GEOCHEMISTRY, TECTONO-MAGMATIC DISCRIMINATION AND RADIOLARIAN AGES OF BASIC EXTRUSIVES WITHIN THE IZMIR-ANKARA SUTURE BELT (NW TURKEY): TIME CONSTRAINTS FOR THE NEOTETHYAN EVOLUTION

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ABSTRACT

The Dağkuplu Mélange in the Central Sakarya Valley represents the northernmost outcrops of the Izmir-Ankara Suture Belt in northwest Anatolia. In addition to blocks and slivers of serpentinite, gabbro, blueschist, neritic and pelagic limestones, it includes blocks of basic volcanic rocks associated with radiolarian cherts, pelagic carbonates and mudstones.

The preliminary geochemical data revealed the existence of a variety of basaltic rocks with magma types ranging in composition of MORB, IAT, OIB and CAB, in the mélange.

The age of the radiolarian assemblage from a tectonic block of chert-mudstone alternation associated with OIB-type basalts within the mélange is assigned to early Berriasian - early Hauterivian, based on the co-occurrence of radiolarian taxa as *Angulobracchia* sp. cf. *A.* (?) *portmanni, Godia nodocentrum*, *Pantanellium masirahense*, *Thanarla brouweri*, *Pseudoeucyrtis hanni*, *Svinitzium mizutanii*, *Mirifusus dianae* s.l., *Tethysetta boesii*. Another block of chert-mudstone alternation associated with MORB-type basalts includes the following Cenomanian radiolarian fauna: *Thanarla pulchra*, *Novixitus mclaughlini*, *Pseudodictyomitra pseudomacrocephala*, *Pseudodictyomitra tiara*, *Stichomitra communis*.

New findings from the Central Sakarya area combined with previous data of the authors reveal that the Izmir-Ankara Ocean started to open already in the Late Triassic. The formation of OIB-type intra-plate seamounts within the Izmir-Ankara Ocean began in late Bathonian and persisted until early Aptian. The the intra-oceanic subduction and the generation of supra-subduction-type volcanism started in early Santonian and the spreading-ridge of the Izmir-Ankara Ocean plate was not subducted until the Cenomanian.

INTRODUCTION

The Izmir-Ankara Suture Belt in northern Turkey (Fig. 1) represents the remnants of the Neotethyan Izmir-Ankara seaway (e.g. Sengör and Yılmaz, 1981; Göncüoglu et al., 2000; Robertson, 2002; 2004) and is one of the key areas in the Eastern Mediterranean to study the formation of ophiolites and related oceanic rocks. These rocks were incorporated into the subduction-accretion prisms and mélange complexes and survived subduction. The study of basaltic extrusive rocks and associated sediments, especially radiolarian cherts, within these mélange complexes may yield valuable and detailed information on the evolution of Neotethys.

Previous geochemical work on these rocks in the western and central segments of the Izmir-Ankara Suture Belt reveals their formation in a variety of tectonic settings, such as mid ocean ridges, island arcs, oceanic islands and fore- and back-arc basins (Floyd, 1993; Önen and Hall, 1993; Yalınız et al., 2000a; 2000b; Floyd et al., 1998; 2000; 2003; Köksal-Toksoy et al., 2001; Göncüoglu et al., 2000). However, the scarcity of age data from these volcanic rocks of different origins prevents to reconstruct the evolution of the Izmir-Ankara Ocean.

This paper presents new radiolarian and igneous geochemical data for the Mesozoic mélange complex of the Izmir-Ankara Suture Belt, NW Turkey. Here the Izmir-Ankara Suture Belt includes huge tectonic slices of almost complete oceanic lithosphere sequence (e.g. Orhaneli Ophiolite; Lisenbee, 1972 or Kınık Ophiolite; Onen, 2003) in a several kilometers-thick mélange complex (e.g. the well-known Ankara Mélange; Bailey and Mc Callien, 1950). Within the mélange complex, dismembered thrust sheets and blocks of basaltic pillow-lava either interbedded with radiolarian cherts or including intra-pillow cherts were sampled in different localities. The geochemical data obtained from the basaltic rocks have been evaluated by M.K. Yalınız (second author), whereas the variably preserved radiolarian faunas have been determined by U.K. Tekin (third author).

The aim of this study is to discuss the evolution of the Neotethyan Izmir-Ankara branch of Neotethys based on the tectono-magmatic discrimination of the basic extrusive rocks and on the new chrono-stratigraphic findings from the associated radiolarian cherts.

GEOLOGICAL FRAMEWORK

The Central Sakarya area is located in NW Turkey on the *Izmir-Ankara Suture Belt*, along which the Sakarya and Tauride-Anatolide continental microplates are juxtaposed (Figs. 1 and 2). Here the Sakarya Valley has deeply truncated the major tectonic units: Somdiken Metamorphics of the Tauride-Anatolide Unit in the south, Central Sakarya Ophiolite Complex in the center and the Sakarya Unit of the Sakarya Microcontinent in the north (Göncüoglu et al., 2000). Related to its crucial position, it provides a unique opportunity to study the structural relationships of the major

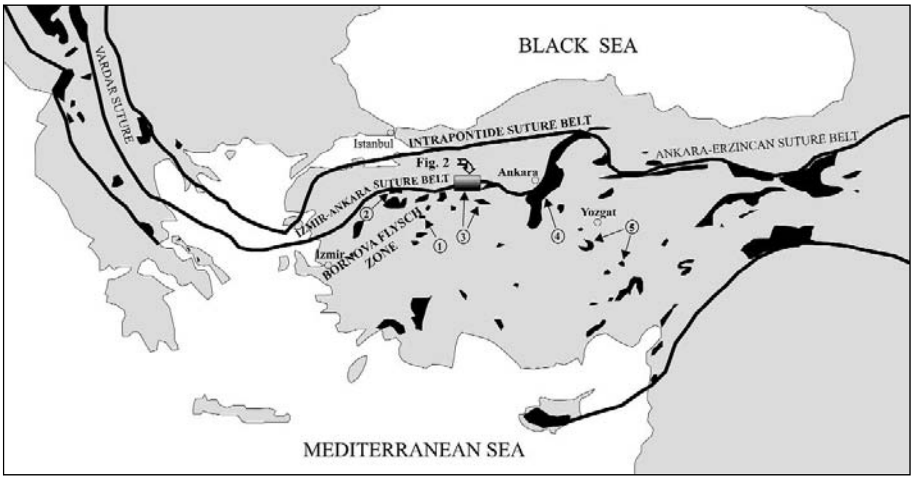

Fig. 1 - The map shows locations of the Alpine sutures, ophiolitic complexes and mélanges in the Eastern Europe and the Eastern Mediterranean realms (simplified after Göncüoglu et al., 1997; Stampfli, 2000). 1- Orhaneli Ophiolite, 2- Kınık Ophiolite, 3- Central Sakarya Ophiolitic Complex, 4- Ankara Mélange, 5- Central Anatolian Ophiolites.

tectonic units as well as to clearly observe the contacts of the rock-units in the mélange-complex. The contact of the Central Sakarya Ophiolite Complex and the Sakarya Unit is a south verging thrust fault that can be followed along-strike for more than 75 km along the Sakarya Valley. The thrust plane is steep in the east (60-70° to the N) but becomes gentle inclined towards the west (30° to the N). The original contact of the Ophiolite Complex and the Somdiken Metamorphics is another south verging thrust fault, where ophiolitic rocks rest on a gently north-dipping thrust plane overriding the metamorphics. The age of the initial juxtaposition is post-early Maastrichtian - pre-Middle Paleocene (Göncüoglu et al., 2000).

The studied Central Sakarya Ophiolite Complex includes two thrust-sheets. The upper sheet is called Taštepe Ophiolite and occurs as an almost 4000 m thick dismembered ophiolitic unit, mainly comprising slices of tectonites and mafic-ultramafic cumulates. Members of the dyke complex and lava sequence are not frequently observed. Discontinuous outcrops of sub-ophiolitic metamorphics, mainly garnet-amphibolites with few alternating bands of marbles and Mn-rich cherts are exposed below the main ultramafic body. The partly serpentinized harzburgites contain chromite pods. Dunite-clinopyroxenite/wehrlite-clinopyroxenite-gabbro cumulates together with troctolites, two-pyroxene gabbros and gabbro-norites, in ascending order, are followed by layered gabbros with distinct hydrothermal metamorphism.

