CO_2 content and relative deviations from the regression lines get at 10% there is no reason for all data to be corrected separately. Therefore corrections are made for the groups only and average compositions are calculated. The SiO_2, MgO and CaO contents are extrapolated by the regression lines to 0,00 % CO_2 and other components are determined arithmetically. Results are calculated on the volatile-free basis (Table 3). A control calculation shows that practically the same data can be got if first all samples to be calculated on the water-free basis and then correlation with CO_2 to be estimated.

TABLE 4

Composition of serpentines in volatile-free form

	Helesfa—1			Helesfa—2			Gyód—2			Perkupa—mine				
	121,0	300,0	400,0	134,6	143,0	300,0	82,0	90,5	125,0	4	5	6	7	11
SiO_2	45.74	43.81	44.89	45.15	45.65	45.03	43.95	44.08	43.76	44.56	43.96	44.96	44.87	44.34
TiO_2	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al_2O_3	1.85	2.81	1.74	2.00	2.32	1.45	2.45	2.52	2.39	3.38	1.25	2.17	2.34	1.89
Cr_2O_3	—	—	—	—	—	—	—	—	—	0.37	0.56	0.41	0.48	0.34
Fe_2O_3	6.68	6.78	6.97	6.92	6.37	6.58	6.49	5.88	6.53	5.15	6.98	5.29	5.47	7.60
FeO	2.40	2.12	2.29	2.47	2.78	2.39	1.72	0.95	0.93	0.91	1.56	1.30	0.87	2.63
MnO	0.16	0.18	0.13	0.09	0.09	0.11	0.10	0.09	0.09	0.12	0.12	0.13	0.16	0.17
MgO	42.83	43.97	43.51	42.60	42.27	44.05	43.08	45.45	45.53	44.95	44.61	45.00	44.99	41.29
CaO	0.12	0.21	0.37	0.58	0.35	0.26	2.05	0.94	0.58	0.35	0.41	0.54	0.70	0.55
Na_2O	0.08	0.05	0.05	0.09	0.09	0.03	0.06	0.02	0.08	0.19	0.55	0.21	0.12	1.20
K_2O	0.09	0.06	0.05	0.08	0.08	0.07	0.09	0.06	0.09	0.01	0.00	0.00	0.00	0.00
P_2O_5	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00

Source of data: Table 1

On the basis of experiences from the calculations given above a further investigation has been made to determine relationship between the CO_2 and other rock-components in the Helesfa and the Gyód serpentines as well as in the Perkupa ones (North Hungary) included in analysis for the comparison. The regression coefficient values (Table 2) show no clear correlation ($r^2 \geqq 0{,}90$) in the Helesfa serpentine but FeO, MgO and CaO in the Gyód serpentine and FeO, MgO and Na_2O in the Perkupa one change in close relationship with CO_2. Since the low CO_2 the analyses calculated on the volatile-free basis without any corrections (Table 4), reflect the petrochemistry about realistically. Corrections are made only for average composition (Table 3) calculations.

Chemical composition of the Ófalu, Helesfa, Gyód and Perkupa serpentine (without H_2O and CO_2) is comparatively constant and differences between samples are insignificant. Average compositions of different bodies are also similar. The Ófalu II group is the only exception. Similarly to other groups, SiO_2 and MgO are dominant but in a very unusual ratio: beside about 56% SiO_2 the MgO is of 32%. Among magmatic rocks of such acidity, even the marianites and boninites (52—57% SiO_2) extreme enriched of MgO, contain only 12—24% MgO (DOBRETSOV *et al.*, 1980). Therefore the analytical data of the Ófalu II group do not reflect any real magmatic rock composition and will be not discussed below. In further discussion the "Ófalu serpentine" will mean average composition of the I group.

