

EUG XI



Symposium LS03

Integrated Tectonic Studies of the Evolution
of the Tethyan Orogenic Belt
in the Eastern Mediterranean Region

Convenors

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LS03

The Evolution of the Tethyan Orogenic Belt

Wednesday PO Session

LS03 : WEpo01 : PO A Comparison of Metamorphic Conditions in Magmatic Sequences of Ophiolite Complex from NE Russia (Povorotny Cape, Taigonos Peninsula) and Cyprus (Result of Investigations Supported by INTAS Grant 96-1880)

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In this study geochemical and mineralogical peculiarities of ophiolite igneous rocks: basalt, gabbro and plagiogranite from Povorotny Cape (NE Russia) and Cyprus (Troodos and Mamonia Complexes), were compared by their metamorphic conditions. All of the gabbroic rocks of Povorotny Cape were subjected to metamorphic recrystallization without textural changes. The metamorphic mineral assemblage in gabbros and dolerites are dominated by actinolite, albite, epidote, chlorite, and aluminous actinolite. This set of minerals is typical of mafic metaigneous rocks of the greenschists facies and corresponds to temperature of approximately 300-350°C and a pressure lower than 2 kbar whereas the presence of low-alumina hornblende in some of the gabbros indicates that metamorphic recrystallization of these rocks took place at temperatures related to the transition between the greenschist and amphibolite (epidote amphibolite) facies i.e., approximately 500°C at a low pressure. A relatively high chlorine concentration was determined in the anion group of high-alumina actinolite or low-alumina hornblende in these plutonic rocks that is typical for metamorphosed igneous rocks that were formed beyond oceanic basins. All types of volcanic rocks from Povorotny Cape also display apparent traces of low-temperature metamorphism of the lower greenschist (actinolite + chlorite + epidote + quartz) and zeolite facies. Obviously, the metamorphic recrystallization of the basaltic rocks occurred at the same temperatures as the low-temperature alterations of the associated plutonic rocks. On the other hand, as it well known there is a clear mineralogical and geochemical similarity in the metamorphic features of the Troodos ophiolite rocks and in the modern oceanic crust. All plutonic and volcanic rocks of ophiolite origin from Cyprus characterized by same metamorphic mineral assemblages and geochemical trends of metamorphism as Povorotny Cape ophiolite igneous rocks. This similarity in metamorphic conditions demonstrate that major agent of metamorphism of both objects examined is fluid of sea water origin and metamorphism took a place by similar geodynamic regimes: in back-arc or fore-arc basins. This work was supported by INTAS grant # 96-1880.

LS03 : WEpo02 : PO Timing of Cenozoic Extension in the Kraishte Region, (SW Bulgaria): Evidence from Track Analysis

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The Kraishte zone (SW Bulgaria) is situated between the Serbo-Macedonian high-grade metamorphic unit, the Rhodope "massif", and the European active margin (Srednogorie volcanic arc). The Alpine history of the Kraishte area began with Cretaceous (to Palaeocene?) thrusting of the Morava unit (pre-Silurian continental basement rocks and lower Paleozoic metasediments) onto the Struma unit (Variscan basement rocks and Mesozoic sediments). This was followed by Eocene to Oligocene (Miocene?) extension. This NE-SW directed extension was associated with retrogressive metamorphism of greenschist-facies and the formation of the shallow-dipping detachment fault zones which produced the denudation and exhumation of the amphibolite-facies basement rocks exposed in high-altitude culminations (Osogovo - Lisets complex) between low-altitude basins. In the basins, sedimentation was initially continental with alluvial deposits (Eocene) evolving in the Oligocene to deep water with the deposition of turbidites. Volcanic activity was contemporaneous with sedimentation; apatite and zircon fission track ages on interbedded tephra range from 45 to 40 Ma. Later,

(32 - 30 Ma), subvolcanic trachytic to dacitic and rhyolitic bodies were intruded into the sediment. During the Miocene, the propagation of the basins continued NE-ward with the deposition of terrigenous coal-bearing sediments. Tectonically the Osogovo-Lisets complex forms the footwall of Tertiary detachments whereas the Morava nappe and Struma unit rest in the hanging wall. This assertion is confirmed by the zircon FT ages obtained in the both units. The ZFT ages from hanging wall are between 298 and 69 Ma, while the oldest ZFT age in the footwall of the Osogovo detachment is 47 Ma. The hanging wall had thus cooled to 250°C by about 70 Ma. In general, the samples from Osogovo - Lisets complex have apatite ages ranging between 46 and 27 Ma and long mean track lengths ranging between 14.65 - 14.13µm. The close similarity of the zircon and apatite ages, as well as the long lengths, is indicative of rapid cooling of the footwall of the Osogovo detachment, typical of metamorphic core complexes. On the other hand, some - but not all - of the apatite ages from the hanging wall are younger - 35 to 33 Ma, with slightly shorter mean track lengths of 13.99 - 13.85µm. We suggest that this was perhaps due to disruption by the next set of normal faults which cut the old detachment which was by that time inactive.

LS03 : WEpo03 : PO Paleomagnetic Results from the Tarim Block. Toward a Comprehension of the Jurassic Configuration of Eurasia

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The collision of India with Eurasia about 50 My ago has involved the displacement of the Tibetan and Central Asian continental blocks. Most of the paleomagnetic studies carried out in Asia focused on the Cretaceous as it immediately preceded the collision. Older periods, such as the Jurassic, have not received the same attention. Furthermore, some Jurassic results from the northeastern part of the Qaidam block argue in favor of a partition of the post-Jurassic northward convergence of this block into a first part accommodated by the Mongol-Okhotsk collision between Siberia to the north and other continental landmasses to the south, and a second part accommodated later, during the Tertiary, by the India-Asia collision. If confirmed, this idea would have very large scale tectonic implications as to the understanding of the tectonic evolution of the Eurasian continent. However the Jurassic paleomagnetic database is presently too poor to be conclusive on the question. For this reason, we started a Sino-Japanese cooperation program that aims to establish an accurate Jurassic configuration of Eurasia. During a field trip that was carried out during September-October 2000, forty six sites were sampled in four Lower to Middle Jurassic sections for paleomagnetic purposes in the southern and northern parts of the Tarim block. The demagnetization process of these samples is presently in progress. These paleomagnetic and rock magnetism results will be combined to coeval results from the Qaidam, Mongolia and Siberia, and a plausible tectonic interpretation, even though preliminary, will be presented and discussed in a large scale tectonic frame.

LS03 : WEpo04 : PO The Grigoriou Plutonic Complex (Mt Athos, Greece): A Component of the North Aegean Eocene-Oligocene Calc-Alkaline Magmatism

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The Mt Athos peninsula extends on the southwest fringe of the Rhodopian massif in northeastern Greece. The peninsula consists of metamorphic rocks intruded by plutonic, mainly granodioritic complexes, such as the Grigoriou massif. This 25 km² large massif emplaced at rather great depth within high-grade gneisses which show scattered

pegmatite dykes in the NE aureole. The massif is bounded to the NW by a vertical screen of andesitic gneisschists, while its SE limit is a detachment fault, whose hanging-wall includes greenschist-facies meta-ophiolites and metasediments (Athos marbles). Ductile deformation of the granitic footwall suggests that the granite emplacement and the detachment are coeval.

The Grigoriou complex is mainly made up of, either a typical, almost isotropic, porphyritic granite, or a weakly foliated granodiorite crosscut by aplitic dykes. Along the southwest coastal fringe of the massif, foliated or almost isotropic gabbros and diorites are observed either as boudinaged inclusions within the granodiorite, or as wide screens brecciated and intruded by granodioritic-granitic rocks. The geometric relationships between the various rocks indicate a broadly simultaneous emplacement of basic and acidic magmas.

The SiO₂ enrichment from gabbros to granites is accompanied by a regular decrease of FeO, MgO, CaO and TiO₂ contents. Mantle-normalized multi-element patterns in all these rocks are broadly parallel. They show important enrichments in LILE, Th, U and LREE relative to HREE, as well as strong Nb, Ta and Ti depletions. These geochemical characteristics are typical for high-K, calc-alkaline magma series and suggest fractional crystallization during the genesis of the Grigoriou pluton.

K/Ar dating of biotite separates from the Grigoriou granite yielded a 43±1 Ma age. The Grigoriou complex belongs to an important set of Eocene-Oligocene magmatic stocks emplaced in the N-Aegean domain, from NW Turkey to Bulgaria. The nearby, medium-K calc-alkaline Sithonia massif is dated at 50-40 Ma. Younger (ca. 30 Ma) granitic intrusions of restricted size are scattered further north. The eastern Rhodopes volcanic rocks (37-25.5 Ma) display calc-alkaline and shoshonitic affinities. Being coeval with post-orogenic extensional movements, this magmatism could characterize a back-arc area related to the northward subduction of a residual Tethyan lithosphere beneath the European margin and previously accreted units.

LS03 : WEpo05 : PO Mount Athos Paleomagnetism: A Hint for Fault Controlled Deformations in the North Aegean Area

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The Mt Athos granite (Grigoriou massif, Southern Serbo-Macedonian Massif) was subjected to a paleomagnetic, structural and geochemical-geochronological study. This granodioritic intrusion which outcrops over about 25 km² in NE Greece, yielded a 43.3 ±1.0 Ma K/Ar biotite age (R.M.). The Mt Athos granite was therefore emplaced in Late orogenic, extensional/transensional conditions within the Rhodopian nappe stack.

Fourteen sites have been cored or block sampled and 220 standard specimens measured for both magnetic component analysis and anisotropy of magnetic susceptibility. The anisotropy degree averages 8% ; the AMS fabric is related to the batholith geometry and to its internal structure (e. g. magnetic foliation parallels foliated zones).

Magnetic properties indicate the occurrence of two types of samples with i) predominant magnetite and ii) maghemite or pyrrhotite as magnetic carriers. Both groups show similar , NE direct and SW reverse, magnetic components. The mean site directions are fairly well-grouped , except one faulted and tilted site , and close to the direction obtained from the coeval and nearby Sithonia granite. These ca. 40° of clockwise rotation can be ascribed to a fault controlled deformation of the thickened Rhodopian crust North of the N. Aegean Trough boundary.

LS03 : WEpo06 : PO
Palaeozoic as well as Mesozoic Sedimentation
and Polymetamorphism in Central Rhodope
(N. Greece) as Inferred from U-Pb
SHRIMP-Dating of Detrital Zircons

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Based on the concept that the age of the youngest detrital zircon in a (meta)sediment provides evidence for a maximum age of sedimentation, we dated, by SHRIMP II (ANU Canberra and GSC Ottawa), detrital zircons from the following rock types of Central Rhodope: 1) a gt-ky-gneiss along the road Xanthi-Echinos, ca. 7 km north of Xanthi. Cathodoluminescence (CL) pictures of the zircons show relic cores surrounded by broad metamorphic rims. The youngest detrital core-ages range between 588 ± 24 and 564 ± 22 Ma (2σ), which implies that sedimentation of the protolith of this rock is uppermost Proterozoic or Palaeozoic. It is worth mentioning that the oldest detrital zircon core dated was 3230 ± 90 Ma. Preliminary data of the metamorphic rims show a clustering around 148 Ma. 2) a gt-ky-gneiss enclosing an eclogite boudin in the area of Siroko. The zircons of this rock show, in CL, relic cores surrounded by metamorphic rims. The youngest ages within one core range between 205 ± 8 and 223 ± 10 Ma (2σ) implying Triassic to post-Triassic sedimentation. The metamorphic rims have an age of 138 ± 6 Ma (95% c.l.) and show lead-loss due to a younger metamorphic event (most probably at 40 Ma; Liati and Gebauer, 1999). It is noted that the eclogite enclosed in this gt-ky-gneiss yielded an age of 139 ± 4 Ma (95% c.l.) in the same type of zircon domains and significant lead-loss down to 40 Ma. 3) a deformed quartz vein within calc-silicate paragneisses, concordant with their schistosity, close to Sminthi. Impurities of the country rock are common in this quartz vein. CL-pictures of the detrital zircons from the country rock usually show three different types of domains: inherited cores overgrown by younger magmatic domains which are in turn surrounded by wide metamorphic rims. The youngest magmatic domains are Carboniferous (292 ± 10 Ma, 313 ± 10 Ma; 2σ). We therefore infer a Mesozoic age of sedimentation. The zircon rims record a metamorphic age at ca. 40 Ma, the T-peak for the Eocene metamorphism (Liati and Gebauer, 1999). In conclusion, our SHRIMP results show that sedimentation in Central Rhodope was both uppermost Proterozoic or Palaeozoic, as well as Mesozoic. Regarding the ages obtained for the metamorphic rims, these may correspond either to two subduction events in Upper Jurassic/Lower Cretaceous and Eocene times or, more probably, to rift-related Upper Jurassic/Lower Cretaceous underplating of mafic magmas and Eocene subduction of a basement-cover series.

