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Triassic limestone, turbidites and serpentinite–the Cimmeride orogeny in the Central Pontides

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Abstract – The basement of the Central Pontides, and by implication that of Crimea, consists of pre-Permian low-grade metaclastic rocks intruded by latest Permian – Early Carboniferous (305–290 Ma) granitoids. Further up in the stratigraphic sequence are Triassic limestones, which are now preserved as olistoliths in the deformed Upper Triassic turbidites. New conodont and foraminifera data indicate an Anisian to Carnian (Middle to Late Triassic) age for these hemi-pelagic Hallstatt-type limestones. The siliciclastic turbidites surrounding the Triassic limestone contain the Norian (Late Triassic) bivalve *Monotis salinaria*; the same species is also found in the Tauric series in Crimea. The Upper Triassic flysch in the Central Pontides is locally underlain by basaltic pillow lavas and includes kilometre-size tectonic slices of serpentinite. Both the flysch and the serpentinite are cut by an undeformed acidic intrusion with an Ar–Ar biotite age of 162 ± 4 Ma (Callovian–Oxfordian). This indicates that the serpentinite was emplaced into the turbidites before Middle Jurassic time, most probably during latest Triassic or Early Jurassic time, and that the deformation of the Triassic sequence pre-dates the Middle Jurassic. Regional geological data from the circum-Black Sea region, including widespread Upper Triassic flysch, Upper Triassic eclogites and blueschists of oceanic crustal affinity, and apparent absence of a 'Cimmerian continent' between the Cretaceous and Triassic accretionary complexes indicate that the latest Triassic Cimmeride orogeny was accretionary rather than collisional and is probably related to the collision and accretion of an oceanic plateau to the southern active margin of Laurasia.

Keywords: Triassic, biostratigraphy, Cimmeride orogeny, Pontides, conodonts, foraminifera.

1. Introduction

Scarce Triassic outcrops in the circum-Black Sea region outline three facies belts (Fig. 1). In the west in the Balkans the Triassic sediments were deposited on a continental to shallow marine platform passing to a deep shelf or platform margin at Dobrugea and Istanbul (Gedik, 1975; Muttoni *et al.* 2000; Seghedi, 2001; Derman, 2002; Bedi *et al.* 2013). They rest unconformably on the eroded remnants of the Variscan orogen, which include deformed Carboniferous sedimentary rocks and Permo-Carboniferous granitoids. In the north between the Caspian Sea and the Crimea is a Triassic magmatic belt (Nikishin *et al.* 2001, 2012; Alexandre *et al.* 2004; Natal'in & Şengör, 2005). This is known almost solely from subsurface data (Tikhomirov, Chalot-Prat & Nazarevich, 2004) but is also inferred from abundant Triassic clastic zircons in the Mesozoic sediments in the Pontides (Karslıoğlu *et al.* 2012; Okay *et al.* 2013; Ustaömer *et al.* 2014) and in Crimea (A. Nikishin, pers. comm.). South of the magmatic belt and extending westward to the Aegean Sea are strongly deformed, thick turbidite sequences, which are associated in the Pontides with Upper Triassic eclogites and blueschists (Fig. 1; Okay, 2000; Nikishin *et al.* 2001, 2012; Okay & Göncüoğlu, 2004). These include the Karakaya Complex in western Turkey (Okay & Göncüoğlu, 2004), the Küre Complex in the Central Pontides (Ustaömer & Robertson, 1994), the Tauric series in Crimea and the Dizi series in the Caucasus (Adamia *et al.* 2011; Fig. 1). The significance and origin of this deformation and metamorphism, known as the Cimmeride orogeny, is poorly understood; it is either related to the collision of a 'Cimmerian continent' with the Laurasian margin (Şengör, 1984) or to accretional processes along the active Laurasian margin (Okay, 2000).

Stratigraphic and geochronological data are critical in constraining the origin and timing of the Cimmeride orogeny in the circum-Black Sea region. Here we present new palaeontological and isotopic data on the Triassic series and its basement in the Central Pontides. The data include characterization of a late Variscan metamorphic–plutonic basement, a Middle to Upper Triassic pelagic limestone sequence and pre-Middle Jurassic serpentinites, which occur as tectonic slices in the Upper Triassic turbidites. The Cimmeride deformation is envisaged as an accretionary rather than

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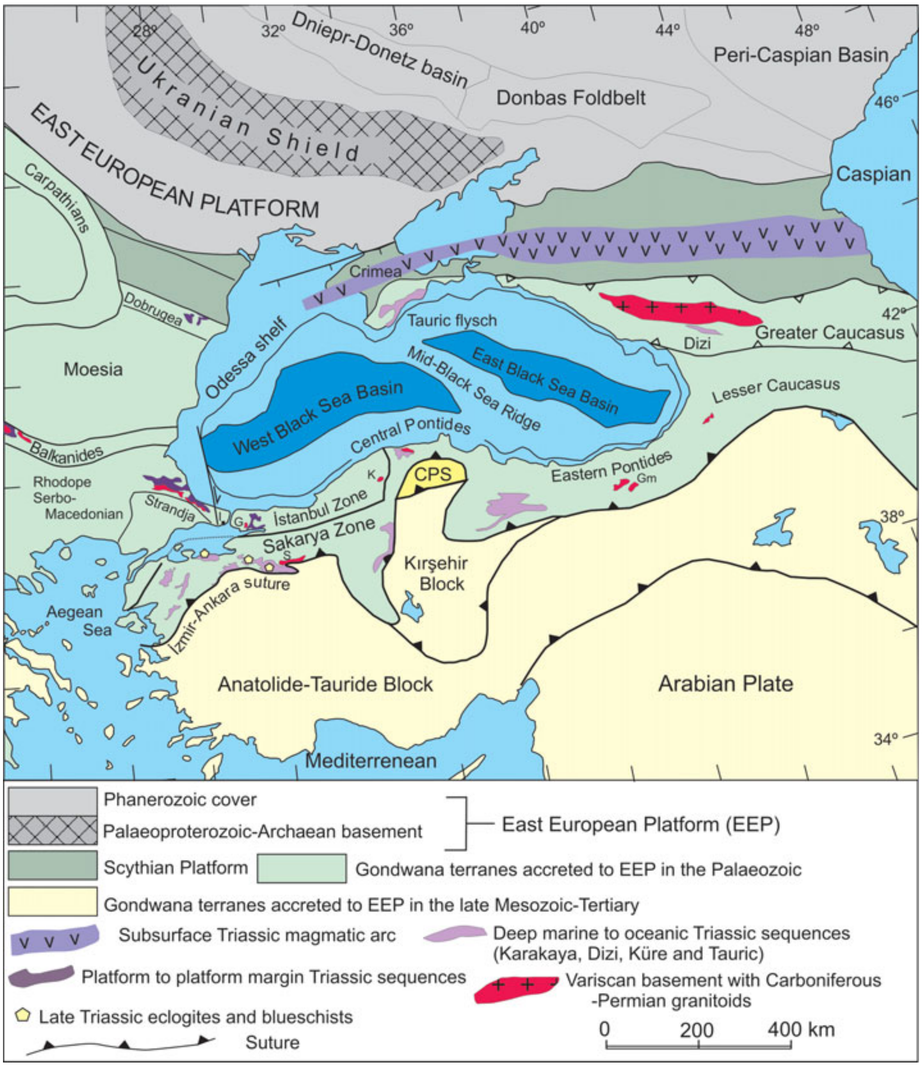

Figure 1. (Colour online) Tectonic map of the circum-Black Sea region showing the outcrops of Triassic strata north of the İzmir–Ankara suture (modified from Okay & Tüysüz, 1999). Abbreviations: CPS – Central Pontide Supercomplex; Permo-Carboniferous granitoids: G – Gebze; Gm – Gümüşhane; I – Istanbul; K – Kürek; S – Söğüt.

collisional orogeny involving latest Triassic attempted subduction and accretion of oceanic edifices.

2. Geological setting

The Central Pontides include two Pontic terranes: the Istanbul Zone in the west and the Sakarya Zone in the east (Fig. 1). They share a common Upper Jurassic shallow marine limestone cover in the Central Pontides but show different pre-Jurassic development (Fig. 2). The Istanbul Zone is characterized by a well-developed Palaeozoic (Ordovician to Carboniferous) sedimentary sequence, including Carboniferous coal measures (Görür *et al.* 1997; Dean *et al.* 2000), which rests on a late Neoproterozoic granitic basement (Chen *et al.* 2002; Ustaömer, Mundil & Renne, 2005). The Palaeozoic sequence is intruded by Permian granitoids (Şahin *et al.* 2009; Okay *et al.* 2013) and is unconformably overlain by Permo-Triassic red beds and by the Middle Jurassic lacustrine limestone and shale (Fig. 2).

The crystalline basement of the Sakarya Zone in the Central Pontides is represented by poorly exposed Permo-Carboniferous granitoids and metamorphic rocks close to the Black Sea margin (Fig. 1; Nzegge *et al.* 2006; O. M. Nzegge, unpub. Ph.D. thesis, Univ. Tübingen, 2008). The large area of metamorphic rocks in the southern part of the Central Pontides, the Central Pontide Supercomplex (Figs 1, 3), which is shown as Triassic and older basement on the geological maps and in publications (e.g. Yılmaz & Şengör, 1985; Tüysüz, 1990; Ustaömer & Robertson, 1994, 1999; Yılmaz *et al.* 1997; Yiğitbaş, Elmas & Yılmaz, 1999; Uğuz, Sevın & Duru, 2002), has recently been shown to be of Jurassic and Cretaceous age (Okay *et al.* 2006, 2013).