The main body of the lower thrust-sheet is represented by the Dağkuplu Mélange (DM), which has been sampled in detail. The complex mainly comprises blocks of spilitic metabasalt, radiolarian chert, blueschist, pelagic limestone, serpentinite, and neritic limestone of mainly Mesozoic age. Blocks of amphibolite, intermediate volcanics (mainly andesites), layered gabbros, pyroclastic rocks and volcanoclastic sandstones occur in minor amounts. The limestone blocks may be up to several kilometers across and have sharp contacts against adjacent blocks. Polymictic breccias and greywackes that locally occur as matrix between blocks are dominated by clasts of basic volcanic rocks and red cherts. The mélange in general is strongly sheared and faulted. Locally, sheared and folded successions, up to 50 meters in thickness, of volcanogenic sandstones and argillaceous sediments with thin chert interlayers can be observed.

Pillowed and massive basaltic rocks dominate over other knockers and are associated in some cases with red to brick-colored cherts, micritic limestones and red, black and violet mudstones (Fig. 3).

The basaltic rocks sampled for geochemical work and associated chert/mudstones for radiolarian determinations come from two localities. The first locality is on the road cuttings to south of the Dağkuplu Village (Fig. 2, sampling area 1), where massive lavas and pillowed basalts are interlayered with thin bands and lenses of brick-colored radiolarian cherts. Three distinct thrust-slices with volcanic rocks separated by schistose serpentinized ultramafic rocks and mudstones were sampled in this locality. Two of the slices corresponding to samples 1-3 (group 4) and 4-7 (part of group 3) are more than 150 meters thick and several hundred-meters long and are juxtaposed along a pinching-and

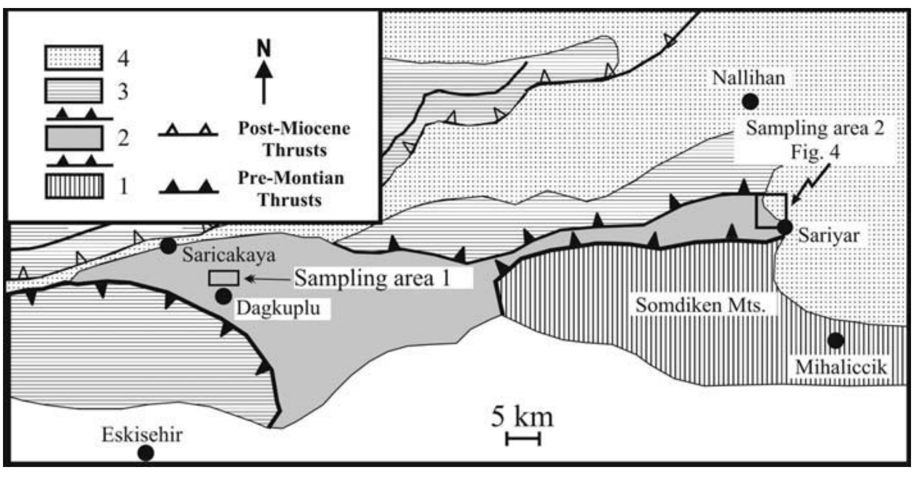

Fig. 2 - Simplified map of the main structural units in the Central Sakarya area (after Göncüoglu et al., 2000). Explanations: 1- Somdiken Metamorphics (Tauride-Anatolide Platform); 2- Central Sakarya Ophiolitic Complex, 3- Sakarya Composite Terrane; 4- Tertiary Cover.

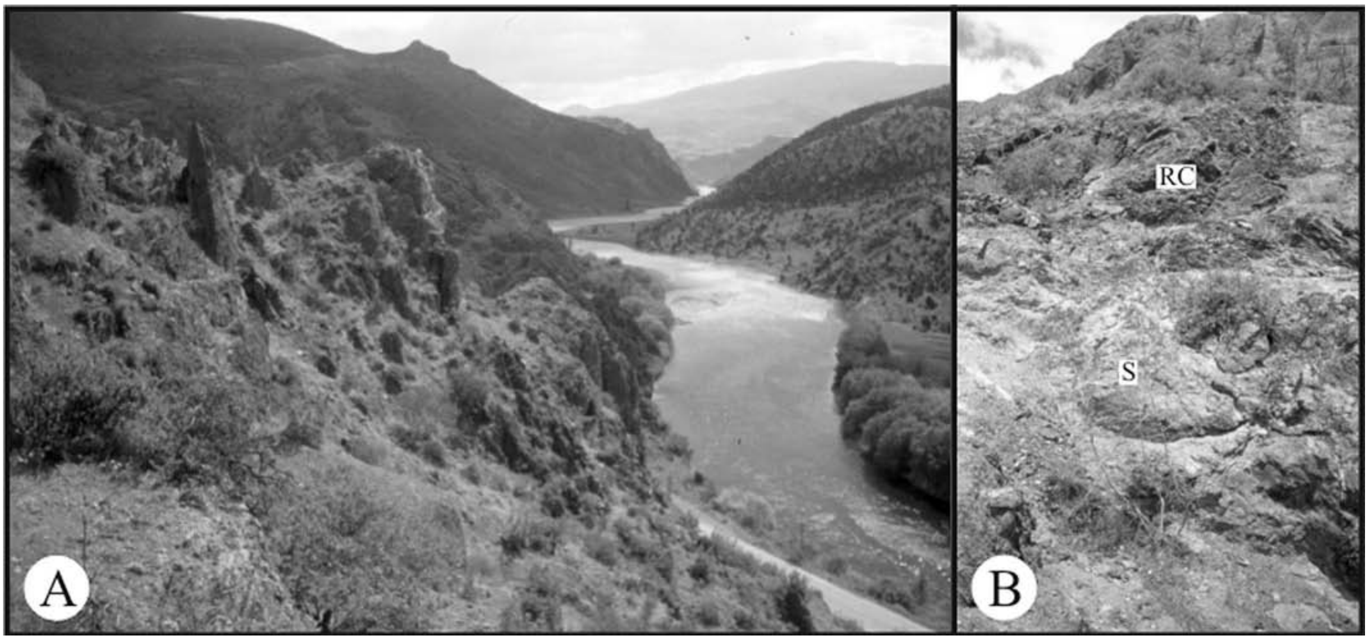

Fig. 3 - A. General view of the Dağkuplu Mélange within the Sakarya Valley; B. Tectonic relationship between the radiolarian chert blocks (RC) and serpentinites (S).

swelling zone with 2 meters thick, highly sheared serpentinites. Samples 8-9 (group 2) are from another slice with slightly metamorphosed pillow-lavas cut by diabase dykes. Cherts sampled from this locality are also recrystallized and no radiolarians could be extracted.

The second locality is further to the east, located in a gorge south of the Emremsultan village (Fig. 2, sampling area 2). In this location, the road cutting along the Sakarya Valley and that in the Emremsultan Gorge perpendicular to it, provide an unique opportunity to observe the tectonic relations. From several blocks of volcanic rocks with sheared boundaries against each other only two of them include sedimentary admixtures. The upper slice (Fig. 4 and 5) from where the radiolaria-bearing samples 99-UKT-26 and 27 derived, consists of pillow and massive lavas (samples 10-15 of group 3) and pillow breccias. In the upper part of this slice, thin-bedded and slightly folded cherts alternate with red mudstone. The sedimentary succession is only 5.5 meters thick (Figs. 5 and 6)

The second slice tectonically underlies the former one (Fig. 5) and can be followed for more than 200 meters along-strike. It mainly consists of pillow-lavas with brick-red, well-bedded ribbon-cherts (samples 99-UKT-25 in cross-section (Fig. 5) and 99-UKT 32 indicated as a star (Fig. 4)). The basaltic lavas in this slice are characterized by well-preserved pillow-structures, up to 30 cm in diameter and include fine epidote and prehnite-bearing vesicles. The intra-pillow fillings between the lobes include green hyaloclastics and radiolarian cherts. The samples collected (16-19 of Group 1) are fine-grained and relatively fresh.

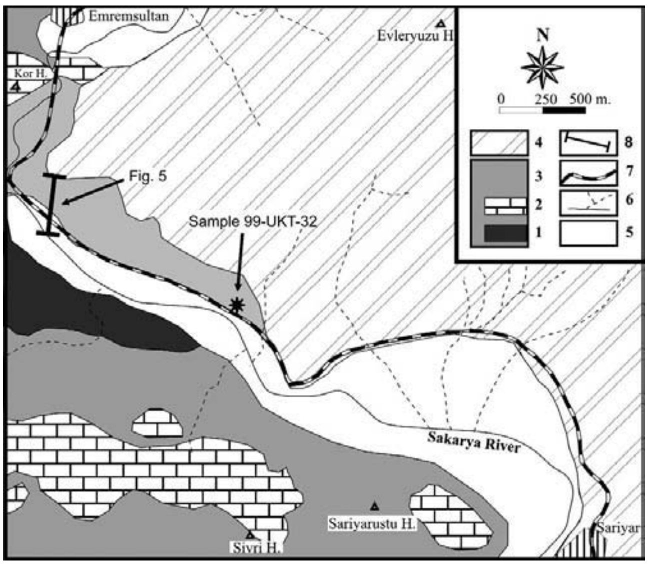

Fig. 4 - Geological map of the fossiliferous outcrops. Legend: 1-3- Central Sakarya Ophiolitic Complex; (1- Blocks of serpentinized peridotite, pyroxenite and gabbro; 2- Blocks of recrystallized limestone; 3- Undifferentiated mélange); 4- Tertiary cover; 5- Quaternary deposits, 6- Drainage system; 7- Main road; 8- Location of cross-section.

