TURKISH ASSOCIATION OF PETROLEUM GEOLOGISTS

THE GEOLOGICAL FIELD GUIDE SERIES

FAULTING, BASEMENT UPLIFT AND CARBONATE SEDIMENTATION:

ÇATALCA REGION, WEST OF ISTANBUL

ARAL I.OKAY AND ERCAN ÖZCAN

AAPG International Conference & Exhibition 2014
İstanbul, Turkey

PRE-CONFERENCE FIELD TRIP - 4, SEPTEMBER 13, 2014

Faulting, basement uplift and carbonate sedimentation: The Geology of the Çatalca region, West of İstanbul

Aral I. Okay & Ercan Özcan

İstanbul Technical University

Eurasia Institute of Earth Sciences and Faculty of Mines, Department of Geology, İstanbul, Turkey

okay@itu.edu.tr

ozcanerc@itu.edu.tr

Cover Photo: Eocene shallow marine limestones capped by a thin carapace of lagoonal sandy and pebbly limestones presumably of Oligocene age in a disused quarry in Büyük Çekmece. In the background are the city limits of İstanbul.

Introduction

The Çatalca excursion will introduce the geology of the western part of the Greater İstanbul area. It has two main objectives: 1. To show the geology of the two major Pontic terranes: the İstanbul Zone in the east and the Strandja Massif in the west (Fig. 1). 2. To show the post-tectonic Eocene and younger strata, which unconformably cover both of the Pontic terranes (Figs. 2 and 3).

Most of the city of İstanbul is underlain by a thick well-developed Paleozoic sedimentary sequence ranging in age from Ordovician to Carboniferous, which formed part of the passive margin of the Rheic ocean (e.g., Görür et al., 1997; Özgül, 2012). In the eastern part of the ancient city Constantinopolis and along the coast of the Marmara Sea, the Paleozoic rocks are unconformably covered by brackish Miocene sandstone, shale and limestone (Fig. 3). Farther west, outside the City, there are a range of NW-SE trending hills made up of metamorphic rocks. The town of Çatalca is located at the foot of these hills (Figs. 2 and 3). The metamorphic rocks, cropping out in the Çatalca hills, represent the southeastern extension of the Strandja Massif, a large area of metamorphic and granitic rocks, forming a modest mountain range along the southwestern Black Sea coast and extending from Bulgaria to Turkey. The low-lying area between the Çatalca hills and the outcrops of Paleozoic rocks, thought to be the location of a major dextral strike-slip fault (the Western Black Sea Fault) is occupied by Eocene and younger sedimentary rocks. During the excursion, we will study the Eocene and younger strata in this belt and the underlying Paleozoic sedimentary series and the metamorphic rocks of the Çatalca hills.

The basic geology of the Çatalca region is based on Erentöz (1949) and Akartuna (1953). Geological maps of the region were published by Yurtsever & Çağlayan (2002) and Duman et al. (2004).

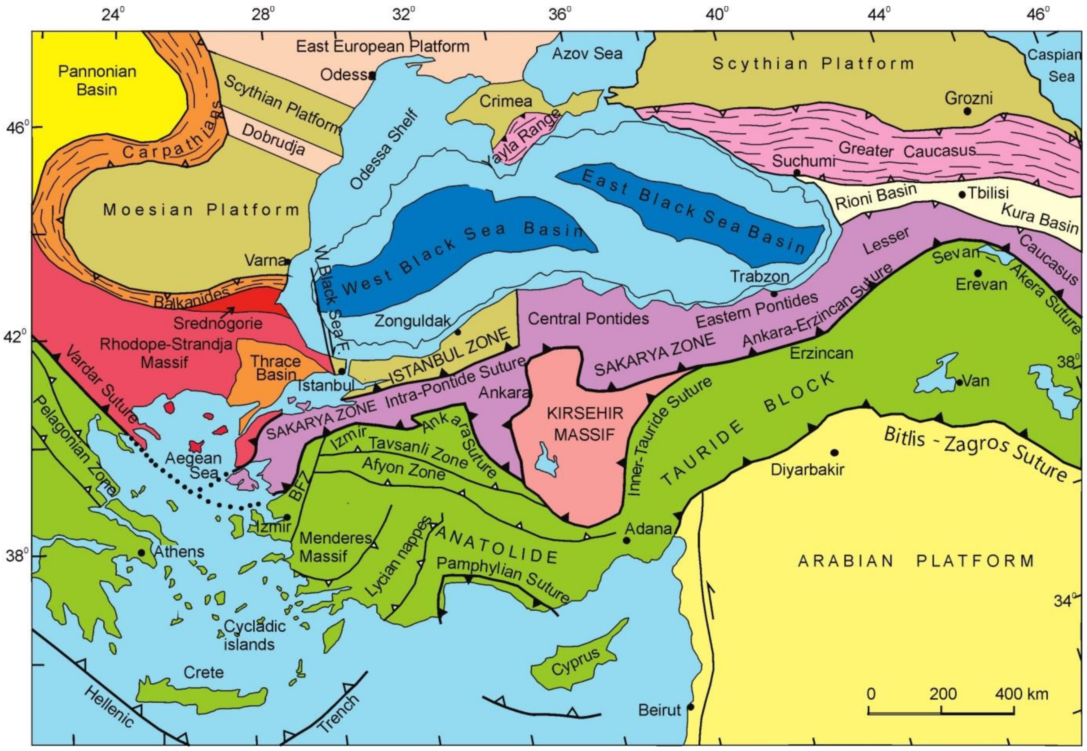

Fig. 1. Tectonic map of the Eastern Mediterranean showing the location of İstanbul between two Pontic terranes (modified after Okay & Tüysüz, 1999).

