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Uppermost Triassic Limestone in the Karakaya Complex–Stratigraphic and Tectonic Significance

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Abstract: Two important tectonostratigraphic units of the Karakaya Complex in northwest Turkey are: a lower metamorphic sequence of metabasite, phyllite and marble, called the Nilüfer Unit; and an upper clastic sequence with Permian and Carboniferous limestone olistoliths called the Hodul Unit. In northwestern Turkey, the Hodul Unit consists of arkosic sandstones, which pass upward into greywacke and siltstone with Permian and Carboniferous limestone blocks. A scarce macrofauna in the sandstones indicates a Norian age for the Hodul Unit. We report for the first time Norian–Rhaetian *limestones*, here named the Kaşal Limestone Member, from the Hodul Unit to the southwest of Balıkesir. The Kaşal Limestone Member forms ~80-m-thick, several-hundred-metres large blocks in a sheared siltstone, sandstone, and shale matrix of Norian age. The clastic matrix also includes neritic Permian limestone blocks. The Kaşal Limestone Member is a variegated, medium-bedded, nodular limestone with abundant coral, brachiopod, lamellibranch, crinoid, gastropod, algae, bryzoa, sponge spicules and foraminifera. A varied microfauna in the limestone indicates a Norian–Rhaetian age. The age similarity between the matrix and the Kaşal Limestone, and transition to a muddy facies observed in one of the blocks indicate that, unlike the exotic Permian limestones, the Kaşal Limestone Member represents *in situ* carbonate deposition in the Hodul basin. The subsequent shearing of the limestone contacts occurred during the deformation associated with the arrival of the olistostromes. The deformation leading to the closure of the Hodul basin is constrained to Rhaetian–Hettangian; that is, between 210 to 202 Ma, from the age of the Hodul Unit and that of the overlying Bayırköy Formation. This age is similar to the isotopic age of regional metamorphism in the Nilüfer Unit (215 to 205 Ma), and suggests that Cimmeride deformation in northwestern Turkey occurred over a short interval in the latest Triassic–earliest Jurassic.

Key Words: Karakaya Complex, Norian, Rhaetian, northwestern Turkey, reefal limestone

Karakaya Kompleksi İçindeki En Geç Triyas Yaşta Kireçtaşlarının Stratigrafik ve Tektonik Önemi

Özet: Kuzeybatı Anadolu'da geniş bir alanda mostra veren Karakaya Kompleksi'ni oluşturan iki önemli tektonostratigrafik birim Nilüfer ve Hodul birimleridir. Altta yer alan Nilüfer Birimi metabazit, fillit ve mermer ardalanmasından oluşur, ve üzerinde klastik kayalardan yapılmış ve Permiyen–Karbonifer yaşta kireçtaşı blokları kapsayan Hodul Birimi yer alır. Hodul Birimi kumtaşlarında bulunan seyrek makrofauna Noriyen yaşını vermektedir. Bu çalışmada Balıkesir'in güneybatısında Hodul Birimi içinde, Kaşal Kireçtaşı Üyesi adını verdiğimiz, Üst Triyas kireçtaşları tanımlanmaktadır. Kaşal Kireçtaşı Üyesi, Norian yaşta, makaslanmış bir silttaşı, şeyl, ve kumtaşı hamuru içinde yaklaşık 80 m kalınlıkta, yüzlerce metre büyüklükte bloklar oluşturur. Bölgede Kaşal Kireçtaşı bloklarının yanısıra Permiyen yaşta kireçtaşı blokları da yer almaktadır. Kaşal Kireçtaşı Üyesi bolca mercan, brakiyopod, lamellibranş, krinoid, gastrapod, alg, briozoa ve sünger spikülleri kapsayan alacalı renkli, orta tabakalı yumrulu bir kireçtaşıdır. Kireçtaşı içindeki mikrofauna Noriyen–Resiyen yaşını verir. Kaşal Kireçtaşı Üyesi'nin, Permiyen kireçtaşları gibi ekzotik bir olistolit olmayıp, Hodul havzasında çökeldiği düşünülmektedir. Buna ait veriler Kaşal Kireçtaşı Üyesi'nin çevresindeki klastik kayalarla benzer yaşta olması, ve bloklarda gözlenen kireçtaşından çamurlu bir fasiyese geçiştir. Daha sonraki deformasyon sırasında Kaşal Kireçtaşı Üyesi dokanakları boyunca makaslanmıştır. Hodul havzasının kapanmasına yol açan deformasyonun yaşı, Hodul Birimi'nden elde edilen Noriyen ile bu birim üzerinde uyumsuzlukla yer alan Bayırköy Formasyonu'nda bulunan Sinemuriyen yaşı ile sınırlanır. 210–202 milyon sene aralığına tekabül eden bu yaş aralığı, Nilüfer Birimi'nden elde edilen Ar-Ar izotopik yaşları ile çakışmaktadır (215–205 my). Bu durum kuzeybatı Anadolu'da Kimmeriyen orojenezinin Triyas sonu ile Jurasik başlangıcı arasında nispeten kısa bir devrede gerçekleştiğini gösterir.

Anahtar Sözcükler: Karakaya Kompleksi, Noriyen, Retiyen, kuzeybatı Anadolu, resifal kireçtaşı

Introduction

The Karakaya Complex consists of strongly deformed, partially metamorphosed Permian–Triassic orogenic sequences, which represent subduction-accretion units of the Palaeo-Tethys ocean (Tekeli 1981). The Karakaya Complex crops out over large areas in the Sakarya Zone in northern Turkey, and is unconformably overlain by little deformed Jurassic–Cretaceous clastic and carbonate rocks (Figure 1; Bingöl *et al.* 1975). In northwestern Turkey the Karakaya Complex consists principally of a metamorphic unit overlain by strongly deformed but unmetamorphosed clastic and volcanic sequences. The metamorphic unit is a strongly deformed metabasite-phyllite-carbonate sequence called the Nilüfer Unit. Scarce conodonts from carbonates interbedded with the metabasites indicate an Early to Middle–Triassic depositional age for the Nilüfer Unit (Kaya & Mostler 1992; Kozur *et al.* 2000). The deformation of the Nilüfer Unit includes isoclinal folding and thrust stacking; individual thrust slices show greenschist-, blueschist- and eclogite-facies regional metamorphism. Ar-Ar isotopic data on phengites and amphiboles indicate a latest Triassic (215–205 Ma) age for the regional metamorphism of the Nilüfer Unit in northwestern Turkey (Okay & Monie 1997; Okay *et al.* 2002). The Nilüfer Unit is interpreted as an accreted Permo–Triassic oceanic plateau (Okay 2000), or a series of oceanic seamounts (Pickett & Robertson 1996).