Original magmatic rocks of four Hungarian serpentine bodies are very similar to each other petrochemically. On the one hand, the Ófalu and Helesfa, and on the other hand, the Gyód and Perkupa serpentines correspond in particular well. In the first pair there is of 2% more FeO and less MgO than in the second one. At the same time, the Ófalu and Gyód serpentines on the one hand, and the Helesfa and Perkupa ones on the other hand are similar in their SiO_2 contents and more acidic rocks of Helesfa and Perkupa contain less Al_2O_3 and Fe_2O_3 than more basic ones of Ófalu and Gyód.

Concerning original magmatic rocks, two alternatives were born: the peridotite [ERDÉLYI, 1970, 1971, 1974; GHONEIM and SZEDERKÉNYI, 1979] and the pyroxenite

[Szederkényi, 1974, 1976a, 1977a] ones. Through comparison with the Nockolds' averages [Huang, 1962] (see Table 3), pyroxenite is to be excluded: they contain much more SiO_2, Al_2O_3 and particularly CaO and much less MgO. The "peridotite average" is nearer to the discussed rocks and shows a deviation of the same direction as the "pyroxenite average". This "peridotite average" presents sum of various continental rocks named "peridotite".

Peridotites occur on continents in various magmatic complexes [Kuznetsov, 1964]. In most of them, peridotites play a subordinate role and form layer- or band-like derivatives of dominant basic or alkalic magmatic rocks, for example, in gabbro—pyroxenite—dunite complexes of folded area or in differenciated gabbro—norite complexes of cratons occurring, as a rule, in lopoliths. Alkalic—ultramafic—carbonatite complexes are found also in cratonic area as pillar-form intrusion of vertical position and concentric structure. Last two cases can be excluded on the basis of their tectonic position (craton) and the first one is not suitable because of its metallogenetic character (Ti—Fe—V).

Analogues of the South Transdanubian serpentines are to be found first of all among rocks of dunite—harzburgite complexes (i.e. "Alpine type ultramafics"). This complex is the lower member of ophiolitic series which latter, in turn, is a fragment of oceanic lithosphere overthrusted on continent. That is why analogues of the South Transdanubian serpentines have to be looked for among oceanic rocks (Table 3).

Identity of chemical composition of the Ófalu and Helesfa serpentine with the oceanic harzburgite average is doubtless and similarity of the Gyód and Perkupa serpentine is also very high. At the same time, deviation from the oceanic lherzolite average is also clear. In their Al_2O_3 contents, the South Transdanubian rocks are much nearer to harzburgite, and considering the trend of differences between the oceanic lherzolite and harzburgite in SiO_2, MgO and CaO, the South Transdanubian serpentines get beyond harzburgite, perhaps trending to dunite. Consequently, the *South Transdanubian serpentines have been originated from rocks being very similar to present oceanic harzburgite.*

3. ORIGIN AND POSITION OF PERIDOTITES

The South Transdanubian serpentines are located in uppermost levels of continental lithosphere. According to principles of the classic geology, their intrusive origin seemed to be obvious. There are two possibilities: to assume either upward rise of ultramafic material direct from the mantle or origin through differentiation of other magmas. Upward rise of magmas is always caused first of all by hydrostatic forces. Magma of basic or alkalic composition can rise into the upper levels of continental crust if it has originated from the deeper horizons of mantle, and the density excess compared to the continental crust is overcompensated by the density deficit compared to the mantle material. Peridotites originated from these magmas through intracrustal differentiation, are commonly subordinated and characterized first of all by clinopyroxene (*CPx*) beside olivine (*Ol*) with scarcity of orthopyroxene (*OPx*). Therefore these peridotites are dominantly of wehrlite (*Ol*+*CPx*) composition and even lherzolite (*Ol*+*CPx*+*OPx*) are rare and harzburgite (*Ol*+*OPx*) are practically absent. As seen, relationships with these intrusive complexes have been excluded also on the basis of other data.