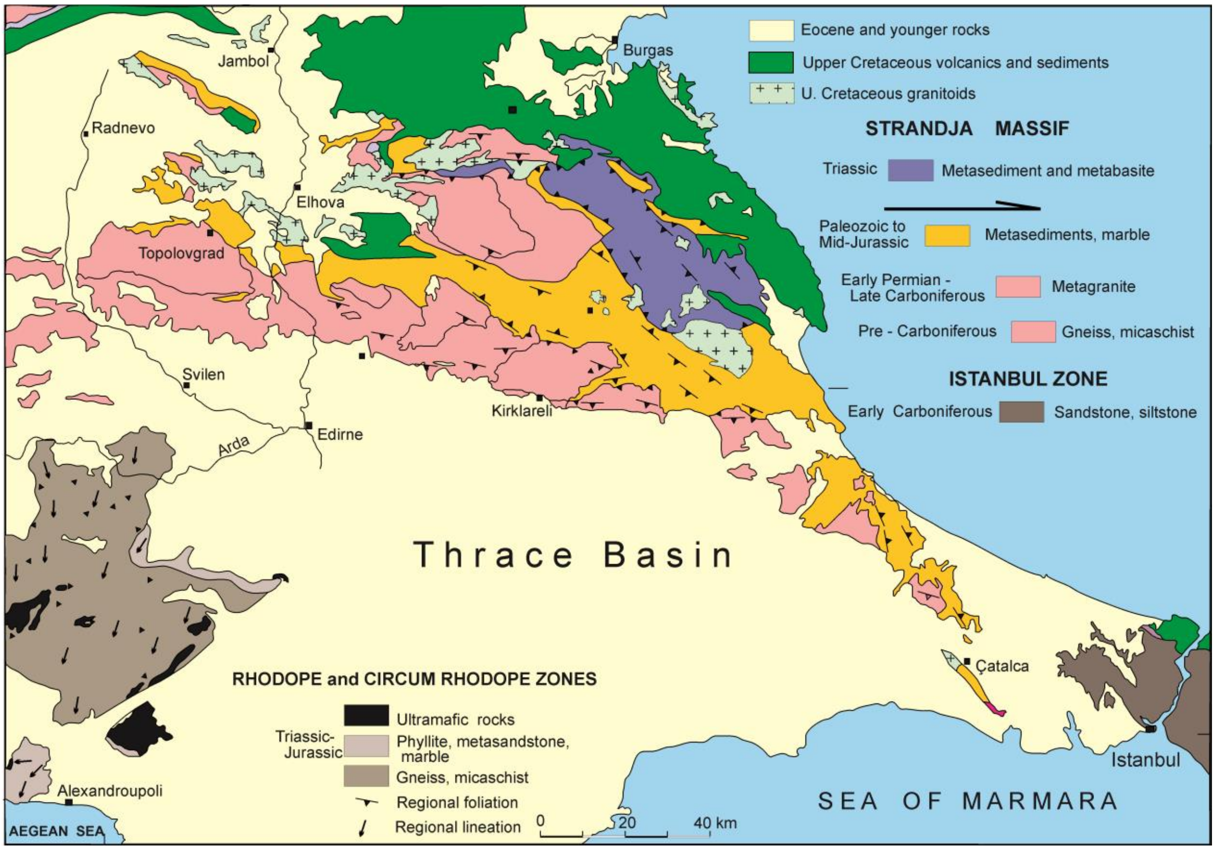

Fig. 2. Tectonic map of Thrace showing the outcrops of the Strandja and Rhodope massifs and that of the İstanbul Paleozoic sequence in the extreme east (modified from Okay et al., 2001).

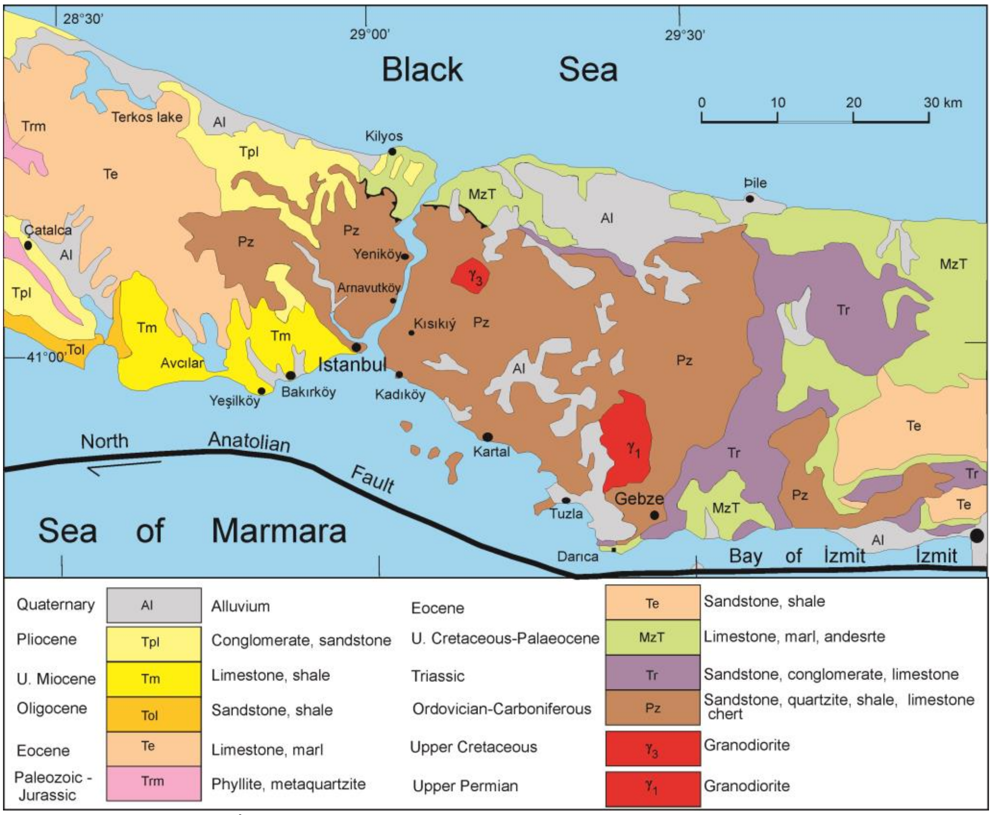

Fig. 3. Geological map of the İstanbul region.

Geological Setting

The Çatalca region encompasses the border zone between two major Pontic terranes: the İstanbul Zone in the east and the Strandja Massif in the west (Figs. 1 and 2). The boundary between these two terranes is covered by Eocene and younger post-tectonic sedimentary rocks (Fig. 3).

The İstanbul Zone is characterized by a late Neoproterozoic-Cambrian crystalline basement overlain by a continuous well-developed Paleozoic sedimentary sequence extending from Ordovician to Carboniferous (Fig. 4). The sedimentary sequence has a transgressive character ranging from Ordovician red beds through Upper Silurian-Lower Devonian shallow marine limestones to Upper Devonian pelagic limestones and Lower Carboniferous (Tournasian) black radiolarian cherts. The sequence finishes with thick Lower Carboniferous (Visean) siliciclastic turbidites (N. Okay et al., 2011; Özgül, 2012). The Paleozoic sequence was deformed during the Late Carboniferous and was intruded by Late Permian granitoids exposed on the eastern side of the Bosphorus (Fig. 3). The deformed Paleozoic sedimentary rocks are unconformably overlain by a transgressive Triassic series extending from lowermost Triassic red beds through thick Lower Triassic shallow marine carbonates to Middle Triassic pelagic limestones and Upper Triassic (Carnian) turbidites. Jurassic and Lower Cretaceous series are missing in the western part of the İstanbul Zone, and Upper Cretaceous (Campanian-Maastrichtian) to Paleocene deep marine marly limestones lie unconformably over the Paleozoic and Triassic rocks (Özcan et al., 2010).

In contrast to the İstanbul Zone, the Strandja Massif is constituted mainly of metamorphic and granitic rocks. A Variscan basement made up of metamorphic rocks and voluminous intrusive Late Carboniferous and Permian granitic rocks is unconformably overlain by continental to shallow marine Triassic-Jurassic clastic and carbonate rocks (Okay et al., 2001; Sunal et al., 2006, 2008). The basement and the sedimentary cover were deformed and metamorphosed during the latest Jurassic – Early Cretaceous (Okay et al., 2001; Elmas et al., 2010; Sunal et al., 2011). The Ar-Ar and Rb-Sr mica ages from the metamorphic rocks range from 156 Ma to 137 Ma. The deformation was contractional and comprised north-vergent thrusting, whereby the basement slices were thrust on top of the Mesozoic cover rocks. The metamorphic rocks of the Strandja Massif are unconformably overlain by late Upper Cretaceous (Cenomanian) sandy limestones, which pass up into Senonian volcanic and volcanoclastic rocks comprising part of the Late Cretaceous Pontide - Sredna Gora magmatic arc (Okay et al., 2001).

There are several major geological differences between the İstanbul Zone and the Strandja Massif. 1. The Late Jurassic – Early Cretaceous greenschist facies metamorphism and contractional deformation, a prominent feature of the Strandja Massif, is not observed in the İstanbul Zone. 2. The İstanbul Zone has a well-developed fossiliferous Paleozoic sedimentary sequence, which is not recognized in the Strandja Massif. 3. A major part of the basement of the Strandja Massif is formed by Late Carboniferous – Permian granitic rocks, such intrusives are rare in the İstanbul Zone. 4. Prior to the intrusion of the Permo-Carboniferous granitoids, the Strandja Massif has undergone regional metamorphism, most probably during the Carboniferous. In contrast the Paleozoic sedimentary sequence of the İstanbul Zone is free of metamorphism.