The Permo-Carboniferous granitoids in the Central Pontides are overlain in the south by the Upper Triassic turbidites, which constitute part of an orogenic Triassic volcano-sedimentary unit called the Küre Complex (Ustaömer & Robertson, 1994). The Upper Triassic turbidites also crop out in the southern Crimea as the Tauric series (Zonenshain, Kuzmin & Natapov, 1990). The Küre Complex and the Tauric series are intruded by Middle Jurassic shallow level intrusions and are

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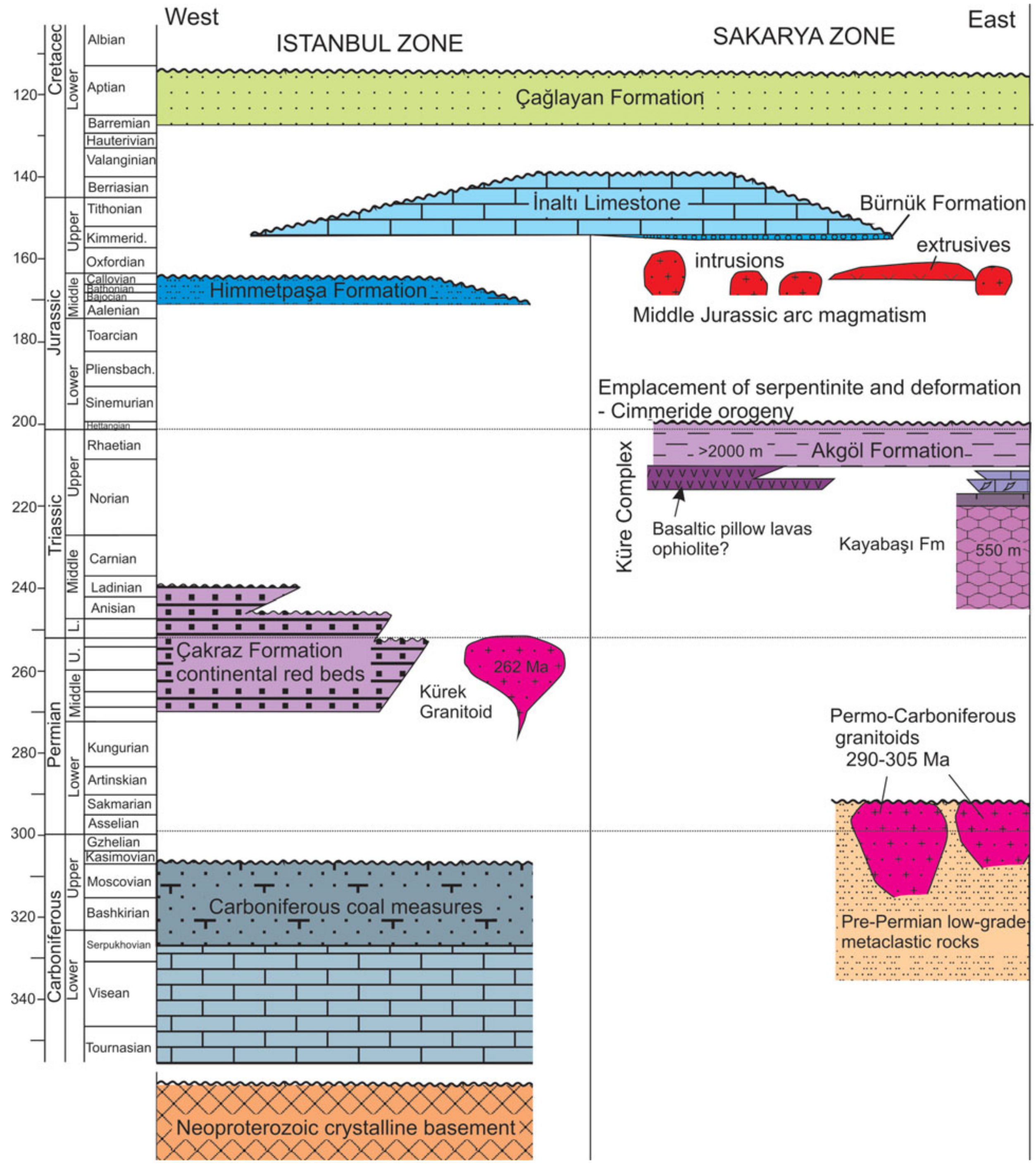

Figure 2. (Colour online) Stratigraphic section of the Istanbul and Sakarya zones in the Central Pontides (modified from Okay *et al.* 2014). The geological time scale is after Cohen *et al.* (2013).

unconformably overlain by Upper Jurassic continental clastic rocks and limestones (Fig. 2). For this study we worked in detail in the Central Pontides and made a geological field trip to Crimea.

3. The late Variscan basement

Palaeozoic low-grade metasedimentary rocks intruded by Permian and Carboniferous granitoids constitute the basement of the Central Pontides. The basement crops out poorly in the densely vegetated coastal region south of İnebolu and Abana (Fig. 3). The metasedimentary rocks consist of black to brown slates to phyllites interbedded with metasiltstone and fine-grained metasandstone (Boztuğ & Yılmaz, 1983). A serpentinite lens, *c.* 100 m thick occurs within the slates close to the Late Carboniferous granitoid (Fig. 4, UTM co-ordinates 36T 0573450–4633030) and has undergone contact metamorphism, which indicates a pre-Permian age for the serpentinite. Boztuğ & Yılmaz (1983) also described from further east a serpentinite lens in the contact metamorphic aureole of the Late Carboniferous granitoid. The metaclastic rocks are lithologically similar to the Upper Triassic turbidites, and have

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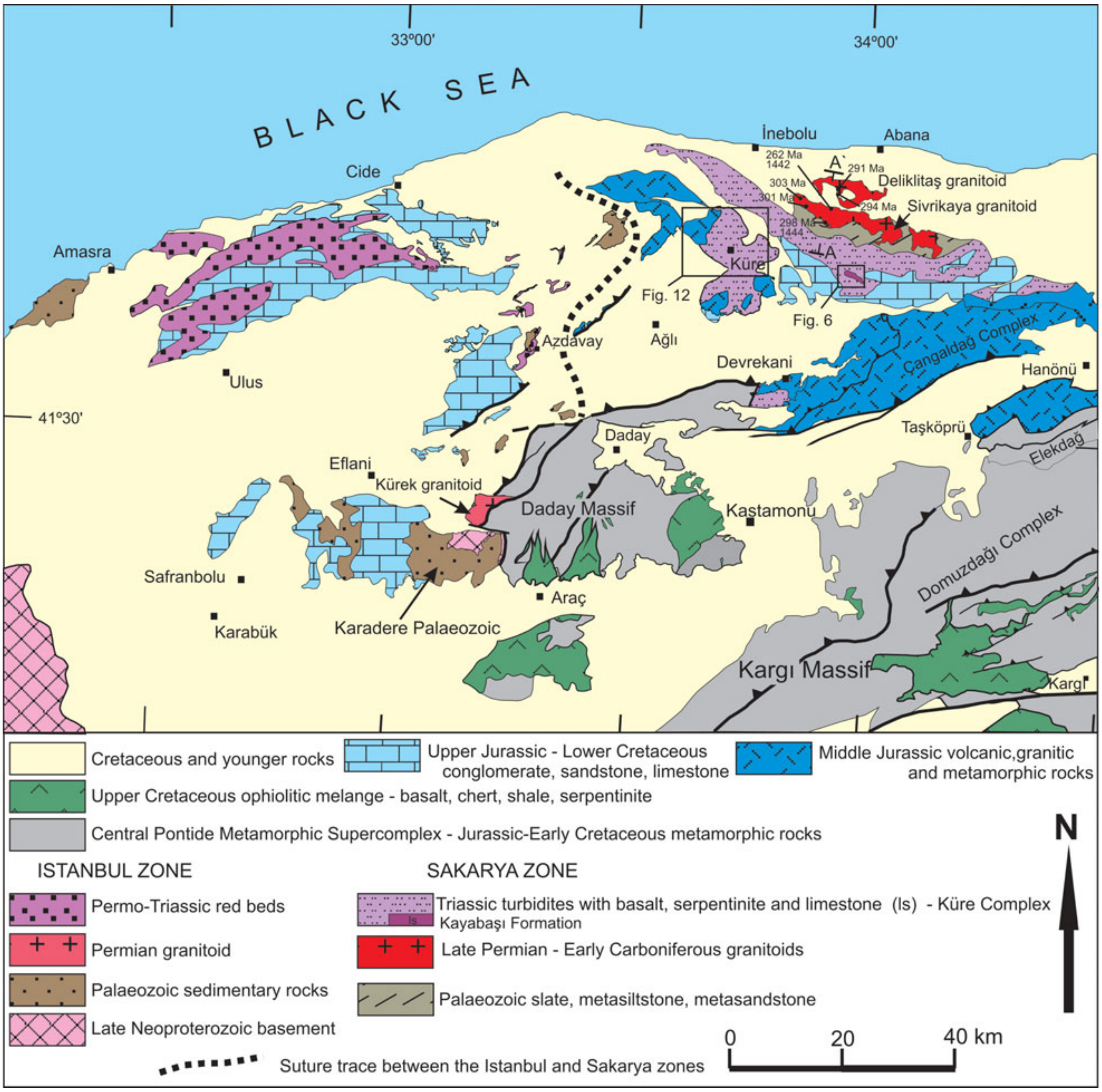

Figure 3. (Colour online) Geological map of the Central Pontides with outcrops of pre-Cretaceous units and Central Pontide Metamorphic Supercomplex (based on Aydın *et al.* 1995; Aksay *et al*. 2002; Uğuz, Sevın & Duru, 2002; Okay *et al.* 2013).

previously been mapped as such (Boztuğ & Yılmaz, 1983); however, they have undergone a low-greenschist-facies regional metamorphism, and a penetrative cleavage is well developed even in sandstones. The region is later deformed by thrusting and folding and is cut by normal faulting, all probably of Eocene and younger age (Fig. 4).

The metasedimentary rocks are intruded by granitoids leading to the generation of hornfels in the contact aureole. Previously, these granitoids were considered Middle Jurassic in age (Boztuğ & Yılmaz, 1983; Boztuğ *et al.* 1984, 1995). However, isotopic dating by Nzegge *et al.* (2006) produced latest Carboniferous and Early Permian ages (Table 1). The Variscan granitoids comprise the Deliklitaş granitoid in the north and the Sivrikaya Granitoid in the south; they may be connected under the Cretaceous cover (Figs 3, 4). Close to the northern margin of the Sivrikaya Granitoid, there are numerous of 1–10 m thick enclaves of gneissic micaschists with the mineral assemblage of quartz + K-feldspar + muscovite + biotite + sillimanite.

In terms of mineral assemblage, the Deliklitaş and Sivrikaya intrusions range from hornblende-biotite granodiorite to two-mica granite (Boztuğ & Yılmaz, 1983; Nzegge *et al.* 2006). They are peraluminous, calc-alkaline and high-K in composition (Nzegge *et al.* 2006). Geochemical features of the granitoids, including their $\varepsilon Nd_{(t)}$, $\delta^{18}O$ values and $Sr_{(i)}$ ratios, suggest derivation by dehydration melting of metapelitic and mafic crust (Nzegge *et al.* 2006). This is also supported by the presence of primary muscovite and enclaves of high-temperature metamorphic rocks in the

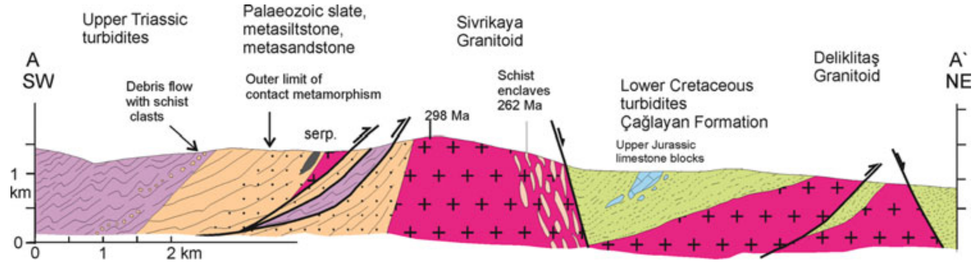

Figure 4. (Colour online) Geological cross-section from the northern part of the Central Pontides showing the relationship between the Variscan basement and the overlying units. For location of the section see Figure 3.