The Nilüfer Unit is overlain by strongly deformed but generally unmetamorphosed clastic sequences, which comprise characteristic olistoliths of Carboniferous and Permian limestone (Okay *et al.* 1991; Altıner *et al.* 2000). One such clastic sequence is the Hodul Unit, which crops out widely in northwestern Turkey. It consists of arkosic sandstones at its base, which pass upward into greywacke, siltstone and shale with olistoliths of Permian and Carboniferous limestone. Macrofauna in the siltstones below the olistostrome horizon indicates a Norian age (Figure 2). The Hodul Unit is unconformably overlain by Lower Jurassic sandstones and conglomerates of the Bayırköy Formation. On the Biga Peninsula northeast of Havran, the arkosic sandstones of the Hodul Unit lie unconformably over the Çamlık Granodiorite dated as Early Devonian (399 Ma; Okay *et al.* 1996). In the Kozak Range the Hodul Unit lies over the Nilüfer Unit along a probable unconformity (Figure 2; Akyürek & Soysal 1983).

Here, we report the discovery of Upper Triassic limestones in the Hodul Unit in northwestern Turkey southwest of Balıkesir. We present data on their stratigraphic and structural position, and on their faunal content, and discuss their significance for constraining the age of deformation of the Karakaya Complex.

Geological Setting

The study area is located in the Sakarya Zone in northwestern Turkey, southwest of Balıkesir close to the İzmir-Ankara suture (Figure 1). It forms the northern extension of the anticlinal Kozak Range, which in its core exposes the Nilüfer Unit overlain by the Hodul Unit (Figure 3). In the Kozak Range the Nilüfer Unit consists of metabasic rocks intercalated with marble and phyllite, over 2 km thick. The metabasic rocks represent metamorphosed basic tuff, pyroclastic rock and lava flows. The regional metamorphism is in low-greenschist facies with development of actinolite + epidote + chlorite + albite + leucoxene in the metabasites, and decreases gradually upward in the sequence (Okay & Siyako 1993). Kaya & Möstler (1992) report Middle Triassic (Upper Anisian–Lower Ladinian) conodonts from the uppermost part of the Nilüfer Unit in the Kozak Range (Figure 3). The basic volcanic rocks of the Nilüfer Unit are overlain by a thick arkosic sandstone-shale sequence, which constitutes the lower part of the Hodul Unit. The contact between the Nilüfer and Hodul formations in the Kozak Range is probably a sheared unconformity (Akyürek & Soysal 1983; Okay & Siyako 1993). The arkosic sandstones and shales in the Kozak Range are succeeded by tectonised debris-flow deposits with numerous Upper Permian limestone blocks that range in size from a few centimetres to several hundred metres.

The İzmir-Ankara suture passes 10 km southeast of the Kozak Range. The suture trace, which is covered by Neogene volcanic rocks, juxtaposes the clastic rocks of the Hodul Unit with the Maastrichtian–Palaeocene greywackes of the Bornova Flysch Zone (Figure 3). The Bornova Flysch Zone is made up of Maastrichtian–Palaeocene greywacke and shale with Upper Triassic to Cretaceous limestone and dismembered ophiolite blocks (Okay & Siyako 1993).

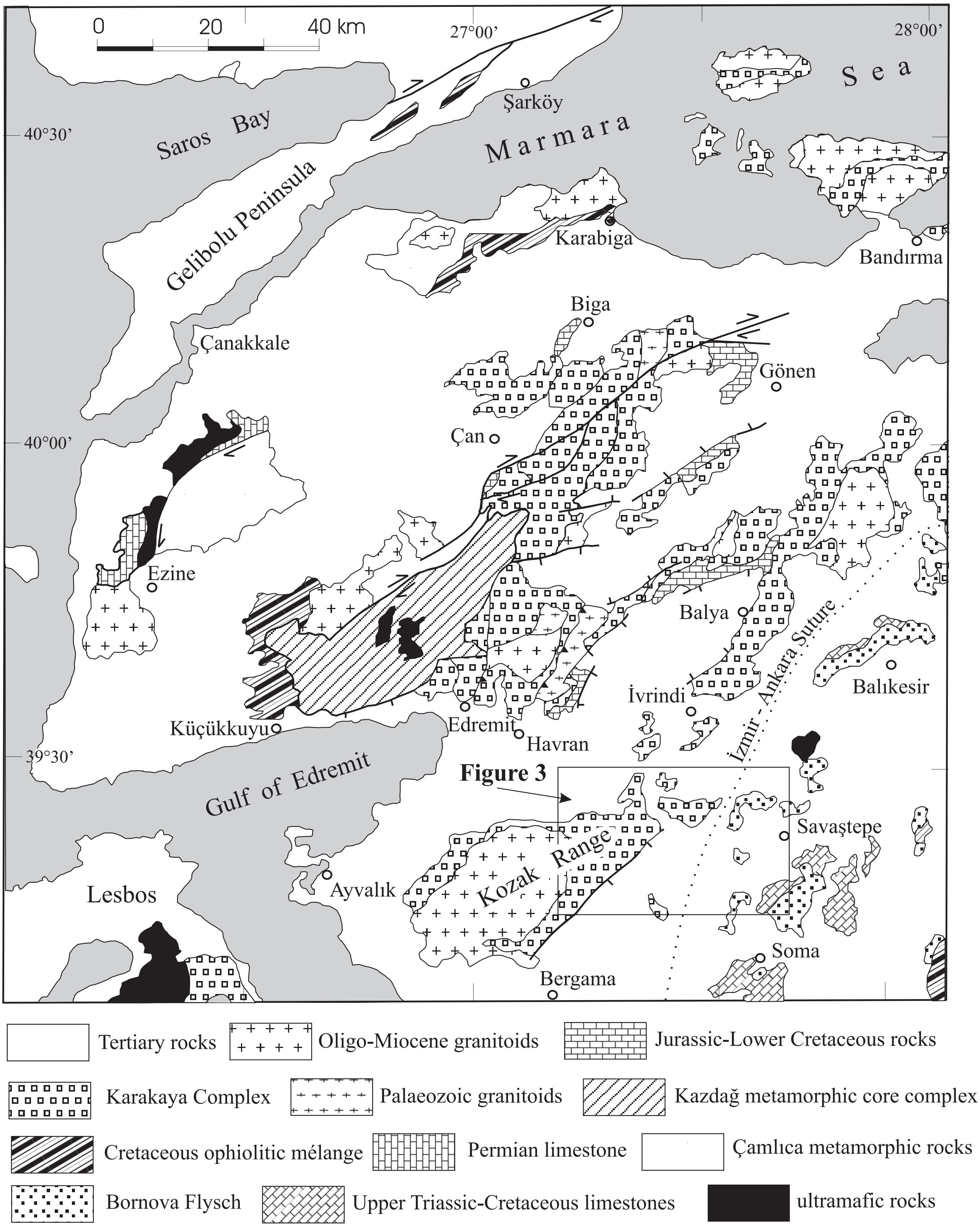

Figure 1. Tectonic map of the Biga Peninsula and the surrounding region.