Material of dunite—harzburgite complexes originates from mantle. Density of these ultramafics is much more as compared to continental crust and approximately coincides with the mantle density. Such a material in mantle surrounding cannot become bouyant and rise into the upper levels of continental crust and form intrusive or effusive bodies there. The same density excess excludes also tectonic rise upward from mantle independently from plasticity of serpentines.

Therefore, the South Transdanubian serpentines cannot be originated from under continental crust. According to petrochemistry, they are analogues of the oceanic harzburgites. Accounting this analogy for a proof of the *oceanic origin,* the only realistic explanation can be got. Two kinds of mechanism for explanation of the peridotite appearance in continental surrounding exist. Both of them are related to subduction processes.

First mechanismus is the so-called *obduction,* i.e. overthrusting of oceanic lithosphere on continental crust. Obduction takes place during the continent — island arc collision when a continental slab subduces beneath an island arc [ZONENSHAIN et al., 1976]. The island arc itself is generated by subduction of an oceanic slab. *Collision* takes place if the oceanic part of the subducing slab has consumed and the continent being located on the contrary coast of the former ocean, arrives at the island arc (for example, as Australia at the Indosenian arc). It is a substantial thing that subducing slab descends with a sharp break. Continental lithosphere cannot be broken such a way that is why it can subduce up to former break only, i.e. about 100—150 km from the oceanic border of the island arc *(Fig. 9).*

Island arcs often are generated on oceanic lithosphere (*i.e.* through subduction of ocean—ocean type). Thus, in the basement of island arcs oceanic lithospheric elements can exist. That has been proved by sampling of oceanic tholeiites, gabbro and peridotites on the inner (i.e. island arc) slope of oceanic trenches [KASHINTSEV *et al.,* 1979; SHARASKIN *et al,* 1980]. All these rocks get above the continental slab subduced: that is the obduction.

After the collision finishing, the cooling effect illustrated in general by geoisotherm bending *(Fig. 10),* stops and *thermic equalization* takes place. It results in partial melting of the subduced continental slab. Melted material is of less density and becomes bouyant and rises upward like a diapir being intruded into the oceanic — island arc complex. In this process, the deepest subduced crustal sections, *i.e.* the former edge of the continent only participate. Further from this edge, the oceanic-island arc complex covers the subduced continental crust as a nappe system.

Subducing oceanic slab drags the continental one which is in rigid connection with it. Density of oceanic slab is higher than that of underlying astenosphere that is why it sinks in astenosphere and drags continental slab not only forwards but also down. After the collision finishing, the dragging effect stops and an *isostatic equalization* takes place: continental lithosphere of less density emergences. Anatexis and granite intrusion mentioned above can be considered also as elements of this process.

The assemblage of thermic and isostatic equalization is the process named by classic geology "orogeny". During this process, the obduced oceanic-island arc complex suffers a deep erosion and its fragments only may be preserved. These fragments originated from the lowermost horizons of obduced oceanic lithosphere consist mostly of peridotite. These fragments are of two main types: the first in the granitization zone and the second before it. Structural position of peridotites in general depends on these types and is of two varieties, the first of them can be named "disjuncted" and the second one "plicated".

Peridotite of *disjuncted position* has got at present site from side or from above through tectonic movements dismembering obduced nappes. The same density excess

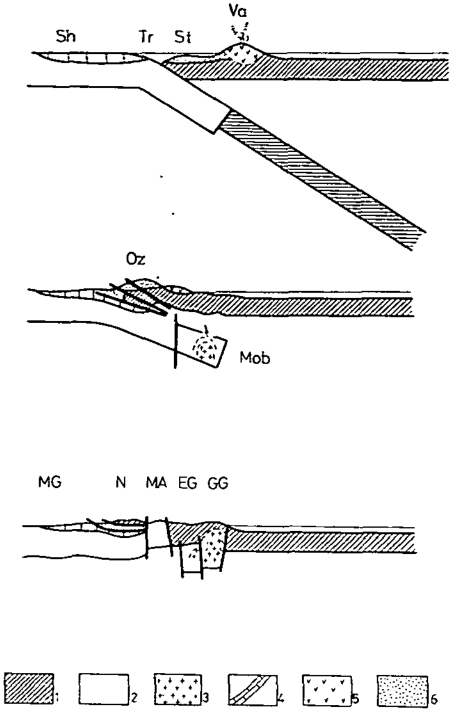

Fig. 9. Principal scheme of continent — island arc collision according to ZONENSHAIN *et al.* [1976] modified