The dextral strike-slip West Black Sea Fault, which separates the İstanbul Zone from the Strandja Massif (Fig. 1) , was responsible for the opening of the West Black Sea basin, which has oceanic crust overlain by Cretaceous to Recent sediments over 10-km in thickness (Okay et al., 1994). The İstanbul Zone is correlated with the Moesian Platform and was displaced southwards during the Late Cretaceous (mainly Coniacian-Santonian) activity of the west Black Sea Fault. The Eocene shallow marine limestones, which cover both the Strandja Massif and the İstanbul Zone are (Fig. 5), provide an upper limit for the activity of the west Black Sea Fault

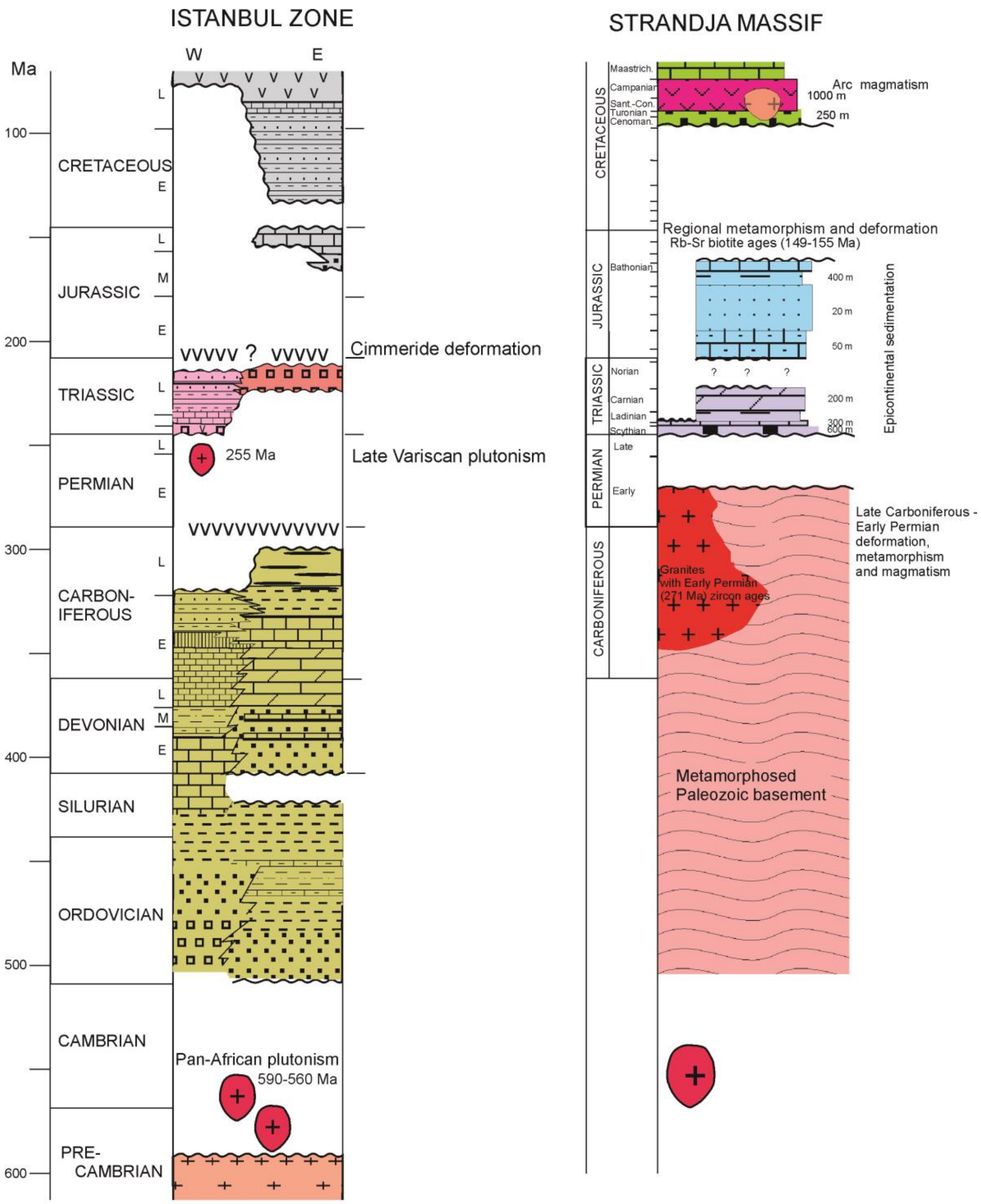

Fig. 4. Synthetic stratigraphic sections of the İstanbul Zone and the Strandja Massif. The Paleozoic and Triassic stratigraphies of the İstanbul Zone show marked lateral stratigraphic differences between the western and eastern parts. İstanbul is located in the western part of the İstanbul Zone.

Description of the Field Stops

We leave İstanbul early in the morning from the front of the International Congress Center at Taksim. Most of the city of İstanbul, including the Taksim neighbourhood, is built on Paleozoic (Ordovician to Carboniferous) sedimentary rocks, however, there are hardly any outcrops. We will take the motorway (TEM) towards the direction of Edirne (Fig. 5). The white rocks near the toll booths on the motorway are Miocene marls and mudstones, which unconformably cover the Paleozoic rocks in the southern part of İstanbul. They tend to amplify the seismic acceleration; during the 17th August 1999 earthquake there was extensive damage in the southern part of European İstanbul, especially at Avcılar, built on Miocene mudstone and marl.

The motorway crosses the northern margin of the lagoonal lake of Küçükçekmece via the Yarımburgaz viaduct. A quarry wall of Eocene (Bartonian) reefal limestones can be seen north of the viaduct. A large cave in these Eocene limestones (Yarımburgaz) next to the Küçükçekmece Lake contains middle Pleistocene (390 000 - 161 000, Lower Paleolithic) human artifacts and constitutes the earliest evidence of human habitation in İstanbul. Farther on, the satellite towns along the motorway (at 31-32 km) are built on Eocene limestone and marl, which here separate the Paleozoic and the Miocene strata.