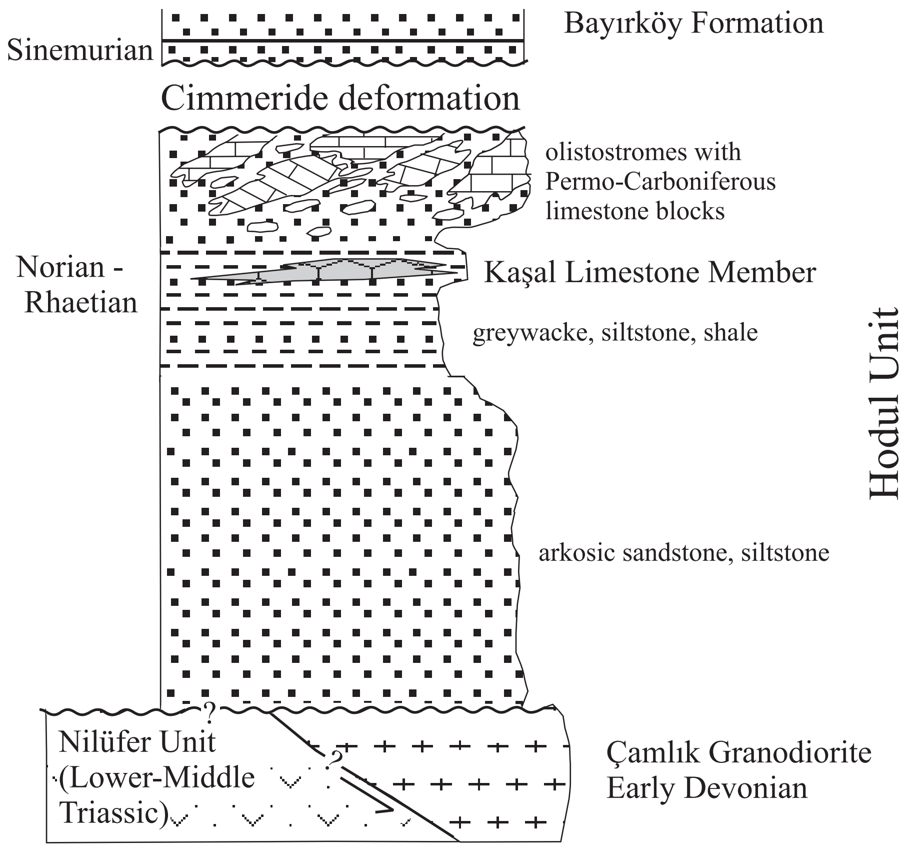

Figure 2. Synthetic stratigraphic section of the Hodul Unit showing the original stratigraphic position of the Kaşal Limestone Member.

Upper Triassic and Permian Limestone Blocks

Upper Triassic and Permian limestone blocks are located around the village of Kaşal, about 15 km southwest of İvrindi (Figures 3 & 4). In the Kaşal region, pre-Neogene rocks crop out in a small area, ~2 km across, surrounded by Miocene volcanic and sedimentary rocks. The geology around the village of Kaşal is characterised by a sheared clastic matrix with limestone blocks, all ascribed to the Hodul Unit. The clastic matrix consists of greenish-grey siltstone and shale, medium- to coarse-grained, yellowish-brown sandstone with well-rounded quartz, feldspar, sparse limestone pebbles, and coalified wood fragments. The clastic rocks are cut by abundant shear zones several metres to several tens of metres apart so that it is not possible to establish any meaningful stratigraphy. The clastic matrix is of Norian age, possibly Middle to Late Norian, based on brachiopod and nautiloid fossils found at two localities in the sandstones (4066, 4214, Figure 4): *Zugmayerella* sp., *Anadontophora* cf. *griesbachi* BITTNER, *Amonotis* (?) sp. and *Gonionautilus securis* (DITTMAR). A similar Norian age, based again on macrofauna in the sandstones and siltstones, is described from the Hodul Unit in the Balya (Aygen 1956; Okay *et al.* 1991; Leven & Okay 1996), Havran (Gümüş 1964; Aslaner 1965; Krushensky *et al.* 1980) and Iğdır, Bursa regions (Erk 1942).

The limestone blocks around the village of Kaşal are of two types. One type is a white to dark grey, thickly bedded to massive, partially recrystallised micritic Permian limestone with scarce fusulinids. This type of limestone olistoliths are widespread in the upper parts of the Hodul Unit throughout northwestern Turkey (Okay *et al.* 1991; Leven & Okay 1996). The Permian limestone blocks around Kaşal range in size from centimetres to several hundred metres. A sample from the largest