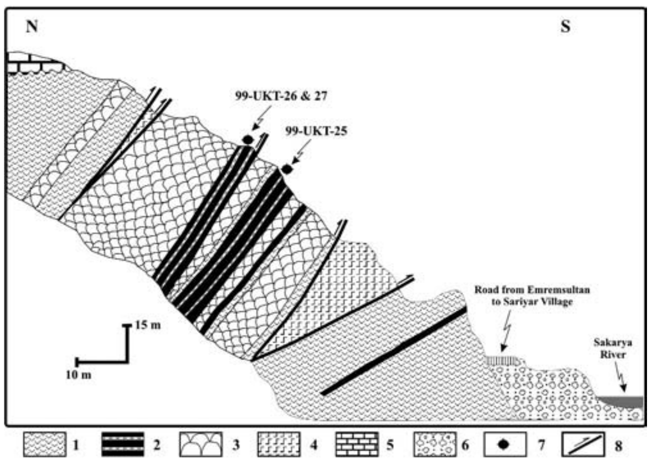

Fig. 5 - Cross-section of fossiliferous rocks within the Sakarya Valley. Legend: 1- Green to black volcanics; 2- Red to green cherts with silicified mudstone intercalations; 3- Green to black pillow-lava; 4- Serpentinite; 5- Miocene lacustrine limestone; 6- Quaternary terrace sediments; 7- Radiolaria-bearing samples; 8- Main faults.

GEOCHEMISTRY OF BASALTIC ROCKS

Volcanic samples representing different magmatic compositions have been collected from different localities within the DM in the Central Sakarya Valley (Fig. 2). Eighteen samples were selected for whole-rock X-ray fluorescence (XRF), major and trace element analysis (Table 1). All samples were analyzed with an ARL 8420 X-Ray Fluorescence spectrometer (Department of Earth Sciences, University of Keel). Details of methods, accuracy and precision are given in Floyd and Castillo (1992). All of the analyzed samples show secondary mineralization. Secondary processes affecting the samples range from low-temperature sea floor alteration to lower greenschist facies metamorphism.

In this study, all chemical assesments and discrimination rely mainly on the trace elements that tend to be immobile under low grade alteration. These elements can be used to define petrologic groups and determine the tectonic environment in which a suite of igneous is rocks formed (Fig. 7).

Magma series

Basaltic samples from the DM are distinguished primarily by their subalkaline versus alkaline signatures. Therefore, all analyses were plotted on the Zr/TiO2 vs Nb/Y classification diagram of Winchester and Floyd (1977), which involves only relatively immobile elements (Fig. 7a). On this diagram the samples form three tight groups and plot within distinctly different fields. The majority of the DM basalts plot in the field of alkaline basalt. However, some samples have much lower Nb/Y values, which imply that they belong to subalkaline (tholeiitic) magma series and are therefore clearly distinct from alkaline magma series. Interestingly, three samples plot in the field close to the sub alkaline-alkali basalt demarcation line, suggesting that they have a weak alkaline affinity.

Petrographic and geochemical characteristics

Petrogenetic discrimination diagrams can be used to distinguish between suites of rocks with different genetic origins. These diagrams are empirical and indicate the statistical likelihood that a given suite of rocks was formed in the indicated environment. After analyzing discrimination and multi-element variation diagrams of the analyzed samples, they can also be further subdivided into four chemically distinct sample groups: (1) MORB, (2) IAT, (3) WPB and (4) CAB.

MORB like basalts range from subophitic-textured, through intersertal-textured with plagioclase and augite phenocrysts, to occasional olivine and plagioclase phyric or plagioclase and augite phyric basalts with largely devitrified glass rims. Except for a few unaltered glass pillow rims in which fresh olivine is preserved, sparse olivine phenocrysts are replaced by chlorite, and chlorite and calcite. IAT basalts mainly consist of clinopyroxene and plagioclase. WPB's, instead, are characterized by the occurrence of Ti-augite nearby the plagioclase. On the other hand, CAB display subhedral to euhedral brown to green amphibole, plagioclase and diopside. All samples show secondary alteration minerals (calcite, chlorite, epidote, clay minerals, quartz). Plagioclase is almost completely albitized; in some altered samples plagioclase instead is replaced by epidote, clay minerals and clinozosite, while clinopyroxene is altered to uralite. Amphibolization and sericitization also commonly occur in the basalts.

The sample groups fall quite well within single tectonic fields in the discrimination diagrams (Fig. 7). The Ti-Zr-Y diagram of Pearce and Cann (1973) separates over 95% of within plate and calc-alkali basalts from other magma types and also achieves a partial separation of mid-ocean ridge basalt (MORB) and island arc tholeiite (IAT) (Fig. 7b). Most within-plate basalts can be distinguished from MORB by their Ti/Zr and Zr/Y vs. Zr ratios (Pearce and Cann 1973; Pearce and Norry 1979) (Fig. 7c, 7d). Furthermore, most IAT can be distinguished from MORB by their lower mean values of the immobile incompatible elements, Zr and Ti (Fig. 7c, 7d). On the Ti-Zr-Y diagram group 3 and 4 samples clearly plot in WPB and CAB fields respectively, whereas all other samples of groups 1 and 2 plot almost exclusively within the MORB+IAT+CAB field (Fig. 7b). The WPB and CAB geochemical characters of group 3 and 4 are also evident in the Ti-Zr and Ti-Zr-Sr discrimination diagrams of Pearce and Cann (1973) (Fig. 7c, 7e). Pearce and Norry (1979) have suggested that the Zr/Y ratio of lavas from oceanic settings decreases steadily from WPB, MORB to IAT compositions with a concomitant decrease in the absolute Zr abundances. A ratio such as Zr/Y plotted against Zr should therefore be most effective in distinguishing these lava types. For the DM sample groups, this can be observed in Fig. 7d where samples of groups 3 and 4 are clearly separated from groups 1 and 2 on the basis of their higher Zr/Y content. Groups 1 and 2 cannot be distinguished again from MORB and IAT, although group 2 shows a slight decrease in Zr/Y ratio relative to group 1, which is characteristic for the IAT lavas. Hence, no definitive conclusion can be drawn as to the tectonic setting of group 1 and 2 using these diagrams alone. Shervais (1982) suggested that plots of Ti vs.

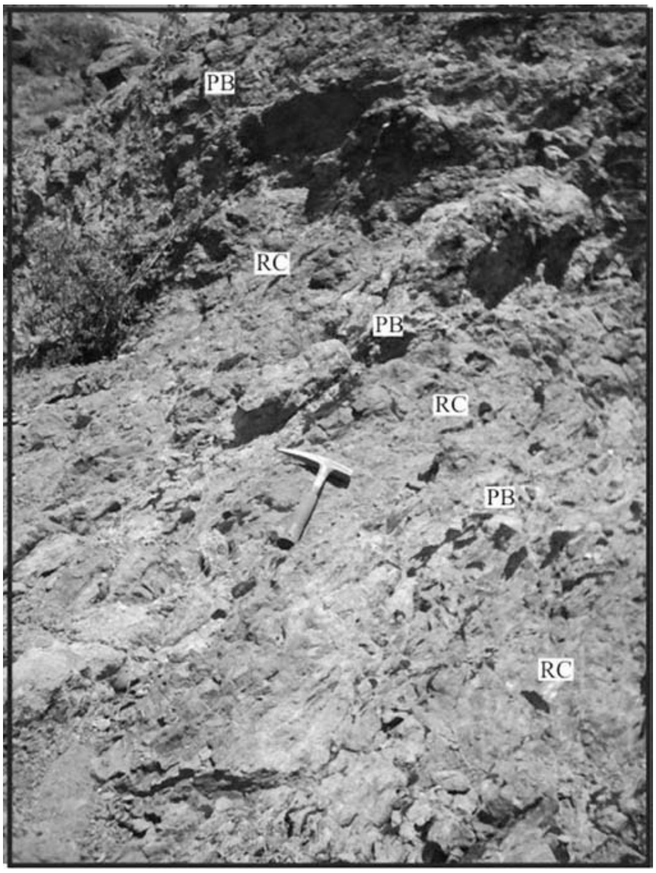

Fig. 6 - Close-up view of radiolarian cherts (RC), from where sample 99-UKT-32 was collected, and associated pillow basalts (PB).