Liati, A. & Gebauer, D. *Contrib. Mineral. Petrol.*, **135**, 340-354, (1999).

LS03 : WEpo07 : PO
Geochronological Constraints on Carboniferous
and Triassic Magmatism in the Cyclades:
SHRIMP U-Pb Ages of Zircons from Syros,
Greece

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In order to unravel the pre-metamorphic history of the Cycladic island Syros, zircons from 8 meta-acidic samples, subjected to Alpine subduction and from various tectono-stratigraphic units, were analysed using SHRIMP.

1.) The Lower Main Unit (LMU) is composed of acidic gneisses and metabasites in basal position, overlain by a marble-schist sequence, ophiolitic metabasites with associated plagiogranites and a second marble-schist sequence. White mica ages suggest that the blueschist-eclogite facies metamorphism is at least Eocene. However, it may be as old as Cretaceous, inferred from U-Pb zircon data (Bröcker & Enders 1999) and resetting of Lu-Hf system (Lagos et al. 2001). The base of the LMU is made up of sheared

K-feldspar augen-gneisses. One metagranitic sample from Komito bay yields a medium to long prismatic, oscillatory zoned zircon population. The age of 315 ± 3 Ma (2σ , N=4) from pristine domains is interpreted as magmatic age of the protolith. This may indicate that pre-Alpine basement, similar to other Cycladic islands or the Pelagonian, is preserved on Syros. Other meta-acidic occurrences consist of alternating layers of mafic to felsic tuffite, in the LMU below the main marble succession. One of these felsic layers from northern Azolimnos bay yields a uniform magmatic zircon population with an age of 243 ± 2 Ma (2σ , N=8). Another sample from this occurrence contains an additional population from a Carboniferous magmatic source.

II.) The Upper Vari Unit (UVU) comprises plagiogranitic gneisses, metabasites and schists with some intercalated marbles. The main metamorphic imprint is of epidote-amphibolite facies. Ar-Ar stepwise heating, Rb-Sr white mica ages and SHRIMP U-Pb ages on metamorphic zircon rims yield consistent results (ca. 95-100 Ma) and constrain this metamorphic event to the Cenomanian (Tomaschek et al. 2000). Coarse-grained metaplagiogrinites in the UVU are interfolded with aplitic varieties. Magmatic zircons of an aplitic sample from near Azolimnos, give an age of 243 ± 4 Ma (2σ , N=11), in agreement with a magmatic age of 240 ± 2 Ma from the Vari granitoid (Keay 1998) and an additional granitoid sample from Phokia locality. Interestingly, some zircons from the Phokia sample yield Carboniferous ages on oscillatory zoned cores and Triassic ages on oscillatory zoned outer rim regions. These patterns may reflect remelting or assimilation of Variscan basement material during Triassic plutonism.

Our data from Syros constrain ca. 240 Ma as a major magmatic episode. So far, this episode is not well established in the Cyclades, although detrital zircons of that age are also present in Mesozoic metasediments (Keay 1998). Ages of 220 to 250 Ma can be correlated with a magmatic episode well established from Menderees granitoids and contemporaneous with magmatism in other segments of the Alpine chain (e.g. the Pelagonian).

Bröcker M & Enders M, *Geol. Mag.*, **136**, 111-118, (1999).
 Keay S, *PhD. thesis, ANU Canberra*, (1998).

Lagos M, Munker C, Tomaschek F & Ballhaus C, *this volume*, (2001).

Tomaschek F, Baumann A, Villa IM, Kennedy A & Ballhaus C, *Beih. z. Eur. J. Mineral. Vol. 12*, 1, 214, (2000).

LS03 : WEpo08 : PO
The Geology of Western Crete (Greece):
Heritage of the Interplay between Arc-Normal
Compression and Arc-Parallel Extension Since
the Middle Miocene

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Detailed stratigraphical and structural studies of both the Alpine basement and the late Neogene deposits of western Crete (Greece) make it possible to better constrain the timing and nature of deformation processes concomitant with arc migration since the Middle Miocene. We propose a four-episode evolution, which includes:

1) Deposition of limestone conglomerates in fluvio-lacustrine environments bordering a pronounced relief in the north, during an ill-defined interval in the Middle Miocene. The conglomerates (Topolia Formation) predominantly consist of components of the non-metamorphosed "upper plate" Gavrovo-Tripolitza unit; paleocurrent readings indicate transport to the south and southwest. 2) Large-scale, gravity-induced, southward-directed sliding of the Topolia breccias along with slices of the "upper plate" (Gavrovo-Tripolitza and Olonos-Pindos) units in latest Middle Miocene to earliest Late Miocene time (between ?12 and 10 Ma ago), resulting in a stacked sequence of upper plate slices and Topolia Formation conglomerates. 3) Origin or reactivation of NNE - SSW trending normal faults and simultaneous development of a WNW - ESE striking anticlinal structure in the central part of Western Crete - exposing the High Pressure / Low-Temperature metamorphic "lower plate" - in the early Late Miocene (~ 10 - 9 Ma ago) expresses the effects of the interplay between arc-normal compression and arc-parallel extension. Arc-parallel extension accounts for the origin and evolution of Late Neogene basins on top of the Alpine basement or the stacked sequence formed during phase 2. The contempora-

neous arc-normal compression (expressed by blind thrusts) is proposed to occur in response to the inception of the southward migration of a supracrustal slab. 4) Continuing southward displacement of the supracrustal slab is proposed to ultimately cause (or at least contribute to) the uplift of Western Crete, along with large-scale tilting to the northeast from the latest Late Miocene onward (from ~ 5.6 Ma ago to Recent) (Meulenkamp et al., 1994).

Meulenkamp JE, Van der Zwaan GJ & Van Wamel WA, *Tectonophysics*, **234**, 53-72, (1994).

LS03 : WEpo09 : PO
Morphotectonic Structures at the Eastern Edge
of the Boundary between the Cretan Back-Arc
Basin and the Aegean Volcanic Arc, using Swath
Bathymetric Data

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A multibeam bathymetric survey of the area of the central Dodekanese islands (Kos, Nisyros, Tilos) was carried out by R/V AEGAEON in three successive cruises: April, June and November 2000. Both deep (SEABEAM 2100, 20 kHz) and shallow (SEABEAM 1180, 180 kHz) mode multibeam systems were used in order to fully accomplish the whole bathymetric range. Operating the system for totally 12 days with an average speed of 10 knots resulted in a complete coverage of 3,500 km² from shallow depths of 50 m to great depths of 1600 m.

The resulted bathymetric map of the area revealed a unique detailed sea-floor morphology. The identified structures can be well correlated with the overall neotectonic structure of the area, as this has been analyzed by onshore observations to the islands of Kos, Nisyros, Tilos and the neighboring islets, and has been also confirmed from lithoseismic profiles obtained during November 1997 - November 1999, by R/V AEGAEON.

One of the main tectonic features is the northern Karpathos basin, which constitutes the eastern part of the Cretan back-arc basin. This is exposed as a narrow tectonic graben in the N-S direction, enclosed between the Nisyros - Tilos - Chalki uplifted block in the east and the Astypalaea - Syma block to the west. The absence of flat lying sediments in the basin is remarkable even though the vertical subsidence of the graben is of the order of 1,0 to 1,5 km. On the contrary, the overall morphology is highly complicated showing a rather squeezed narrow zone which indicates that the regional stressfield is not a simple E-W extension.

The main tectonic trend of the eastern Aegean volcanic arc, in the Kos - Nisyros area is in an ENE-WSW direction, with prominent structures forming a tectonic horst in the middle, and two adjacent grabens, one between Kos-Astypalaea and Syma-Nisyros in the northwest and another between Nisyros and Tilos in the southeast.

All the recent volcanic centres of the area have been developed on the tectonic horst, which borders to the north the development of the Karpathos basin. The western boundary of the volcanism along this ridge-horst structure can be traced 1 Km east of Kondeliousa Islet. Additionally, an E-W fault-zone running north of Tilos and Kondeliousa islands seems to border the volcanism southwards.

The very distinctive structure of the shallow-water plateau, observed towards Syma in the southwest is remarkable, compared to the complex partly submarine volcanic chain of Nisyros and surrounding islets to the northeast.

LS03 The Evolution of the Tethyan Orogenic Belt

LS03 : WEpo10 : PO Role of Crustal Extension and Basin Inversion in Late Palaeozoic-Early Tertiary Tectonic Evolution of the South Margin of Eurasia in the Circum-Black Sea Region

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The tectono-stratigraphy of the circum-Black Sea region documents a series of events related to the evolution of the Tethys ocean to the S, including subduction-accretion, crustal extension, basin formation and stratigraphic inversion (Robertson, 1994). During Carboniferous-Early Permian time the N margin of Tethys can be interpreted as an Andean-type continental margin, comprising the Moesian-Pontides-Caucasus-Scythian region. In response to northward subduction in the Triassic, marginal rift and back-arc basins opened in the modern Black Sea region. Remnants of these basins are now found in the Caucasus (Svanetia), S Crimea (Tavrik Flysch), Central Pontides (Küre Complex) and Dobrogea (Ustaömer and Robertson, 1993, 1997). Continental fragments are believed to have rifted from Gondwana and drifted northward as Tethys was consumed beneath Eurasia. These fragments, together with oceanic seamounts, eventually collided with the active margin of Eurasia during Carnian-Hettangian time giving rise to "Cimmerian" compressional deformation. Collision in turn triggered stratigraphic inversion of the rifted Triassic borderland basins. Specifically, the Triassic Svanetia rift basin was inverted and converted into a foreland-propagating fold and thrust belt, leading to basin closure in some areas, but leaving remnant flysch basins in others. During the Sinemurian-Early Aalenian, renewed crustal extension, possibly related to splitting of a Sinemurian volcanic arc, created further "back-arc" basins along the S-Eurasian margin, as seen in the E Pontides and the Great Caucasus Trough. Large-scale calc-alkaline magmatism is documented during Bajocian time along the S margin of the Great Caucasus, in the Crimea and the E and Central Pontides. A regional compressional event dating from the Aalenian-Bajocian boundary then triggered stratigraphic inversion and regional deformation, including final consumption of the Küre-Crimea Dobrogea Triassic rifts. The compression is preserved as foreland basins in northern areas of the Caucasus, Dobrogea and Crimea (e.g. Bitak and Beshuy basins). Subsequently, the Great Caucasus-Crimea region underwent further crustal extension from Callovian-Berriasian time, as seen in the S Caspian, Great Caucasus Trough, S Crimea and Dobrogea. Further W in the Balkan region, seismic profiles document Late Jurassic extension and subsidence along the S margin of the Moesian Platform and elsewhere. Further back-arc rifting commenced during the mid-Cretaceous, associated with northward subduction of Tethys, culminating in formation of the western Black Sea basin in mid to late Cretaceous time. Areas further south underwent strong, but localised, tectonic inversion in Campanian-Palaeocene time, whereas deformation of the European continent is limited to stratigraphic inversion. Throughout the Balkan-Turkish region to the S of Eurasia localised orogenic events continued during Palaeogene-Neogene time, but collision of Eurasia and North Africa remains incomplete today.