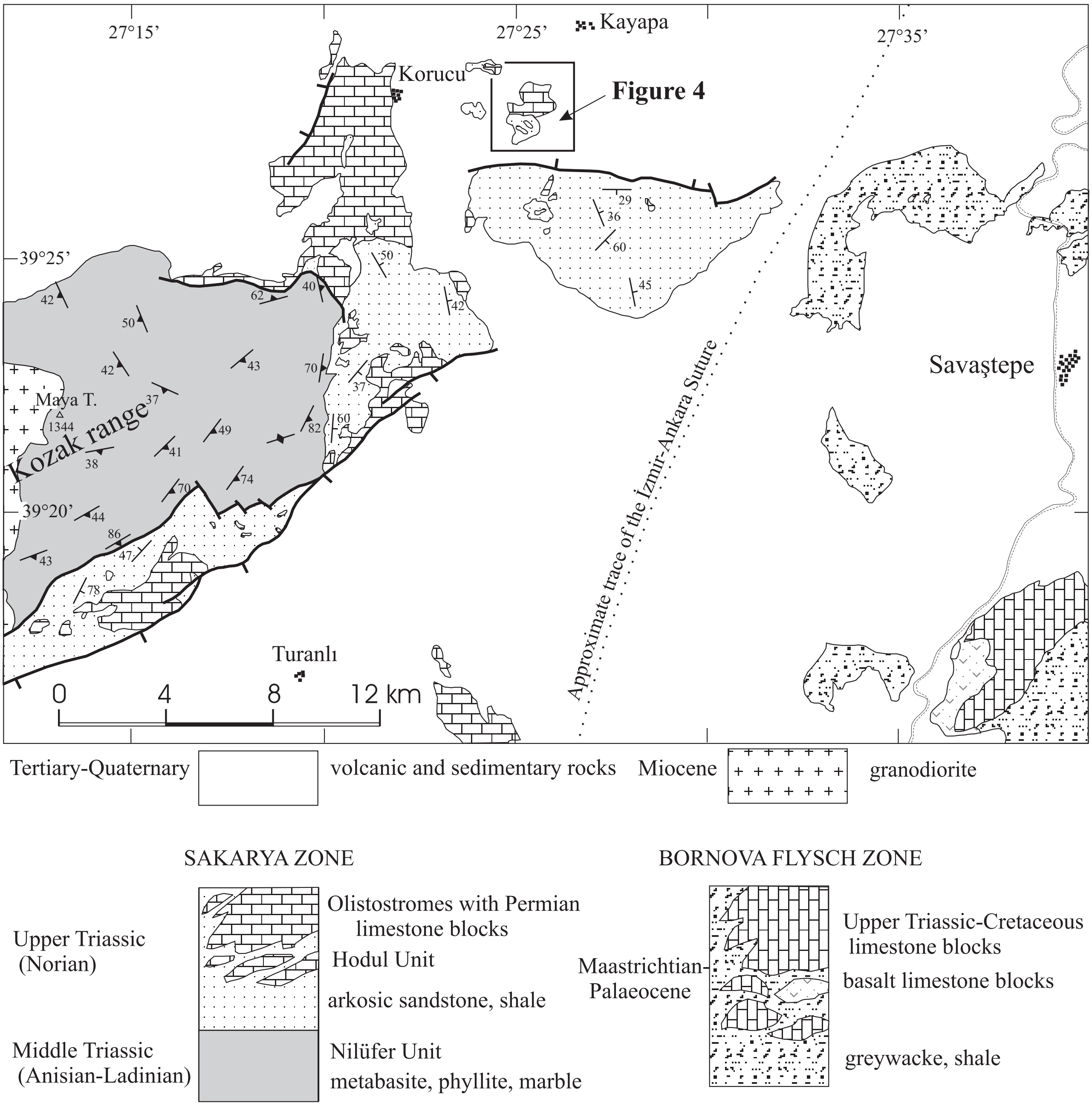

Figure 3. Simplified geological map of the Kozak-Savaştepe region in northwestern Turkey (modified after Okay & Siyako 1993).

limestone block (4213) has an Upper Permian (Murghabian) fauna of *Tuberitina* sp., *Frondina permica, Hemigordius renzi*, *Ichthyolaria* sp. Small limestone pebbles from a sandstone sample (4214) contain Permian foraminifera *Hemigordius* sp. and *Lunucammina postcarbonica*. The same sample also contains *Gonionautilus securis* (DITTMAR) of Mid–Late Norian age providing a time frame for the arrival of the olistostromes into the Hodul basin.

The other type of limestone is lithologically distinct from the Permo–Carboniferous limestone olistoliths, and apparently occurs only as three blocks, 100 to 500 m across (Figure 4). This Upper Triassic limestone, here

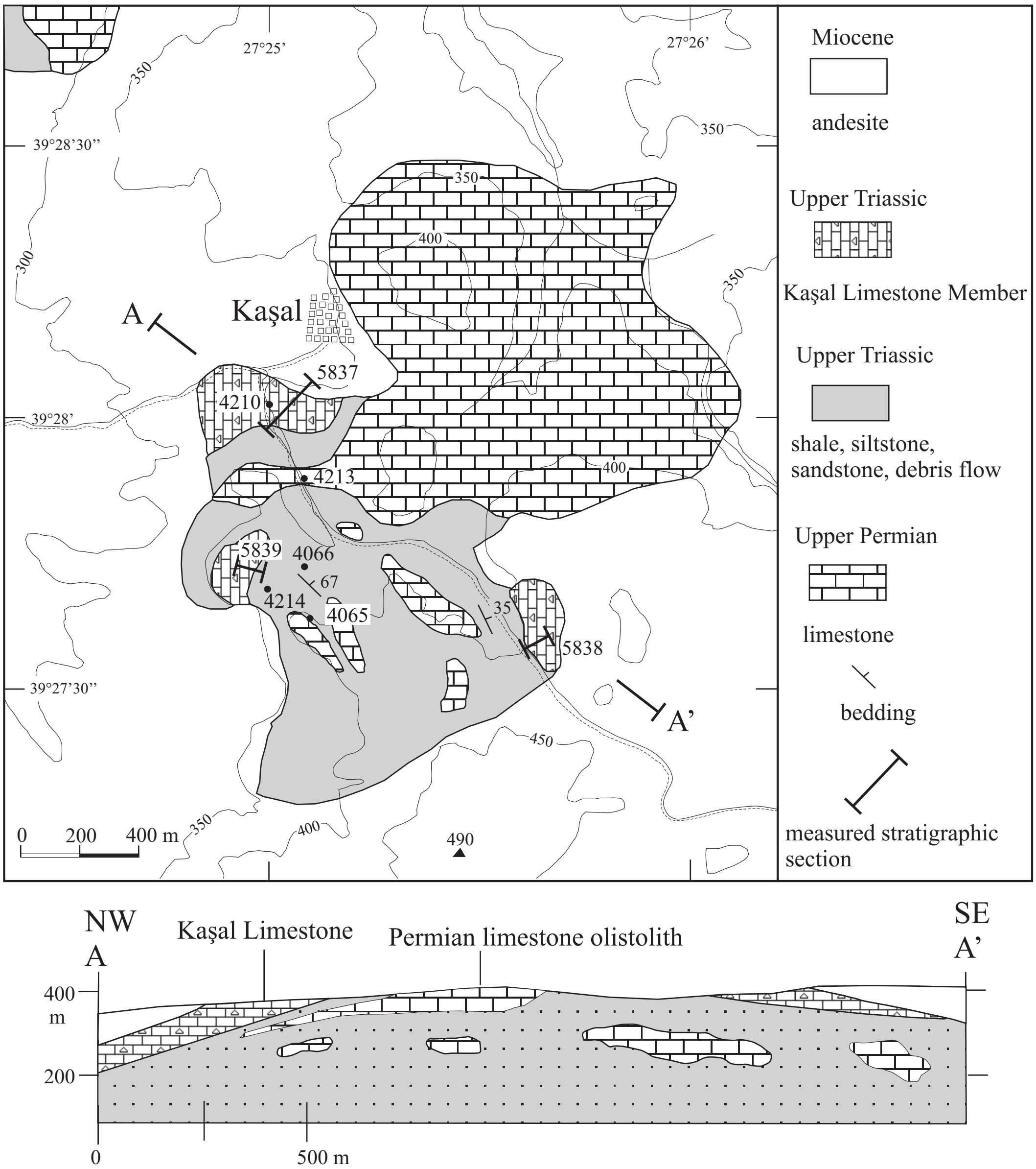

Figure 4. Geological map of the Kaşal region with the Upper Triassic limestones. For location see Figure 2.