Legend:
Sh — shelf
Tr — oceanic trench
St — sedimentary terrace
Va — volcanic arc
Oz — obduction zone
MG — "miogeosynclinal zone"
N — nappes
MA — "marginal anticlinorium"
EG — "eugeosynclinal zone"
GG — granite — gneiss doming zone
Mob — mobilization of subduced continental crust
1 — oceanic lithosphere
2 — continental lithosphere
3 — palyngenetic granite mobilized (accompanied by hT metamorphism)
4 — carbonate shallow-marine sediments
5 — island arc volcanites
6 — continental rise sediments (mostly turbidites)

which excludes rise upward of peridotites through continental crust, helps for its sinking into fracture zone generated during emergence due to isostatic equalization. Therefore, the origin from above is more probable even in lateral-slip faults. Disjuncted position probably is characteristic for areas far from the granitization zone.

Plicated position comes into being through folding of an obduced nappe system together with its continental basement. In the granitization zone, both can become so plastic as to undergo isoclinial and multiple folding. In a deep eroded state, syncline hinges of lowermost position only are preserved as peridotite bodies of lens-like form in a horizontal plane and of wedging out downward form in a vertical cross-section.

Form of the South Transdanubian serpentine bodies corresponds to both alternatives. According to thermal effects and to country rock folding, the Gyód and the Ófalu serpentines may be of syncline position. The Helesfa serpentine within granite is rather of disjuncted position. The only certain consequence, however, is that all South Transdanubian serpentine bodies wedge out downward and don't have any "roots".

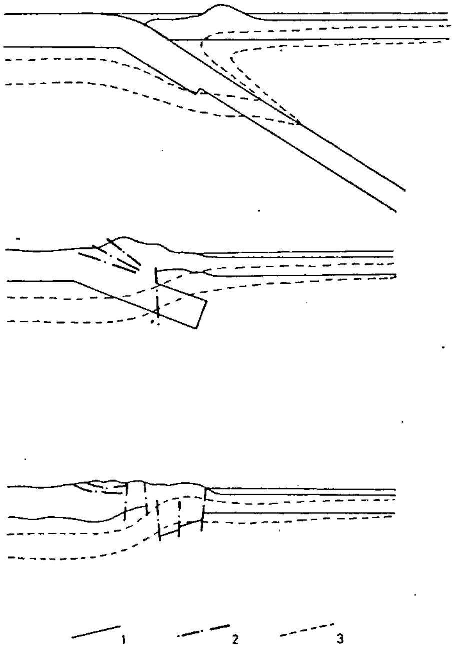

Fig. 10. Geoisotherms in the continent — island arc collision according to Zonenshain *et. al.*, [1976] modified

Legend:
1 — contours of lithospheric slabs (from the *Fig. 9)*
2 — main faults (from the *Fig. 9)*
3 — geoisotherms (schematically)

Another mechanism of the peridotite appearance in continental surrounding is related to mélanges or olistostromes. In a mature state of subduction an *accretionary wedge* develops on oceanic side of island arcs from sediments being scraped off the descending oceanic slab and folded—thrusted before the wedge-like edge of the island arc lithosphere *(Fig. 11)*. Between volcanic arc and oceanic trench, undersea terraces appear then a non-magmatic high comes into being as a second island row (for example, Andaman or Mentawai Islands in front of the Indonesian volcanic arc). Along the overthrusting plane within fan-like structure of accretionary wedges *(Fig. 12)*, *mélange* can be formed. On the rim of the shallow-marine area, on one hand, and on the inner trench slope, on the other hand, rocks outcrop which roll down along