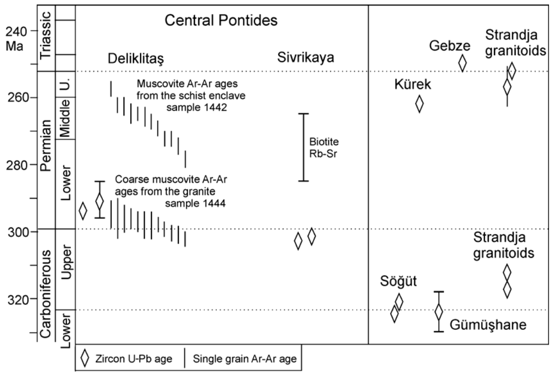

Figure 5. Isotopic age data from the Permo-Carboniferous granitoids in the Pontides (Yılmaz, 1975; Nzegge *et al.* 2006; O. M. Nzegge, unpub. Ph.D. thesis, Univ. Tübingen, 2008; Okay *et al.* 2001, 2013; Şahin *et al.* 2009; Sunal *et al.* 2006; Topuz *et al.* 2010; Ustaömer, Ustaömer & Robertson, 2012; this study).

Deliklitaş granitoid. On the tectonic discrimination diagrams most samples plot in the field of volcanic arc granitoids (Nzegge *et al.* 2006). Their peraluminous nature, high K and Sr contents, high Rb/Sr values and initial Sr ratios point to crustal melting and suggest an episode of crustal thickening.

U–Pb magmatic zircon ages from two samples of the Sivrikaya Granitoid are 303 ± 2 Ma and 301 ± 2 Ma (latest Carboniferous) (Nzegge *et al.* 2006; O. M. Nzegge, unpub. Ph.D. thesis, Univ. Tübingen, 2008; Table 1). During this study, coarse muscovites from a sample of the Sivrikaya Granitoid were dated using the Ar–Ar laser probe at the Open University in the UK. The location of sample 1444 is shown in Figure 3. The mineral separation and analytical methods are explained in the online Supplementary Material available at http://journals.cambridge.org/geo; the analytical data are given in Table S1 in the online Supplementary Material available at http://journals.cambridge.org/geo. Twelve grains of muscovite produced a mean age of 298 ± 2 Ma (Fig. 5; Table 1), which is similar to the zircon U–Pb ages. The muscovites in the sample are 4–10 mm long, and the blocking temperature for such coarse-grained muscovites may reach 600–650 °C (Cliff, 1985). To constrain the cooling history of the Sivrikaya Granitoid, we used the Ar–Ar method to date small muscovites (*c.* 0.4 mm long) from a micaschist enclave (sample 1442 in Fig. 3; Table 2). The micaschist consists of quartz + muscovite + biotite + sillimanite. Eleven muscovite grains gave ages ranging from 279 Ma to 262 Ma with an average of 267 ± 6 Ma (Fig. 5; Table 1; Table S1 in the online Supplementary Material available at http://journals.cambridge.org/geo), suggesting a long period of cooling. O. M. Nzegge (unpub. Ph.D. thesis, Univ. Tübingen, 2008) also obtained a biotite whole-rock Rb–Sr age of 275 ± 10 Ma from the Sivrikaya Granitoid. The zircon U–Pb, muscovite Ar–Ar and biotite Rb–Sr ages indicate that the Sivrikaya Granitoid crystallized in latest Carboniferous time (*c.* 302 Ma) and underwent a slow cooling during Permian time.

The Deliklitaş Granitoid is slightly younger than the Sivrikaya Granitoid; two samples from the granitoid produced Early Permian zircon U–Pb ages of 294 ± 1 Ma and 291 ± 5 Ma (Nzegge *et al.* 2006; O. M. Nzegge, unpub. Ph.D. thesis, Univ. Tübingen, 2008; Table 1). The Sivrikaya and Deliklitaş granitoids crystallized at around the Permian–Carboniferous boundary, and this was followed by a prolonged cooling. The magmatism appears to have changed from slightly metaluminous in latest Carboniferous time to peraluminous S-type in Early Permian time (Nzegge *et al.* 2006). Granitoids of Early Carboniferous to latest Permian age occur over a wide area in the Pontides (Figs. 1, 5; Table 1) and are also described from the core of the Greater Caucasus (Hanel, Gurbanov, & Lippolt, 1992; Somin, 2011). They constitute a link between the Variscan belt of central Europe and the Urals.

The Palaeozoic metasedimentary rocks are overlain in the south by the Upper Triassic turbidites (Figs. 3, 4). No clear contact can be observed in the field; however, the presence of debris flows with metamorphic rock clasts in the Upper Triassic turbidites just above the contact suggests the presence of an unconformity (Fig. 4).

4. The Küre Complex

The Küre Complex consists of a thick siliciclastic Upper Triassic turbidite sequence, called the Akgöl Formation, associated with basalt, gabbro and serpentinite (Ustaömer & Robertson, 1994). Economic massive sulphide deposits occur along the shale–basalt contacts.

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Table 1. Selected isotopic ages from the Central Pontides

Sample	UTM coordinates	Formation	Rock type	Method	Dated mineral	Mean age (Ma)	Error ±	No. of analysis	Ref.
SG-116		Sivrikaya Granitoid	tonalite	U–Pb isotope dilution	zircon	303.0	0.5	3 fractions	a
SG-132		Sivrikaya Granitoid	granodiorite	U–Pb isotope dilution	zircon	301.1	1.4	3 fractions	a
1444	36T 05 41 483 – 45 97 700	Sivrikaya Granitoid	granite	Ar–Ar single grain	muscovite	298.0	2.0	10 grains	b
1442	36T 05 41 513 – 45 97 409	Sivrikaya Granitoid	micaschist enclave	Ar–Ar single grain	muscovite	267.0	6.0	11 grains	b
DLG-114		Deliklitaş Granitoid	monzogranite	U–Pb isotope dilution	zircon	294.3	1.1	4 fractions	a
DLG-83		Deliklitaş Granitoid	monzogranite	U–Pb isotope dilution	zircon	291.0	5.0	5 fractions	a
1723	36T 05 24 926 – 45 77 225	Karaman Granitoid	granitoid	Ar–Ar single grain	biotite	162.0	4.0	10 grains	b, c
2478	36T 05 19 320 – 45 82 570	Kürek Granitoid	diorite	U–Pb laser ICP-MS	zircon	261.9	2.8	13 grains	d

a – Nzegge *et al.* 2006; O. M. Nzegge, unpub. Ph.D. thesis, Univ. Tübingen, 2008; b – this study; c – Okay *et al.* 2014; d – Okay *et al.* 2013.
The UTM coordinates are from the European 1979 grid, which is closely compatible with the 1: 25 000 scale topographic maps of Turkey.

Table 2. Ar–Ar data from the Middle Jurassic porphyry intruding into serpentinite

Biotites from dacite-porphyry of the Karaman pluton, sample 1723																						
UTM coordinates 36T 0554646–4631215																						
grains	^{40}Ar	+/−	^{39}Ar	+/−	^{38}Ar	+/−	^{37}Ar	+/−	^{36}Ar	+/−	^{40}Ar*/^{39}Ar	+/−	**Age (Ma)**	+/−	+/− (no J error)	39/40	+/−	36/40	+/−	37/39	+/−	38/39	+/−
1	0.472036821	0.0033116	0.041170318	0.0003422	0.00060537	4.33E-05	0.0069663	0.0001519	0.0002324	2.26E-05	9.797128795	0.198455	**166**	3	3.218546166	0.0872184	0.00094862	0.0004924	4.80E-05	0.1692069	0.0039491	0.0147039	0.001057817
2	0.869879945	0.0035099	0.075085834	0.0006517	0.0012595	6.29E-05	0.01144851	0.000152	0.0005113	4.14E-05	9.573110912	0.1886169	**163**	3	3.065164447	0.0863175	0.00082616	0.0005877	4.76E-05	0.1524723	0.0024181	0.0167741	0.000850707
3	0.375695514	0.0029463	0.03084543	0.0003731	0.00060537	5.30E-05	0.00781208	0.000152	0.0003122	3.18E-05	9.188908383	0.33792069	**156**	6	5.510532697	0.0821022	0.00118353	0.000831	8.49E-05	0.2532653	0.0058034	0.0196258	0.001735333
4	0.50947467	0.0026854	0.043110351	0.0004968	0.00072802	4.33E-05	0.01143214	0.0001521	0.0003113	3.18E-05	9.684413433	0.25258953	**164**	4	4.100655816	0.0846173	0.00107237	0.0006109	6.25E-05	0.2651832	0.0046675	0.0168873	0.001022149
5	0.564965457	0.0024976	0.041453459	0.0005691	0.00065647	5.30E-05	0.01658793	0.0001522	0.0005899	3.18E-05	9.423893692	0.26777225	**160**	4	4.35735434	0.0733734	0.00105824	0.0010441	5.64E-05	0.4001579	0.0066071	0.0158363	0.001297464
6	0.38280888	0.0024142	0.028070976	0.0003937	0.00058492	6.29E-05	0.03104991	0.0001522	0.0004161	3.18E-05	9.257387182	0.36905397	**158**	6	6.014505821	0.073329	0.00112765	0.0010869	8.33E-05	1.1061215	0.016434	0.0208373	0.002260919
7	0.442439163	0.002143	0.03325948	0.0008686	0.00061559	6.29E-05	0.01441242	0.0001523	0.0003905	3.18E-05	9.833477183	0.38709179	**167**	6	6.275809826	0.075173	0.0019966	0.0008825	7.20E-05	0.4333326	0.0122082	0.0185086	0.001952963
8	0.168385994	0.0014654	0.012430615	0.000301	0.00025786	5.30E-05	0.00537932	0.0001524	0.0001729	2.26E-05	9.436846672	0.59534184	**160**	10	9.686636019	0.0738221	0.00189949	0.0010266	0.00013444	0.4327474	0.0161274	0.0207437	0.004295063
9	0.932827755	0.0030611	0.065860794	0.0007136	0.00118795	0.0001032	0.02157562	0.0001525	0.0010786	3.18E-05	9.324376857	0.18084396	**159**	3	2.945447871	0.0706034	0.00079934	0.0011562	3.43E-05	0.3275943	0.0042378	0.0180374	0.001578808
10	0.801447331	0.0021012	0.058842641	0.0005381	0.00103464	6.29E-05	0.02296087	0.0001525	0.0008282	4.14E-05	9.46106257	0.2277968	**161**	4	3.705606984	0.0734205	0.00069849	0.0010334	5.17E-05	0.3902079	0.0044104	0.0175832	0.001081547

In the flysch there is also a large outcrop of Triassic limestone, which was studied in detail.

4.a. Middle–Upper Triassic limestone

In the Central Pontides the Permo-Carboniferous granitoids are unconformably overlain by the Upper Triassic turbidites indicating a period of uplift and erosion before Late Triassic time. The earlier Triassic sequences are found as sedimentary blocks in the Upper Triassic flysch. The largest block, known since Blumenthal documented it in 1948, crops out northeast of Devrekani (Fig. 3). Önder (1988) named the limestones the Kayabaşı Formation, and ascribed a 'topmost Middle Triassic – Late Triassic' age based on conodonts. The Kayabaşı Formation is of palaeogeographic and stratigraphic importance as it constitutes the only coherent marine limestone Triassic section in the Pontides with the exception of the Triassic in the western part of the Istanbul Zone. The Kayabaşı Formation was mapped in detail, several stratigraphic sections were measured and over 80 samples were collected for foraminifera and conodonts (Fig. 6).