named the Kaşal Limestone Member of the Hodul Unit, shows sheared contacts with the surrounding siltstones and shales. The Kaşal Limestone Member is a variegated, medium-bedded, nodular limestone with abundant coral, brachiopod, lamellibranch, crinoid, gastropod, algae, bryzoa and sponge spicules. Some of the corals in the limestone blocks are in growth position.

Three sections were measured in the Kaşal Limestone Member (sections 5837, 5838 and 5839; Figure 4):

Section 5837

This is the largest block close to Kaşal village (Figure 4), and we measured a thickness of 77 metres. In this measured stratigraphic section, there is little variation in the lithological features of the Kaşal Limestone, except that structurally upward the limestone becomes slightly marly and the bedding becomes nodular.

Twelve samples were collected along the section (Figure 5). Samples KO-1, KO-2, KO-3 and KO-9 are

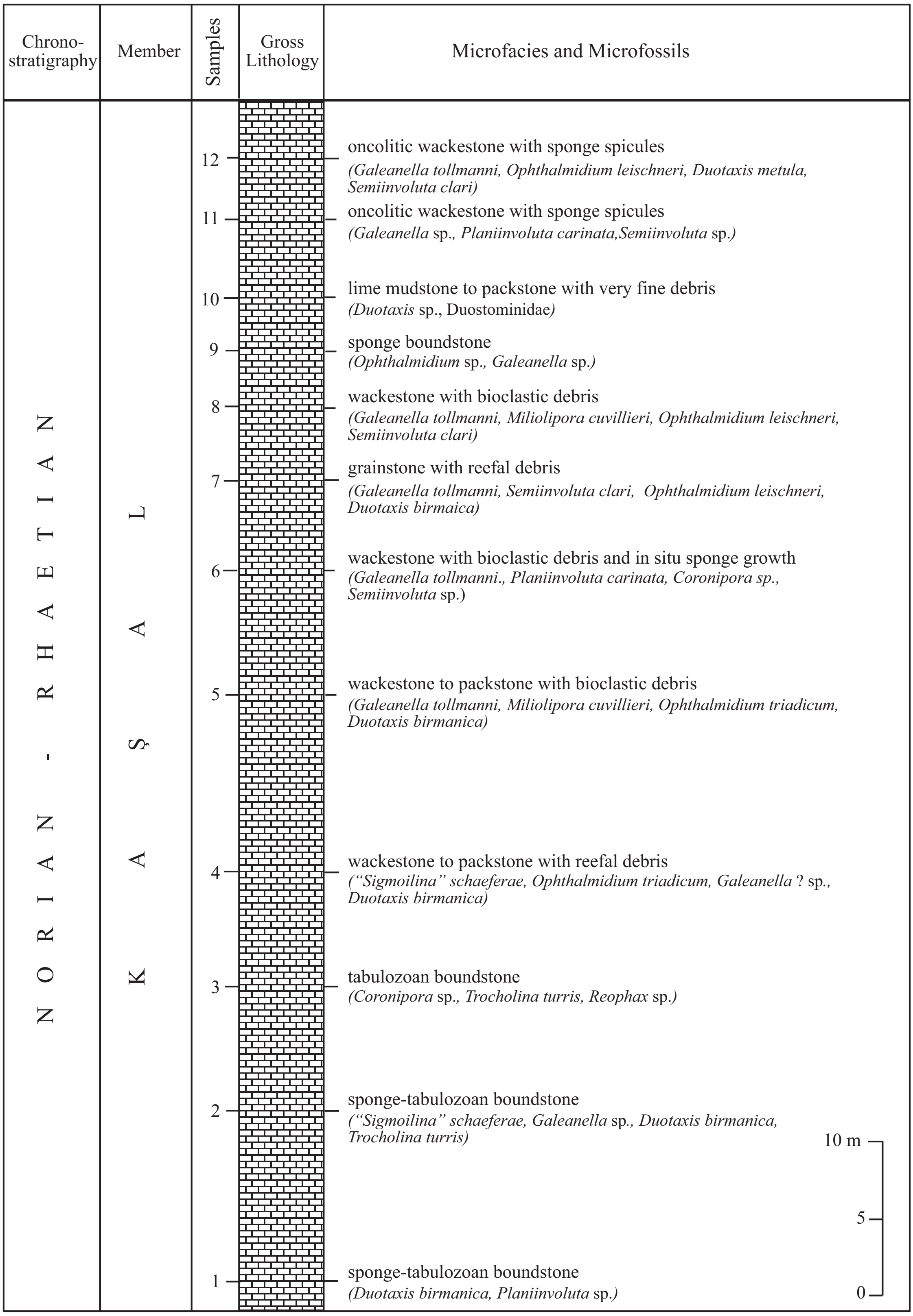

Figure 5. Measured stratigraphic section (5837) from the Upper Triassic Kaşal Limestone Member.

sponge-tabulozoan boundstones and contain rare foraminifera in the reefal cavities filled with bioclastic debris. Foraminifera and associated taxa include *Ophthalmidium* spp., *Galeanella* sp., '*Sigmoilina' schaeferae* ZANINETTI, ALTINER, DAŞER & DUCRET, *Planiinvoluta* sp., *Agathammina* sp., *Trocholina turris* FRENTZEN, *Coronipora* sp., Oberhauserellidae, *Duotaxis birmanica* ZANINETTI & BRÖNNIMANN, *Duotaxis* sp., *Reophax* sp., *Globochaete* sp. and *Tubiphytes* sp.