Table 1 - Chemical analyses of the Central Sakarya basalts

Sample	DK-1	DK-2	DK-3	DK-4	DK-5	DK-6	DK-7	DK-8	DK-9	DK-10	DK-11	DK-12	DK-13	DK-14	DK-15	DK-16	DK-17	DK-18
Chemical groups	CAB	CAB	CAB	WPB	WPB	WPB	WPB	IAT	IAT	WPB	WPB	WPB	WPB	WPB	WPB	MORB	MORB	MORB
Si02	51.78	53.41	53.06	48.54	37.2	42	41.47	52.18	55.03	44.61	46.3	45.75	47.45	42.17	42.92	48.21	48.37	49.06
TiO2	0.99	0.95	0.98	2.67	2.57	3.79	3.58	0.66	0.59	3	2.79	2.38	3.03	3.41	2.9	1.11	1.19	1.08
Al2O3	15.19	16.19	15.73	10.87	9.75	13.34	13.05	14.63	15.51	12.12	10.62	11.56	12.34	11.75	12.26	14.62	13.63	14.92
Fe2O3t	7.68	7.68	7.84	11.47	11.16	15.75	15.29	9.18	8.82	12.96	12.48	12.45	10.32	13.1	12.92	9.26	9.97	9.21
MnO	0.13	0.18	0.13	0.14	0.18	0.22	0.19	0.21	0.19	0.18	0.16	0.16	0.12	0.17	0.17	0.15	0.16	0.15
MgO	6.49	5.38	6.01	8.01	8.31	6.33	6.92	6.87	5.13	8.63	9.61	9.09	7.01	7.33	8.74	6.87	5.62	5.35
CaO	7.49	6.12	6.85	11.49	16.3	9.72	11.38	6.86	5.23	10.48	10.12	10.5	12.24	11.76	10.07	11.96	13.03	11.96
Na2O	4.22	4.22	4.52	3.27	3.31	2.75	2.54	5.55	6.05	2.36	2.67	3.19	3.71	3.67	2.35	3.02	3.86	3.91
K2O	3.5	4.29	3.52	0.37	0.46	2.22	1.6	0.11	1.13	1.76	1.68	1.25	0.61	0.84	2.57	0.01	0.01	0.06
P2O5	0.6	0.63	0.62	0.43	0.53	0.85	0.79	0.06	0.07	0.57	0.48	0.37	0.49	0.55	0.53	0.12	0.15	0.11
Lol	1.56	1.09	0.98	3.27	10.54	3.45	3.5	3.29	2.33	3.8	2.96	3.58	2.64	5.29	4.24	4.81	3.91	4.39
Total	99.63	100.08	100.24	100.53	100.51	100.42	100.31	99.6	100.08	100.47	99.87	100.28	99.96	100.04	99.67	100.14	99.9	100.2
Ba	1310	1507	1377	212	165	644	414	71	159	118	105	153	59	114	349	34	44	21
CeX	204	203	201	79	54	136	103	4	17	103	84	73	84	118	87	3	6	10
Cl	2	3	14	2	3	2	2	2	5	1	2	3	2	1	1	2	3	1
Cr	97	54	91	295	680	335	348	49	38	414	480	685	140	202	665	437	363	296
Cu	70	75	70	94	74	82	79	10	43	70	87	98	68	98	74	67	68	50
Ga	16	15	17	16	15	20	21	17	16	20	17	16	16	18	21	16	17	18
LaX	95	107	101	38	29	61	47	1	2	63	40	31	43	41	36	2	2	1
Nb	19	22	19	48	45	68	64	2	3	67	56	43	56	64	51	2	5	3
NdX	81	76	73	34	34	59	46	8	15	42	40	39	39	56	46	13	7	18
Ni	36	30	36	79	166	115	105	32	30	156	155	199	84	93	295	160	285	94
Pb	39	39	47	9	11	15	13	3	3	11	10	11	10	14	9	5	9	8
Rb	39	46	38	8	10	58	37	4	28	34	31	26	13	17	50	1	1	3
S	78	80	116	21	18	173	342	2	42	52	39	667	38	419	35	89	174	111
Sr	1045	1050	986	124	426	161	184	73	20	188	129	275	142	633	344	86	100	85
V	170	166	189	253	272	328	314	281	264	254	277	246	234	320	361	269	258	258
Y	29	29	28	24	25	34	29	21	34	30	27	25	30	30	28	27	30	33
Zn	65	71	73	84	97	136	126	60	51	112	106	97	86	13	111	71	70	66
Zr	166	179	163	199	193	242	224	41	70	261	226	187	233	261	227	67	78	71

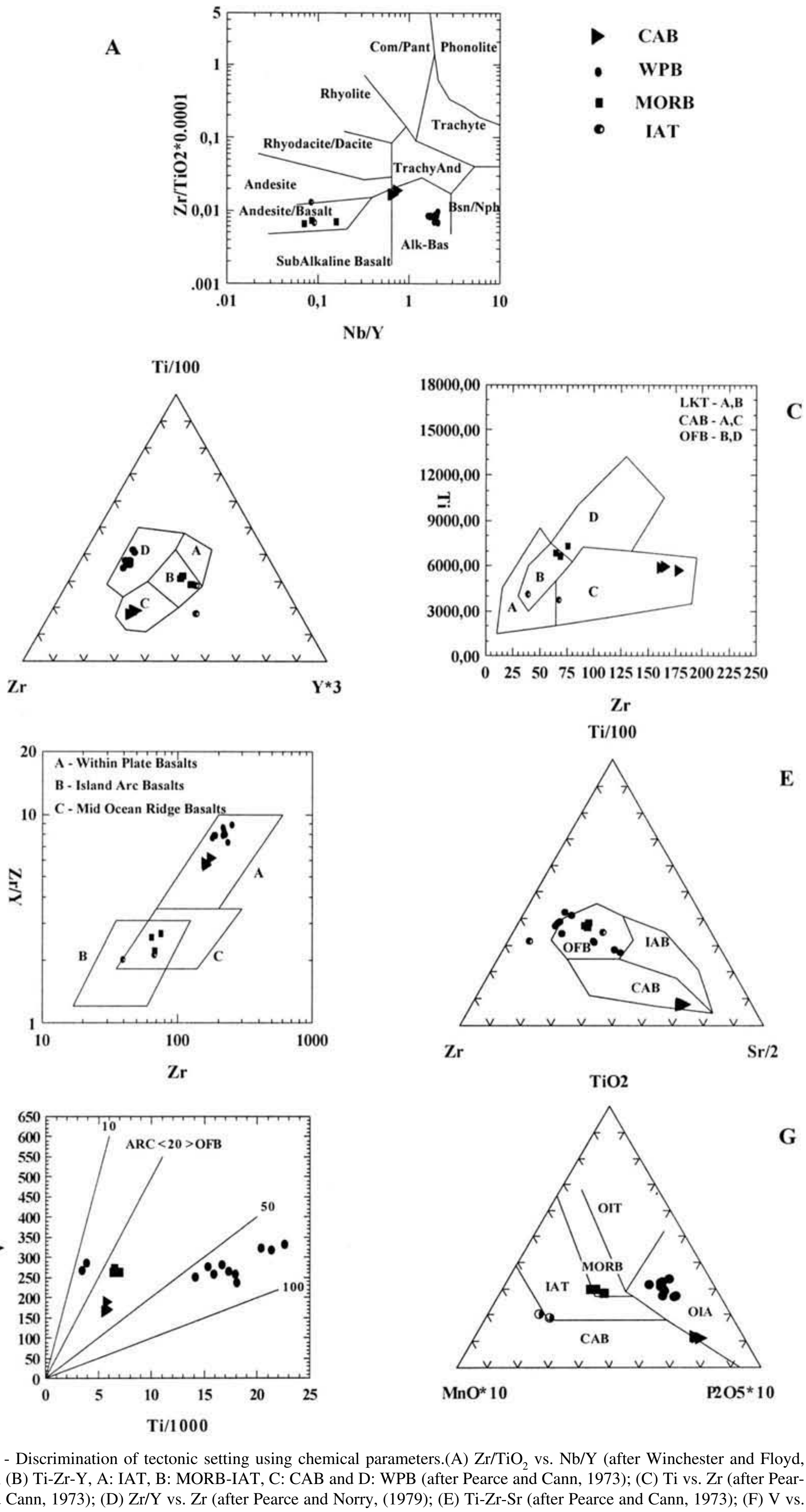

Fig. 7 - Discrimination of tectonic setting using chemical parameters.(A) Zr/TiO_2 vs. Nb/Y (after Winchester and Floyd, 1977); (B) Ti-Zr-Y, A: IAT, B: MORB-IAT, C: CAB and D: WPB (after Pearce and Cann, 1973); (C) Ti vs. Zr (after Pearce and Cann, 1973); (D) Zr/Y vs. Zr (after Pearce and Norry, (1979); (E) Ti-Zr-Sr (after Pearce and Cann, 1973); (F) V vs. TiO_2 (after Shervais, 1982); (G) Ti/MnO/P_2O_5 (after Mullen, 1983).