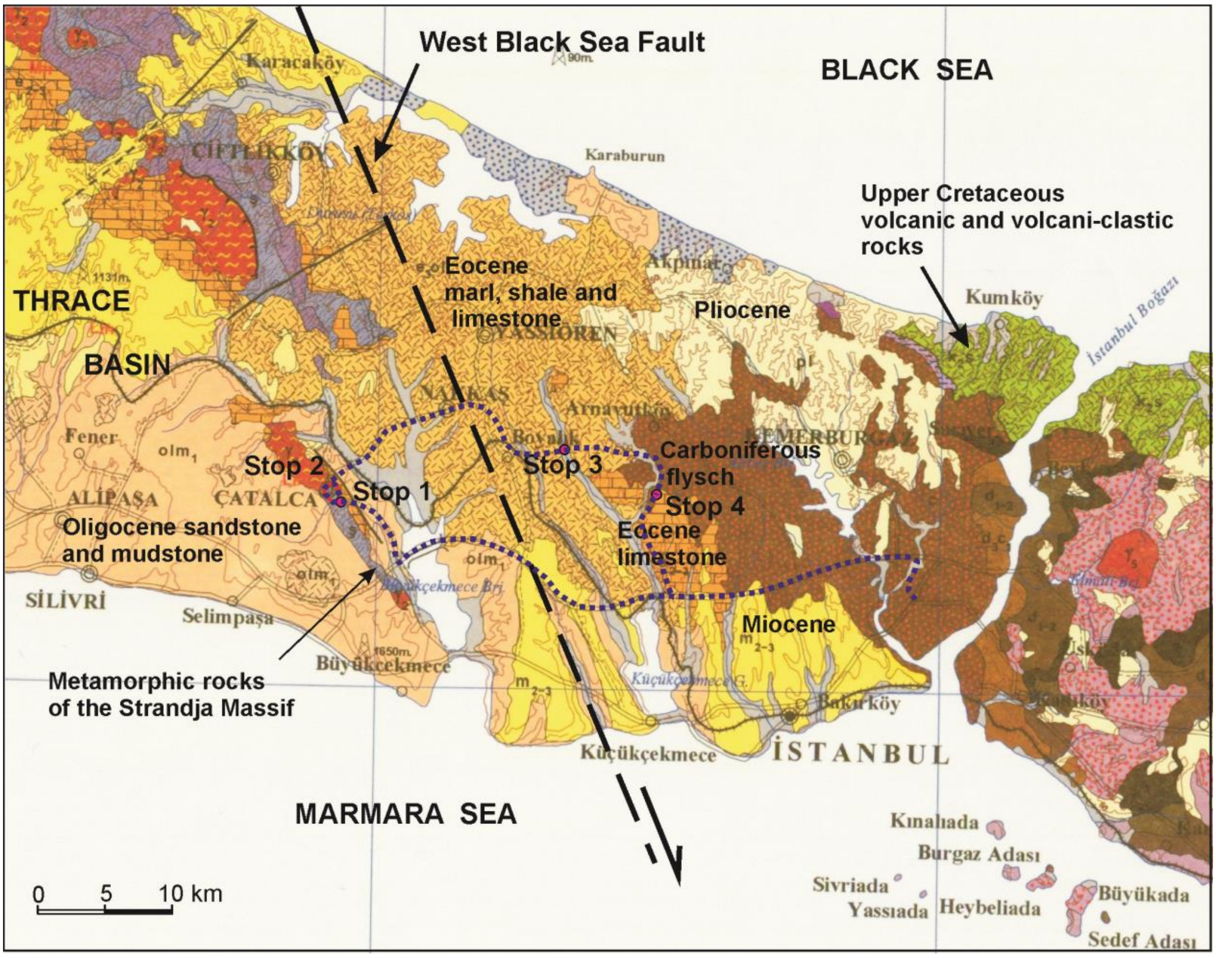

Fig. 5. Geological map of the İstanbul region showing the field trip route in dotted blue line and the location of the field Stops. The map is from Türkecan & Yurtsever (2002).

Farther on, there is good view of the Çatalca ridge, a fault-bounded horst-like feature extending NW-SE on the western margin of the lake of Büyükçekmece. The ridge is made up of metamorphic rocks unconformably overlain by Eocene limestones. The Eocene limestones are extensively quarried for gravel, and hence the large white patches on the landscape. The Çatalca ridge is located along a NW trending major pre- Late Miocene dextral strike-slip fault, which constitutes part of a major terrane boundary. The fault is not active, and the clustering of small earthquakes in the Çatalca region, seen in seismological maps, is due to the frequent quarry blasting.

We will leave the motorway at the Çatalca junction and drive towards Çatalca. About one kilometer before Çatalca, we will take a side road, which follows the only valley cutting through the Çatalca ridge (Fig. 6). Our first Stop will be in this small valley.

Stop 1. Çatalca – Metasiltstones and phyllites of the Strandja Massif overlain by Eocene and Oligocene limestones

Location: Disused quarry along the road between Çatalca and the village of Ovayenice. Geographic coordinates 41°7'34.1 N – 28°28'14.5E. See Figs. 5 and 6.

This disused quarry on the Çatalca Ridge shows three units in stratigraphic contact:

1. At the base there are highly wheathered metasiltstones and phyllites belonging to the Strandja Massif. We will see much fresher and better exposures in the next stops.

2. The low-grade metamorphic rocks are unconformably overlain by Upper Eocene shallow marine limestones. The limestones are white, thickly bedded to massive and are rich in corals, algae, bivalves and contain a benthic foraminifera fauna indicating a Late Eocene (Priabonian) age (Less et al., 2011). The unconformity is well exposed in the quarry wall, and one can observe the Eocene limestones filling up the irregularities in the sea floor (Fig. 7). There are also large number of Neptunian dykes, sills and veins in the phyllites filled by Eocene carbonates. The Neptunian dykes are of variable thickness (1 cm to several meters) and show a range of orientation. The irregular sea floor topography before the Late Eocene transgression, and the presence of Neptunian dykes indicate tectonic activity during the Early Eocene, possibly the West Black Sea Fault had not completely ceased its activity at this time. The transgressive upper Eocene carbonates (shallow benthic zones 19-20) contain some stratigraphically important key foraminiferal taxa such as *Heterostegina gracilis*, *Spiroclypeus* sp., *Praebullalveolina afyonica* in the lowermost part of the section. This indicates a Priabonian age. Some of these taxa are illustrated in Figure 8.

3. At the top of the quarry the Upper Eocene limestones are overlain by a parallel unconformity by light grey, thickly bedded, porous sandy limestones full of partially dissolved brackish bivalves. This sandy limestones belong to the Pınarhisar Formation of presumed Oligocene age.

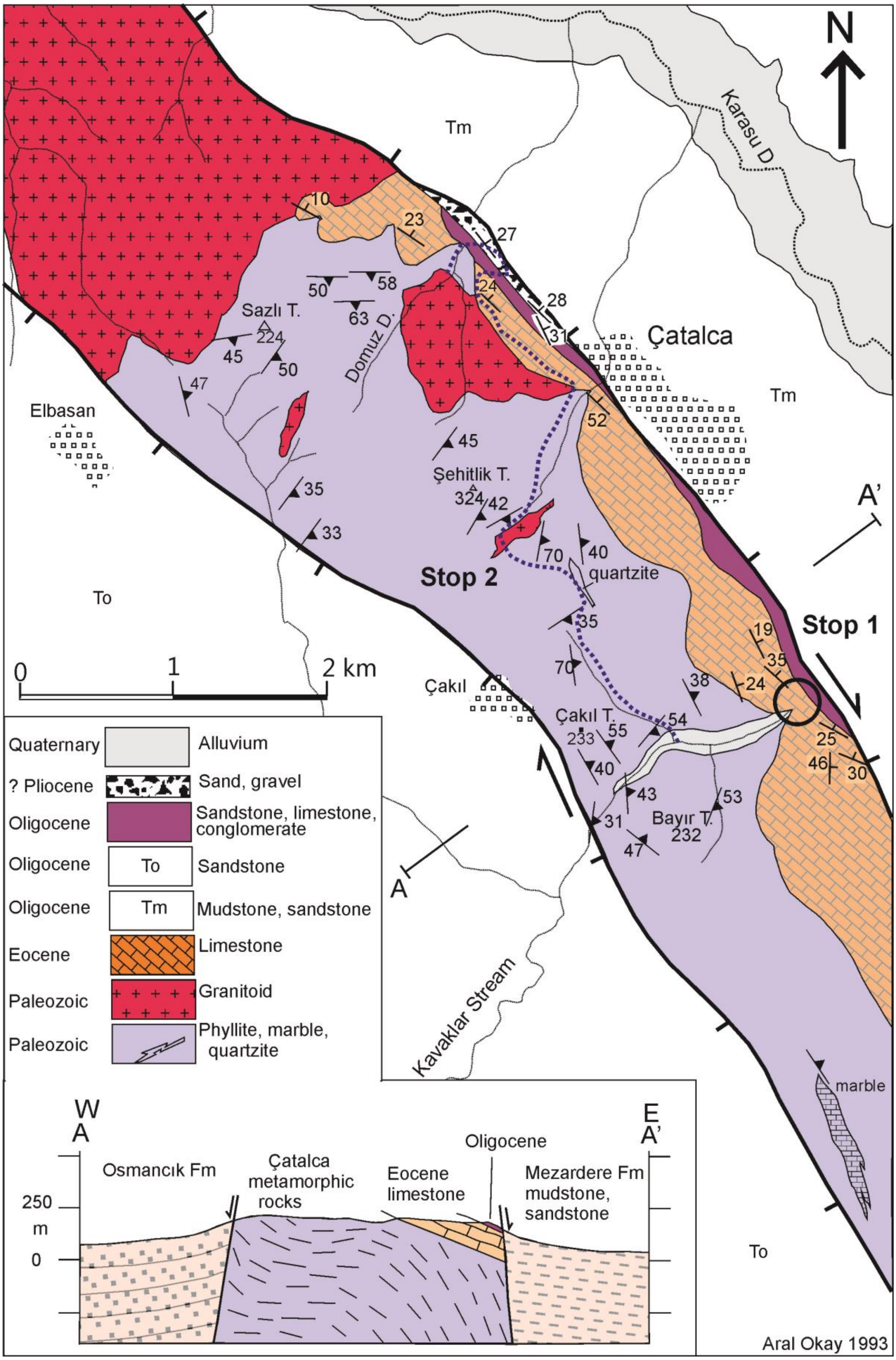

Fig. 6. Geological map of part of the Çatalca Ridge. Location of Stop 1 and the route for Stop 2 are also shown. For location see Fig. 5.

