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Late Permian (Tatarian) fluvio-lacustrine successions in NW Anatolia (Zonguldak Terrane, Turkey): palaeogeographic implications

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Abstract – Late Permian fluvio-lacustrine successions of the Çakraz Formation in the Zonguldak Terrane between the regions of Akçakoca and Ereğli were investigated in order to describe the litho- and biostratigraphic properties and explain the depositional environment. The studied succession with black, dark-grey to greenish-grey shales, siltstones and limestones is named the Alaplı Member to distinguish it from the classical red clastic successions, which are tentatively named the Ereğli Member of the Çakraz Formation. The organic-rich black shales, mudstones and limestones of the Alaplı Member yielded palynological assemblages suggesting a Lopingian (Tatarian) age. The lack of any marine macro- or microfossils, the fine-grained character of the lithofacies with abundant plant material and the association of poorly sorted conglomerates in the middle part of the succession indicate possible deposition in a broad range of fluvial and lacustrine environments. Successions of similar age and depositional environment are known from the East European Variscan Belt in Bulgaria and Romania. Common successions were also developed in actively extending shallow-marine platforms on the NW Palaeotethyan margin at the end of the Permian Period.

Keywords: Permian, Lopingian, Tatarian, pollen, Zonguldak Terrane, Turkey.

1. Introduction

The formation of the Variscan Belt in Europe occurred as a result of the closure of the Rheic Ocean. In western and central Europe, the rock units of the Variscan Belt (Variscan Terrane assemblage/Variscan successions) and their stratigraphic properties have been studied in detail (Martinez Catalan *et al.* 2004; Mazur *et al.* 2006; Seghedi, 2012). The coeval occurrences of Variscan successions towards eastern Europe can be followed in the Balkan (Yanev, 1993, 1997, 2000) and Moesian and Caucasian (Yanev & Adamia, 2010) terranes (Fig. 1). In NW Anatolia, the Ordovician–Carboniferous Variscan successions on both sides of Bosphorus have been known as the 'Palaeozoic of İstanbul' since the mid-nineteenth century (Verneuil, 1836–1837; Strickland, 1840; Tchihatcheff, 1854), also known as the İstanbul zone (Şengör, Yılmaz & Sungurlu, 1984). This tectonic unit (Fig. 2a) was described in the sense of Howell (1989) as a Variscan Terrane by Göncüoğlu, Dirik & Kozlu (1997). Later, Göncüoğlu & Kozur (1998), Göncüoğlu & Kozlu (2000) and Yanev *et al.* (2006) suggested that the northwestern Black Sea region including NW Anatolia actually comprises a terrane assemblage consisting of two different Gondwana-derived microplates. The İstanbul Terrane (IT) in the west covers İstanbul, Gebze and South Çamdağ areas and the Zonguldak Terrane (ZT) is located (Fig. 2b) in Çamdağ, Zonguldak and Safranbolu areas in the east and NE (e.g. Göncüoğlu, 2010). The differences in lithostratigraphy, structural and metamorphic features and palaeobiogeography of these terranes was discussed in earlier studies in considerable detail (Göncüoğlu & Kozur, 1998; Göncüoğlu & Kozlu, 2000; Kozur & Göncüoğlu, 2000; Dojen *et al.* 2004; Yanev *et al.* 2006; Bozkaya, Yalçin & Göncüoğlu, 2012*a*, *b*; Sachanski *et al.* 2012; Okuyucu, Vachard & Göncüoğlu, 2013). In contrast to the detailed evaluation of the Ordovician – lower Carboniferous marine deposition in the IT and ZT, our knowledge of the stratigraphy, ages and depositional environment of the Permian – Lower Triassic overstep sequences are very scarce. These overstep sequences mainly comprise red continental clastics with a few volcanic inlayers, named the Çakraz Formation in NW Anatolia (Akyol *et al.* 1974).

Recently, we discovered (Göncüoğlu, Okuyucu & Dimitrova, 2011) dark-coloured fluvio-lacustrine deposits of Tatarian age in the Ereğli area (Fig. 1), which were erroneously taken for Silurian black