V are diagnostic of the tectonic setting of several lava associations. He showed that boninites have Ti/V ratios < 10, island-arc tholeiites have Ti/V ratios < 20, MORB and continental tholeiites have Ti/V ratios of 20-50, and alkaline rocks have Ti/V ratios generally > 50. Back-arc basin basalts are not distinguished from MORB, whereas calc-alkaline rocks overlap with the IAT and MORB fields. The sample groups referred to above are clearly different and fall in different tectonic setting fields in the Ti/V discrimination diagram of Shervais (1982) (Fig. 7f). Groups 1 and 2 are clearly separated and fall in the MORB and IAT fields respectively. Group 3 again falls in the OIB field, however, we are unable to see CAB geochemical characters of group 4 because a major failing of this diagram is the inability to distinguish CAB from true MORB; this is discussed above. The geochemical characteristics of the sample groups, clearly observed in the diagram of Shervais (Fig. 7f), are also evidenced in the diagram of TiO2-MnO*10-P_2O_5 (Mullen, 1983) as four distinct different tectonic settings of the sample groups (Fig. 7g).

N-MORB normalized multi-element patterns are presented for the sample groups in Fig. 8. The geochemical patterns of groups 1 and 2 are characterized by lower abundance of HFSE with respect to groups 3 and 4. The geochemical patterns of group 1 have incompatible element abundances that lie within the range of N-MORB (Fig. 8a). However, the group 2 samples are more enriched in some LFSE (K, Rb, Ba, and Sr) and more depleted in HFSE (Nb, Zr, Ti, P and Y) contents in contrast to group 1 ones (Fig. 8b). N-MORB normalized plot exhibits the depletion of HFSE coupled with the strong enrichment of selected LFSE and broadly confirms an island arc tholeiites setting rather than an oceanic spreading ridge (N-MORB) one for group 2 samples (Fig. 8b).

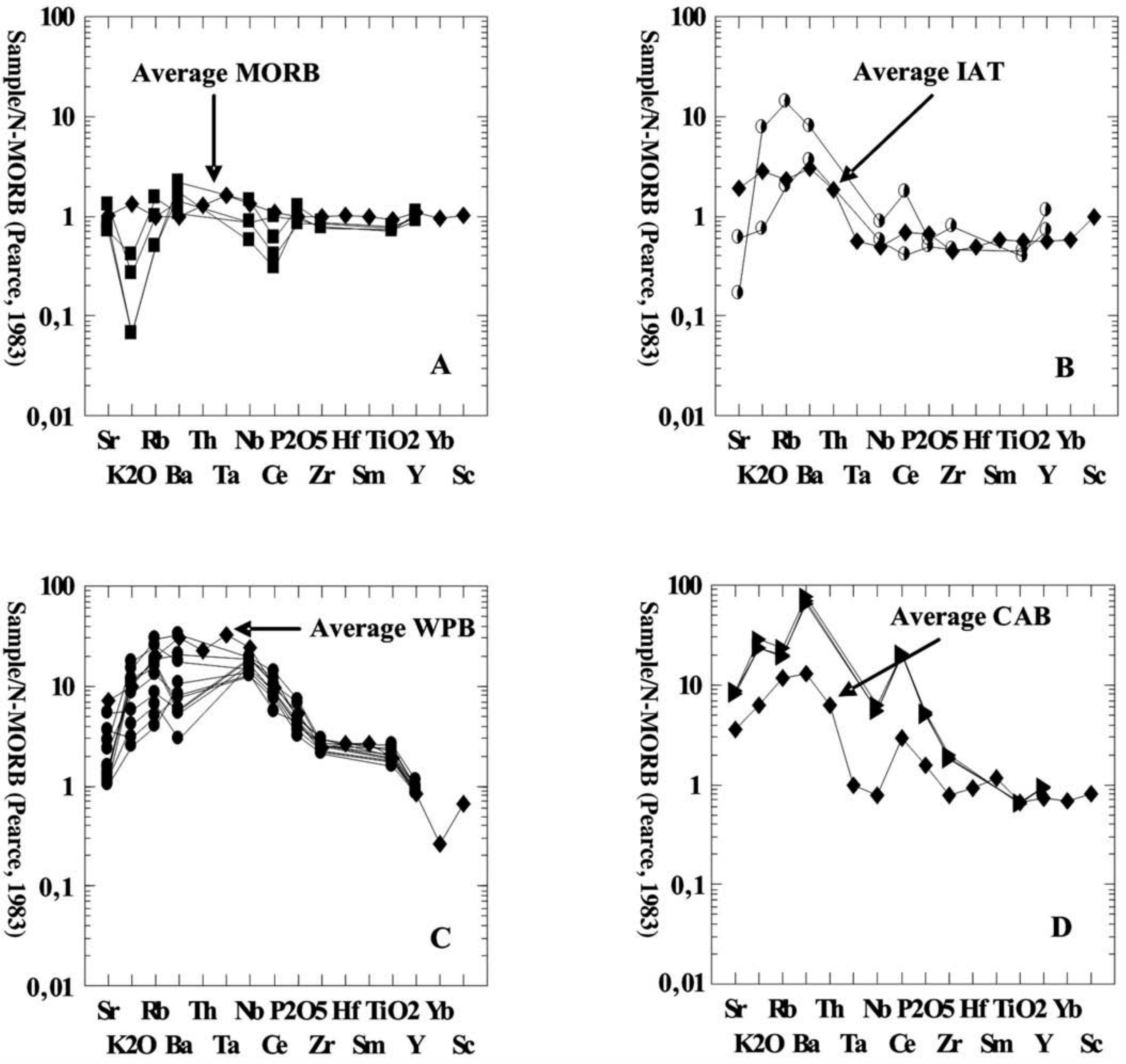

Fig. 8 - N-MORB normalized multi-element diagrams for the Sakarya basalts. A: Group 1 Basalts (MORB), B: Group 2 Basalts (IAT), C: Group 3 Basalts (WPB) and D: Group 4 Basalts (CAB). Normalization factors from Pearce (1983). Average data (diamond symbols) taken from Pearce (1982).

Of these patterns, that of sample group 3 is perhaps the most distinctive. It displays a selective enrichment (relative to N-type MORB) of elements that are incompatible with a garnet lherzolite mantle, the most incompatible elements (Ba and Nb) showing the greatest enrichment (Fig. 8c). Absolute abundances of these elements are also high relative to the sample groups 1, 2 and 4. Nb for example reaches 68 ppm in group 3 as opposed to 2-3 ppm in group 2, 2-5 ppm in group 1 and 19-22 ppm in group 4. Furthermore, Ti/Nb, Zr/Nb and Y/Nb ratios are much lower in group 3 than in groups 1 and 2. These geochemical characteristics point to the close resemblance of group 3 to alkalic lavas from within plate ocean island basalts, as pointed out from the discrimination diagrams.

The geochemical patterns of group 4 samples are also distinctive (Fig. 8d). They display three main features: 1) a greater degree of enrichment in LFSE (Sr, K, Rb and Ba) relative to N-MORB; 2) a strong depletion of Nb relative to LFSE and Ti relative to the other LFSE and HFSE; 3) a Ce and P_2O_5 enrichment relative to Zr, TiO_2 and Y. High LFSE/HFSE ratios and negative anomalies of Nb, and Ti are typical of all island-arc calc-alkaline and tholeiitic rocks (Fig. 8d). Comparison of the patterns for typical island arc calc-alkaline and tholeiitic basalts shows that Sr, K, Ba, Ce, P, and Sm have an even greater degree of enrichment in the former. However, the HFSE still define a relatively flat trend parallel to the MORB pattern, presumably reflecting the pre-subduction characteristics of the mantle wedge. Ce, P and Sm are much more likely to be transported in a partial melt than an aqueous fluid, and this may reflect a fundamental difference in the petrogenesis of magmas of the tholeiitic and calc-alkaline series (Hawkesworth and Powell, 1980). Hole et al. (1984) suggest that the negative anomalies of Ti, Ta, and Nb and the high ratio of LFSE/HFSE of arc rocks are the result of addition to the upper mantle of pelagic sediments that are deficient in Ta, Nb, and Ti and rich in LFSE. Especially the high ratio between LFSE/HFSE appears to be consequence of the enrichment of the mantle wedge by Ba-rich subduction-zone fluids, with much of the Ba being derived from subducted oceanic sediments (Hole et al. 1984). Group 4 is also characterized by highest K_2O/Na_2O ratios (0.778; 0.829; 1.017) and Na_2O+K_2O percentage higher than 5 (7.72; 8.51; 8.04), in contrast to the other groups. These major and trace element characteristics reveal a close resemblance of group 4 samples to island arc calc-alkalic basalt, as pointed out also from the discrimination diagrams.