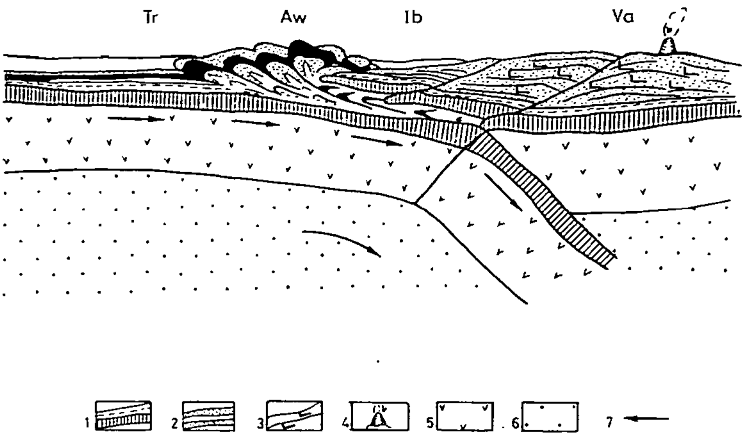

Fig. 11. Crustal structure model of an active island arc according to Sorokhtin, [1979] modified

Legend:
Tr — oceanic trench
Aw — accretionary wedge
Ib — interarc basin
Va — volcanic arc
1 — oceanic crust with sedimentary cover
2 — sediments of the continental slope and continental rise
3 — sedimentary—volcanogenic sequence
4 — active volcano
5 — upper mantle part of the oceanic lithosphere
6 — asthenosphere
7 — motion

the steep slope of terraces or of non-magmatic high, and are buried in lower position as olistolithes. Sediments rich in olistolithes are called *olistostromes*. Consequently, mélange and olistostrome mark practically identical geodynamic conditions and differ in forming mechanismus only. Both can contain peridotite blocks. Their amount is significant mostly in mélanges.

During obduction in a late phase of the continent — island arc collision, mélange and olistostrome get above the continental slab subduced. During nappe forming, new mélange zones are coming into being and olistostrome-lenses are occurring in the molasse complexes of foredeeps developed from oceanic trenches. Therefore, appearance of peridotite blocks in mélanges or olistostromes marks the same geodynamic situation as fragments of obduced nappes. In South Transdanubia the only Ófalu serpentine can be supposed to be of such origin according to proportions and form.

In any case, the South Transdanubian serpentines give evidence of a continent — island arc collision and postcollisional thermic—isostatic equalization. Possibilities of their position are as follows: for Helesfa—disjuncted, for Gyód — syncline-like or disjuncted, for Ófalu — olistolithe, block in mélange, disjuncted or syncline-like.

4. METAMORPHISM OF SERPENTINES

The first serpentinization was taking place as late as during subduction, and the peridotite bodies are getting at obduced position having been serpentinized. Lizardite—chrysotile composition would correspond to this metamorphism but in the same way, it could be a product of any latest 1T metamorphism. Concerning the postcollisional metamorphism, numerous problems are raised:

a) The borehole Helesfa—1 penetrated talc schists beneath serpentine with serpentine "intercalations". Talc can develop in serpentines in consequence of both hydrothermal ifluence and metamorphism in greenschist facies [Deer *et al.*, 1963]. Erdélyi [1974] that talc had originated from olivine and/or orthopyroxene at 700—800 °C in hydrous conditions. Thus, talc may be originated either from serpentine or from olivine and enstatite showing a higher temperature metamorphism in any case.