The Kayabaşı Formation forms a *c.* 550 m thick and 4 km long block in the turbidites of the Akgöl Formation, cropping out along a NW–SE-trending ridge (Fig. 7a). The bedding in the limestone is difficult to recognize; when it is recognized it dips steeply (60–70°) south to southwest forming an inverted sequence (Fig. 6). The limestone is bounded in the northeast by a normal fault, and is stratigraphically overlain in the south by the turbidites of the Akgöl Formation. The Akgöl Formation above the Kayabaşı Formation includes small blocks of Triassic limestone (Fig. 7b).

The Kayabaşı Formation is subdivided into three members (Fig. 8):

(a) The limestone breccia member (Anisian). It constitutes the basal 200 m of the Kayabaşı Formation and is best observed on the ridge east of Çal village (Fig. 6). It consists of limestone breccia, with 1 to 10 cm sized light grey carbonate clasts set in a red micritic or sandy matrix (Fig. 7c). The limestone breccias are locally separated by thinly bedded micritic limestone beds. Textures showing a transition from bedded limestone to breccia, and the preservation of ghost bedding in some of the breccias (Fig. 7d) suggest that brecciation occurred largely *in situ* without significant transport.

A sample from the thinly bedded micritic limestones from the lower part of the succession (sample 1874) contains foraminifera characteristic of the Anisian: *Meandrospira pusilla*, *Meandrospira dinarica*, *Endoteba controversa*, *Nodasoria elabugae* and *Trochammina* sp. (Fig. 9). Samples from further up in the sequence contain Anisian conodonts: *Neogondolella regalis* (sample 1866), *Gladigondolella timorensis budurovi* (juvenile) and *Neogondolella regalis* (sample 1868) (Fig. 10). These beds also contain Anisian foraminifera: *Arenovidalina amylovoluta*, *Arenovidalina chialingchiangensis*, *Opthalmidium*? *ubeyliense* (sample 1867) and *Arenovidalina amylovoluta* (sample 1868; Fig. 9). The palaeontological data indicate an Anisian age for the limestone breccia member.

(b) The Hallstatt-type micritic limestone member (Anisian to Carnian). This includes pinkish, ammonoid-bearing pelagic limestones, which form the middle part of the Kayabaşı Formation and is *c.* 300 m thick. It is best observed on the Kayabaşı ridge east of Mermerli Stream (Fig. 6). The basal part of the Hallstatt member consists of dark grey micritic limestones. These pass upwards into Hallstatt-type pinkish, slightly nodular, micritic limestones locally with intercalations of grey medium-bedded calc-arenite. Ammonites of the Arcestidae group, characteristic of the Middle–Upper Triassic, occur in the pink limestones.

A 220 m thick section was measured in the Hallstatt member. Anisian conodonts (*Paragondolella bulgarica* and *Neogondolella regalis*, samples 1883 and 1884), the Anisian–Ladinian conodont *Neogondolella constricta* and Anisian–Ladinian foraminifera *Arenovidalina chialingchiangensis*, *Arenovidalina chialingchiangensis rhombea*, *Arenovidalina amylovoluta*, *Arenovidalina* spp., *Hoyanella* sp., *Eoophthalmidium tricki*, *Ophthalmidium* sp. and '*Nodasaria*' *skyphica* (sample 1886) occur in the basal massive grey micrites. A sample taken 20 m above sample 1886 contains Ladinian conodonts: *Gladigondolella tethydis* and *Metapolygnathus excelsa* (sample 1888). Ladinian to Carnian conodonts (*Gladigondolella tethydis*, *Metapolygnathus* Gr. *excelsus-inclinatus*, M. *inclinatus*, *M.* cf. *fueloepi* and *M. carpathicus*, sample 1889) and foraminifera (*Turriglomina mesotriasica* and *Turriglomina scandonei*, sample 1889) and Carnian foraminifera (*Gsolbergella spiriloculiformis*, *Ophthalmidium* sp., *Cucurbita* sp., *Endoteba kuepperi*, *Endoteba obturata*, *Endotebanella* sp. (sample 1890) associated with *Tubiphytes obscurus*, and *Baccanella floriformis*) were determined in the succeeding samples. A sample taken from the top part of the Hallstatt limestone member comprises Carnian conodonts: *Gladigondolella tethydis* and *Metapolygnathus polygnathiformis* (sample 1892), and *Gladigondolella malayensis* and *M. tadpole* (sample 1895). The palaeontological data indicate an Anisian to Carnian age for the Hallstatt member.

(c) The black limestone–shale member. Black limestone and interbedded shale occur in the northernmost part of the limestone ridge and constitute stratigraphically the upper member of the Kayabaşı Formation. Its contact with the Hallstatt member is not exposed in the field. The member consists of medium-bedded black limestone with abundant thin-shelled bivalve fragments intercalated with thin black shale beds. Limestone samples from this member contain Lagenid-type foraminifera and thin-shelled bivalves but no age diagnostic fossils.

The palaeontological data indicate an Anisian to Carnian age for the Kayabaşı Formation. In terms of facies and age, it can be compared with the Triassic sequence in Dobrugea (Seghedi, 2001) and to a lesser degree with the Triassic in the western part of the Istanbul Zone (Yurttaş-Özdemir, 1971; Assereto, 1972);

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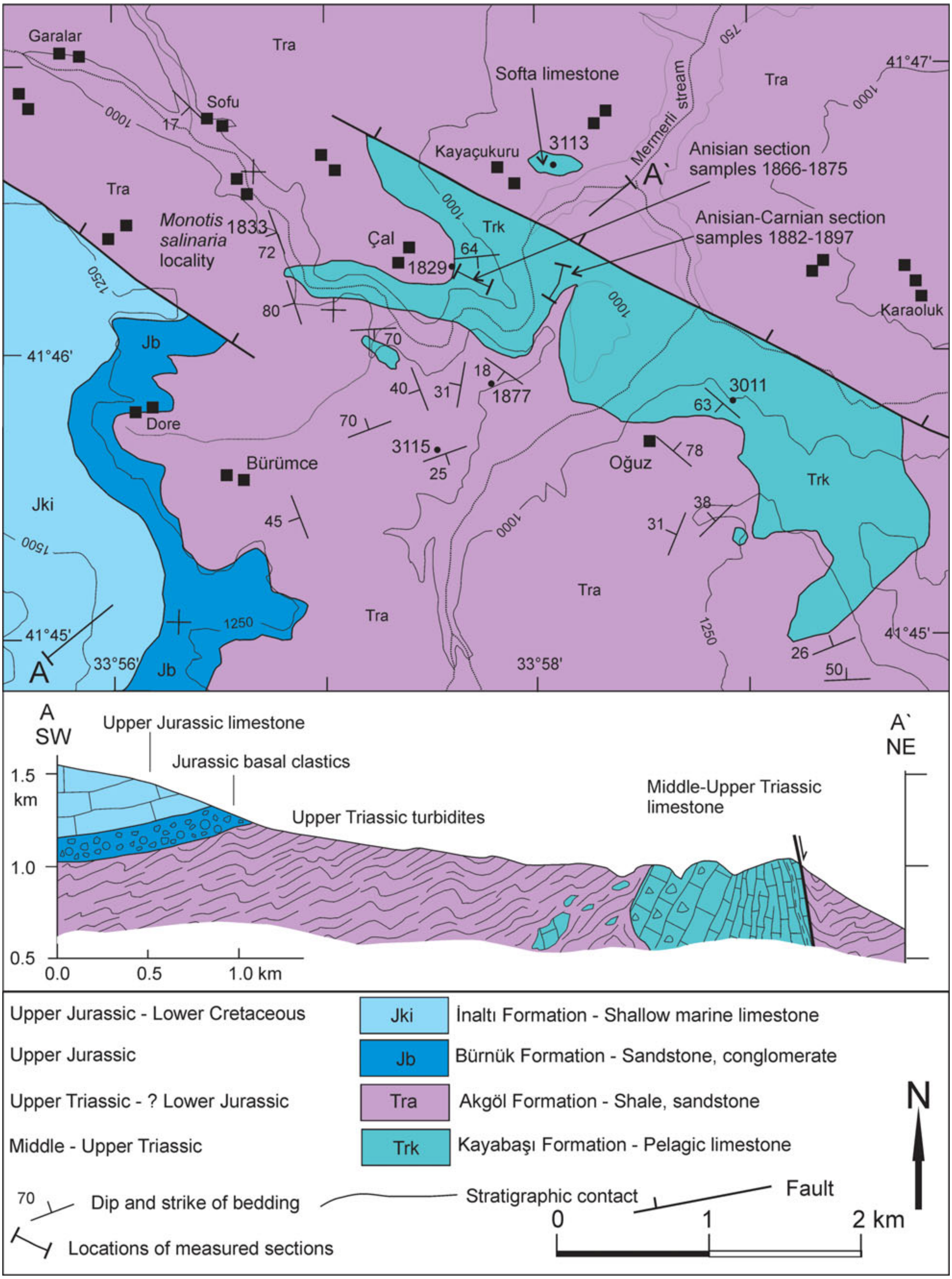

Figure 6. (Colour online) Geological map and cross-section of the Triassic limestones northeast of Devrekani. For location see Figure 3.

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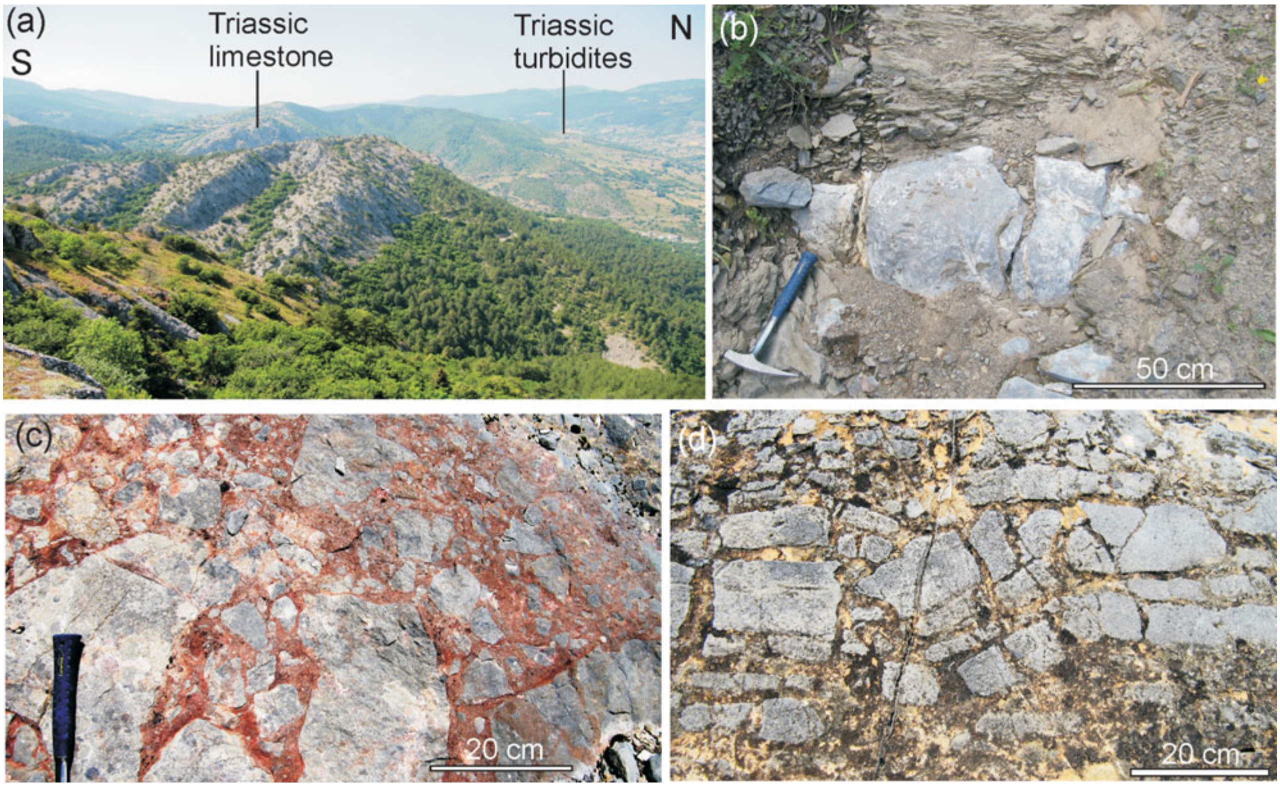

Figure 7. (Colour online) Field photographs from the Triassic limestone in the Central Pontides. (a) The Triassic limestone ridge looking towards the west. The low-lying ground on the right (north) consists of Upper Triassic turbidites. (b) Triassic limestone clast in the Upper Triassic sandstone (locality 1877). (c) Limestone breccia – micritic limestone clasts in a red sandy-carbonate matrix (locality 1870). (d) Limestone breccia. The limestone beds are boudinaged but the continuity of the bedding suggests *in situ* brecciation with minimum transport (locality 1872). For locations see Figure 6.