Robertson, AHF, *Earth Science Reviews*, **37**, 139-213, (1994).

Ustaömer, Tand Robertson, AHF, *Geological Journal*, **28**, 219-238, (1993).

Ustaömer, Tand Robertson, AHF, *AAPG Memoir*, **68**, 245-290, (1997).

LS03 : WEpo11 : PO Pre-Eocene Exhumation of the Nigde Metamorphic Dome, Central Anatolia, Turkey

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The timing of exhumation of the Nigde metamorphic dome, at the southern extremity of the Central Anatolian Crystalline Complex, is a matter of debate. For most authors, the Nigde high-grade metamorphics reached the surface before late Maastrichtian-early Paleocene times, because they are reported to be overlain unconformably by sediments of that age. In contrast, Whitney and Dilek (1997) have recently argued that the Nigde dome represents an extensional core complex of Oligo-Miocene age, finally unroofed during the late Miocene. According to this hypothesis, southern Central Anatolia experienced core complex-type extension at the same time as the Aegean region further west, but this extension proceeded in two distinct geodynamic environments, the Aegean developing as a large back-arc basin at the rear of the South Aegean subduction zone, whereas Central Anatolia evolves in a pure orogenic setting since at least the Upper Eocene.

Our study of the Nigde area documents the following. Along the southern boundary of the Nigde dome, the high-grade metamorphics (marbles, quartzites, paragneiss) and weakly deformed granitoids are overlain non-conformably by a coarse-grained conglomerate, up to 3 m thick, showing a clear erosional basal surface. This conglomerate (known as Camardi formation) contains pebbles, up to one metre in size, of the various lithologies of the Nigde metamorphics and the granitoids. The conglomerate grades upward into alternating microconglomerates and sandstones. A few tens of metres higher in the section, several continuous horizons of limestone with abundant Nummulites are intercalated in the detritic series. Conglomeratic lenses bearing pebbles of the Nigde basement are still present among the detritic sediments in between the limestones. The fossil content of this sequence (known as Evliyatepe formation) indicates that sedimentation started during the Ilerdian (early Lower Eocene). On the one hand, therefore, the exhumation of the Nigde metamorphics is older than the Eocene, and there is no evidence for core complex-type extension during the Oligo-Miocene in southern Central Anatolia.

On the other hand, we cannot confirm the unconformity of the Maastrichtian-Paleocene sequence onto the metamorphic rocks. Along the southwestern border of the Nigde dome, where the corresponding fine-grained detritic sediments are dated, a late normal fault always separates them from the metamorphics. Further east, no structural break or unconformity is observed between the basal conglomerate deposited onto the metamorphics (Camardi formation) and the Nummulites-bearing sediments (Evliyatepe formation). The two formations appear to belong to the same upward-fining sequence. In localities where the Camardi formation is reported to lie between the basement and Paleocene limestones, we observe no conglomerate but massive cataclastic developed at the expense of metaquartzites, the limestones being themselves strongly sheared. Altogether, these data suggest that the earliest sediments deposited onto the exhumed metamorphics of the Nigde dome are early Lower Eocene.

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LS03 : WEpo12 : PO Tectonomorphologic Evolution of Tuzgözü (Salt Lake)– Central Anatolia, Turkey

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The Tuzgözü Basin, a NW-SE trending depression, is one of the largest basins of Central Anatolia. The basin started to form in the Late Cretaceous and continued its evolution until present. Two active fault systems, the Yeniceoba-Cihanbeyli-Sultanhanı fault zone on the west and the Tuzgözü fault zone on the east controls the margins of this basin. The lithology, vertical and lateral facies changes of the units of the basin; erosional and depositional surfaces; tectonomorphologic landforms reflect the effect of both climatic conditions and tectonics on the evolution of the basin and surrounding regions. The Tuzgözü Basin has been

initiated with tensional movements during the Late Cretaceous and has been evolved under the effects of transtensional movements upto Middle Eocene. This period was followed by the compressional episode that resulted in the shallowing and isolation of the basin from an open sea during the Late Eocene. Following the Late Eocene-Oligocene uplifting and erosion, a wide plateau (Anatolian Peneplain) has been formed in Central Anatolia during Early-Middle Miocene. The erosional and depositional surfaces formed during Miocene-Early Pleistocene, reflects the effect of the climate and tectonism on the landscape in Central Anatolia. Reactivation of the Tuzgözü, Yeniceoba-Cihanbeyli-Sultanhanı fault zones and other parallel fault systems resulted with the development of NW-SE trending, fault controlled basins on the wide Late Miocene plateau. The activity of the marginal faults of some basins ceased by the Early Pliocene-Late Pliocene period and new depositional surfaces developed in this basins. However, the Tuzgözü basin continued its development until present. The pattern of the Early Pleistocene and younger lake shore lines are also the important evidence of the tectonism controlling the evolution of the Tuzgözü. The recent earthquake epicenters with magnitudes upto 5.2, strongly suggest that the margin-boundary fault systems of the Tuzgözü and surrounding area are still active.

LS03 : WEpo13 : PO The Arabia/Anatolia Collision as Reflected by Detrital Modes of Miocene Flysch and Modern Sand (North Cyprus, Turkey, Syria)

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Arabia detached from Africa and began to collide with Anatolia along the Bitlis suture zone at Miocene times, when large volumes of detritus were produced and carried axially westward along a paleo-Euphrates/proto-Ceyhan drainage system. The thick orogenic turbidites accumulated in the Cilicia-Adana trough, but subsequently involved in strike-slip deformation at the border of the Anatolia plate and uplifted, are exposed today in the Kyrenia Range of North Cyprus (Kithrea Flysch; Weiler, 1970). Petrographic composition of these syn-orogenic clastic wedges indicates mixed oceanic and continental-margin sources, including a variety of volcanic, sedimentary, and metafelsite to metabasite lithics, along with common serpentinite and chrome spinel (Q 20 F 10 Lv 8 Lc 34 Lp 4 Lch 9 Lm 9 Lo 7). Nearly identical suture-belt signatures characterize modern sands transported by the Ceyhan and Seyhan rivers and accumulated in the Gulf of Iskenderun to Adana plain of southern Turkey (Q 20 F 11 Lv 5 Lc 38 Lp 6 Lch 4 Lm 9 Lo 6). Limestone and dolostone grains from Mesozoic successions are invariably abundant, becoming dominant along the Misis/Kyrenia transpressional range (Kempfer & Garfunkel, 1994). From north of Iskenderun to south of Lattakia, detritus today is mostly derived from ophiolite sequences obducted onto the Arabian margin at Late Cretaceous times and later incorporated in the collision zone (Kizildag and Baer Bassit complexes; Robertson, 1998), including abundant to dominant serpentinite grains from mantle rocks, associated with gabbroic rock fragments, plagioclase, diabase to metabasite, basaltic and sedimentary grains from progressively shallower levels of the multilayered oceanic crust (Q 4 F 5 Lv 5 Lc 25 Lp 2 Lch 11 Lm 8 Lo 38). Chert is most common in sand from the Baer-Bassit Complex, resembling detritus from the Mamonia continental-margin successions of South Cyprus. Diopside, orthopyroxenes, amphiboles and spinel are the main dense minerals, as in modern sand from the Troodos Ophiolite (Garzanti et al., 2000). Similar detrital modes, with abundance of limestone, chert, lathwork basaltic to diabase and serpentinite grains, characterize modern sand deposited on the northern side of the Cilicia basin, largely shed by the Mersin ophiolite (Q 7 F 5 Lv 12 Lc 29 Lp 2 Lch 18 Lm 6 Lo 20). Detritus from all of these ophiolite source terranes is characterized by dominant plagioclase (P/F \geq 95), gabbroic (Im/I \geq 90), mafic volcanic to subvolcanic (Vm/V \geq 85), metabasite (Mb/M \geq 65) and cellular serpentinite (Sc/S \geq 75) grain types. Composition of orogenic sediments and dispersal patterns along the Arabia/Anatolia suture zone may be compared with the larger-scale analogue represented by the proto-Himalayan suture belt in the first stages of the India/Asia collision (Graham et al., 1975; Garzanti et al., 1996).

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LS03 : WEpo14 : PO

First Results from GPS Measurements on Present day Iranian Kinematics

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Iran appears to be a key to understand how is distributed the continental deformation during a young intra-continental collision. The present tectonic of Iran results from a North-South convergence between Eurasia and Arabia, with a rate of about 3 cm/year. The shortening is accommodated by large reverse faults along mountain ranges (Zagros and Makran in the South, Alborz and Kopet-Dag in the North) and strike-slip faults surrounding stable areas such as the Central Iran block and the Luth block. The accumulated sum of seismic moments of earthquakes suggests that 80-90% of the deformation is aseismic. The precise distribution of the deformation is poorly constrained. The study of the deformation of this region should improve the understanding of the mechanisms which govern the preliminary stages of major orogens. In September 1999, a high-precision GPS network of 28 sites was installed to measure how is distributed the crustal deformation within Iran. 25 stations were installed in Iran, 2 stations in Oman and 1 station in Uzbekistan. Each site of the network has been recorded during four sessions of 24 hours. This network will be measured every two years. In this preliminary presentation we present the network and a first estimation of the deformation rate within Iran comparing our results with the results obtained in 1997 and 1998 by the Asia-Pacific GPS network. Both networks coincide for 6 sites and allow a first rough estimation of how is the deformation distributed within Iran.