The middle part of the section is characterised by wackestones or wackestones to packstones with bioclastic or reefal debris consisting of sponge, brachiopod, gastropod, echinoid and *Tubipytes* debris (samples KO-4, KO-5, KO-6 and KO-8). The level KO-6 is characterised by *in situ* sponge growth. The level KO-7 is, on the other hand, a high-energy grainstone containing broken debris derived from the laterally occurring reefal boundstones. These levels (KO-4 to KO-8) contain a richer foraminiferal assemblage comprising *Galeanella tollmanni* (KRISTAN), *Galeanella variabilis* ZANINETTI, ALTINER, DAŞER & DUCRET, *Galeanella ? minuta* ZANINETTI, ALTINER, DAŞER & DUCRET, *Galeanella* ? sp., *Miliolipora cuvillieri* BRÖNNIMANN & ZANINETTI, *Ophthalmidium triadicum* (KRISTAN), *Ophthalmidium martanum* (FARINACCI), *Ophthalmidium leischneri* (KRISTAN-TOLLMANN), *Gsoelbergella* sp., *'Sigmoilina' schaeferae*, *Agathammina* sp., *Planiinvoluta carinata* LEISCHNER, *Trocholina turris*, *Trocholina umbo* FRENTZEN, *Trocholina* sp., *Turrispirillina* sp., *Semiinvoluta* sp., *Coronipora* sp., Duostominidae, *Paleolituonella meridionalis* (LUPERTO SINNI), *Duotaxis birmanica*, *Duotaxis inflata* (KRISTAN), *Duotaxis metula* KRISTAN, *'Tetrataxis' nana* KRISTAN and several sections of lagenoids.

The upper part of the section is characterised either by lime mudstones to packstones with very fine debris of macrofossil fragments (KO-10) or by pinkish oncolithic wackestones with sponge spicules (KO-11, KO-12). The microfossils identified are similar to those from the lower levels of the section: *Galeanella tollmani*, *Galeanella* sp., *Ophthalmidium martanum* (FARINACCI), *Ophthalmidium leischneri*, *Ophthalmidium* sp., *'Sigmoilina' schaeferae*, *Planiinvoluta carinata* LEISCHNER, *Trocholina turris*, *Trocholina* spp., *Semiinvoluta clari* KRISTAN, *Semiinvoluta* sp., Dustominidae, *Duotaxis metula*, *Duotaxis* sp., *Globochaete* sp.

Section 5838

This section consists of two parts separated by an observation gap (Figure 6). The lower part, measuring about 7.5 m, was sampled at two levels. The sample KO-20 is a bioturbated argillaceous lime mudstone suggesting that the boundary between the Hodul Unit and the Kaşal Limestone Member is gradational. The sample KO-21 is a mudstone to wackestone with reefal debris containing sponge, bryozoa and echinoid fragments. This level contains a diversified foraminiferal fauna including *Ophthalmidium* spp., *'Sigmoilina' schaeferae*, *Miliolipora cuvillieri* BRÖNNIMANN & ZANINETTI, *Galeanella variabilis*, *Galeanella* sp., *Trocholina* sp., *Turrispirillina* sp., *Semiinvoluta clari, Semiinvoluta* sp., *Coronipora* sp., *Paleolituonella* sp ?, *Duotaxis* sp., *Reophax* sp., Ataxophragmiidae and several unidentified lagenoid forms.

The upper part of the section, measuring 20 m in thickness (Figure 6), consists of three distinct facies. Samples KO-19, KO-18 and KO-16 are packstones with sometimes current-oriented reef debris composed of sponges, tabulazoans, brachiopods, echinoids and gastropods. The following foraminifers and other taxa are present in the samples: *Ophthalmidium* spp., *'Sigmoilina' schaeferae*, *Miliolipora* ? sp., *Galeanella* sp., *Coronipora* sp., Oberhauserellidae, *Ammobaculites* ? sp., *Duotaxis birmanica*, *Duotaxis* sp., *Gaudryina* sp., lagenoid-type foraminifers, *Globochaete* sp. and *Tubiphytes obscurus* MASLOV. The samples KO-17 and KO-15 are true boundstones made up of sponges and tabulazoans. The micritic and sparitic cavities in the facies contain *Ophthalmidium* spp., *Seminvoluta clari* and *Duotaxis birmanica*. The uppermost two levels in the section (KO-14 and KO-13) are grainstones with local current-oriented bioclastic debris and contain a relatively more diversified fauna comprising *Ophthalmidium traidicum*, *Ophthalmidium* spp., *Mililipora cuvillieri*, *Planiinvoluta* sp., *Aulotortus friedli* (KRISTAN-TOLLMANN), *Trocholina acuta* OBERHAUSER ? , *Trocholina* sp., *Semiinvoluta* sp., Oberhauserellidae, *Glomospirella* sp., *Duotaxis birmanica*, *Duotaxis metula* and several lagenoid foraminiferal sections.

Section 5839

This section measures about 11 m (Figure 7) and rests on the clastic levels (mudstones, siltstones) of the Hodul