RADIOLARIAN DATING

Of several samples collected from radiolarian cherts associated with basalts only four yielded Radiolaria relatively well-preserved to be determined.

Neocomian radiolarian fauna

Moderately-preserved Neocomian radiolarian faunas are obtained from the red chert-mudstone alternations in the Emremsultan Gorge to the west of Sariyar in the Sakarya Valley. (Fig. 4). The radiolarian faunas of samples 99UKT-26 and 27 are the same and comprise (Plate 1): *Crucella* sp., *Angulobracchia* sp. cf. *A.* (?) *portmanni* Baumgartner s.l., *Godia nodocentrum* Dumitrica, *Pantanellium masirahense* Dumitrica, *Thanarla brouweri* (Tan) sensu O'Dogherty, *Pseudoeucyrtis hanni* (Tan) sensu O'Dogherty, *Svinitzium mizutanii* Dumitrica, *Mirifusus dianae* s.l. (Karrer), *Tethysetta boesii* (Parona).

The lower limit of the fauna can be estimated as early Berriasian, because of the first appearance datum of *Pseudoeucyrtis hanni* (Baumgartner, 1992; O'Dogherty, 1994). Although two taxa (*Thanarla brouweri, Svinitzium mizutanii*) in the assemblage appear for the first time in late Tithonian (Aita and Okada, 1986; O'Dogherty, 1994; Dumitrica et al., 1997), characteristic upper Tithonian to middle Berriasian radiolarian taxa as *Eucyrtidiellum pyramis* (Aita), *Bistarkum breviliatum* Jud, *Fultacapsa concentrica* (Steiger) are absent in these samples. Therefore, a late Tithonian age could be excluded.

According to Dumitrica et al. (1997), *Svinitzium mizutanii* in the assemblage obtained from samples 99-UKT-26 and 27 has its last appearance datum in early Hauterivian. Therefore the age of the fauna could not be younger than early Hauterivian, and is assigned to early Berriasian - early

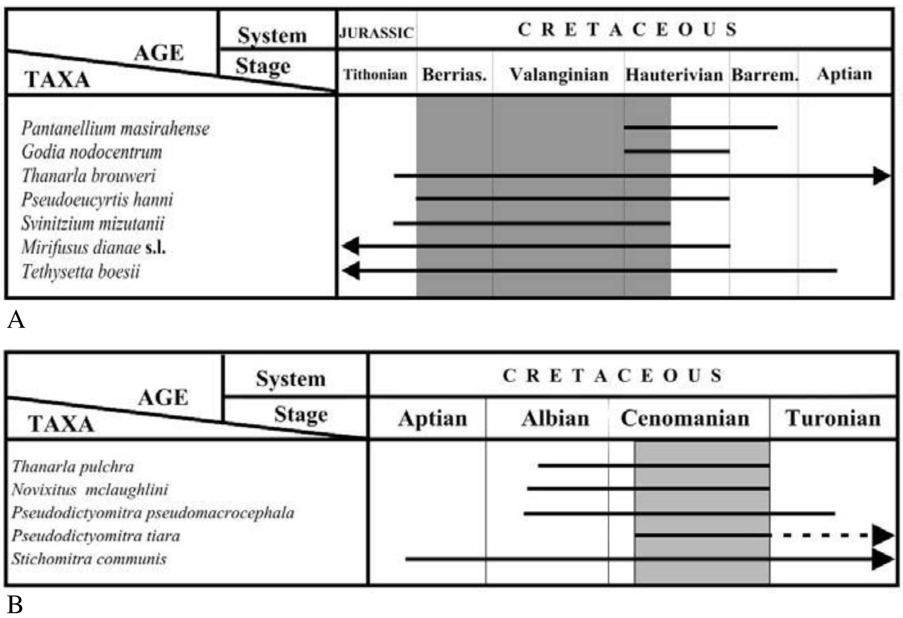

Fig. 9 - Stratigraphic ranges of the selected radiolarian species from two different locations: A. Radiolarian assemblage of samples 99-UKT-26 and 27 indicate an early Berriasian-early Hauterivian age. Grey area indicates the supposed age for these samples. Ranges of taxa are taken from Aita and Okada (1986), Baumgartner (1992), O'Dogherty (1994), Baumgartner et al. (1995) and Dumitrica et al. (1997). B. Ranges of radiolarian assemblage in sample 99-UKT-25. Grey area indicates the supposed age for this sample. Ranges of taxa are based on O'Dogherty (1994).

Hauterivian based on these data (Fig. 9A). Because *Godia nodocentrum* and *Pantanellium masirahense* have their first appearance datum in the basal part of Hauterivian and taking into consideration LAD of *Svinitzium mizutanii* as early Hauterivian (Fig. 9a), the age of these samples could be early Hauterivian; however, we prefer an early Berriasian - early Hauterivian age assignation for these samples as *Godia nodocentrum* and *Pantanellium masirahense* are only known from limited locations (Oman, Italy) according to Dumitrica et al. (1997) and should be more studied in many localities.

Cenomanian radiolarian fauna

The moderately-preserved radiolarian fauna of sample 99-UKT-25 was obtained from red to brown, thin-bedded chert-mudstone alternations in the Emremsultan Gorge, only 5 meters below the first sample locality with early Berriasian - early Hauterivian radiolarian fauna. It is separated from the former one by a sheared zone of NW-SE direction with serpentinites. Sample 99-UKT-32 is located approximately 1250 meters SE of sample 99-UKT-25 on the road-cuttings along the Sakarya River and yielded the same Cenomanian radiolarian fauna as sample 99-UKT-25 (Fig. 4). The radiolarian fauna of sample 99-UKT-25 includes (Plate 1):

Thanarla pulchra (Squinabol) sensu O'Dogherty, *Novixitus mclaughlini* Pessagno, *Pseudodictyomitra pseudomacrocephala* (Squinabol), *Pseudodictyomitra tiara* (Holmes) sensu O'Dogherty, *Stichomitra communis* Squinabol.

Pseudodictyomitra tiara in this assemblage is important to define the lower age limit of the fauna. According to O'Dogherthy (1994), *Pseudodictyomitra tiara* appears for the first time in late early Cenomanian. This taxon is well-known and studied in many localities such as the Pacific and European Tethys. Therefore the age of this fauna could not be older than Cenomanian (Fig. 9B).

Both *Thanarla pulchra* and *Novixitus mclaughlini* have their last appearance datum (LAD) at the Cenomanian - Turonian boundary. According to O'Dogherty (1994), these two taxa could not be observed in Turonian sediments in many localities as California, Japan, Europe etc. Therefore, the upper limit for the age of the sample could be estimated as late Cenomanian. Although the well-known taxon (*Pseudodictyomitra pseudomacrocephala)* has a wide range (middle Albian to early Turonian), its maximum abundance was found in late Albian - late Cenomanian deposits in previous studies (e. g. Pessagno, 1977; O'Dogherty, 1994). This data also support the Cenomanian age assignment for this sample.

GEOLOGICAL EVOLUTION

Combined radiolarian datings and geochemical studies on associated oceanic extrusive rocks within mélange-complexes provide snap-shots in the geological evolution of oceanic sea-ways. Considering that most of the MOR- and SSZ-type oceanic crust and volcanic islands are subject to elimination by deep subduction, accretion complexes are the only places where they survived as more or less disrupted sequences.

The Dağkuplu Mélange in the Central Sakarya area, one of the key areas to study these sequences, provided new information at this regard. The first important result of the present work is to show for the first time that fragments of extrusive rocks from different oceanic settings are preserved in the DM. In the previous petrological work, only pieces of OIB (Floyd, 1993; Tankut, 1990; Rojay et al., 2004) or fore-arc-type volcanics (Yalınız et al., 1996; Tankut et al., 1998) have been recognized by reliable geochemical data including REE. The present study has shown that MORB, IAT, OIB and CAB-type volcanic rocks may occur together within the mélange, and this confirms the preliminary suggestion of Göncüoglu et al. (2000). The arc-related IAT and CAB-types are recognized for the first time in this study. By this it is evident that, although not very frequently determined yet, the intra-oceanic subduction within the Izmir-Ankara branch of Neotethys has not only produced fore-arc volcanism (Yalınız et al., 1996; 1998; 2000 a, b; Yalınız and Göncüoglu, 1998; Göncüoglu et al., 1998; 2001) but also initial and mature stages of island arcs.