LS03 : WEpo15 : PO

A New Approach to 3-D Gravity Modelling and its Tectonic Implications in the Eastern Mediterranean

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The three innovative elements of a computational scheme have been applied for increasing the reliability of geophysical interpretations in tectonic terms. They have been (1) forming the density contrasts of geological bodies relative to the upper mantle (3,32 gm-3) at the M in a tectonically stable pre-Cambrian platforms, (2) reducing calculated gravity attractions to the reference effect (-870 mgal) of its cross-section, and (3) automated inputting the maps of density contrasts to a PC by scanning. The first two components have made it possible to incorporate into 3-D modelling a strictly quantitative approach to estimating regional and local residual anomalies and the third one has substantially enhanced the resolving power of the approximation of the Earth's crust. The study region (1100x640 km) includes the Eastern Mediterranean Sea and the adjacent continents. The scale of 3-D gravity has been 1:4000000. A model has been computed on a 10x10 km

grid. It has comprise 5 layers: (1) water, (2) Pliocene-Quaternary sediments, (3) evaporites, (4) pre-evaporite consolidated deposits, (5) crust. The 3-D start model has been seismically constrained. In case of need density boundaries have been changed to fit empirical relationship between crustal thickness on the one hand and observed and computed fields, bathymetry, thickness of sediments on the other hand, with it being derived from observations along seismic lines. The computed effect of the final crustal model has been subtracted from the measured field to yield residuals referred to as the mantle components (MCs) of the Earth's gravity field. The MCs reflect integral influence of density distortions in the mantle which are associated with geodynamic processes in tectonically active regions such as the Eastern Mediterranean. For the first time MCs have constituted the basic material for tectonic zoning in this region. The main results of present study are as follows. The MC values over whole East Mediterranean Sea are negative. East Mediterranean mantle is less dense than those of the pre-Cambrian platform. The Cretan arc-trench system is distinctly marked by a regional intensive MC. In turn each tectonic elements of the system is clearly recognised on the VCs map. Another pronounced MC is associated with the Cyprean Arc. The submarine continuation of the African and Arabian Plates is reflected by relatively low MC values. A long narrow belt of MCs is observed along the continental rise from the Rodos Basin to the Adan Basin. There occur three crustal types in the study area. The Eastern Mediterranean Basin south of the Cretan arc-trench system is floored by the oceanic crust. The thinned continental crust exists in the Aegean Sea and within a 50-60 km wide strip offshore Egypt and Israel. The Herodotus and Levantine Basins are underlain by the crust of a particular kind which is absent from other basins. Further studies are needed to gain insight into its origin.

LS03 : WEpo16 : PO

Radiolarians from the Umber of the Perapedhi Formation, Late Cretaceous, Cyprus

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The metalliferous, fine grained sediments of the Perapedhi Formation in Cyprus are the oldest in situ sediments deposited at the site of the spreading centre. The age of these deposits therefore has significant implications for the understanding of the genesis and rate of spreading of the ocean rifting.

The umbers are thought to have been the product of hydrothermal fluids and previous attempts to place an age constraint have included both radiometric and biostratigraphical techniques, both methods giving an oldest age of Turonian and a youngest age of Campanian. No continuous section has been published. The umbers crop out at various localities on the margins of Troodos and occur above and between the pillow lava sequence.

A number of localities have been sampled for microfossils and whilst the occurrence is patchy, several well preserved assemblages of radiolarians and benthic foraminifera have been recovered. This work presents examples of diverse and well preserved radiolarians from two localities, Mangaleni and Dhrapia, on the southern margins of Troodos and from one locality, Trouli, to the east of Troodos. Radiolarians are the fossil group which has the best biostratigraphical potential for constraining the age and documenting the history of deposition of the umbers.

KEY WORDS: Cyprus, Radiolaria, Umber, Upper Cretaceous

LS03 : WEpo17 : PO

Peri-Tethyan Platforms Palaeogeography

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The Peri-Tethys Program followed the Tethys Program (Dercourt et al, 1993) which drew, in 14 maps, the Tethys evolution during alpine times. One of the continuing questions of the Tethys Program concerned the cratons behaviour relative to the Tethys Ocean progress. To fill this lack the Peri-Tethys Program team has drawn 24 maps at the scale of 1/10 millions, from the Carboniferous (300 Ma) to

Last Glacial Maximum (18 000 a). Each map deals with the European craton (from Atlantic to Oural) and African craton (including African, Somalian and Arabian blocs).

Each map shows the involved cratonic blocs in their relative palaeogeographical position. The synthetic model published in the previous Atlas Tethys (Ricou, 1994) has been revisited to fit the new data relative to the Iberian and Corso-Sardinian blocs during the Mesozoic times and to the Arabian plate during the Cainozoic times. On each map the nowadays outcropping strata belonging to the slice of time related to that map one are plotted at their palaeogeographical position with a pattern indicating their facies. These factual observations are coloured and interpolated relatively to their sedimentary environmental significance (16 environmental classes are distinguished). The drawn geodynamic features concern the palaeostress and the fault tectonics activity. They give the trend of the tectonic evolution during the geological time fixed on the map. Some major questions arose during the maps elaboration. One was the biostratigraphical correlation between the West and the East European part. The collaboration with the eastern geologist has given answer particularly on Permian times and Tithonian times.

The resulting maps illustrate some major conclusions :

1) The European craton is compound of two units. The Tornquist-Teysseire line is clearly evidenced by the environmental data during the Mesozoic times. To the Southeast the deposits indicate clearly deeper environmental conditions than to the Northeast. This feature leads us to understand that the Mediterranean lithospheric seuil (Vrielynck et al., 1994) depicted by the Tethys maps is wider than previously drawn. The south-eastern part of European craton seems to belong to this seuil of which the lithosphere is thinner.

2) During the Cainozoic times the environments distribution indicate the progressive uplift of the European craton from the alpine front to the Northwest. Map by map we see the marine environments superificies decrease with a Northwestward gradient.

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LS03 The Evolution of the Tethyan Orogenic Belt

Thursday AM Session

LS03 : THam01 : F2

Palaeozoic and Early Mesozoic Magmatism and Metamorphism in the Serbo-Macedonian Massif, Central Macedonia, Northern Greece

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The Serbo-Macedonian Massif (SMM) is one of the major geotectonic units of northern Greece. It mainly comprises amphibolites, amphibolite-facies schists and gneisses, in places migmatitic, and marbles. According to recent studies the SMM represents the western extension of thrust units belonging to the Rhodope metamorphic core complex, the latter interpreted as a complex of Cretaceous synmetamorphic nappes characterized by south- to southwestward stacking and associated with both coeval and subsequent extension in an Alpine active margin setting (Ricou et al., 1998).

Kockel et al. (1977) subdivided the SMM into two series, the underlying Kerdillon Series to the east and the overlying Vertiskos Series to the west. Burg et al. (1995) have nonetheless demonstrated that the Vertiskos Series is in fact a composite sequence comprising a lower metaturbiditic and orthogneissic sequence, with few amphibolites and distinct marble layers, and an upper migmatitic para- and orthogneissic sequence, separated by a metaophiolite-bearing mylonite zone.

We present single zircon Pb/Pb evaporation data from Lower Vertiskos orthogneisses that document, for the first time, Ordovician intrusion ages (469.1±3.2 Ma) as well as Late Triassic migmatitisation ages (222.9±4.9 Ma), the latter probably related to a rifting event. Rifting of the continental area was initiated by Earliest Triassic with deposition of a volcano-sedimentary succession, dated by foraminifera in its upper part (Ferrière & Stais, 1995) and U-Pb in rhyolitic zircon (240 Ma; R. Frei, unpubl. report). It was followed by deposition of limestones throughout the Triassic and extrusion of basalts with WPB/MORB transitional chemistry towards the Late Triassic (Dimitriadis & Asvesta, 1993). Further evidence for continental rifting comes from the Arnaea granite. This is a large, highly evolved granitic intrusion, contained within the Lower Vertiskos sequence. It is probably an S-type granite resulting from crustal anatexis and displays within-plate geochemical characteristics. In contrast to earlier work (de Wet, 1989) suggesting a Late Jurassic age, our single zircon Pb/Pb evaporation data indicate a Late Triassic time of intrusion (215.0±1.8 Ma). We, therefore, interpret the Arnaea granite as a crustal melt associated with continental rifting. The development of phengite (Si=3.5 a.p.f.u.) parallel to the foliation in the Arnaea granite is ascribed to Early Cretaceous underthrusting of the Lower Vertiskos sequence at depths corresponding to pressures of 11-14 kb and temperatures of ca. 500-600°C. Sodic aplite apophyses of the Arnaea granite at its eastern boundary contain amphibolite inclusions, thus strongly demonstrating the pre-Alpine metamorphic history of certain parts of the SMM.

We furthermore emphasize that Vardarian subduction under Lower Vertiskos must have been established by Lower Jurassic as indicated by our single zircon Pb/Pb evaporation data for the Monopighadon volcanic-arc granite (192.5±3.8 Ma). This also bears important implications as to the founding of the Guevgueli magmatic arc.

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LS03 : THam02 : F2

The Basement beneath Mt. Olympus, Greece: Remnants of a Permo-Carboniferous Magmatic Arc

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The Mt. Olympos region in N Greece belongs to the Pelagonian zone which, together with the Attic-Cycladic Massif, forms the central crystalline belt of the Hellenides. Cretaceous and Tertiary tectono-metamorphic processes associated with the Alpine orogeny are responsible for the complex nappe structure of the Pelagonian zone seen today. Mount Olympos itself is generally considered as a tectonic window that allows one to look through the nappe pile. One of these nappes consists of crystalline basement, mainly orthogneisses, that tectonically overlie Mesozoic limestones. We investigated the geochronology and geochemistry of these orthogneisses, which are well exposed to the west of Mt. Olympos.

Deformation of these gneisses is variable ranging from almost undeformed granite to highly sheared augengneisses. According to their chemical composition the orthogneisses are classified as metamorphosed granitoids. Trace element characteristics such as low concentrations of HFSE indicate an origin in a magmatic arc, most probably in an active continental margin environment.

We dated gneisses from several localities west of Mt. Olympos as well as from a small klippe lying at high altitude on the SE slopes of the mountain using the single zircon Pb/Pb evaporation technique. The ages obtained range from ca. 280 to 290 Ma for the samples west of the mountains; only a few zircon grains were around 300 Ma. The sample from the klippe appears to be slightly younger with ca. 270 Ma. These ages imply that the granitoids crystallized during the uppermost Carboniferous - lower Permian, and are therefore younger than the basement gneisses of other regions of the Pelagonian zone which yielded ages around 300 Ma (e.g. De Bono, 1998; Yarwood & Aftalion, 1976; Mountrakis, 1983; Engel & Reischmann 2001). However, they are identical within error to the white mica Ar-Ar cooling ages from Ossa mountain (Lips, 1998). According to these geochronological data the magmatic evolution that formed the basement lasted for at least 30 Ma.

The data indicate that the gneisses in the Mt. Olympos region belong to a Permo-Carboniferous magmatic arc that extended all along the Pelagonian zone to the Cyclades islands. We favour the subduction of a branch of Palaeotethys as the most plausible scenario for the formation of such a magmatic arc. The detailed palaeogeographic situation, however, is still to be elaborated.

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LS03 : THam03 : F2

Upper Carboniferous Magmatism in the Central Aegean Region: Evidence from Basement Gneisses of the Cyclades

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The geodynamic evolution of the eastern Mediterranean region is characterized by opening and closure of the Palaeo- and Neotethys since the Palaeozoic. Such geodynamic processes are well documented in the basement of the Cyclades. Here we present single zircon Pb/Pb evaporation ages and Rb-Sr and Sm-Nd isotope data for this base-

ment in order to unravel the geological record of the prealpine evolution of this region. The Cyclades are part of an arcuate crystalline belt extending from the Pelagonian Zone in N Greece to the Menderes Massif in W Turkey. The crystalline rocks in the Menderes Massif display similarities with that of the Cyclades concerning mineral content, texture, metamorphic degree and geochemical composition. Therefore, the crystalline units of both regions were thought to be connected. The Central Cyclades are built up by basal gneisses with amphibolite facies overprint covered by nappe piles comprising Late Palaeozoic to Mesozoic metasediments as well as Jurassic to Cretaceous ophiolites. The basement is exposed on Delos, Paros, Antiparos, Naxos, Sikinos and Ios. It consists of leucocratic gneisses that are classified as granites, granodiorites and quartzdiorites with slight S-type character. Trace elements support a convergent plate margin as the most suitable tectonic setting. The zircon ages vary from 300 to 315 Ma. We interpret these ages as the igneous formation ages of the granitic protoliths. Older grains (0.5 - 2.3 Ga) are interpreted as inherited zircons that indicate incorporation of older crustal material. The initial ⁸⁷Sr/⁸⁶Sr ratios vary from 0.705091 to 0.712725. εNd values range from -6 to -8, their model ages from 1.8 - 1.9 Ga. Sr and Nd isotopes reflect a crustal signature. In addition the existence of inherited zircons also indicates the participation of Proterozoic crust. The scatter of the initial isotopic compositions implies that the granitoids were not derived from a homogeneous source. A hybrid origin from various sources appears to be more likely. The prevailing ages of 300 to 315 Ma prove a major igneous phase during Late Carboniferous time. This can be correlated to Carboniferous plutonism of the Pelagonian zone in Greece and the Sakarya continent in NW Turkey. However, the Sr- and Nd isotopes as well as the zircon ages show differences to the neighbouring Menderes Massif reflecting a distinct formation history. The magmatism that produced the basement of the Cyclades might be interpreted as the result of Palaeotethys closure during northward movement of the "Pelagonian-Cycladic-Terrane" and reflects the approach to Laurasia.