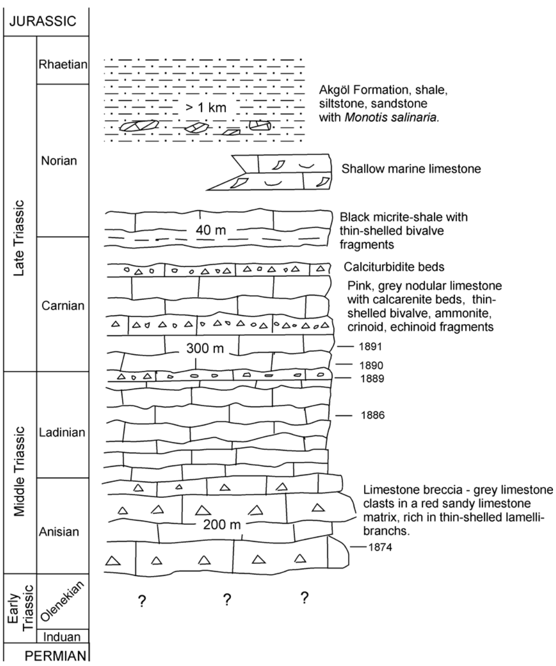

Figure 8. Composite stratigraphic section of the Kayabaşı Formation and the overlying turbidites of the Akgöl Formation. Approximate positions of some important biostratigraphic samples are indicated.

however, the conodont fauna in the Istanbul–Gebze region is quite different (Gedik, 1975; A. M. Kılıç, unpub. Ph.D. thesis, Cumhuriyet Univ., 2004).

Sandstone beds overlying the Kayabaşı Formation contain debris flow horizons with clasts of Triassic limestone (Fig. 7b). The following lower–middle Anisian foraminifera were determined in one of the limestone clasts: *Meandrospira dinarica*, *Meandrospira pusilla*, *Pilammina* sp., *Endoteba controversa*, *Planiinvoluta*? *mesotriasica* and *Trochammina almtalensis* (sample 3115E in Fig. 6). Similar Anisian limestone clasts are described by Kozur *et al.* (2000) from a debris flow in the Akgöl Formation between İnebolu and Küre.

The large limestone outcrop of the Kayabaşı Formation is surrounded by the sandstones and shales of the Akgöl Formation. This observation, the irregular contacts between these two units (Fig. 6) and the presence of Triassic limestone clasts in the surrounding sandstones (Fig. 7b) indicate that the Triassic limestone forms a large slide block in the turbidites. The *in situ* brecciation observed in the basal parts of the Kayabaşı Formation (Fig. 7d) most likely occurred during sliding of the block into the basin.

A different type of limestone block occurs in the Upper Triassic turbidites a few hundred metres north of the Kayabaşı Formation close to the village of Softa (Fig. 6; Yılmaz & Boztuğ, 1987). It consists of *c.* 20 m thick, thickly bedded to massive, bluish grey, bioclastic limestone with abundant brachiopods, lamellibranchs, coral, algae, sponge spicules, bryozoa and echinoid spine fragments, deposited probably in a

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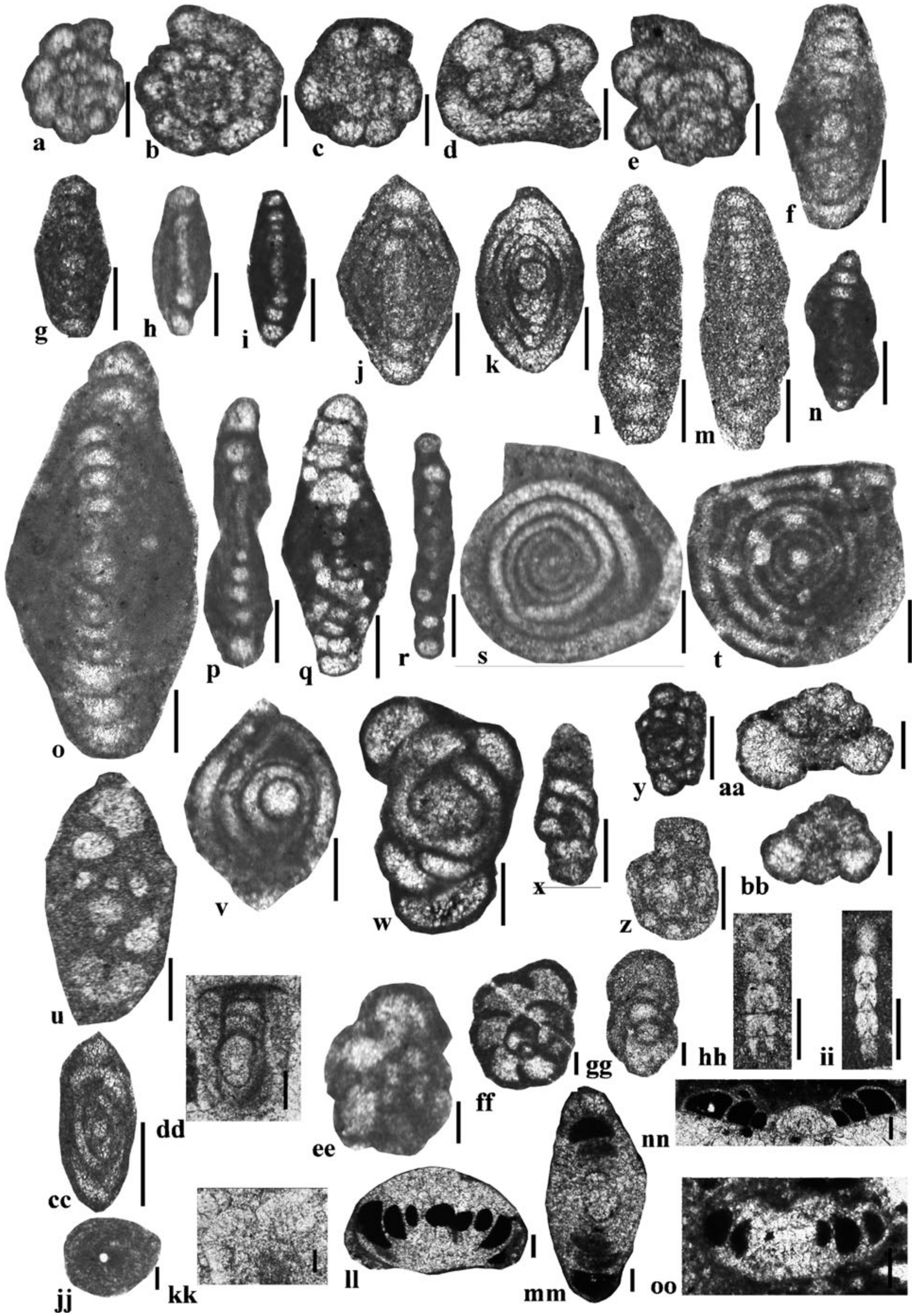

Figure 9. Photomicrographs of foraminifera from the Kayabaşı Formation. For location of the specimens see Figure 6. (a) *Meandrospira pusilla* (Ho), sample 3115E. (b, c) *Meandrospira dinarica* Kochansky-Devidé & Pantic: (b) sample 1874, (c) sample 3115E. (d, e) *Planiinvoluta*? *mesotriasica* Baud, Zaninetti & Bronnimann, sample 3115E. (f–i) *Arenovidalina chialingchiangensis* Ho: (f, g, i) sample 1886, (h) sample 3011A. (j, k) *Arenovidalina chialingchiangensis rhombea* Ho, sample 1886. (l, m)

fore-reef environment. The foraminiferal fauna include *Decapoalina schaeferae*, *Lenticulina* sp. and *Opthalmidium* sp. (Fig. 9, sample 3113-ST-2) and indicates a Norian–Rhaetian age, although some of the agglutinating forms recognized in the upper part of the block are suggestive of the lowermost Jurassic. A 20 cm large reddish limestone clast east of Çal village also contains Norian–Rhaetian foraminifera of *Aulotortus communis*, *Aulotortus* sp., *Auloconus*? sp., *Semiinvoluta* sp., *Planiinvoluta carinata*, *Caronipora* sp. and *Lenticulina* sp. (Fig. 9, sample 1829). These blocks can be compared with the uppermost Triassic limestone block described from the Karakaya Complex in NW Turkey (Okay & Altıner, 2004).

4.b. Upper Triassic – ?Lower Jurassic turbidites: the Akgöl Formation

The Akgöl Formation, which includes the Middle–Upper Triassic limestone blocks, consists of black shale intercalated with thin beds of dark siltstone and sandstone (Fig. 11a); the average shale to siltstone and sandstone ratio is 65:35, although their distribution is highly uneven with black shale making up over 90 % in some outcrops. The sandstones are generally thinly to medium-bedded, generally fine grained and of greywacke type. Graded bedding is observed in some outcrops; sole marks are rare. The sandstones are poorly sorted, and consist mainly of angular quartz, feldspar and rock clasts; the latter are dominated by andesitic and more acidic volcanic rocks. The sedimentological features indicate a distal turbidite fan. The geochemistry of the shale and sandstone suggests deposition in an active continental margin (Ustaömer & Robertson, 1994). The thickness of the flysch is difficult to determine because of strong deformation but is in excess of 2000 m. In most outcrops the Akgöl Formation shows intense deformation by shearing and folding, and has been transformed into a broken formation (Fig. 11b). The wavelength of the folding is at the metre to decimetre scale. This intense deformation is not observed in the stratigraphically overlying Upper Jurassic sequences or in the Middle Jurassic intrusive rocks and hence is constrained to latest Triassic or Early Jurassic time. The Akgöl Formation is not metamorphosed; however, the illite crystallinity indicates high diagenetic conditions (Ustaömer & Robertson, 1994).