b) In serpentine of the borehole Gyód—2 clinoenstatite and forsterite was determined by Erdélyi [1971]. According to him [Erdélyi, 1974], serpentine minerals decompose over 800 °C to produce forsterite and partly enstatite which latter at 1140 °C turns into clinoenstatite. By the study of 2—3 cm clinoenstatite crystals were first chloritized (at about 500—600 °C) then substituted by lizardite (under 400 °C), therefore progressive metamorphism was followed by retrograde one, raising a question on existence of several generations of 1T serpentine minerals.

c) The Helesfa and the Gyód serpentines are crossed by aplite-microgranite veins. I suppose that the source of Mg during their strong metasomatism was the serpentine rock itself. Hydrothermal origin of this metasomatism does not seem to be probable because there are no traces of hydrothermal effects in country granites. This metasomatism can be regarded rather as a metamorphic feature, i.e. as a result

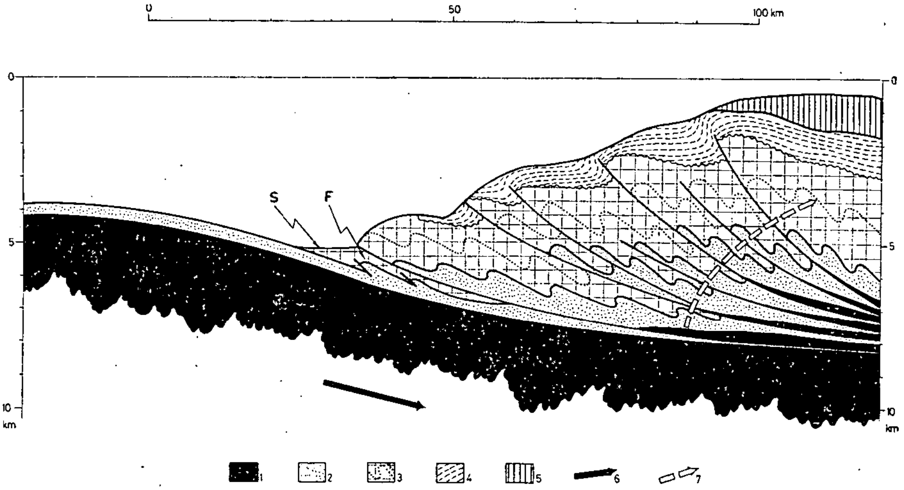

Fig. 12. Accretionary wedge model according to Seeley *et al.*, [1974] modified

Legend:
S — sedimentation level
F — folding zone
1 — oceanic crust
2 — pelagic sediment
3 — trench sediment (also in folded state)
4 — continental slope sediment
5 — shallow-marine sediment
6 — motion
7 — folding and imbrication oldering

of reactions between acidic magma and ultramafic rocks at *hT—hP* conditions. Identity of this metamorphism with that resulted in appearance of aplite-microgranite magma through partial melting seems to be the simplest assumption. It would mean, however, a quite high temperature (min. 700—800 °C) what should be reflected also in alteration of serpentine minerals. Clinoenstatite and forsterite in the Gyód serpentine and talc in the Helesfa one and chlorite in both of them may reflect this thermal effect, and the later rise of lizardite and chrysotile bulk should be resulted from that. Since the lack of acceptable textural analysis it is not proved. It is also difficult to understand why clinoenstatite and forsterite occur in the Gyód serpentine and talc appears in the Helesfa one only while aplite-microgranite veins undergone Mg metasomatism, are known in both sites.

d) According to GHONEIM and SZEDERKÉNYI [1979], antigorite appears in the outer zones of the Ófalu serpentine body. That would reflect a later thermal influence. Thickness of about several meters of these outer zones and the lizardite — chrysotile composition of central part of the body would show weakness of this thermal influence. According to ERDÉLYI [1974], antigorite is absent in the Ófalu serpentine but his two samples may have been taken from the central part. He describes a large amount of forsterite, enstatite and clinoenstatite of contact origin and presence of monoclinic chlorite and of the γ-Al_2O_3 originated from böhmite at 800—1000 °C. That would be understable only assuming the later origin of lizardite and chrysotile. If antigorite really is limited to outern zones, it can be product of a more later metamorphism.