LS03 : THam05 : F2

Collisional History of the Southern Neotethys Ocean in the Easternmost Mediterranean Region

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It is widely accepted that the Kyrenia-Misis-Andirin tectonic lineament in the easternmost Mediterranean region records the Mesozoic-Tertiary evolution of the N margin of the S Neotethys ocean (e.g. Robertson, 1998). However the Late Cretaceous-Tertiary closure/collision history is controversial. Alternatives are: 1. Closure accompanied latest Cretaceous southward ophiolite obduction; 2. Closure occurred in Eocene, coeval with deformation of the Syrian Arc to the south; 3. Collision was delayed until the Late Miocene, followed by Plio-Quaternary left-lateral strike slip and westward tectonic escape of Anatolia. In one well known hypothesis, closure was followed by Miocene transtensional basin opening, followed by a phase of Late Miocene compression. Building on earlier work in N. Cyprus, we have investigated the several hundred km-long Misis-Andirin-Munzur lineament during 1999-2000. Our main findings are: 1. Ophiolites and related units were emplaced onto the N margin of the S Neotethys in latest Cretaceous as coherent thrust sheets; 2. Passive margin conditions were restored in the Palaeogene; 3. Collision of the Eurasian continent with Arabia took place in Eocene-Oligocene time, recorded by mass wasting of N margin units to create a vast tectonic-sedimentary melange with a marine sedimentary matrix (Mises-Andirin Melange). In the Mises area, Upper Cretaceous ophiolitic extrusives (previously viewed as Miocene) were accreted/underplated to the northern margin during Eocene-Oligocene collision; 4. Further compression in the Miocene tightened the suture, creating a regional foreland basin (Adana-Karamanmaraş-Lice basin), that was finally overthrust by N margin units in latest Miocene time. The Misis-Andirin suture is transected by widely distributed left-lateral strike-slip faults of Plio-Quaternary age related to westward tectonic escape of Anatolia. In the Misis area in the S the present topography of sub-parallel narrow, elongate ranges separated by young sediments is seen as resulting from localised transpression. By contrast, further NE the Andirin and Munzur Ranges experienced regional uplift to the N of the South Anatolian transform fault zone. Finally, the

Kyrenia-Misis-Andirin-Munzur units are seen as a continuous tectonic lineament that shared a similar evolution, rather than as separate units with contrasting histories as in some previous interpretations.

Robertson, AHF, *Proceedings of the Ocean Drilling Program, Scientific Results/Proceedings of the Ocean Drilling Program, Scientific Results*, **160**, 723-782, (1998).

LS03 : THam06 : F2 First Structural Data Related to the Low-Grade High-Pressure Metamorphism in the Metasediments of the Lycian Nappes, SW Turkey

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In the southwestern part of Turkey, the Lycian nappe complex overlies an extensive autochthonous basement, composed of the Menderes massif and the Bey Dag platform. This nappe complex consists of metasediments, a mélange unit and an ophiolitic sequence from base to top. Fresh Fe-Mg-carpholite occurrence in the metasediments points out a high pressure-low temperature metamorphic event. We describe the distribution of carpholite and its breakdown products, such as pyrophyllite and chloritoid on the Bodrum peninsula, south of the Menderes crystalline massif as well as in klippen of Lycian nappes on the top of the Menderes Massif. The distribution of Fe-Mg-carpholite and its relics shows that the low-grade high-pressure metamorphism affected a widespread area in the lower units of the Lycian nappes. On the Bodrum peninsula, ductile deformation analysis in HP-LT metasediments of the Lycian thrust sheets indicates shear senses top-to-the-northeast to top-to-the-east. This deformation is mainly contemporaneous with the retrogression of high pressure-low temperature parageneses and therefore corresponds to the exhumation of these low-grade high-pressure rocks. At the top of the Menderes massif cover series, close to the contact with the Lycian nappes, similar eastward displacements are observed and trajectories of the stretching lineations are continuous from the Lycian nappes to the Menderes massif across the contact. These observed movements are incompatible with the southward transport of the Lycian nappes over the Menderes massif and a later tectonic event, in relation to the exhumation of the Menderes massif is discussed.

LS03 : THam07 : F2 The Beyşehir-Hoyran-Hadim (B-H-H) Nappes: Mesozoic Marginal and Oceanic Units of the Northern Neotethys in Southern Turkey

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The Beyşehir-Hoyran-Hadim (B-H-H) Nappes (Özgül, 1997) occur in four main outcrop areas, over ca. 300 km, laterally: Karaman (in the E), Bozkır, Beyşehir and Hoyran (in the W). Regional units in upward tectonic order are: 1. Autochthonous Tauride carbonate platform (Cambrian-M. Eocene); 2. Allochthonous Hadim Nappe- Devonian-Late Cretaceous); 3. Ophiolite-related units (e.g. harzburgitic thrust sheets and U. Cretaceous mélange); 4. Allochthonous Bozkır Nappes (Triassic-Late Cretaceous). However, the Hadim Nappe is absent from the Hoyran area(W). Our talk will focus on the Bozkır Nappes, the uppermost regional unit. In the type(central) area the nappes begin with a thrust sheet (ca.400 m thick) of mainly redeposited carbonates, quartzose sandstones and mudstones of Mid-Late Triassic age (Korulan Fm.), interpreted as a proximal slope/base-of-slope succession. Tectonically above is an intact succession (ca. 1 km) of Mid-Late Triassic alkaline volcanics and volcanoclastics (Huglu/Dedemli unit), interbedded with minor pelagic carbonates, viewed as rift-related volcanism. This is depositionally overlain by a thin (<100 m) succession of Upper Triassic-Upper Cretaceous pelagic carbonate and radiolarian chert. Above, the uppermost unit comprises

sheared thrust sheets, broken formation and mélange, including Jurassic shallow-water carbonates, radiolarian chert and Upper Cretaceous pelagic limestone. Similar units are seen elsewhere in the B-H-H Nappes, but the stacking order varies (e.g. Beyşehir). Zones of tectono-sedimentary mélange ("wildflysch") commonly separate higher units (e.g. Beyşehir area). The B-H-H Nappes document Triassic rifting and later-Mesozoic seafloor spreading within the northerly Neotethys. The harzburgitic ophiolite (e.g. Dipsiz Gol ophiolite) probably formed above a subduction zone. The ophiolite was emplaced southwards onto the N margin of the Tauride platform in latest Cretaceous (future Hadim Nappe). Suturing was delayed until the Eocene when the Hadim, plus Bozkır, nappes were thrust further south. Assuming in-sequence thrusting, the Bozkır Nappes restore to a location north of the Tethyan spreading axis. More probably, they originated near the northern margin of the Tauride microcontinent, but reached their final position by Eocene out-of-sequence (re)thrusting.

Özgül N, M. T. A *Dergisi*, **119**, 113-174, (1997).

LS03 : THam10 : F2 The Granitic Rocks of the Southern Menderes Massif and their Tectonic Significance

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The Menderes Massif is a regional, large-scale, elongate metamorphic core complex with its long axis trending NE-SW, covering an area of more than 40,000 km² of western Turkey. The massif is conventionally subdivided into northern, central and southern submassifs, where the seismically active E-W-trending Gediz graben in the north and Buyuk Menderes graben in the south are taken as dividing lines between the submassifs, respectively. The Menderes Massif consists typically of a thick, tri-partite lithologic succession with a 'gneiss core' at the base, a Palaeozoic 'schist envelope' covering the gneiss core, and a Mesozoic-Cenozoic 'marble envelope' overlying both, with metamorphism increasing towards the core. The latter two units are known as 'cover rocks'. The age of the core augen gneisses is controversial. While some suggests that they represent Pan-African basement in the massif, others argue that they are Tertiary granitoids. The relationship between the core augen gneisses and cover schists has been largely obscured by the polymetamorphic and structural complex history of the Menderes Massif and is almost everywhere structural. It has been the subject of debate among geoscientists for many years. Geochronological evidence (single zircon ages) from the augen gneisses of the southern Menderes Massif (SW Turkey) suggests that the granitic precursors were intruded during the Late Precambrian and Early Cambrian. These ages apparently contradict the intrusive contact relations between the granitic protolith of the gneisses and the structurally overlying metasediments. It is important to note that rocks exposing to the north of so-called 'core-cover' contact in the Southern Menderes Massif is regarded as 'core' rocks. The recent field campaign in the southern submassif around Yatagan has revealed that the so-called augen gneisses in the submassif can be divided into two types: orthogneisses and metagranite. These differ from one another in intensity of deformation, degree of metamorphism and kinematics; the former are typical orthogneisses and display asymmetric structures formed during top-to-the N-NNE shearing under high amphibolite facies conditions while the latter is a typical metagranite and possesses top-to-the S-SSW fabrics formed under greenschist to (?) lower amphibolite facies conditions. The intrusion of this granite into the metasediments induced a very weak contact metamorphism. The top-to-the N-NNE ductile mylonite fabrics from the augen gneisses has yielded Eocene Ar-Ar laser probe white mica ages, suggesting that the protolith was transformed into augen gneisses during the Eocene MMM. The metagranite displays crosscutting relationships not only to the structurally overlying metasediments but also to the augen gneisses with the top-NNE ductile fabrics. This clearly indicates that the intrusion age of the precursor to the metagranite must be younger than Eocene, thus confirming previous contentions that there are Tertiary granites in this part of the Massif.

LS03 : THam11 : F2 Tectonic Implications of Sedimentation and Volcanism in the Lower Tertiary Ulukisla Basin, South Central Turkey

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The Lower Tertiary Ulukisla Basin, located 120 km north of Adana, lies geologically along a proposed suture zone between the Taurus-Menederes Block to the south and the Kırşehir Block to the north. This suture zone is believed to be a remnant of the Inner Tauride Ocean, a strand of Northern Neotethys. The Ulukisla Basin may thus preserve evidence for the tectonic development of a suture zone, prior to, during and after final closure of this branch of Northern Neotethys.

A major feature of the Ulukisla Basin is the Ulukisla Volcanics, a thick sequence, (< 2 km), of basaltic to andesitic lava breccias, lava flows and pillow lavas, with subordinate limestone intercalations. Geochemical analysis provides insights into the origin of this volcanic suite. Whole-rock analysis by XRF indicates a within plate-origin for the Ulukisla Volcanics, with a notable subduction signature (e.g. Nb depletion). It is suggested that this is a remnant chemical signature following subduction of the Inner Tauride Ocean.