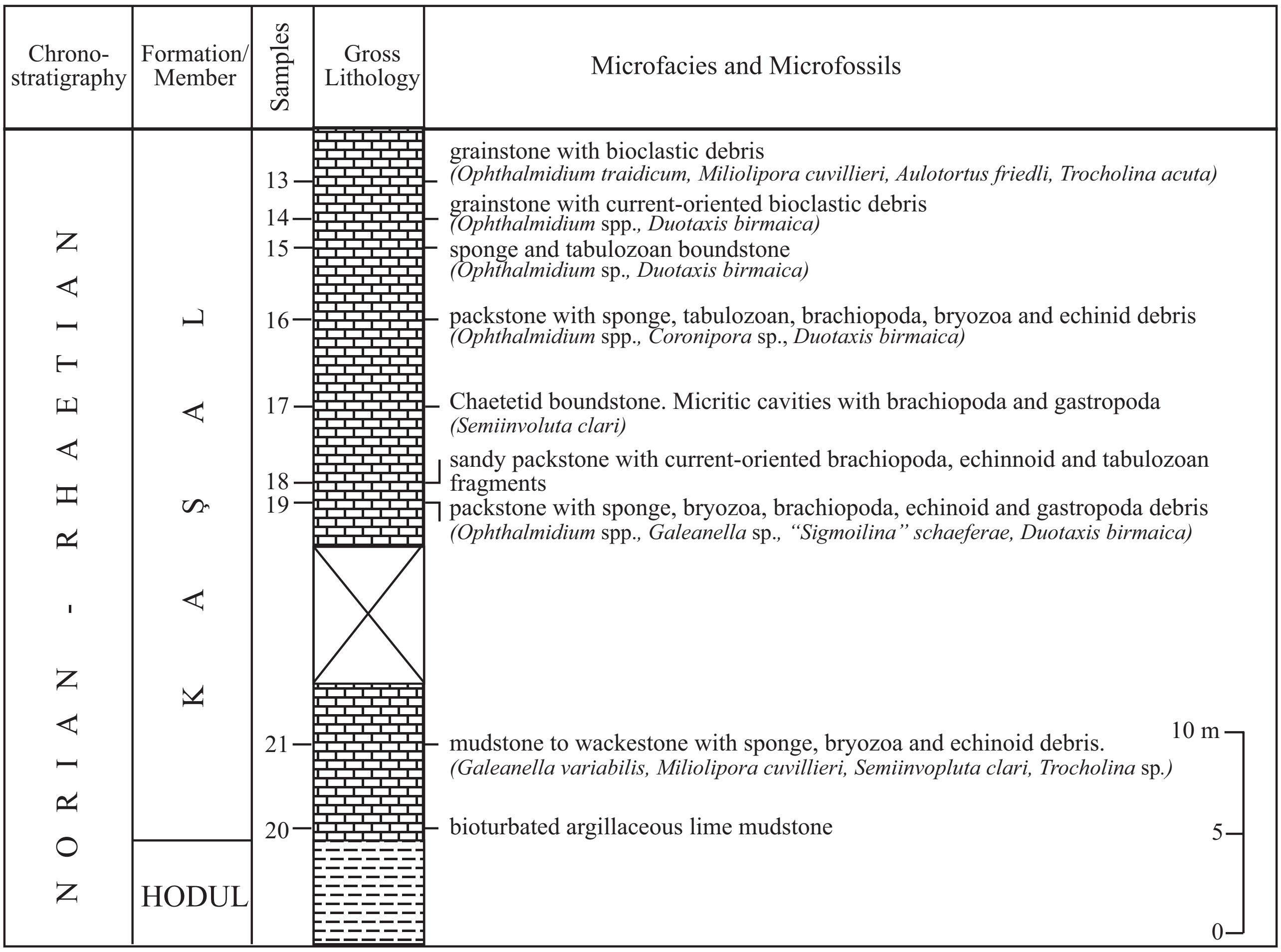

Figure 6. Measured stratigraphic section (5839) from the Upper Triassic Kaşal Limestone Member.

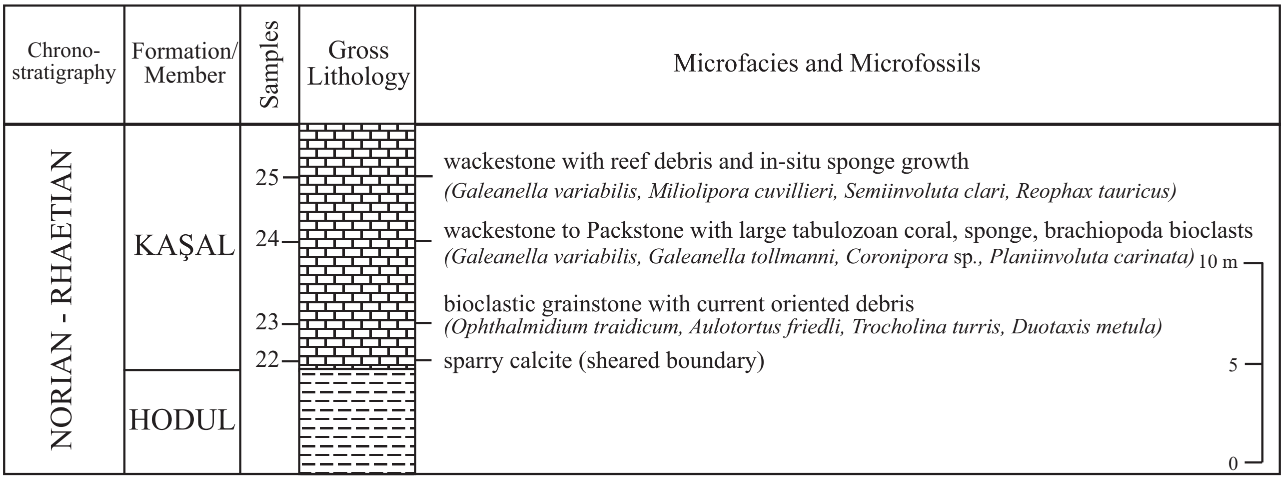

Figure 7. Measured stratigraphic section (5838) from the Upper Triassic Kaşal Limestone Member.

Unit. The first level sampled (sample KO-22), lying immediately above the highest clastic lithology of the formation, is a sparry calcite suggesting a sheared boundary which possibly destroyed the original composition and fabric of the Kaşal Limestone Member. The higher levels of the section display an obvious fining in carbonate grain size. Samples KO-23 and KO-24 are bioclastic grainstone and wackestone to packstone containing large tabulozoan, coral, sponge and brachiopod bioclasts. These levels contain an interesting and diversified fauna consisting of *Ophthalmidium triadicum*, *Galeanella variabilis*, *Galeanella tollmani*, *Galeanella* sp., *Planiinvoluta carinata* LEISCHNER, *Aulotortus friedli*, *Trocholina turris*, *Semiinvoluta* sp., *Coronipora* sp., Duostominidae, *Pseudobolivina* sp., *Pliammina* ? sp., *Reophax* sp., *Duotaxis birmanica*, *Duotaxis metula*.

The uppermost level sampled in this section (KO-25) is a wackestone with reef debris characterised also by the presence of *in situ* sponge growth in the facies. The foraminiferal fauna consists of a rich and diversified assemblage including *Ophthalmidium triadicum*, *Ophthalmidium* spp., *'Sigmoilina' schaeferae*, *Miliolipora cuvillieri*, Miliolidae, *Galeanella variabilis*, *Galeanella laticarinata* AN-SHAIBANI, CARTER & ZANINETTI, *Galeanella tollmani*, Galeanella sp., *Trocholina turris*, *Trocholina* sp., *Turrispirillina* sp., *Semiinvoluta clari*, *Coronipora* sp., Oberhauserellidae, *Textularia* sp., *Pseudobolivina* sp., *Reophax tauricus* ZANINETTI, ALTINER, DAGER & DUCRET, *Duotaxis birmanica*, *Duotaxis metula* and several sections of lagenoid foraminifers.