The Akgöl Formation is intruded by Middle Jurassic (Bathonian–Callovian) dacite-porphyries and granitoids (Yılmaz & Boztuğ, 1986; Okay *et al.* 2014) and is unconformably overlain by the Upper Jurassic (Kimmeridgian) – Lower Cretaceous limestones (Fig. 11c, d), which provide an upper age limit. The lower age limit is set by the Carnian and Norian limestone blocks (Kozur *et al.* 2000; this study). Clastic zircons from a sandstone sample from the Akgöl Formation are dominated by Permian and Triassic zircons (Karslıoğlu *et al.* 2012).

The only precise palaeontological data on the age of the Akgöl Formation, with photographs and information on location, is the trace fossil *Torlessia* sp., which indicates a Late Triassic (Carnian–Norian) age (Kozur *et al.* 2000). During our study we found a siltstone bed in the Akgöl Formation (location 1833 in Fig. 6, UTM coordinates 36T 0578661–4625270) containing thin-shelled bivalves identified as *Monotis salinaria* (Fig. 11e, identification by Leopold Krystyn), characteristic of the Norian (e.g. McRoberts, 2010). This constitutes the first precise fossil identification from the Akgöl Formation. The same bivalve species also occurs in the Tauric series in Crimea (Fig. 11f). In summary, the palaeontological data indicate a Late Triassic (Norian) age for the Akgöl Formation; its age may go into the Early Jurassic, as generally accepted for the Tauric flysch in Crimea.

4.c. Upper Triassic dismembered ophiolite

Associated with the turbidites of the Akgöl Formation there are thick sequences of basaltic pillow lavas and pillow breccias (Fig. 12; Bailey, Barnes & Hupfer, 1967; Ustaömer & Robertson, 1994). The basalts are tholeiitic and mostly of mid-ocean ridge (MORB) type with some analyses falling in the island-arc tholeiite field (Ustaömer & Robertson, 1994). Most of the contacts between the basalt and turbidite are represented by faults; however, at a few localities basaltic pillow lavas and pillow breccias are overlain stratigraphically by black shales of the Akgöl Formation (Fig. 11g), as also observed by Bailey, Barnes & Hupfer (1967) and Ustaömer & Robertson (1994). The ancient Küre copper mine with chalcopyrite and pyrite as the main ore minerals is located along the contact between the basalt and black shale (Fig. 11h); the mineralization has developed mainly in the basalt (Bailey, Barnes & Hupfer,

Arenovidalina amylovoluta Ho, sample 1867; (n–p) *Arenovidalina* spp.: (n, o) sample 1886, (p) sample 3011A. (q) *Arenovidalina* sp. or *Eoophthalmidium* sp., sample 1886. (r) *Ophthalmidium*? *ubeyliense* Dağer, sample 3011A. (s, t) *Eoophthalmidium tricki* Langer: (s) sample 3011A, (t) sample 1886. (u) *Decapoalina schaeferae* (Zaninetti, Altıner, Dağer & Ducret), sample 3113-ST-2. (v) *Ophthalmidium* sp., sample 1886. (w) *Hoyenella* sp., sample 1886. (x) *Turriglomina mesotriasica* (Koehn-Zaninetti), sample 1890. (y) *Turriglomina mesotriasica* (Koehn-Zaninetti) form B?, sample 1889. (z) *Turriglomina scandonei* Zaninetti, Ciarapica, Martini, Salvini-Bonnard & Rettori, sample 1889. (aa, bb) *Trochammina almtalensis* Koehn-Zaninetti: (aa) sample 1869, (bb) sample 3115E. (cc) *Gsolbergella spiriloculiformis* (Oraveczne Scheffer), sample 1890. (dd) *Cucurbita* sp., sample 1890. (ee) *Endoteba controversa* Vachard & Razgallah, sample 3115E. (ff, gg) *Endoteba kuepperi* (Oberhauser), sample 1890. (hh) '*Nodosaria*' *elabugae* Cherdyntsev, sample 1874. (ii) '*Nodosaria*' *skyphica* Efimova, sample 1886. (jj) *Tubiphytes obscurus* Maslov, sample 1890. (kk) *Baccanella floriformis* Pantic, sample 1890. (ll) *Auloconus* ? sp., sample 1829B. (mm) *Aulotortus communis* (Kristan), sample 1829B. (nn) *Planiinvoluta carinata* Leischner, sample 1829A. (oo) *Semiinvoluta* sp., sample 1829B. Scale bars equal 100 μm.

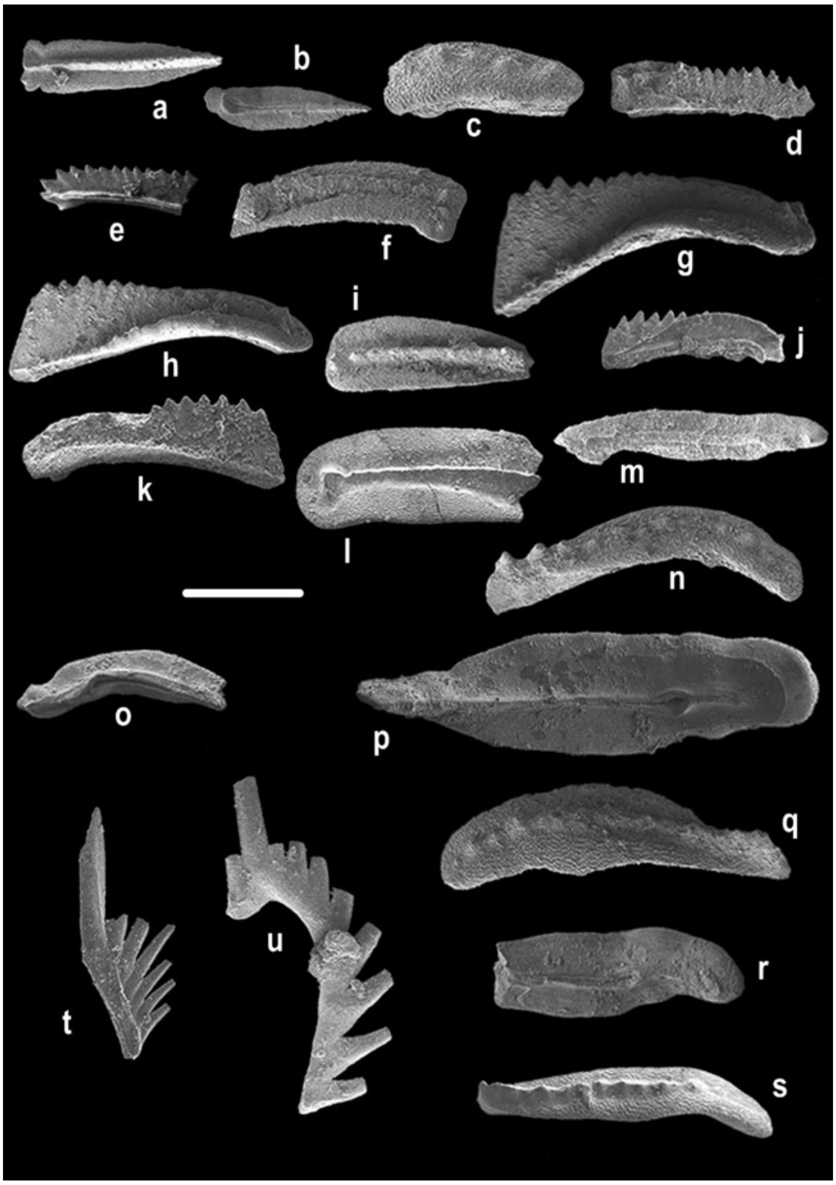

Figure 10. Electron microscope images of conodonts from the Kayabaşı Formation. For location of the specimens see Figure 6. (a, b) *Neogondolella constricta*, Mosher & Clark; middle–upper Illyrian – lower Fassanian (upper Anisian – lower Ladinian): (a) upper view; adult specimen shows constriction near posterior end and probable slight bifid basal cavity, sample 1897; (b) lower view; younger specimen, small loop-like pit, sample 1897. (c) *Gladigondolella malayensis,* Nogami; Julian (Carnian); sample 1895. (d) *Metapolygnathus tadpole* (Hayashi); Cordevolian – lower Tuvalian (Carnian); angular view, sample 1895. (e) *Neogondolella regalis* (Mosher); middle Aegean – Bithynian (Anisian); sample 1868. (f) *Metapolygnathus inclinatus* (Kovarcs); Julian (Carnian); sample 1895. (g–i) *Metapolygnathus* cf. *fuelopi*; Ladinian; sample 1889. (j) *M.* Gr. *inclinatus*; Julian (Carnian); sample 1894. (k, l) *Metapolygnathus* Gr. *excelsus-inclinatus*; Late Ladinian – Early Carnian; sample 1889. (m–u) *Gladigondolella tethydis*; Middle Triassic: (m–s) P element, (t) S1, (u) M element; (m, n) sample 1892, (o–u) sample 1889. Scale bar equals 500 µm

1967). Apart from the basalt, there are a few hundred-metre-sized bodies of gabbro and plagioclase-lherzolite within the basalts. The plagioclase-lherzolites consist mainly of olivine, plagioclase and clinopyroxene (Çakır, Genç & Paktunç, 2006) and are probably cumulate bodies.

Serpentinite occurs as large slices in the turbidites of the Akgöl Formation. Because of its significance as a possible mantle rock, the serpentinite was mapped in detail (Fig. 12). It occurs as up to 4 km long tectonic slices surrounded by shale and sandstone of the Akgöl Formation, and consists of completely serpentinized massive harzburgite. The lack of serpentinite clasts or debris flows in the surrounding sandstone–shale sequence indicates that the serpentinite was emplaced tectonically.