e) Garnet was mentioned from the Helesfa serpentine by SZEDERKÉNYI [1970] and from the Ófalu one by JANTSKY [1979]. If this garnet is of metamorphic origin, it reflects pressure corresponding with about 15—20 km depth [LUTS, 1974]. Even if the heat-flow was normal, that means a temperature of about upper existence limit of antigorite or higher, therefore both the Helesfa and Ófalu serpentinization could take place after garnetic metamorphism only. Higher more temperature is shown by the Görcsöny eclogite in several km west of Gyód [RAVASZ—BARANYAI, 1969]. This eclogite, perhaps, is originated from basic magmatic rock associated with the Gyód peridotite, and its mineral composition and texture give evidences of multiphase retrograde metamorphism [RAVASZ—BARANYAI, 1969] what supports the idea of late rise of serpentine mineral bulk.

Thus the South Transdanubian serpentines were affected by complicated multiphase metamorphism which is not analysed and cannot be interpreted. Lizardite and chrysotile in the Helesfa and Gyód serpentines are expected to be products of the last low-grade metamorphism while antigorite of the Ófalu serpentine fixes a stronger thermal effect as the last metamorphic event.

5. GEOLOGICAL HISTORY AND AGE

For reconstruction of geological history, two sure objects only exist: peridotite and granite. First of them marks a continent — island arc collision and the second one marks a postcollisional thermic — isostatic equalization. Supposition of causal relations between them seems to be the simplest concept resulted in several statements as follows:

a) Aplite-microgranite veins occurring in both the Gyód and Helesfa serpentine as well as the thermal metamorphism affected these bodies, are products of a postcollisional granitization taken place immediately after obduction of peridotites above continental crust.

b) On the basis of real dimensions of the Earth and of observable plate motion rates, a concrete piece of oceanic crust can exist maximally for 150—200 m. yr. Since granitization was produced by a process finishing total disappearance of oceanic crust in a concrete area, peridotite can be older than granite maximally of 150—200 m. yr.

c) Granitization begins in deep horizons of continental crust. These deep horizons are everywhere on the Earth of Middle Proterozoic or older age [Dobretsov, 1980]. Therefore presence of such metamorphics in granitized complexes of any age is natural. Melted granite together with fragments of their original country rocks is intruded into oceanic — island arc complex which forms the bulk present country rocks. Through purposeful investigations only, it can be established which part of metamorphic rocks are originated from the subduced continental slab and which one are generated from the oceanic basement and volcanogenic—sedimentary cover of the island arc.

d) Peridotite and granite fixes the following events: normal oceanic spreading, subduction (island arc), continent — island arc collision and postcollisional thermic—isostatic equalization.

Age of these events can be determined only going backward in the time. Upper age boundary of granitization and metamorphism connected with postcollisional equalization, is fixed by presence of detrital material of related rocks in Upper Carboniferous — Lower Permian sediments [Szederkényi, 1974]. These sediments are of molasse type and are supposed to have been accumulated in depressions of a mountain system. Origin of this mountains can be related most simple to postcollisional emergence what fixes age of granitization and metamorphism in Lower Carboniferous. Collision can be finished maximally 10 m.yr before this date and can be started maximally 15—20 m.yr before the second date. Thus collision can begin only as early as in Upper Devonian. Subduction time interval cannot be estimated but according to the age of collision, oceanic lithosphere cannot be formed earlier as in Ordovician, corresponding with conclusions based on analogies that the Ófalu complex seems to be of Silurian [Szederkényi, 1970], partly perhaps of Ordovician [Szederkényi, 1977a] or of Devonian [Szederkèny, 1977d] age.