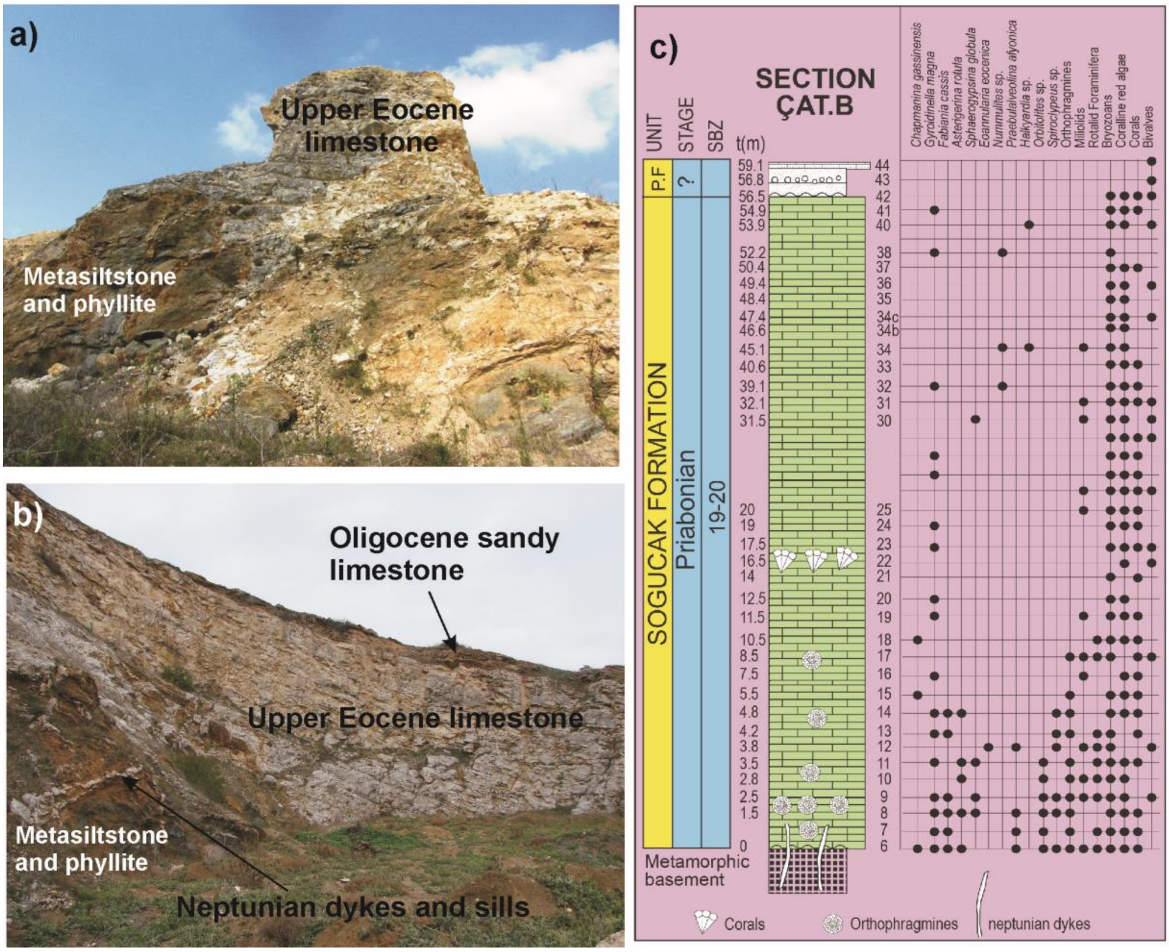

Fig. 7. (a) and (b) show Upper Eocene limestones overlying altered metasiltstones and phyllites of the Strandja Massif. The metamorphism is of Early Cretaceous age and the unconformity represents a gap of nearly 100 million years. Note the irregular stratigraphic contact between the two units characterized by onlap and Neptunian dykes, sills and veins. In (b) the lagoonal Oligocene sandy limestones can be seen forming a thin (approx. 2 m) carapace over the Eocene limestones. The benthic foraminifera in the Eocene limestones in this section are shown in (c). Some stratigraphically important benthic foraminifera are illustrated in Figure 8. The fauna indicates a Late Eocene age (Less et al., 2011).

We will climb up to study the sandy limestones of the Pınarhisar Formation. The limestones are porous mainly due to dissolution of the brackish bivalve *Mactra* sp., which makes up a large part of this limestone. From this vantage point we can also have a feel for the fault bounding the Çatalca ridge from the southeast. The low-lying green areas to the east, including the Büyükçekmece Lake are made up of Oligocene mudstone, siltstone and marl; exposures are mainly limited to building excavations. The abrupt topographic break between the low-lying Oligocene mudstones and the hill made up of Oligocene-Eocene limestones markes the trace of the Çatalca Fault. The Çatalca Fault must have been active after the Oligocene, probably during the Miocene as a transtensional fault. It has also a more important earlier geological history dating back to the Cretaceous. However, with the exception of the quarry blasts, there is no recorded seismic activity along the Çatalca Fault, which is oriented highly oblique to the present displacement vectors, hence it is not active at present.

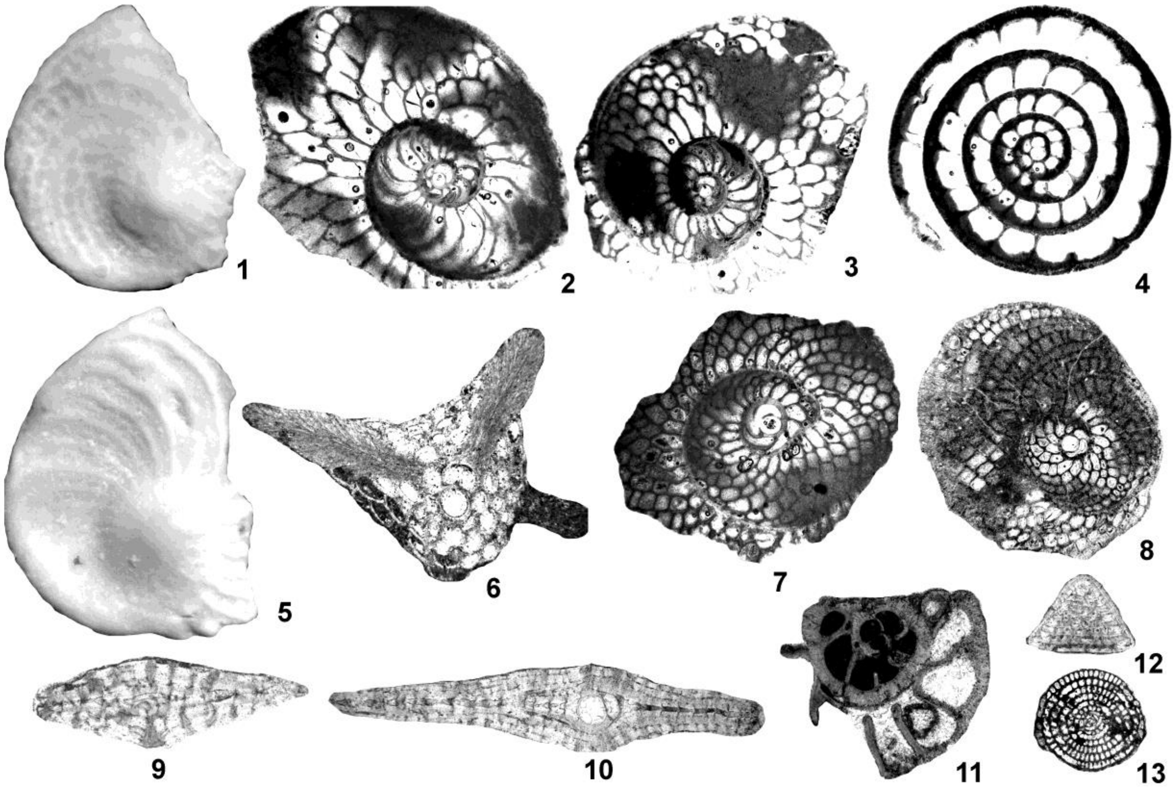

Fig. 8. The key larger benthic foraminiferal taxa in Bartonian (1-6) and Priabonian (7-13) Soğucak Formation near Şamlar and Çatalca regions respectively. 'primitive' stage of *Heterostegina reticulata* (1-3), *Nummulites* ex. interc*. garganicus-hormoensis* (4) *Operculina* ex. gr. *gomezi* (5) and *Silvestriella tetraedra* (6) are from the lower part of Soğucak Formation in Şamlar region. 'advanced' stage of *H. reticulata* (7-8), *Spiroclypeus* sp. (9), *Heterostegina gracilis* (10), *Gyroidinella magna* (11), *Chapmanina* sp. (12) and *Praebullalveolina afyonica* (13) are from the Soğucak Formation in Çatalca region. 7 and 8 are from the lower part of Soğucak Formation in Domuzdere valley in Çatalca.