The age of the serpentinite is critical for the tectonic interpretation of the Akgöl Formation. Cretaceous ophiolitic melange with serpentinite slivers occurs 40 km south of the serpentinite outcrop (Fig. 3), and the serpentinite could have been emplaced any time after the Late Triassic and possibly during Cretaceous time. The serpentinite and the turbidites of the Akgöl Formation are intruded by the Karaman granitoid, which forms an intrusive body measuring 5 km by 5 km (Fig. 12). It is part of a series of

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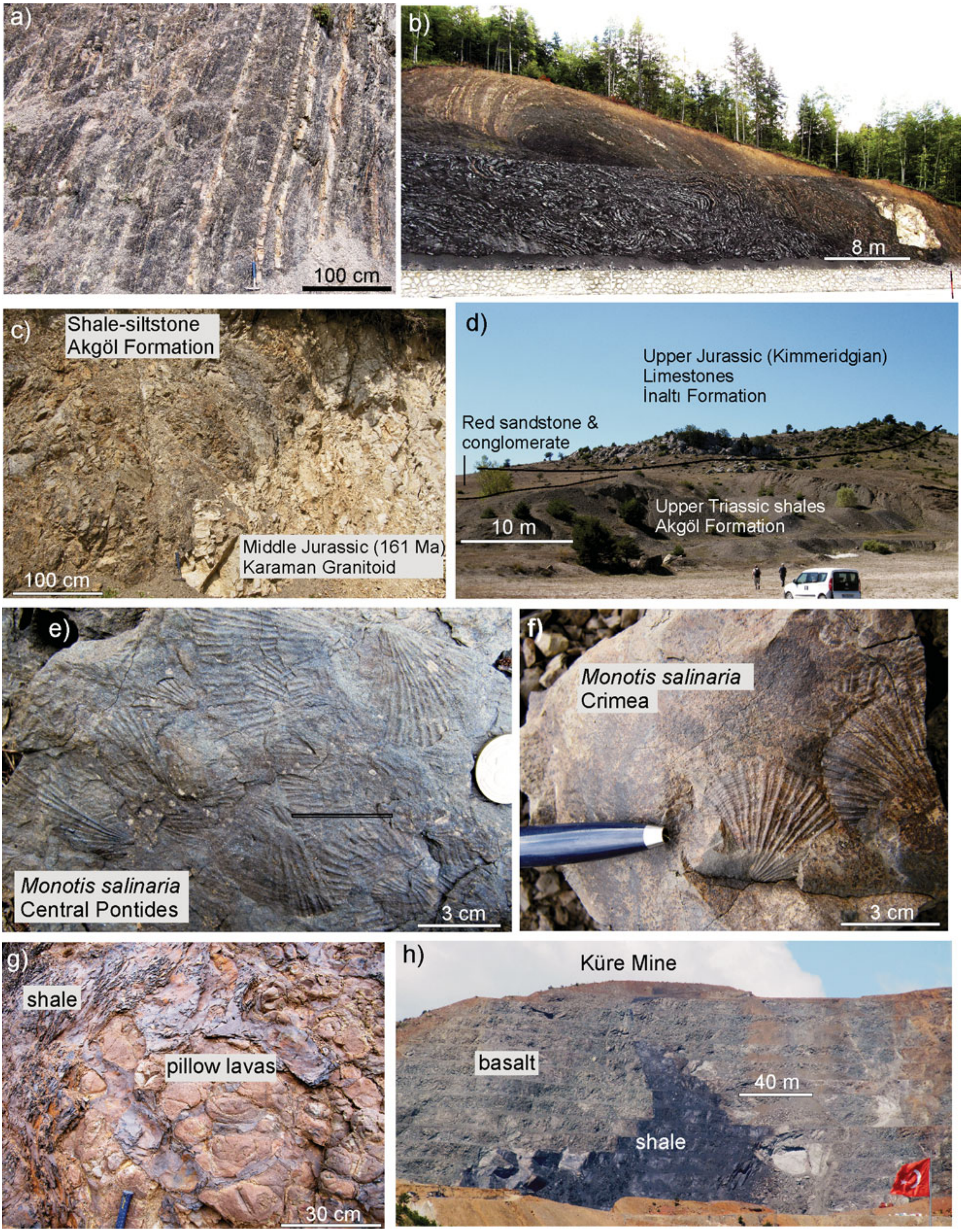

Figure 11. (Colour online) Field photographs from the Triassic Küre Complex. (a) Distal turbidites of the Upper Triassic Akgöl Formation. (b) Sheared and folded turbidites of the Akgöl Formation; the light coloured block on the right is a sandstone boudin. (c) The Akgöl Formation intruded by the Middle Jurassic Karaman Granitoid. (d) Black shales of the Akgöl Formation overlain unconformably by the fluviatile red sandstone and conglomerate and by the shallow marine limestones of the Upper Jurassic (Kimmeridgian) İnaltı Formation. (e, f) The Late Triassic (Norian) bivalve *Monotis salinaria* in the siltstones of the Akgöl Formation in the Central Pontides (sample 1833) (e) and in the Tauric flysch in Crimea (location 54, Table S2 in the online Supplementary Material available at http://journals.cambridge.org/geo) (f). (g) Basaltic pillow lavas overlain stratigraphically by the black shales of the Akgöl Formation. (h) Black shale and basalt in the Küre mine; the chalcopyrite mineralization occurs in the shales along the contact. The height of the mine face is approximately 70 m.

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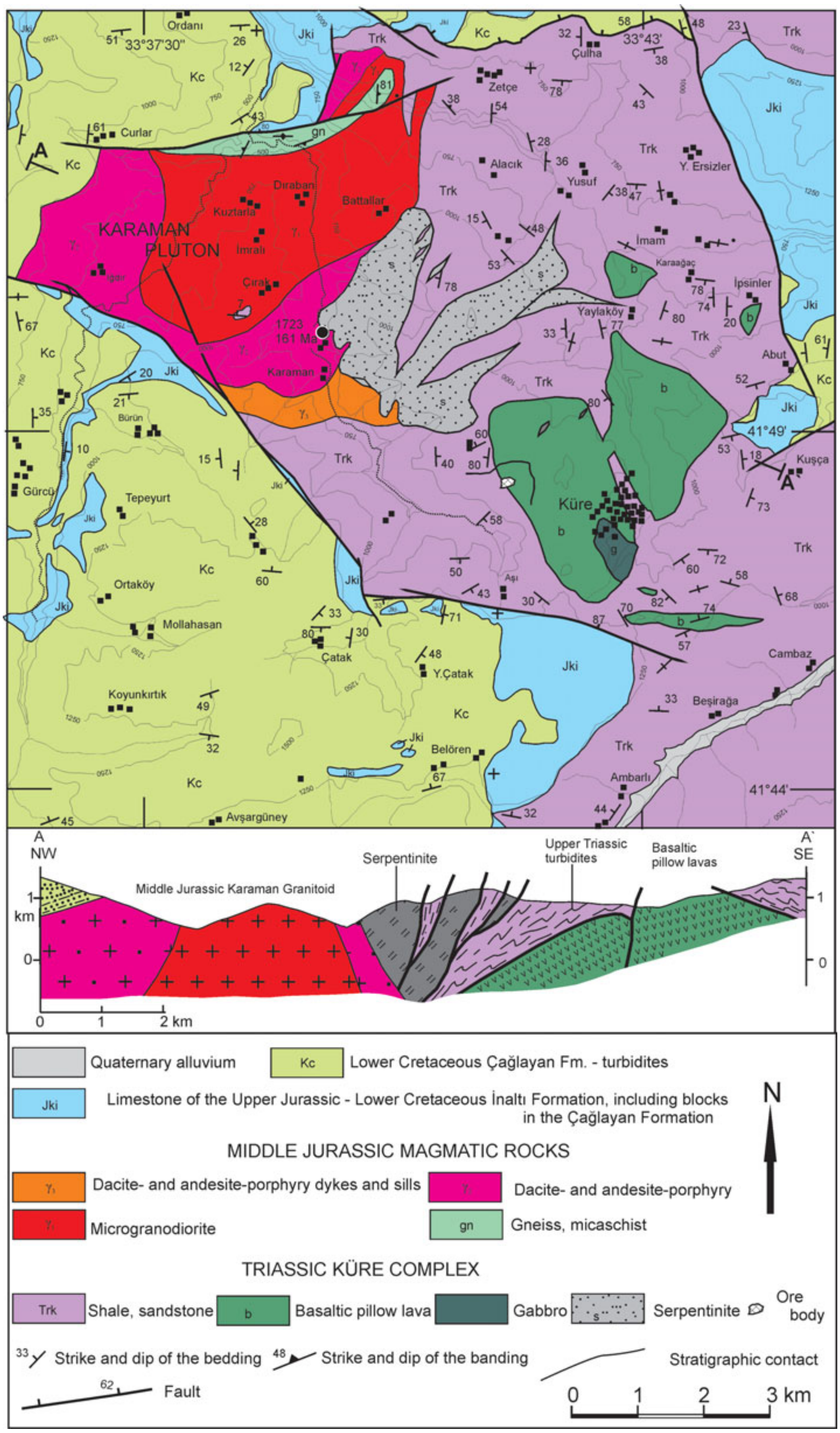

Figure 12. (Colour online) Geological map and cross-section of the Küre region based on Bailey, Barnes & Hupfer (1967), O. Tüysüz *et al.* (unpub. report, 2000), Okay *et al.* (2014) and this study. For location see Figure 3.

Middle Jurassic intrusions emplaced along a major magmatic arc (Yılmaz & Boztuğ, 1986; Okay *et al.* 2014). The Karaman intrusion has a zonal structure with a core of medium-grained microgranodiorite to microdiorite surrounded by dacite-porphyry. The microgranodiorite, which makes up the bulk of the intrusion, has the mineral assemblage of plagioclase + biotite + quartz ± hornblende ± cordierite (Okay *et al.* 2014). The marginal dacite-porphyry consists of plagioclase, biotite and quartz and locally hornblende phenocrysts in a fine-grained matrix of the same minerals. To constrain the age of the

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serpentinite, we dated ten biotite grains from a dacite-porphyry sample (1723), which gave a coherent age of 162 ± 4 Ma (Table 2; Okay *et al.* 2014). This shows that the serpentinite was emplaced prior to Middle Jurassic time. Considering the association of serpentinite with the Upper Triassic turbidites and pillow lavas, a Triassic age is likely for the serpentinite. The serpentinite, gabbro and basalt most probably constitute a dismembered ophiolite on which the Upper Triassic to ?Lower Jurassic turbidites of the Akgöl Formation were deposited (Ustaömer & Robertson, 1994).

5. Comparison with the Tauric Flysch in Crimea

Upper Triassic turbidites in the Central Pontides and those in Crimea share several common features. (1) In both regions the Upper Triassic sequence consists predominantly of distal siliciclastic turbidites, with a dominance of black shales. (2) At least part of the turbidite sequence is of Late Triassic (Norian) age based on the macrofauna. *Monotis salinaria*, a bivalve characteristic for the Norian, is found both in the Crimea and Central Pontides (Fig. 11e, f). The turbidite sequence in Crimea is thought to extend into the Lower Jurassic. (3) Clastic zircon populations from both regions are similar (Karslıoğlu *et al.* 2012; A. Nikishin pers. comm.) with a dominance of Triassic and Permo-Carboniferous zircons. (4) The turbidites in the Crimea and Central Pontides have undergone a strong contractional deformation during latest Triassic – Early Jurassic time. (5) They are intruded or overlain by Middle Jurassic magmatic rocks. Upper Jurassic shallow marine carbonates lie also unconformably over the Triassic flysch. These features indicate that prior to the Late Cretaceous opening of the Black Sea as a back-arc basin (e.g. Okay, Şengör & Görür, 1994), the Upper Triassic turbidites in Crimea and in the Central Pontides were contiguous and were deposited in the same basin.