The Lower Tertiary Ulukisla Basin stratigraphy comprises Maastrichtian transgressive shallow-water carbonates, passing up into Palaeocene-Lower Eocene deep-marine turbidites. During the Middle Eocene the Ulukisla Volcanics, overlying shallow-water carbonates and a second phase of turbidites were all formed. Basinal deposition terminated with Upper Eocene evaporites. Sedimentological study combined with subsidence analysis reveals a complex history of subsidence, basin infilling and uplift. The basin underwent fold-and-thrust shortening at the end of the Eocene, constrained by a basal Oligocene unconformity with terrestrial clastic sedimentation above. This phase of compressional deformation reflects final suturing of the region.

Currently, we are considering two possible tectonic origins for the Ulukisla Basin. In the first, the Inner Tauride Ocean was already completely sutured and transtensional rifting followed in the Early Tertiary related to oblique tightening of the suture zone. In the second, the Inner Tauride Ocean remained partially open after Late Cretaceous southward ophiolite emplacement and the Ulukisla Basin was related to consumption of a partly subducted oceanic slab. Any interpretation must take account of other comparable Lower Tertiary basins of Anatolia, including the Tuzgözü, Sarkisla and Sivas Basins.

LS03 : THam12 : F2 Mesozoic Crustal Extension and Basin Inversion Events at Nikishin-Black Sea Region

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Tectono-stratigraphy of the Circum-Black Sea region documents a long-lived subduction-accretion, multiple phases of crustal extension, basin formations and inversions associated with evolution of Tethys. The Moesian-Pontides-Caucasus-Scythian region was consolidated during the Carboniferous-Early Permian as an Andean-type orogenic system, bordered to the south by Tethys. Northward subduction of Tethys caused collapse of the orogen and associated crustal extension resulted in formation of an oceanic marginal basin system in the Triassic in the area of modern Black Sea. Remnants of this basin are now found in the Caucasus (Svanetia), South Crimea (the Tavrik

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Flysch), Central Pontides (the Küre Complex) and Dobrogea. Gondwanian continental terranes and seamounts drifted northward and collided with the trench during the Carnian to Hettangian period, causing collisional deformations. This collision triggered inversion of the Triassic rifted basins. The Svanetia basin was closed by the Liassic, while foreland propagating fold and thrust belts inverted the Triassic rifts onto the Scythian Platform and narrowed the basin considerably elsewhere, with a remaining flysch basin. During the Sinemurian to early Aalenian, renewed crustal extension created back-arc basins, including the E Pontides and the Great Caucasus Trough that formed by rifting of the Sinemurian volcanic arc. Large scale calc-alkaline magmatic arc originated during the Bajocian time along southern margin of the Great Caucasus, Crimea and the E and Central Pontides in a regional compressional event. It was connected with inversion event at the Aalenian-Bajocian boundary and orogenic events during the Bajocian-Bathonian time. A regional orogeny took place by collision of the Tethyan active margin by consummational obliteration of the Küre-Crimea-Dobrogea basin. Extensive foreland molasse basins originated along northern margin of the Caucasus, Dobrogea and Crimea (Bitak and Beshuy basins) during the Aalenian-Bajocian period. After the pre-Callovian orogenic phase, the Great Caucasus-Crimea area was affected by a new rifting cycle that commenced during the Callovian and terminated in Berriasian. Main late Jurassic rifts were the South Caspian-Great Caucasus Trough-South Crimea and Dobrogea. Similar extensional events are recognised in the Balkanides, where reflection seismic data document a system of Late Jurassic syn-depositional normal faults that controlled the subsidence of the southern margin of the Moesian Platform. New back arc rifting cycle commenced during the Middle Cretaceous period, associated with northward subduction of Tethys and resulted in formation of the W Black Sea basin. This rifting cycle was followed by large-scale orogeny in Turkey during Campanian to Palaeocene which was consistent with inversion events in a stable Europe.

LS03 : THam13 : F2 Geodynamic Evolution of the Biga Peninsula (N-W Turkey)

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The aim of this paper is to better constrain the structural relationships between the Çetmi accretionary melange, the Kasdag Massif and the overlying rocks, which are outcropping in the Biga Peninsula in Northwest Turkey.

The Çetmi Melange (Okay et al., 1991) is made of different types of limestone of various ages (Anisian to Middle Carnian, Norian-Rhaetian, Late Jurassic-Early Cretaceous (?)) and Late Cretaceous, sandstone, siltstone, red or green radiolarite (Late Jurassic), spilite, pillow and minor serpentinite; two large tectonic slices of garnet-micaschist and eclogite also occur. An upper limit on the subduction-accretion and emplacement of the Çetmi accretionary Melange is provided by the little deformed Middle Eocene-Oligocene limestones and clastics rocks, which lies unconformably over older sequences in Northwest Turkey. This melange represents a former mixed accretionary complex with different origins for its components (Beccaletto and Stampfli, 2000).

The Kasdag metamorphic massif is a structural dome made of gneiss, marble, amphibolite and meta-ultramafic rock. It underwent high temperature regional metamorphism during the latest Oligocene at a depth of 14 km (Okay and Satir, 2000).

A north dipping shear zone of strongly mylonitised gneiss and serpentinite, two kilometres in thickness, occurs between the Kasdag Massif and the accretionary melange in the north, along which the Kasdag Massif is thought to have been partly exhumed (Okay and Satir, in press). Moreover we have mapped in the south a low angle brittle normal fault dipping to the south separating the Kasdag Massif from the Cenozoic cover rocks. An undeformed granodioritic intrusion dated at 24 Ma is intruding the mylonites and the melange (Okay and Satir, 2000).

Reinterpreting existing radiochronologic data and using new detailed field evidence, we propose a new model for the exhumation of the Kasdag Massif since the Late

Oligocene. This has been made in the larger frame of the geodynamic history of the whole area, particularly by taking the Aegean extension into account and reviewing the role of the North Anatolian Fault. Giving a new role to the mylonitic zone (which predate the pick metamorphism), we argue that most of the exhumation has been controlled by the southward dipping low angle normal fault during the Latest Oligocene and the Miocene, accompanied by the deposit of lacustrine sediments and volcanism. A new normal fault located slightly southward took over the previous fault during the Pliocene and is still accommodating the present extensional regime (deposition of about 2 km thick Plio-Quaternary sediments in the down-thrown compartment).

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Beccaletto L., Stampfli G. M., *IESCA 2000, Volume with Abstracts*, (2000).
Okay A. I., Satir M., *Geological Magazine*, **137**, 495-516, (2000).

LS03 : THam14 : F2 New ⁴⁰Ar/³⁹Ar and U/Pb Radiometric age Data from the Western Pontides, N Turkey: Implications for Tectonic Evolution

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The Pontides tectonic belt of northern Turkey is located to the north of the main Izmir-Ankara-Erzincan suture and is believed to be Eurasian in origin. The western Pontides is a tectonic mosaic of continental and oceanic assemblages, amalgamated in the Late Mesozoic-Early Tertiary time. The continental assemblages record different stratigraphic development, dated at least from the Palaeozoic up to Late Mesozoic. An important common element of these continental assemblages is the presence of high grade metamorphic rock associations at their structural base. This study aimed at better understanding of tectonic evolution of the basement units by focussing tectono-stratigraphy, geochemistry, structure and geochronology of the individual assemblages. Four different basement units are separated. The Istanbul Fragment to the north has a metamorphic and igneous basement, unconformably overlain by an early Ordovician to Early Carboniferous transgressive sequence. The basement of this unit comprises Cadomian arc type volcanics and volcanoclastics (the Çarstepe Formation), intruded by granitoid intrusions (the Tüllükiris and Kapıkaya plutons). Structurally underneath is a high grade metamorphic assemblage, represented by gneisses and amphibolites (the Sünnece Group). Three different metamorphic associations are exposed to the south of the Istanbul Fragment in the Armutlu Peninsula and further east (Akartuna, 1968; Göncüoğlu et al., 1987; Yılmaz et al., 1997). The Armutlu metamorphics comprises gneisses and amphibolites and extensively expose in the Armutlu Peninsula. This unit is in tectonic contact with a lower grade Triassic to Late Cretaceous continental margin sediments, known as the Iznik Metamorphics. The Pamukova metamorphics further south are made up of gneisses and amphibolites with occasional marbles, intruded by granitoid plutons. This unit is separated from the Armutlu and Iznik metamorphics by a Late Mesozoic flysch and melange. A third metamorphic unit is exposed in the Almacik area in the east, where structural basement of the Iznik Metamorphics comprises gneisses and amphibolites, similar to the Armutlu Metamorphics, but intruded extensively by carbonatitic intrusions. New radiometric age data on amphibolites and granitoid intrusions from each of the above basement units will be documented and constraints and implications for tectonic evolution of the Western Pontides will be discussed during this presentation.

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Thursday PM Session

LS03 : THpm21 : F2 The Impact of Cretaceous Pillow Basaltic Lavas from North Anatolian Ophiolitic Melange (Central Anatolia, Turkey) in the Geodynamic Evolution of Neo-Tethys along Izmir-Ankara- Erzincan Suture Belt

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The most widespread blocks within the Cretaceous North Anatolian Ophiolitic Melange in Central Anatolia are ophiolitic fragments, Jurassic-Cretaceous carbonate blocks and pillow basalts. Pillow basalts in Cretaceous ophiolitic melange are exposed as discrete blocks in close proximity to radiolarites and ophiolitic units in the region extending from south of Ankara (central Anatolia) to Çorum (north-east Anatolia).

New geochemical results indicate that the analyzed pillow basalts are within-plate ocean island alkali basalts. N-MORB normalized spider diagrams show enrichment of most incompatible trace elements and a far greater range of absolute abundance than N-MORB. The enrichment of incompatible elements and patterns of trace elements indicate the ocean island environment and enriched MORB compositions.

Intrafrills between basalt lobes and possible atolls have close relationship with these ocean island pillow basalts. The "Protoglobigerina" (possibly Globuligerina) associated with miliolid and epistominid foraminifers, indicates an age range from Callovian - Barremian for the biomicritic intrafrills between pillow basalt lobes. The Late Barremian-Early Aptian age is assigned to volcanic and radiolarite detritus bearing orbitolinid and Baccinella bioclastic limestones that are rich in corals and rudist fragments. It is clear that the atolls developed along this segment of the belt during Late Barremian-Early Aptian interval.

The results collectively support the presence of seamounts constructed on Neo-Tethyan oceanic crust during the Callovian - Barremian interval that, in turn, proves the presence of an oceanic crust along the Northern Branch of Neo-Tethys during that period.