Stop 2 – A walk along the Çatalca Ridge – Phyllites, marble, calc-schist, metaquartzite, granitoid and overlying sediments

Location: This Stop will involve an extended walk along the Çatalca Ridge. See Fig. 6 for the route.

After Stop 1 we will board our minibus and drive about one kilometer to our next Stop. Stop 2 involves a long walk following a tributary valley, which climbs up to the top of the Çatalca Range (Fig. 6). This valley has been used in the past as a quarry and therefore has the best exposures of metamorphic rocks in the Çatalca region. Unfortunately, it was also used as a rubbish dump.

Initially we will cross a thick succession of dark grey, silvery phyllites, which show evidence of several phases of deformation. A prominent cleavage is cut by two crenulation cleavages at right angles. There are also locally well-developed kink bands, and shear zones. The phyllites are cut by deformed, discontinuous quartz veins. Mineralogically the phyllites are made up mainly of quartz, muscovite and chlorite, and the metamorphism is of low greenschist facies.

In the upper reaches of the valley, the phyllites are underlain by a sequence of grey calc-schist and marble, about 40 m in thickness. This carbonate horizon is off-set by tear faults on the opposite hill-side. Farther up in the top of the hill there are exposures of thickly bedded to massive metaquartzite.

The protoliths to the metamorphic sequence represent a transgressive sedimentary series starting with quartzites, passing to carbonates, which are overlain by a thick sequence of dark mudstones. In the southern part of the Çatalca Ridge, the phyllites are intruded by the Tepecik granitoid, which gave Late Permian (256 Ma) zircon ages (Aral Okay, unpublished data), hence the depositional age of the metamorphic sequence must be Paleozoic. Based on lithological correlation with the Paleozoic sequence of the İstanbul Zone, the metaquartzites of the Çatalca Ridge could have Ordoviciaon, the carbonates Silurian-Devonian and the phyllites Carboniferous depositional ages.

The northwestern margin of the Çatalca Ridge

Close to the outcrop of metaquartzites, we are located above the village of Çakıl on top of the Çatalca Ridge (Fig. 6). From here there is a good view towards the southwest. The Çakıl Fault, which bounds the Çatalca Ridge from the southwest, passes just above the village. It is less apparent than the Çatalca Fault but has several hundred meters of dip-slip offset. The undulating hills to the southwest are made up of Oligocene sandstone and shale of the Osmancık Formation. It is a paralic sequence and has several economic lignite horizons, and constitutes the main gas reservoir in the Thrace Basin. Oil wells drilled 6 km west of the Çatalca Ridge has cut through 1100 m of Oligocene-Eocene sediments without reaching the metamorphic basement. Here we are on the western margin of the Thrace basin, a hydro-carbon-bearing Eocene-Oligocene basin with over 5 km of clastic sediments (Turgut et al., 1991; Görür & Okay, 1996; Siyako & Huvaz, 2007).

After seeing the metaquartzites we will continue walking northwest along the top of the Çatalca Ridge. The path cuts through grey phyllites; the sequence is probably repeated tectonically. There is also an outcrop of white, altered leucocratic granite. It is a 100 m wide body in the phyllites. The contacts with the phyllites are not exposed, and are probably tectonic.

We will walk through more phyllites and poorly exposed small bodies of leucocratic granitic bodies. After a while we come up to the northeastern side of the Çatalca Ridge; here the town of Çatalca lies below us. Here there are also large blocks of white Eocene limestone, which form the carapace of the metamorphic rocks, and are the continuation of the Eocene limestones, which we saw at the first Stop (Fig. 6). Looking to the north towards the horizon we can see the tree covered hills, which are made up of the metasedimentary rocks of the Strandja Massif.

Unconformity surface between the Eocene and Oligocene

We will continue walking northwest and shortly come up to a disused quarry, where the unconformity surface between the Eocene limestones of the Soğucak Formation and the poorly cemented sandstone, conglomerate and limestone of the Oligocene Pınarhisar Formation is well exposed. The surface of unconformity dips dips gently to the southeast and a hard ground is locally visible above the Eocene limestones (Fig. 9a). The limestones have a rich macrofauna of corals, bivalves and algae. The Pınarhisar Formation here is of different facies than that observed at the first Stop (their attribution to the Pınarhisar Formation is also somewhat speculative). Here it consists of poorly consolidated sandstone, pebbly sandstone, conglomerate. The clasts in the conglomerate are mostly of metamorphic rocks.

Farther down there are large blocks of conglomerate and a block of Eocene limestones with a fantastic corals.

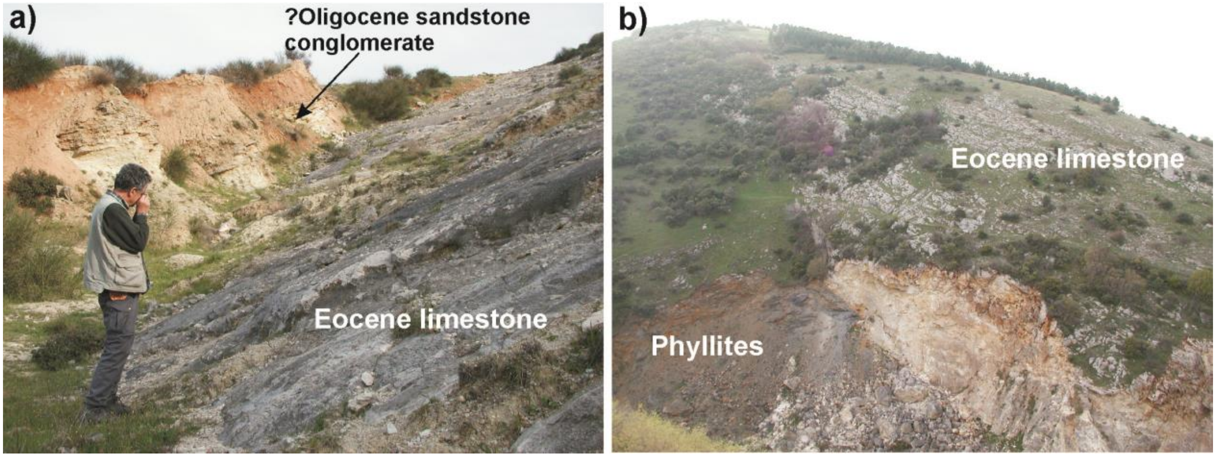

Fig. 9. (a) shows the unconformity between the Upper Eocene limestones and the overlying poorly consolidated sandstone and conglomerate presumably belonging to the Oligocene Pınarhisar Formation. In (b) Eocene limestones lie with a normal fault contact on the phyllites in the Domuzdere.