Regarding the radiolarian data, only two slices or blocks within the DM in central Anatolia yielded reliably radiolarian ages to constrain the timing of the events within the Izmir-Ankara Ocean. The older radiolarian ages, as early Berriasian - early Hauterivian, found within the OIB-type basalts show evidences that the formation of plume-related oceanic islands continued in Early Cretaceous. This finding is in good agreement with Yalınız et al. (1998), Göncüoglu et al. (2001) and Rojay et al. (2004).

The Cenomanian ages determined from radiolarian cherts within the MORB-type basalts of DM, on the other hand, are so far the youngest ages obtained from the mélange complexes of the Izmir-Ankara Ocean as well as in its continuation to the west (Vardar Suture) and east (Ankara-Erzincan Suture).

The ages obtained in this study alone are obviously not sufficient to interpret the details of the geodynamic evolution of the Izmir-Ankara branch of Neotethys. However, we will evaluate these data with the partly unpublished geochemical and radiolarian data from other parts of the Izmir-Ankara Suture Zone to understand its geological evolution.

Rifting and ocean basin opening

Originally the opening age of the Izmir-Ankara branch of Neotethys was suggested to be late Early Liassic (Görür et al., 1983). This suggestion was mainly based on the "major break-up unconformity in the marginal sediments of the Neotethyan Ocean", in northern Central Anatolia. Göncüoglu et al. (2003), however, have shown that the rift-related extension to the north of the Tauride-Anatolide plate started in Early Triassic. Moreover, recent findings of blocks of radiolarian ribbon cherts associated with rift-transitional MORB-type (Yalınız et al., in prep.) pillow-lavas within the Izmir-Ankara Suture Zone yielded a late Carnian age (Central Sakarya area; Tekin et al., 2002). In the Lycian Nappes, which are considered to be derived from the Izmir-Ankara Ocean, the pillow basalts transitional between MORB and within-plate basalts, in the Turunc area (Collins, 1997) yielded middle Carnian radiolarians (Tekin and Göncüoglu, 2002). Taking all this radiolarian evidence together, these Late Triassic ages could reflect the rifting of the Izmir-Ankara branch of Neotethys (Fig. 10a, b). These data can be compared with the findings from the easternmost mélange complex of the Vardar Ocean in Greece (Pagondas Mélange - Evia, Avdella Mélange - NW Greece, e.g. Danelian and Robertson, 2001, and references therein).

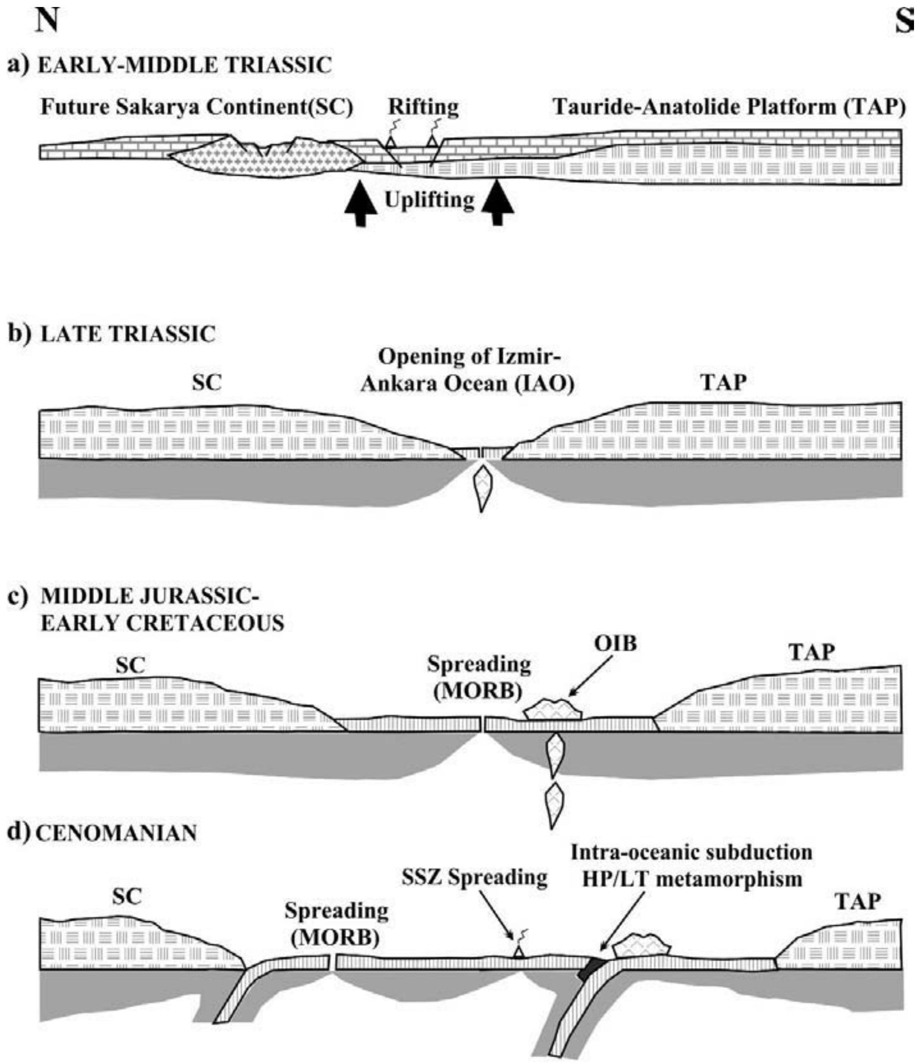

Fig. 10 - Evolutionary cartoons of the Izmir-Ankara branch of the Neotethyan Ocean.

Development of the Izmir-Ankara oceanic lithosphere

The development of oceanic crust can either be studied by dating MORB-type basalts or by dating the oceanic seamounts that were formed within the oceanic crust and escape subduction more frequently than MORB's. The early Late Cretaceous age found in the Central Sakarya area from the MORB-type volcanic rocks is the youngest age obtained yet and indicates that oceanic crust development by ridge spreading lasted until the Cenomanian (Fig. 10c, d). Furthermore, MORB-like basalts associated with radiolarian cherts from Central Sakarya yielded late Bathonian-early Tithonian and late Hauterivian - early Aptian ages (Yalınız et al., 1998; Göncüoglu et al., 2000; 2001). Together with our new findings (early Berriasian - early Hauterivian) from the Central Sakarya area, the biostratigraphic data from OIB-type volcanic rocks are more diverse and include Callovian - early Tithonian, late-Valanginian - Barremian and early Aptian ages (Rojay et al., 2004). Other radiolaria and foraminifera ages from the Ankara Mélange without any characteristic geochemical indication cover the time-span from late Norian- Early Jurassic (Bragin and Tekin, 1996; Tekin, 1999) to Turonian (Boccaletti et al., 1966) and probably to Campanian (Gautier, 1984) but cannot be used for a specific interpretation of the tectonic setting. In brief, the combined age and geochemical data are indicative that MOR spreading in the Izmir-Ankara Ocean ranges from mid Middle Jurassic to middle Late Cretaceous. By this, the statement of Rojay et al. (2004) that "the late Middle to Late Jurassic span is too early for the evolution of a seamount in an evolving young oceanic crust" is misleading. It is true that Early Jurassic ages are scarce in the Izmir-Ankara oceanic assemblages. However, this is a common case in the northern branches of Neotethys (e.g. Danelian et al., 1996) and may be ascribed to the preferential subduction of this earlier formed and cooled oceanic lithosphere during the initial ocean basin destruction or, alternatively, it may be due to the diagenetic conditions, not conductive to radiolarian preservation (Danelian and Robertson, 2001).