LS03 : THpm22 : F2 Metamorphic Evolution of Mafic Granulites from the Metamorphic Sole of Central Dinaric Ophiolites (Bosnia-Herzegovina)

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In the metamorphic sole of the Central Dinaric Ophiolite Belt (CDOB), mafic granulites and amphibolites are found in close contact to overlying peridotites (Lugovic et al., 1991). The main phases are garnet (grt), clinopyroxene (cpx), plagioclase (plg) and amphibole (am). The chemistry of the samples indicates a MORB origin. Sm-Nd dating yielded ages of about 171 Ma. All main phases show strong chemical zonations. In grt, Mg# increases whereas Ca and Mn decrease from core to rim. In one sample Ca first increases from core to rim with a decrease in the outer part of the grain. At the outermost rim (<100 µm), a decrease in Mg# can sometimes be seen, but normally is destroyed by the formation of symplectite. Larger grains of cpx show a two-phase zonation pattern. From core to rim, Al first increases while Si, Mg, Mg# and Ca decrease. The outermost zones show a sharp reversal in the zonation patterns with Al and Na decreasing and Si, Mg, Mg# and Ca increasing. In plg, the anorthite content increases from core to rim. In am, Mg# increases from core to rim whereas Al

and Na decrease. Temperatures were calculated using the grt-cpx thermometer of Krogh (1988). Due to prograde zonation in grt and retrograde zonation in cpx, geothermometry using core analyses would be meaningless. Temperatures calculated with rim analyses of both grt and cpx lie between 820 and 1060°C (1 GPa) indicating a high-temperature metamorphism. Grt-cpx-thermometry using grt analyses with the highest Mg# and core analyses of cpx gives slightly higher (~40 K) temperatures. Retrograde diffusional modification and decomposition of the outermost parts of garnet grains prevent the identification of maximum Mg#, leading to an underestimation of peak temperatures. Since Qtz, Opx and Al₂SiO₅ phases are lacking, maximum pressures could not be determined, but were probably around 1 GPa. Grt and cpx preserve both prograde and retrograde zonation patterns. The preservation of the prograde zonation places strong constraints on the duration of high-temperature metamorphism. Modelling of the diffusional relaxation in garnet shows a significant modification of the measured zonation patterns after 0.1 to 1 Ma even for low temperatures (800°C). To preserve the observed chemical zonations, a rapid cooling from peak temperature to below closure temperature is required.

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LS03 : THpm23 : F2 Structure, Petrology & Geochronology of the Albanian Ophiolites and their Tectonic Evolution within the Neotethyan Orogenic Belt

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The Albanian ophiolites in the Dinaride-Hellenide segment of the Alpine orogenic belt represent the remnants of the Mesozoic Neotethyan ocean and occur in two subparallel zones. The ~6-km-thick ophiolite in the west consists of lherzolite, dunite, troctolite, wehrlite, gabbro-ferrogabbro, plagiogranite, and massive to pillow lavas; upper crustal units locally rest directly on the partially serpentinized upper mantle rocks, reminiscent of slow-spreading modern oceanic crust. The ~10-km-thick ophiolite in the east includes mainly harzburgite, dunite, websterite, gabbronorite, olivine gabbro, diorite, plagiogranite, sheeted dykes, massive to pillow lavas, and radiolarian chert in a relatively intact layered pseudostratigraphy. Both the extrusive sequence and the sheeted dyke complex are cut by extensional normal faults and local structural grabens that display extensive Cu-Fe sulfide mineralization, epidote formation, and hydrothermal alteration. There is no major tectonic break between these two ophiolite zones, and locally the peridotites and extrusive rocks in the western zone are intruded by plagiogranite and quartz diorite plutons of the eastern zone.

The geochemical composition of the majority of the basaltic and basaltic andesite lavas, dykes, and gabbro from the western zone is typically of MORB type and compares best with basalts generated from plume-influenced mantle. However, the composition of the basaltic rocks in the upper 100 m of the c. 600-m-thick volcanic sequence gradually changes towards subduction-influenced magma, as reflected in the upward decreasing incompatible trace elements contents (e.g. Ti, P, Zr, Y, Nb), as well as the Nd-isotopes that change from c. $\epsilon_{Nd} +7.3$ at the lowest to $\epsilon_{Nd} +6.5$ at the highest structural level. Lavas and dykes in the eastern zone range in composition from basalts to basaltic andesites as the earliest, and andesites and dacites as the latest products. Throughout the volcanic sequence these rocks show low contents of incompatible trace elements, suggesting subduction zone influence in their origin. The ϵ_{Nd} values of the basaltic and basaltic andesite lavas range from c. +7 to +6, whereas the andesitic to dacitic lavas reach values of c. +3 indicating that these end members are genetically unrelated. Intrusive rocks show a higher range in their ϵ_{Nd} values from +6.5 to -4, whereas quartz diorites display the same values as the dacites suggesting a probable genetic link. Gabbros from the

western and eastern zones have distinctively different ϵ_{Nd} values. U/Pb zircon dates from six plagiogranite intrusions from both zones yield igneous crystallization ages ranging between 165 and 162 Ma, indicating that ophiolitic units in the eastern and western zones are nearly coeval and that they appear to be younger than their "metamorphic soles". Based on these new structural, geochemical and geochronological data we propose a new tectonic model for the evolution of the Albanian ophiolites in a regional geological context.

LS03 : THpm24 : F2 From Chalkidiki to Samothraki (Greece): Ultra-Rhodopian Origin of the Vardar Ophiolites

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The Dinaride-Hellenide ophiolites (or most of them) are remnants of a Jurassic arm of Neo-Tethys, i.e. the Vardar (-Meliata) ocean, obducted westward onto the Pelagonian platform during the Early Cretaceous. The Vardar ocean is currently thought to have formed by Triassic rifting between the Pelagonian (west) and Rhodopian (east) continental platforms. Hence, the ophiolites would be autochthonous in the eastern Vardar (-Axios) zone (the alleged Tethyan suture). However :

1) The broad metamorphic structure of northern Greece is not consistent with this way of thinking. By reference to classical subduction-collision belts, the Cretaceous suture is expected to occur along the inner boundary of the higher grade zone, i.e. east of the eclogitic Rhodope nappes (Michard, 1993).

2) The west part of the Vardar-Axios/Rhodope boundary zone (i.e. the external part of the Circum-Rhodope Belt, CRB) is a late orogenic, Late Cretaceous-Paleocene steep belt (Chalkidiki dextral Shear Zone, KSZ), not an Early Cretaceous suture. Age constraints are given by a new 93 Ma K/Ar phengite age from central KSZ, and by the subsequent intrusion of the foliated Sithonia granodiorite (50-43 Ma).

3) During the Early Cretaceous, prior to its final shortening and shearing, the CRB consisted of a pile of nappes with low-grade ophiolitic units on top (Thessaloniki-Kassandra nappe ; Michard et al., 1998), and blueschist/greenschist, oceanic and continental units at the bottom, juxtaposed to the Serbo-Macedonian/Rhodopian eclogite/amphibolite units. A new 117 Ma K/Ar age was obtained from the Serbo-Macedonian Armaia orthogneiss.

4) The Samothraki Island, south of the Rhodope Complex, and 200 km east of the KSZ, shows a pile of ophiolitic units with the same Late Jurassic supra-ophiolitic sediments as those of Thessaloniki-Kassandra (arc-related breccias, cf. Michard et al., 1998), and the same low-grade metamorphism. Similar ophiolitic inliers are described in continental Thrace further east.

In contrast with competing ideas, we infer that the Vardar suture must be located between the Rhodope Complex and the Balkan Mountains, SE of the Late Cretaceous Srednogorie magmatic arc. Then, the Pelagonian platform should extend beneath the Vardar-Axios zone (cf. Paikon window ; Ricou et al., 1998), and the Rhodope nappes should originate from the thinned NE margin of the 'Great Pelagonian' platform.

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LS03 : THpm25 : F2 Reconstructing the Puzzle of the Ophiolite Imbricates Surrounding the Meso-Hellenic Trough: Implications for the Sea-Floor Model

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The ophiolite belt of the Western Hellenides is comprised of countless small to large separated ophiolite-derived units: some like Vourinos are large (450 km²), retain their primary obduction relations, and are relatively internally coherent. Others, like parts of the Pindos and most of Othris, are dislocated from their original obduction basement, imbricated to the extent that the mantle to crustal sections are split-up and over-riding in complex nappe sequences, and some parts are severely deformed and rotated by the tectonism accompanying the formation of the Meso-Hellenic Trough.

The vast research conducted worldwide on ophiolites has established reliable tools which can distinguish the original orientation of the ophiolitic fragment with respect to its original oceanic setting and provide certain features which overlap between fragments. Of the first group, orientations of lavas, included sediment layers, cumulate layering and petrologic trends of cyclic units, overall succession about the position of the petrologic moho are among features that can tell us 'which way is up?' and 'where now is original horizontality.' Overlapping features include ridgecrest direction and form lines of mantle-level structures in peridotite units.

Some of the more salient results shown by comparative analysis between the ophiolitic fragments include the following: Ophiolite lavas associated with the Othris ophiolite indicate a 'towards the ridge' polarity towards the west and opposite to that of older, rifting volcanic sequences. This ridgecrest direction agrees with the 'to the ridgecrest' orientation derived independently in other Othris fragments by angular incongruities between mantle layering and high-temperature foliation, and possible sheeted dyke chilled margin statistics.

A comparison can be made between 'up-section' polarity and horizontality as determined by the magmatic rocks with mantle structures. Such a comparison between Vourinos and major massif units of the Pindos indicate that while the mantle structures retain a constant orientation between these units, their relative 'stratigraphic' orientations reconcile a geometry greatly affected by an obduction geometry.

A compilation of this ophiolite data is in progress for the entire Western Hellenides. Results indicate the need for new studies in critical areas and that marker 'stratigraphies' define previously unknown rotations caused by Meso-Hellenic deformation.

LS03 : THpm26 : F2 Net Tectonic Rotation Analysis of Extreme Rotations in the Ba'r Bassit Ophiolite of N. Syria

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The Ba'r-Bassit ophiolite forms part of a series of thrust sheets emplaced over Mesozoic carbonates of the Arabian platform in the middle Maastrichtian. We present the results of analysis of net tectonic rotations which have affected the ophiolite thrust sheets, determined from palaeomagnetic data from 27 sampling sites. The overall aim has been quantification of the nature of tectonic rotations during ophiolite emplacement and subsequent deformation.

Magnetisations recovered from layered gabbros, sheeted dykes, sills and pillow lavas are proved to be pre-deformational in origin by a positive inclination-only fold test and a reversal test. Site mean directions of magnetisation show apparent large relative rotations of different parts of the ophiolite, following application of standard palaeomagnetic tilt corrections. However, a more sophisticated

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approach to the interpretation of remanence directions is provided by analysis of the poles and angles of net tectonic rotation (NTR), which simultaneously restore sampled units to horizontal/vertical attitudes and remanences back to the appropriate reference direction. This provides additional insights into the nature of rotational deformation, and removes the assumption that tilting occurs around present-day lines of strike.

For the majority of sampled units, the NTR approach identifies a steeply plunging rotation axis around which over 200° of counterclockwise rotation has occurred, producing a more consistent pattern of rotations across the exposed ophiolite than the simple tilt correction approach. These net rotations are almost certainly composite in origin and potentially include components produced during intra-oceanic detachment and subsequent emplacement of the ophiolite onto the continental margin. The similarity of NTR solutions from the northernmost sections and those located within a Neotectonic strike-slip fault system which traverses the central portion of the ophiolite suggests that post-emplacment tectonics have resulted in little relative rotational deformation. Unfortunately, the net rotations can not be further decomposed into intra-oceanic detachment and tectonic emplacement-related components in this ophiolite because of a lack of cross-cutting igneous units generated during progressive deformation. Data are therefore required in more extensive ophiolites where such units are observed in order to resolve the timing of rotational deformation within the peri-Arabian Neotethyan ophiolites.

Finally, new results from the most extensive sheeted dyke section in Ba'r-Bassit emphasise the difficulty of detecting even large rotations by field-based structural studies. Sub-vertical dykes at this locality have a vertically upwards in situ remanence. The strike of these units lies parallel to the thrust emplacement direction of the ophiolite. The unusual vertical magnetisation direction may be explained either by significant components of tilting about a dyke-normal axis or by very large (c. 200°) rotation about a steeply inclined axis. In either case, dykes were in a similar apparent structural orientation both before and after rotational deformation.