Domuzdere – Cambrian granite, metamorphic rocks and faulted Eocene limestone

Our last visit in Stop 2 will be a valley northwest of Çatalca – the Domuzdere Valley (Fig. 6). At the entrance of the valley there are some young poorly consolidated clastics, which are underlain by Eocene limestones. Large number of caves and fault striations are evident on the limestones on the southeastern side of the valley. The Eocene limestones are underlain by dark phyllites and metasiltstones; the contact here is a normal fault: a zone of dark fault breccia and gauge can be seen below the fault plane (Fig. 9b). Father up the valley there is a leucocratic granite, which is dated as Cambrian (Şahin et al., 2013). Our zircon ages from the granite are 531 Ma and support the Cambrian age. The contact between the granite and the metamorphic rocks is faulted.

Afterwards we will walk back to Çatalca to eat deliceous meatballs, beans and salad.

Stop 3 – Sazlıbosna: Carboniferous sandstone and slate overlain by Eocene limestone

Location: Creek section immediately west of the Sazlıbosna village. UTM coordinates 35 T 06 39 672 – 45 57 871.

After lunch we board our minibus and drive east over the low-lying region between the Strandja Massif and the İstanbul Zone. The bed rock is Eocene marl, mudstone and limestone; however, there are very few natural exposures. We will stop just before the village of Sazlıbosna, where along the creek there are Carboniferous clastic rocks overlain by Eocene limestone.
The small Carboniferous outcrop along the creek consists of darky grey sandstone, siltstone and slate. The fine-grained clastic rocks have a distinct cleavage and show a very low-grade metamorphism. They are overlain unconformably by shallow marine Eocene limestones. The limestones contain rounded quartz pebbles, clasts of phyllite and are bioclastic. The fauna is diverse and mostly represented by larger foraminifera such as *Nummulites*, *Assilina* and orthophragmines accompanied by large shells of thick shelled bivalves. The age of the limestone has not been determined precisely yet but must be late Middle to Upper Eocene (Bartonian-Priabonian).

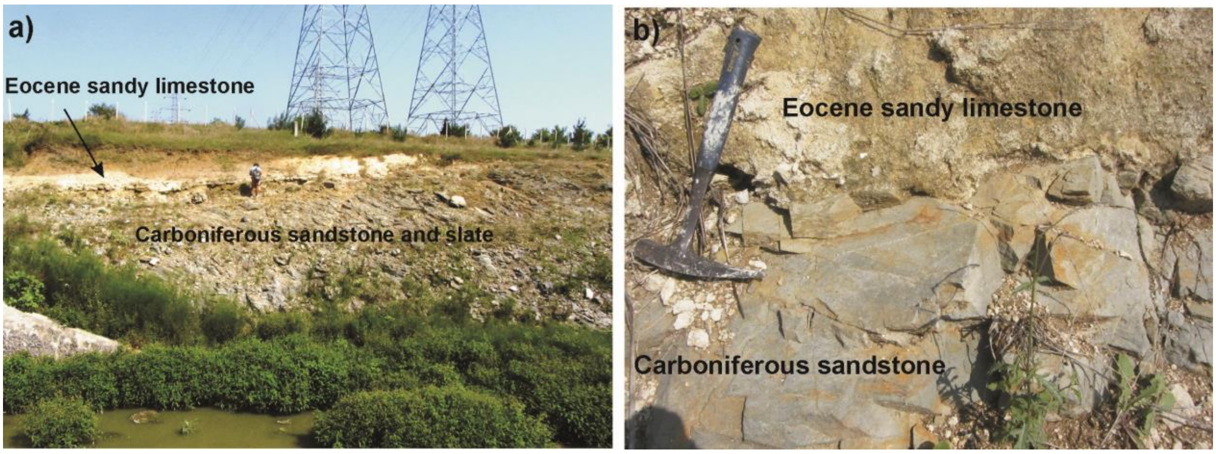

Fig. 10. Photographs of the Sazlıbosna Stop. (a) shows Eocene sandy limestones lying unconformably over the Carboniferous sandstone and slate. A close-up of the unconformity is shown in (b).

Stop 4 – Şamlar: The Eocene section

Location: Above the village of Şamlar, west of İstanbul. UTM coordinates 35 T 06 46 097 – 45 54 697; geographic coordinates 41°07’43.7’’N 28°44’23.1’’. See Fig. 5 for location.

Stop 4 lies close to the village of Şamlar about 7 km southeast of Sazlıbosna. Here Carboniferous turbidites are also overlain unconformably by Eocene limestones, which have a rich benthic fauna of late Middle Eocene age (Less et al., 2011). The Carboniferous is well exposed in the valley below the village, and if there is time and desire, we might go down to the valley to examine the Carboniferous sequence. Altered Carboniferous clastic rocks overlain by Eocene sandy limestones are also exposed along the road. The Eocene succession at Şamlar is about 30 meters thick. A lower section of bioclastic limestones, 22 m thick, is overlain by 10-m-thick reefal limestones (Fig. 11). The key taxa in the lower argillaceous limestones of the Soğucak Formation are *Nummulites* ex. interc. *garganicus-hormoensis*, *N. hormoensis*, *Heterostegina reticulata hungarica*, *Silvestriella tetraedra*, *Assilina* ex. gr.

alpina, *Operculina* ex. gr. *gomezi*. This assemblage indicates an upper Bartonian age. The upper patchy reef mostly contains corals, bivalves and rare larger foraminifera (Less et al., 2011). This suggests that the lower part of the transgressive Eocene unit is slightly older than the limestones at Stop 1 in Çatalca.