6. Discussion

6.a. Late Triassic fore-arc basin on the southern active margin of Laurasia

The pre-Permian basement in the Central Pontides consists of a low-grade metasedimentary sequence of interbedded sandstone and shale. The flyschoid character of the sequence and the presence of pre-Permian serpentinite slivers suggest deposition on a Palaeozoic active margin. The Palaeozoic metasedimentary rocks are intruded by the Late Carboniferous and Early Permian granitoids. A Variscan granitoidic basement in the Central Pontides is also reflected in the high percentage of Permian and Carboniferous zircons in the Triassic (Karslıoğlu *et al.* 2012) and Lower Cretaceous turbidites (Okay *et al.* 2013). This crystalline basement was probably overlain by Triassic carbonates, represented by the Kayabaşı Formation in the Central Pontides. However, absence of Triassic carbonates along the contacts between the late Variscan basement and the Upper Triassic turbidites (Fig. 3) suggests a period of uplift and deformation during Carnian time. The buried Late Triassic volcanic arc in the Scythian Platform in the north (Fig. 1; Tikhomirov, Chalot-Prat & Nazarevich, 2004) and Upper Triassic eclogites and blueschists in the southwest (Okay & Monié, 1997; Okay, Monod & Monié, 2002) suggest that the Upper Triassic turbidites were deposited in a fore-arc basin on the southern margin of Laurasia (Fig. 13a, b). In the north the fore-arc basin rested on continental crust and in the south on oceanic crust, similar to the Great Valley Group in California (e.g. Ingersoll, 1979).

Disrupted Upper Triassic clastic sequences are widespread in the Sakarya Zone in NW Turkey, where they are known as the Upper Karakaya Complex (Fig. 1; Okay & Göncüoğlu, 2004). They contain olistoliths of Middle Triassic, as well as Permian and Carboniferous limestones in an Upper Triassic clastic matrix (Kaya, 1991; Wiedmann, Kozur, & Kaya, 1992; Leven & Okay, 1996; Altıner, Özkan-Altıner & Koçyığıt, 2000). Within the Upper Triassic clastic sequences there are also rare blocks of Permian, Carboniferous and Devonian radiolarian cherts (Okay & Mostler, 1994; Kozur & Kaya, 1994; Göncüoğlu *et al.* 2004; Okay, Noble & Tekin, 2011). The Upper Karakaya Complex shares several common features with the Akgöl Formation of the Central Pontides, including tectonic setting, lithology and age, and was most probably deposited in same fore-arc on the southern margin of Laurasia. The Tauric flysch in Crimea and the Dizi Series in the Caucasus likely formed part of the same basinal deposits.

The Küre basin is commonly described as a back-arc basin (e.g. Ustaömer & Robertson, 1993, 1994; Barrier & Vrielynck, 2008; Nikishin *et al.* 2012); this was based on the presence of 'Permo-Triassic' subduction–accretion complexes (Domuzdağı and Elekdağ complexes) and a Permo-Triassic magmatic arc (Çangaldağ Complex) south of the Küre Complex (Fig. 3). However, recent work has shown that the Domuzdağı and Elekdağ complexes are Early Cretaceous and the Çangaldağ Complex Middle Jurassic in age (Okay *et al.* 2006, 2013, 2014), and there is no Triassic or older unit between the Küre Complex and the İzmir–Ankara suture. Thus, during Triassic time the Küre basin was directly facing the Tethyan ocean in the south (Fig. 13).

6.b. Latest Triassic deformation and the Cimmeride orogeny

A transition from carbonate to clastic deposition is observed in Late Triassic time throughout the circum-Black Sea region, including in the western part of the Istanbul Zone (Yurttaş-Özdemir, 1971; Gedik, 1975), in Dobrugea (Seghedi, 2001) and in the Balkans (Tari *et al.* 1997). In latest Triassic and/or earliest Jurassic time, this clastic basin was inverted, and the circum-Black Sea region, including the Greater Caucasus and the Scythian Platform, was uplifted and eroded (e.g.

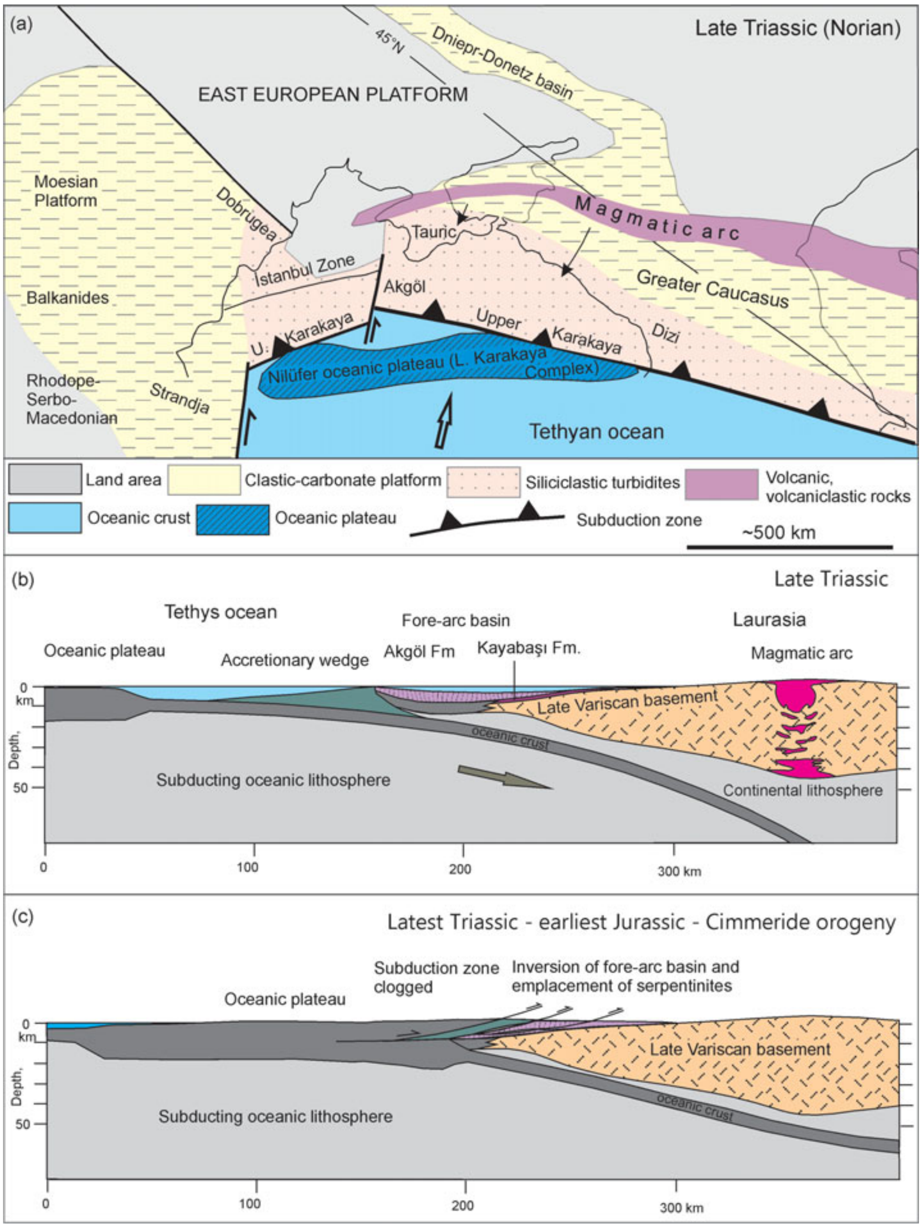

Figure 13. (Colour online) Palaeogeographic map and cross-sections for the Late Triassic to Early Jurassic showing the palaeogeographic location and evolution of the tectonic units discussed in the text (based on Hamilton, 1988; Barrier & Vrielynck, 2008; Nikishin *et al.* 2012).

Gaetani *et al.* 2005; Nikishin *et al.* 2012). In the Central Pontides this was associated with the emplacement of serpentinites, and in NW Turkey that of the uppermost Triassic eclogites and blueschists. The Cimmeride deformation was short lived; the unconformable sedimentary cover over the Cimmeride units is Early Jurassic (Sinemurian) in age in NW Turkey (Altıner *et al.* 1991). In the Central Pontides, the deformed Upper Triassic turbidites and the serpentinite are cut by undeformed Middle Jurassic (Bathonian–Callovian) acidic intrusions.

The Late Triassic deformation in the circum-Black Sea region was ascribed to the collision of a Cimmeride continent or continental blocks (e.g. Şengör, 1984). However, Triassic, Jurassic and Cretaceous accretionary complexes in the Pontides are directly juxtaposed without any intervening continental crustal material (Okay, 2000; Çelik *et al.* 2011; Topuz *et al.* 2013, in press). Furthermore, the brief period of deformation, constrained to *c.* 10 Ma in the latest Triassic – earliest Jurassic (Rhaetian–Hettangian), makes a continent–continent collision an unlikely cause for the Cimmeride orogeny.

During Late Triassic time, large thicknesses of mafic crustal material were accreted to the southern margin of Laurasia. These are known in the Sakarya Zone as the Lower Karakaya Complex or the Nilüfer Unit (Okay, 2000; Okay & Göncüoğlu, 2004; Pickett & Robertson, 2004; Robertson & Ustaömer, 2012). The Lower Karakaya Complex shows metamorphism mainly to greenschist facies but also includes uppermost Triassic eclogites and blueschists (Okay & Monié,

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1997; Okay, Monod & Monié, 2002). The geochemistry of the metabasites in the Lower Karakaya Complex shows within-plate characteristics; this is interpreted as formation in oceanic islands or in an oceanic plateau in Permo-Triassic time (Okay, 2000; Genç, 2004; Pickett & Roberson, 2004; Sayit & Göncüoğlu, 2013; Catlos, Hubert & Shin, 2013). We suggest that the incipient collision of this oceanic edifice in Late Triassic time caused uplift along the Laurasian margin resulting in clastic sedimentation in the fore-arc region (Fig. 13c). This was followed by collision and accretion, which resulted in the inversion and deformation of the fore-arc basin.

7. Conclusions

(1) In the northern Central Pontides there is a pre-Permian basement of low-grade metasedimentary rocks with pre-Permian serpentinite lenses and intrusive Late Permian and Early Carboniferous granitoids (Figs 3, 4). The basement is overlain by the Upper Triassic turbidites. Similar basement rocks should be present under Crimea and under the Scythian Platform.

(2) In the Central Pontides a 550 m thick sequence of hemi-pelagic to pelagic Hallstatt-type limestone occurs as a large olistolith in the Upper Triassic turbidites. Conodonts and foraminifera indicate that the limestone sequence is Anisian to Carnian in age. The surrounding turbidites contain the bivalve *Monotis salinaria*, which indicates a Late Triassic (Norian) age for the clastic sequence. The same fossil is also described from the Tauric flysch in Crimea.

(3) The Upper Triassic turbidites are locally underlain by basaltic pillow lavas and contain kilometre-sized tectonic slices of serpentinite. The turbidites and the serpentinite are intruded by Middle Jurassic age (162 Ma) granitoids (Fig. 12), showing that the serpentinite is pre-Middle Jurassic in age. The Upper Triassic turbidites are deposited in a fore-arc basin above a northward-dipping subduction zone (Fig. 13). The Triassic magmatic arc is located subsurface in the Scythian Platform north of the Black Sea (Fig. 1).

(4) The Upper Triassic turbidites are strongly deformed by folding, faulting and shearing. This deformation is not observed in the Middle Jurassic magmatic rocks or in the overlying Upper Jurassic conglomerates and limestones, indicating that the deformation is of latest Triassic and/or Early Jurassic age.

(5) Data from the Central Pontides and regional geological constraints indicate that the latest Triassic to Early Jurassic Cimmeride deformation is related to accretion of large oceanic edifices to the southern margin of Laurasia rather than to a collision with a Cimmerian continent.

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Supplementary material

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