LS03 : THpm27 : F2 Large Scale Constraints on the Tectonic Evolution of the Anatolian-Eurasian Plate Boundary from Palaeomagnetic and Geochronological Analysis

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The Cenozoic tectonic development of the Eastern Mediterranean, has been dominated by the continued convergence of the African and Arabian plates with Eurasia. In this context, present day Anatolia is an amalgamation of small continental fragments that began to coalesce along the Eurasian margin in the Eocene, probably achieving its present configuration in the middle Miocene, with the collision of Arabia and Anatolia. The plate boundary between Anatolia and Eurasia, however, continued to evolve. Convergence and thickening across Anatolia continued as Arabia moved northward with respect to Anatolia along the Dead Sea Transform. To accommodate this continued convergence Anatolia thickened but it also began to rotate and to extrude laterally along the right-lateral North Anatolian Fault and the left-lateral East Anatolian Fault. With the onset of tectonic escape the plate boundary with Eurasia changed from a collisional boundary to the transform boundary that is observed today.

Palaeomagnetic and geochronological data have been used to constrain the post-Eocene kinematic evolution of the Anatolian plate and its northern margin. Our results show that Neogene declinations are rotated anticlockwise by as much as 35° from the expected values. Rotation rates, however, vary with time: before 12 Ma Anatolia was essentially not rotating (-0.041°/Ma) while from 12-5 Ma the rotation rate increases to 6.5°/Ma. From 5-0 Ma the palaeomagnetic data is in agreement with GPS data and indicates that Anatolia has been rotating slowly at about 1.2°/Ma. We are thus able to show that much of the large-scale rotation of the Anatolian plate probably occurred during thickening but prior to the onset of motion along the bounding North Anatolian and East Anatolian fault zones. This result is corroborated by detailed work along the North Anatolian fault zone, which defines the present day Anatolia-Eurasia plate boundary, that reveals anticlockwise rotations both to the south and to the north of this fault. Therefore, for much of the Neogene, the plate boundary between Anatolia and Eurasia must have been to the north of the present boundary.

LS03 : THpm30 : F2 Differential Neotectonic Rotations in Anatolia and the Tauride Arc: Palaeomagnetic Investigation of the Erenlerdag Complex and Isparta Volcanic District, South-Central Turkey

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In the Anatolian sector of the Alpine-Himalayan collisional belt a palaeotectonic phase of terrane accretion has been succeeded by a neotectonic phase of intracontinental deformation as the Afro-Arabian plate has continued to impinge differentially into the accreted collage. The resulting tectonic escape has, during the last few Ma, extruded and rotated blocks in a south westerly direction. This paper reports a palaeomagnetic investigation of the Erenlerdag Complex and Isparta alkaline volcanic district undertaken to extend analysis of crustal rotation to the south-western part of the Anatolian region, and investigate the interaction with the Isparta reentrant and the extensional province of western Turkey. The Erenlerdag volcanism comprises three phases of volcanism. The oldest Sille Volcanics (11.7-11.4 Ma) yield a mean D/I = 150/-52° rotated anticlockwise during late stages of the palaeotectonic regime with respect to a later Miocene episode (-10.9-8.9 Ma, D/I = 183/-47°) and a Mio-Pliocene episode (D/I = 179/-51°). The latter two episodes indicate that no significant rotation has resulted from neotectonic deformation in this south-western sector of Anatolia. Further to the west within the Isparta Angle the 4.7-4.0 Ma alkaline episode yields a mean of D/I = 186/-53° rotated slightly clockwise. The pattern of palaeomagnetic declinations across Anatolia shows rotations that are strongly anticlockwise in the east near the Arabian pincer and diminish towards the west to become zero or slightly clockwise at the western extremity of the collage. The intervals of rotation also seem to become younger towards the south. Crustal deformation has therefore been distributed and the net effect of terrane extrusion to the west and south has been to expand the curvature of the Tauride Arc and, by inference, the Cretan Arc. Where good age control exists in Cappadocia and the Sivas Basin rotations are found to be concentrated within the last few Ma only and are up to an order higher than rates deduced from GPS. They imply that the neotectonic deformation following collision initially produced crustal thickening resulting in uplift of the Anatolian Plateau; this was only subsequently by tectonic escape.

LS03 : THpm31 : F2 Anatolian Lateral Escape Tectonics: Influence of Paleogene Thickening and Neogene Gravitational Collapse

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We attempt to constrain the relationships between uplift and escape of Anatolia in Turkey. Our arguments explain that thickening of the Anatolian Plateau may not have occurred during the Mio-Plio-Quaternary Arabia-Eurasia relative convergence. Our interpretation of ERS radar and DEM imagery, complemented by structural analysis in the field, show that extension and strike-slip tectonics mostly prevailed during the late Neogene, compression mainly occurring in the Bitlis belt. Paleogeographic data indicate that the Western and Central Anatolian regions were emerged in the Oligocene after collision of Anatolia and the Pontides in the Paleogene. Unfolding a north-south geologic cross-section of the Paleogene layers of Central Anatolia accounts for at least 24% of crustal thickening in the early Oligocene. Metamorphic Core Complex of Western and Central Anatolia indicate that the crust was 55-60 km thick at this time. Crustal flux balances between Arabia, Anatolia and Eurasia show that it is necessary to consider a gravitational collapse of the Anatolian Plateau, which represents 8.5-27% of the total motion of Anatolia. We propose that the main thickening and related uplift of the Anatolian Plateau occurred during the late Eocene-early Oligocene. The amount of gravitational escape motion directly depends from the Anatolian initial crustal thickness. Gravitational escape tectonics only occurs if the Anatolian crustal thickness is less than 42 km before onset

of the Anatolia motion. The Oligocene Turkish orogen has been maintained until opening of the Aegean back-arc basin in the early Miocene. Therefore, the gravitational lateral escape tectonics component of the Anatolian Plateau may be related to the formation of the leaky Aegean plate boundary and incipient east-west gravitational gradient affecting an already thickened crust. Crustal-scale detachments and gravitational escape tectonics play a non negligible part in the Anatolian motion, which does not seem to result from a simple collision-extrusion process of a rigid block.

LS03 : THpm32 : F2 Active Faulting Under the Sea of Marmara: Preliminary Results from High-Resolution Multibeam Bathymetry, Seismic and Sonar Soundings

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The large 1999 earthquakes of Izmit (Mw=7.4) and Düzce (Mw=7.2) are the latest of a sequence of eight large earthquakes that ruptured progressively the North-Anatolian fault (NAF) in the 20th century. Altogether the 1999 events ruptured 180 km of the main branch (Northern Branch) of the NAF, east of the Sea of Marmara pull-apart. Another large earthquake had already ruptured in 1912 the Ganos strike-slip fault located west of the Sea of Marmara, on the other side of the pull-apart. Faults are therefore correctly mapped on land, on both sides, but not under water. Nonetheless, large historical earthquakes causing destruction in Istanbul were probably generated by the main submarine faults, in 1509, 1754, and 1766 (Ambraseys and Jackson, 2000). Also, the seismic hazard appears now increased in the Istanbul area (e.g., Hubert-Ferrari et al., 2000; Parsons et al., 2000). Several conflicting fault models based on multi-channel seismic profiling have been proposed recently for the Sea of Marmara, but none could address adequately the crucial problems of fault partitioning and segmentation within the supposed pull-apart structure. The French-Turkish cruise performed with vessel Suroit in September-October 2000 was devoted to map the active fault structure along the Northern Branch of the NAF, under the Sea of Marmara. Multibeam bathymetry and reflectivity maps with a 25 m gridding were completed over most of the submarine fault system. Several profiles across different fault segments were obtained with surface and deep-towed streamers and with a lateral sonar sounder (PASISAR and SAR). The trace of the main active segments can now be mapped accurately over the sea bottom. Both normal and strike-slip segments are seen, as it was expected from previous tectonic observations on land and from the mere existence of the large pull-apart basin (e.g., Armijo et al., 1999). The very good quality of the imagery acquired allows us to see details along the fault scarps and possibly to identify past earthquake ruptures. We present here a preliminary interpretation of the data.

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LS03 : THpm33 : F2 Syn-Orogenic Exhumation of the Ductile Crust in the Alpine Tectonic Evolution of the Aegean Region; The Misidentification of Causes and Consequences

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Modern tectonic analyses still tentatively quantify orogenic histories by a phase of formation of the orogen, and a subsequent phase of post-orogenic extensional collapse. As today's sensitivity of isotopic dating techniques applied to mineral fabrics with complex metamorphic and/or deformational histories has proven to be extremely powerful in the examination of the regional significance of tectonic events, they allow to temporally constrain syn-orogenic phases of extension which already operated during the initial development of the orogen. It is

presented that metamorphic episodes, tectonic events and absolute ages in the Aegean region have been miscorrelated and that crucial gaps exist in P-T-t paths of currently exposed metamorphosed rocks. It should be commonly accepted that the referred high pressure metamorphic cycle in the region is not a synchronous event across the region. Also important to realize is that the termination of this same event may be well constrained but that the timing of its initiation and of its period of peak pressure metamorphism are hardly identified. Misidentified P-T cycles are corrupt input factors of tectonic and paleogeographic reconstructions. It is introduced that a still immature orogen in the Aegean region suffered from several destabilizing episodes before the regional post-orogenic extensional collapse caused the final fragmentation of the orogen leading to today's configuration. The recognition of such early stages during which the build-up of the orogen was disturbed initiates a two-fold discussion: i) to what extent have similar mountain belts suffered from destabilizing processes in their evolution, and ii) is the initial destabilization of a convergent orogen an essential foundation to its extensive post-orogenic collapse.

that of the pre-messinian frictional wedge. - curved and anastomosed fronts, typical of deforming salt basins, form when the ratio between the basin length and width is large.

**LS03 : THpm34 : F2
New Insights on Tectonic Evolution of Eastern
Mediterranean Ridge: A Multi-Disciplinary
Approach**

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Shortening along the Mediterranean Ridge is the result of oblique convergence between Africa and Eurasia plates and motion of the Aegean microplate. The irregular shape of plate boundaries has resulted in a diachronous collision between the two margins and lateral escapes of both the Ionian and Levantine inner zones of the Mediterranean Ridge. To the East, in the Herodotus basin, deformation style is represented, in a general situation, by gentle asymmetrical folding affecting both the Messinian evaporitic sequence and the Plio-Quaternary terrigenous sediments.

Despite the recent advances in the knowledge of the geological structure of the Eastern Mediterranean, many problems remain still open: (1) is the Eastern Ridge everywhere detaching on the Messinian evaporites? and (2) are the latter constituted by salt in a significant proportion? If so, (3) does the presence of a salt décollement influence the kinematics and thrusting sequence of wedging? In such settings (4) does the oblique convergence cause strain partitioning or is deformation rather homogeneous?

Our study addresses these questions through an integrated seismic reflection data processing and physical modeling in laboratory. Pre-stack partial migration and depth migration of the multichannel seismic reflection profiles from selected areas bearing simpler geological structures provide the basis for an optimum design of scaled physical models. In turn, the results from modeling give new insights accounting for controversial interpretations of geophysical data.

The results of this multidisciplinary study are as follow: - the messinian basins are composed primarily by salt; infra-messinian seismic lamination is produced by thin physical discontinuities with viscous behaviour. - the main detachment of the post-messinian wedge is located at the base of the salt layer. Deformation is mainly related to pure-shear dominated transpression which favours homogeneous strain rather than strain partitioning. - due to its lower taper, the Central Mediterranean Ridge probably detaches on a weak horizon: thin salt or over-pressured fluids - extension occurs in the central M.R. as a result of the geometry of plate boundaries. This extension is considered as a possible cause of shale diapirism. - post-messinian wedge geometry and kinematics differ drastically from