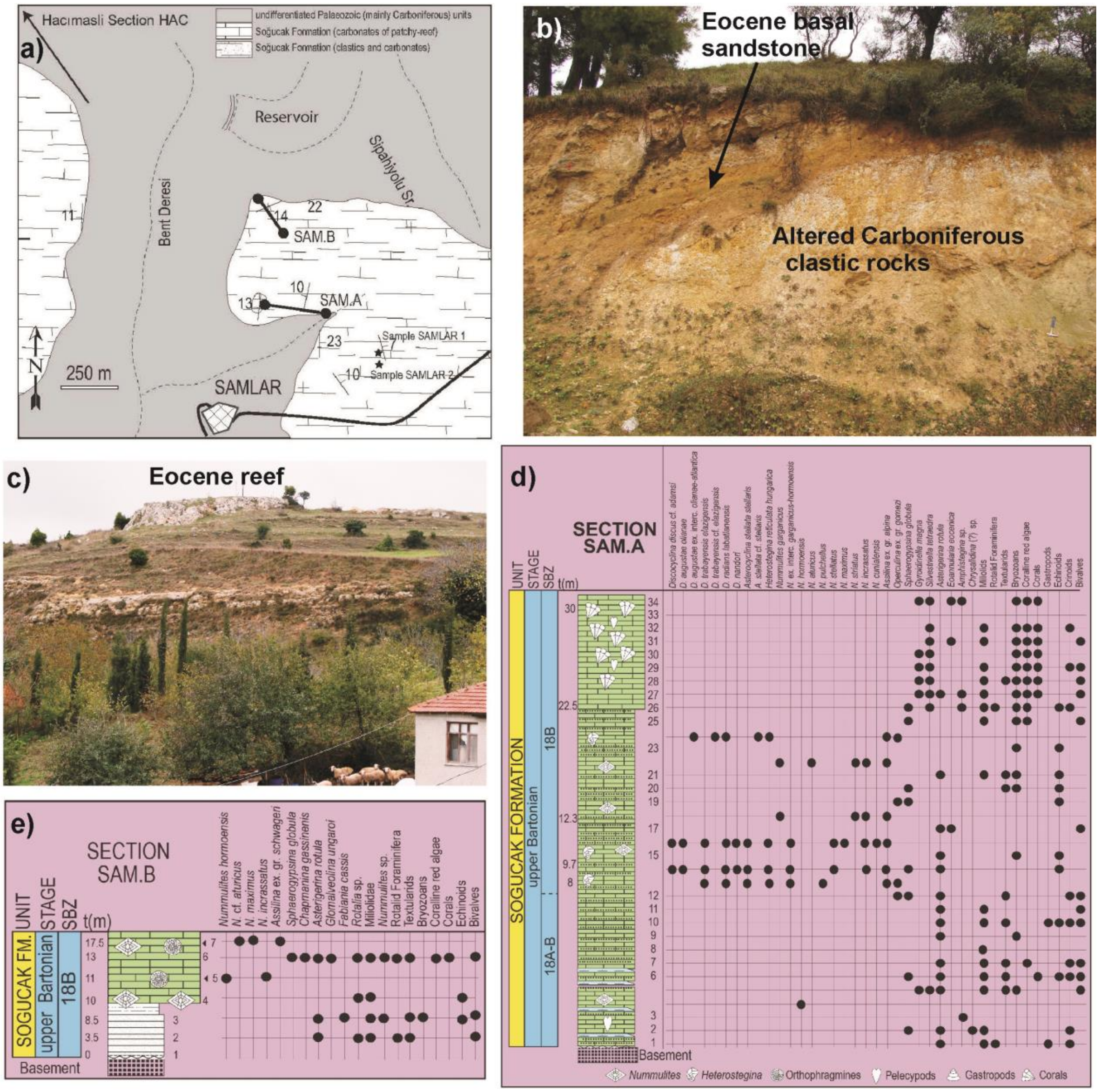

Fig. 11. Şamlar section. (a) shows a geological map fo the Şamlar region with the locations of the measured section. For the general location of the map see Fig. 5. The base of the Eocene over the altered Carboniferous clastic rocks is shown in (b). Şamlar B section is shown in the photograph in (c). Note the Eocene reef at the top. (d) and (e) give the distribution of foraminifera and other fossil groups in the Şamlar A and B sections from Less et al. (2011).

Acknowledgements

Work in Çatalca was supported by the İstanbul Technical University BAP project 34772, TÜBİTAK-NKTH 106Y202 and by Turkish Petroleum Corporation (TPAO).

References

Akartuna, M., 1953. Geology of the Çatalca-Karaköy region (in Turkish). İst. Üniv. Fen Fak. Monogr., No. 13, 88 pp.

Duman, T.Y., Keçer, M., Ateş, Ş., Emre, Ö., Gedik, İ., Karakaya, F., Durmaz, Ş., Olgun, Ş., Şahin, H. & Gökmenoğlu, O., 2004. İstanbul metropolu batısındaki (Küçükçekmece-Silivri-Çatalca yöresi) kentsel gelişme alanlarının yer bilim verileri. Maden Tetkik ve Arama Genel Müdürlüğü, Ankara, 2 cilt, 249 sayfa.

Elmas, A., Yılmaz, I., Yiğitbaş, E., Ullrich, T., 2010. A Late Jurassic–Early Cretaceous metamorphic core complex, Strandja Massif, NW Turkey. International Journal of Earth Sciences, 100, 1251-1263.

Erentöz, C., 1949. About the geology of the Çatalca Massif and its surroundings (in Turkish). İ.Ü. Fen Fak. Mec., B14, 307–320.

Görür, N. & Okay, A.I., 1996. Fore-arc origin of the Thrace basin, northwest Turkey. Geologische Rundschau, 85, 662–668.

Görür, N., Monod, O., Okay, A.I., Şengör, A.M.C., Tüysüz, O., Yiğitbaş, E., Sakınç, M., and Akkök, R. 1997. Palaeogeographic and tectonic position of the Carboniferous rocks of the western Pontides (Turkey) in the frame of the Variscan belt. Bulletin de la Société Géologique de France, 168, 197–205.

Kasar, S. & Okay, A.I., 1992, The geology of the area between Silivri, Kıyıköy and Bosphorus (in Turkish). Turkish Petroleum Corporation (TPAO) Exploration Division, Report No. 3119.

Less, G., Özcan, E. & Okay, A.I., 2011. Stratigraphy and Larger Foraminifera of the Middle Eocene to Lower Oligocene Shallow-Marine Units in the Northern and Eastern Parts of the Thrace Basin, NW Turkey. Turkish Journal of Earth Sciences, 20, 793–845.

Okay, A.I. & Tüysüz, O., 1999. Tethyan sutures of northern Turkey. In "The Mediterranean Basins: Tertiary extension within the Alpine orogen" (eds. B. Durand, L. Jolivet, F. Horváth and M. Séranne), Geological Society, London, Special Publication 156, 475–515.

Okay, A.I., Şengör, A.M.C. & Görür, N., 1994. Kinematic history of the opening of the Black Sea and its effect on the surrounding regions. Geology, 22, 267–270.

Okay, A.I., Satır, M., Tüysüz, O., Akyüz, S. & Chen, F., 2001. The tectonics of the Strandja Massif: Variscan and mid-Mesozoic deformation and metamorphism in the northern Aegean. International Journal of Earth Sciences, 90, 217–233.

Okay, A.I., Satır, M. & Siebel, W., 2006. Pre-Alpide orogenic events in the Eastern Mediterranean region. In: Gee, D.G. & Stephenson, R.A. (eds.), European Lithosphere Dynamics. Geological Society, London, Memoirs 32, 389-405.

Okay; A.I., Özcan, E., Cavazza, W., Okay; N. & Less, G. 2010. Basement types, Lower Eocene series, Upper Eocene olistostromes and the initiation of the southern Thrace Basin, NW Turkey. Turkish Journal of Earth Sciences, 19, 1-25.

Okay, N., Zack, T., Okay, A.I. & Barth, M.2011. Sinistral transport along the Trans-European Suture Zone: detrital zircon-rutile geochronology and sandstone petrography from the Carboniferous flysch of the Pontides. Geological Magazine, 148, 380–403.

Özcan, E., Less, G., Okay, A.I., Báldi-Beke, M., Kollányi, K. & Yilmaz, İ.Ö. 2010. Stratigraphy and larger foraminifera of the Eocene shallow-marine and olistostromal units of the southern part of the Thrace Basin, NW Turkey. Turkish Journal of Earth Sciences, 19, 27–77.

Özgül, N., 2012. Stratigraphy and some structural features of the İstanbul Palaeozoic. Turkish Journal of Earth Sciences, 21, 817–866.

Şahin, S.Y., Aysal, N., Güngör, Y., Peytcheva, I. & Neubauer, F., 2013, Geochemistry and U-Pb zircon geochronology of metagranites in Istranca (Strandja) Zone, NW Pontides, Trkey: Implications for the geodynamic evolution of Cadomian orogeny. Gondwana Research, 26, 755–771.

Siyako, M. & Huvaz, O., 2007. Eocene stratigraphic evolution of the Thrace Basin, Turkey. Sedimentary Geology, 198, 75–91.

Sunal, G., Natal'in, B., Satır, M. & Toraman, E., 2006. Paleozoic magmatic events in the Strandja Masif, NW Turkey. Geodinamica Acta, 19, 283–300.

Sunal, G., Satır, M., Natal'in, B. & Toraman, E., 2008. Paleotectonic position of the Strandja Massif and surrounding continental blocks based on zircon Pb-Pb age studies. *International Geology Review*, 50, 519–545.

Sunal, G., Satır, M., Natal'in, B., Topuz, G. & von der Scmidt, O., 2011. Metamorphism and diachronous cooling in a contractional orogen: the Strandja Massif, NW Turkey. Geol. Mag. 148, 580-596.

Turgut, S., Türkaslan, M. & Perinçek, D., 1991. Evolution of the Thrace sedimentary basin and its hydrocarbon prospectivity. In: Spencer, A.M. (Ed.), Generation, Accumulation, and Production of Europe's Hydrocarbons. Spec. Publ. Euro. Ass. Petrol. Geoscientists. 1, 415–437.

Türkecan, A. & Yurtsever, A., 2002. Geological map of Turkey, İstanbul sheet, 1: 500 000 scale. Maden Tetkik ve Arama Genel Müdürülüğü, Ankara.

Yurtsever, A. & Çağlayan, A., 2002, Geological map of Turkey, shhet F21 and G21, 1:100 000 scale. Maden Tetkik ve Arama Genel Müdürlüğü, Ankara.