Closure of the Izmir-Ankara Ocean

Since the identification of supra-subduction zone (SSZ) type oceanic crust generation in the eastern part of the Izmir-Ankara Suture Belt (Göncüoglu and Türeli, 1993; Yalınız et al., 1996), it is commonly accepted that the Izmir-Ankara oceanic basin started to close by intra-oceanic subduction (e.g. Göncüoglu and Türeli, 1993; Tüysüz et al., 1995; Göncüoglu et al., 1997; Okay and Tüysüz, 1999). We will evaluate the time constraints for the closure history of the Izmir-Ankara Ocean by studying the ages of: i) sub-ophiolitic metamorphism, ii) first occurrence SSZ-type extrusive rocks and iii) high pressure-low temperature (HP/LT) metamorphism. The formation of sub-ophiolitic metamorphic soles is of importance in identifying the age of the initial intra-oceanic decoupling. In the Izmir-Ankara Suture Zone the oldest radiometric ages obtained from the amphibolites range between 101Ma (Harris et al., 1994) and 90 Ma (Önen, 2003) and suggest that the intra-oceanic subduction had already started in the Albian. This data is in accordance with the latest (Santonian - Campanian, Okay and Tüysüz, 1999) radiometric ages from the HP/LT metamorphic oceanic extrusives in SSZ-setting; both the IAT- and CAB-type arc-related pillow basalts within the Dağkuplu Mélange in the Central Sakarya area have not yielded datable radiolarians. Elsewhere along the Izmir-Ankara Suture Belt, back-arc basalts in the Kütahya area yielded radiometric ages of late Cenomanian (94±13 Ma, Önen, 2003). In the eastern part of the Izmir-Ankara Suture Belt in Central Anatolia, fore-arc basalts of the Central Anatolian Ophiolites include foraminifera of middle Turonian - early Santonian ages (Yalınız et al., 2000). Back-arc and arc-type basaltic rocks obtained from Konya (Floyd et al., 2003), and Kırşehir (Köksal-Toksoy et al., 2001) have not yet been dated, therefore the life span of the SSZ-type oceanic lithosphere formation (island arcs as well as fore- and back-arcs) is loosely considered as Albian - Santonian.

Regarding ages and tectonic settings, the oceanic extrusives of the Izmir-Ankara Suture Belt are classified by Robertson (2002; 2004) as the "Cretaceous SSZ-type ophiolites of the eastern region". Our findings, however, suggest that the Izmir-Ankara Branch of Neotethys was not a short lived one and does not only include SSZ-type oceanic lithosphere. In contrast, the related mélange-complex includes fragments of a MOR-type oceanic crust and lithosphere formed by spreading. The ages obtained yet indicate that this spreading continued until early Late Cretaceous. Within this oceanic lithosphere, plume-related oceanic seamounts developed from Middle Jurassic to mid Early Cretaceous (Fig.10c) and from late Early Cretaceous onward the oceanic basin started to close by intra-oceanic subduction, giving way to SSZ-type ophiolites found all along the suture belt (Fig. 10d).

CONCLUSIONS

In conclusion, based on our new findings from the Central Sakarya Zone and on previous data along the Izmir-Ankara Suture Belt between Bornova (Izmir) and Yozgat, we suggest the following evolutionary steps (Fig. 10) for the formation and closure of the Izmir-Ankara Oceanic Branch of northern Neotethys:

1- The Izmir-Ankara Ocean started to open already in Late Triassic, between the Sakarya Microcontinent and the Tauride-Anatolide Platform

2- OIB-type intra-plate seamounts formed within it from late Bathonian until early Aptian.

3- Intra-oceanic northward subduction, decoupling of the oceanic crust and related sub-ophiolitic metamorphism started at the end of Early Cretaceous.

4- The ridge of the Izmir-Ankara oceanic plate was not subducted until Cenomanian.

5- Formation of supra-subduction-type oceanic crust probably began at the end of Early Cretaceous but lasted definitely until early Santonian.

6- Subduction-related HP/LT metamorphism in the Izmir-Ankara Suture Belt that affected the accreted oceanic material started already at the end of Early Cretaceous.

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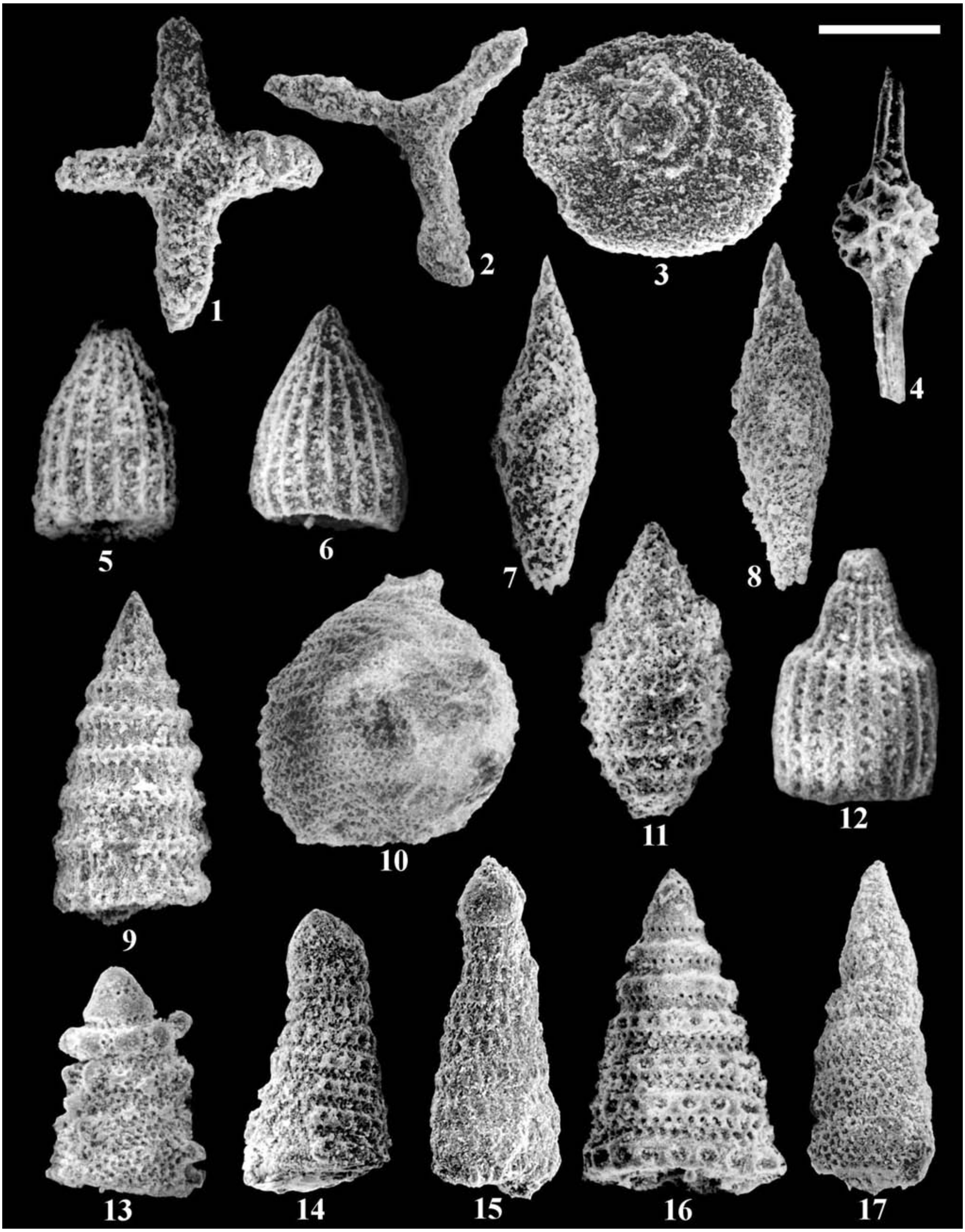

Plate 1 - Scanning Electron Micrographs of radiolarians from the Emremsultan Village, Nallıhan, Eskişehir. 1-11 show the radiolarian fauna of early Berriasian - early Hauterivian ages, from samples 99-UKT-26 and 27: 1) *Crucella* sp., sample 99-UKT-27, scale bar- 100µm; 2) *Angulobracchia* sp. cf. *A.*(?) *portmanni* s.l. Baumgartner, sample 99-UKT-27, scale bar- 122 µm; 3) *Godia nodocentrum* Dumitrica, sample 99-UKT-27, scale bar- 115µm; 4) *Pantanellium masirahense* Dumitrica, sample 99-UKT-27, scale bar- 100µm; 5-6) *Thanarla brouweri* (Tan), both of them are from sample 99-UKT-27, scale bar for both figures- 80µm; 7-8) *Pseudoeucyrtis hanni* (Tan), both of them are from sample 99-UKT-27, scale bar for both figures- 100µm; 9) *Svinitzium mizutanii* Dumitrica, sample 99-UKT-26, scale bar- 80 µm; 10) *Mirifusus dianae* s.l. (Karrer), sample 99-UKT-26, scale bar- 180 µm; 11) *Tethysetta boesii* (Parona), sample 99-UKT-26, scale bar-100 µm. 12-17 show Cenomanian radiolarian fauna from sample 99-UKT-25. 12) *Thanarla pulchra* (Squinabol), scale bar- 75 µm; 13) *Novixitus mclaughlini* Pessagno, scale bar- 110 µm; 14-15) *Pseudodictyomitra pseudomacrocephala* (Squinabol), scale bar-147µm and 180 µm respectively; 16) *Pseudodictyomitra tiara* (Holmes), scale bar- 100 µm; 17) *Stichomitra communis* Squinabol, scale bar- 120 µm.