In summary, the microfacies analysis of the three sections reveals three distinct facies types in the Kaşal Limestone Member, all grading into each other: tabulozoan- and sponge-rich boundstones, grainstones to packstones rich in reefal debris and pinkish wackestones with bioclastic debris. The foraminifers identified are concentrated in the reef cavities and in their adjacent facies. According to Schäfer & Senowbari-Daryan (1981) (see also Wilson 1975; Tollmann 1976; Flügel 1981), coral-sponge facies of the central reef areas grade into the basin with reef detritus-mud facies of the leeward and deepest portions of the reef slopes. The Kaşal Limestone Member, displaying all the fundamental characteristics of a reef- to fore-reefal-type facies, was likely laid down in a basin where the most distal carbonate facies was grading into the fine-grained clastic facies of the Hodul Unit.

The Upper Triassic (Norian–Rhaetian) reef and reef-related forms have been studied by several authors including Kristan (1957), Kristan-Tollmann (1964, 1970), Hohenegger & Lobitzer (1971), Hohenegger (1974), Zaninetti (1976), Piller (1978), Dullo (1980), Schäfer & Senowbari-Daryan (1978, 1981), Flügel (1981), Sadati (1981), Zaninetti *et al.* (1982a, b, 1992), Gaidzicki (1983), Al-Shaibani *et al.* (1983), Senowbari-Daryan (1983, 1984), Stanley & Senowbari-Daryan (1986), Oravecz-Scheffer (1987), Di Stefano *et al.* (1990), Altıner *et al.* (1992), Vuks (1995), Pronina & Vuks (1995) and Martini *et al.* (1997). The foraminiferal species *'Sigmoilina' schaeferae*, *Miliolipora cuvillieri*, *Galeanella variabilis* and *Duotaxis birmanica* are generally accepted as markers of the Norian–Rhaetian interval. However, these taxa occur in association with several other taxa which have been reported only from the Rhaetian or Rhaetian to younger strata belonging to Hettangian and Pliensbachian (Zaninetti 1976). These forms are *Trocholina turris*, *Trocholina umbo*, *Galeanella tollmani*, *Ophthalmidium leischneri*, *Ophthalmidium triadicum*, *Coronipora* sp., *Semiinvoluta clari*, *Duotaxis inflata*, *Duotaxis metula*. Although a Rhaetian age could be proposed based on the foraminiferal species reported (not older than Rhaetian), we prefer to assign in this study a Norian–Rhaetian age for the Kaşal Limestone Member. The reason for this wider age assignment is partly lack of studies revealing the full stratigraphic ranges of the so-called Rhaetian fauna which seem to be highly facies-dependent. Another reason is the presence of the probable hydrozoan fossil *Heterastridium* sp. in the Kaşal Limestone Member, which is regarded as characteristic of the Norian.

Several lines of data suggest that, unlike the Permian limestones, the Kaşal Limestone is not an olistolith but represents *in situ* carbonate deposition in the Hodul basin: (1) At the stratigraphic base of two of the Kaşal Limestone blocks (5838 and 5839 in Figure 4), there are greenish grey, discontinuous marly mudstone and siltstone beds a few metres thick, which are lithologically similar to the matrix of the Hodul Unit. (2) The age of the Kaşal Limestone Member is very close to the that of the "clastic matrix". (3) The Kaşal Limestone Member is only found as large blocks, whereas the Permian limestone blocks occur over a wide size range – from several hundred metres down to few centimetres – as expected in a debris flow. (4) In contrast to the ubiquitous presence of Carboniferous and Permian limestone blocks in the Karakaya Complex, the Upper Triassic limestone blocks are apparently only present at this locality. These arguments suggest that the Upper Triassic Kaşal Limestone Member is not exotic to the Hodul basin as are the Permian limestone blocks (Figure 2). The sheared contacts of the Kaşal Limestone Member with the surrounding fine-grained clastic rocks must be due to post-depositional deformation. This deformation, which disrupted the original stratigraphy of the Hodul basin, was most probably associated with the incoming of the Permian limestone blocks. The blocks were probably derived from a large thrust sheet of Permo–Carboniferous limestone; the thrust sheet itself was either eroded or removed by strike-slip faulting. In regions, such as northeast of Havran, where the olistostromes are absent, there is not a distinct angular unconformity between the Hodul Unit and the Bayırköy Formation (Altıner & Koçyiğit 1992), suggesting that deformation of the Hodul Unit occurred in a foreland basin in front of the advancing Permo-Carboniferous limestone nappe.

Conclusions

The Kaşal Limestone Member was probably deposited as small discontinuous, lenticular local reef knolls or banks on a muddy sea floor. In terms of facies and age, it can be compared with the "Kössen beds" of the North Calcareous Alps, which is a Rhaetian limy argillaceous facies deposited in basins adjoining reefs (e.g., Wilson 1975; McRoberts *et al.* 1997). According to Flügel (1981), towards the end of Late Triassic times the Dachstein and the Hauptdolomite areas (see also Zankl 1971 and Tollmann 1976) were differentiated into basins with terrigenous influx (Kössen beds: terrigenous mud facies) and into areas of small reefs (Upper Rhaetian reef limestones). The limestones in these basins formed small reef knolls or banks developed on piles of shells on mud bottom (e.g., Fabricius 1968). The depositional setting of the Kaşal Limestone indicate that the Hodul basin in the İvrindi region was not deep prior to the arrival of the olistostromes with the Permian limestone blocks.

The deformation of the Hodul basin was associated with the incoming of the Permian limestone debris flows. The age of deformation can be bracketed by the youngest age in the Hodul basin, and the age of the unconformably overlying Bayırköy Formation. The predominantly clastic Bayırköy Formation includes *ammonitico rosso* horizons, which provide useful age constraints. Ammonites and microfauna from the *ammonitico rosso* horizons in northwestern Turkey indicate a predominantly Early Sinemurian and Pliensbachian age (Alkaya 1981; Altıner *et al.* 1991). The age of deformation of the Hodul basin is, therefore, constrained to a relatively short period, namely, the Rhaetian–Hettangian. Using the time scale of Gradstein *et al.* (1994), this period corresponds to 210 to 202 Ma. It is significant that the age of regional metamorphism of the Nilüfer Unit also falls into the same period of 215 to 205 Ma (Okay & Monié 1997; Okay *et al.* 2002). This indicates that deformation in the Hodul basin and the regional metamorphism of at least part of the Nilüfer Unit, which are the hallmarks of the Cimmeride orogeny in northwestern Turkey, occurred over a short interval at the end of the Triassic and the beginning of the Jurassic.

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