CONCLUSIONS

Therefore, the South Transdanubian sequences mark the following events *(Fig. 13)*:

1. Ocean generation with ancient (Precambrian) continents on the coasts — (Ordovician?) — Silurian—(Devonian?).
2. Subduction: island arc coming into being chiefly on oceanic crust — Devonian.
3. Collision: subduction of the ancient continent being scarred with the former oceanic lithosphere, under island arc — (Upper Devonian?) — Lower Carboniferous.
4. Postcollisional equalization: partial mobilization and emergence of the subduced ancient continent — Lower (and Middle?) Carboniferous.
5. Denudation and peneplanation: Upper Carboniferous — Lower Permian.

Conclusions given above are based on an assumption of causal relationship between appearance of peridotite and granitization. In reality, radiometric and paleomagnetic data [Márton—Szalay, 1979] give evidences of Upper Carboniferous age of granite. Relative direction of subduction as well as present position of the collisional suture could be determined on the basis of investigation of structural zonality. Now, this zonality cannot be reconstructed because many problems of metamorphic

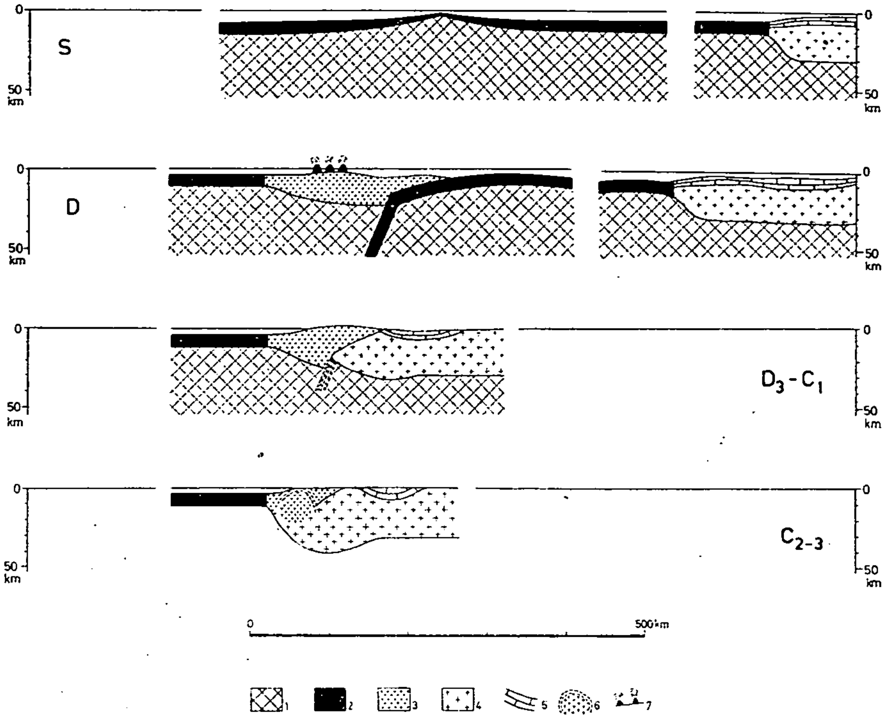

Fig. 13. Scheme of development of the South Transdanubian Paleozoic (todays orientation of the cross-section is unknown)

Legend:
1 — upper mantle
2 — oceanic crust
3 — island arc crust
4 — continental crust
5 — shallow-marine sediments
6 — zone of granitization and metamorphism
7 — active calc-alkalic volcanoes

rocks are unsolved and a later (Alpine) rearrangement must have taken place. For example, the Ófalu complex bearing serpentine coincides with an obvious young (Cretaceous or Cenozoic) tectonic zone which seems to lay between the Helesfa and the Gyód bodies *(Fig. 1)*. On the basis of the plate tectonics concept, cataclastic rocks should be expected in this zone instead of metamorphic ones, although these cataclastic rocks might be originated also from metamorphic ones.

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