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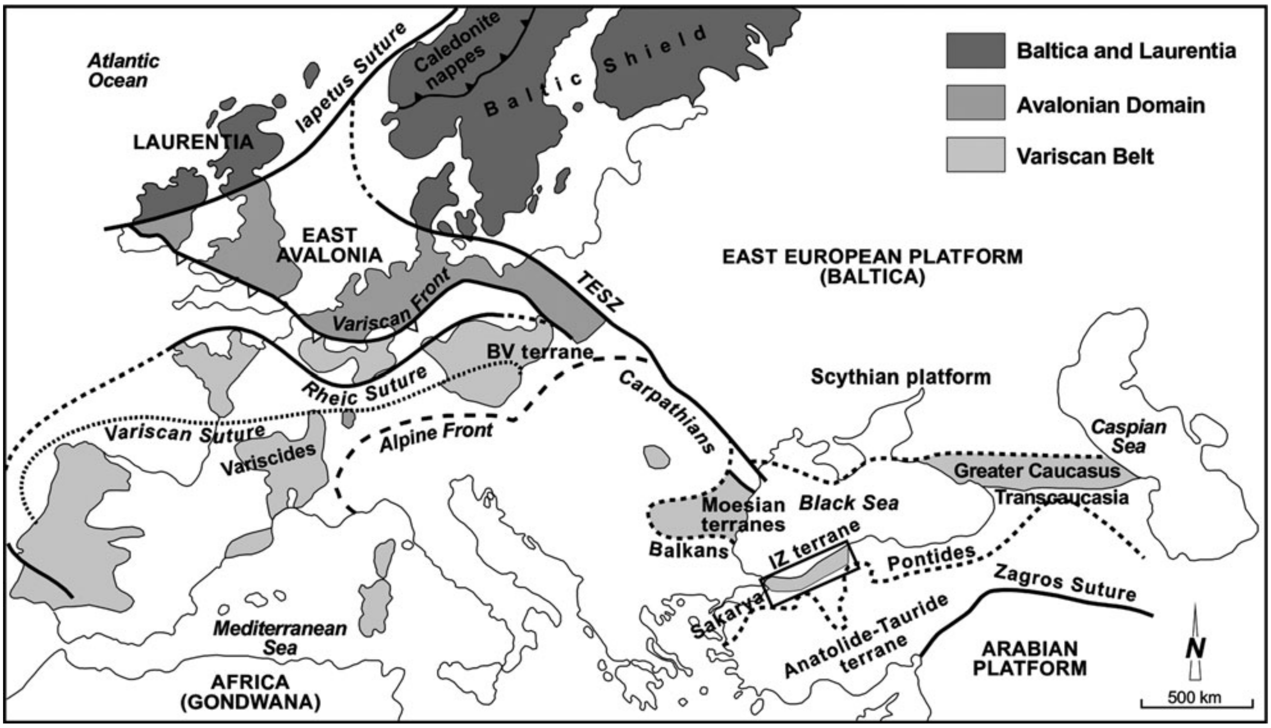

Figure 1. Position of the İstanbul and Zonguldak terranes within the Western and Central European Variscan Belt (IT – İstanbul Terrane; ZT – Zonguldak Terrane) (Bozkaya, Yalçin & Göncüoğlu, 2012*b*).

shales in previous studies (e.g. Timur & Aksay, 2002).

The aim of this study is to describe the litho- and biostratigraphic properties of this recently discovered Tatarian chronostratigraphic unit of Çakraz Formation from the Ereğli area, and to discuss and correlate this succession and its biostratigraphic features with the coeval occurrences in IT and the other Laurasian margin successions. We have attempted to explain the depositional environment of this succession while considering the results of recent biostratigraphic studies (e.g. Alişan & Derman, 1995; Dimitrova & Stolle, 2010; Stolle, 2011, 2014; Gand *et al.* 2011) carried out on this formation in the region.

2. Geological framework

In NW Anatolia the Çakraz Formation occurs as discontinuous outcrops from the İstanbul-Gebze to Kastamonu-Inebolu areas (Fig. 1). The type locality is the Çakraz village to the east of Amasra (Akyol *et al.* 1974; Tüysüz, Aksay & Yiğitbaş, 2004) in the ZT. The ZT and IT share the same late Neoproterozoic (Cadomian) basement. In both terranes Ordovician siliciclastics disconformably overlie this Cadomian basement. The oldest sediments dated by fossils are the early – early late Tremadocian black shales (Göncüoğlu *et al.* 2014) in the ZT. The Early Devonian unconformity above the middle Silurian very-low-grade metamorphic black shales (Bozkaya, Yalçin & Göncüoğlu, 2012*a*, *b*), a well-developed Emsian–Visean carbonate platform succession (Fig. 3) and the Namurian coal-bearing fluvial sediments are the distinguishing features of the ZT. The Çakraz Formation unconformably overlies the Namurian flysch-type deposits in IT (e.g. Özgül, 2012). In the ZT it overlies the Stephanian fluvial sediments (e.g. Kerey, 1984).

The lower part of the Çakraz Formation is dominated by poorly sorted red to violet conglomerates, whereas the upper part is characterized by cross-bedded red sandstones with alternations of conglomeratic sandstones (Güvenç *et al.* 1994; Alişan & Derman, 1995). The thickness of the formation varies over the range 1000–3500 m in the Upper Sakarya valley. Upwards, the Çakraz Formation grades into a light-coloured succession with lacustrine marls and mudstones that are attributed to the Çakrazboz Formation of Late Triassic age (Alişan & Derman, 1995).

Field work undertaken in the area between the Ereğli and Alaplı (Fig. 4) and palynological samples collected in 2004 and 2010 have revealed for the first time the presence of a >1000 m thick succession with black, dark-grey to greenish-grey shales, siltstones and limestones to the south of Alaplı (Fig. 4). This lithostratigraphic unit is named the Alaplı Member of the Çakraz Formation (Göncüoğlu, Okuyucu & Dimitrova, 2011) and will be evaluated in detail. To distinguish the red clastic successions of the Çakraz Formation from the newly discovered fluvio-lacustrine unit, we tentatively named the classical red fluvial succession the Ereğli Member of the Çakraz Formation.

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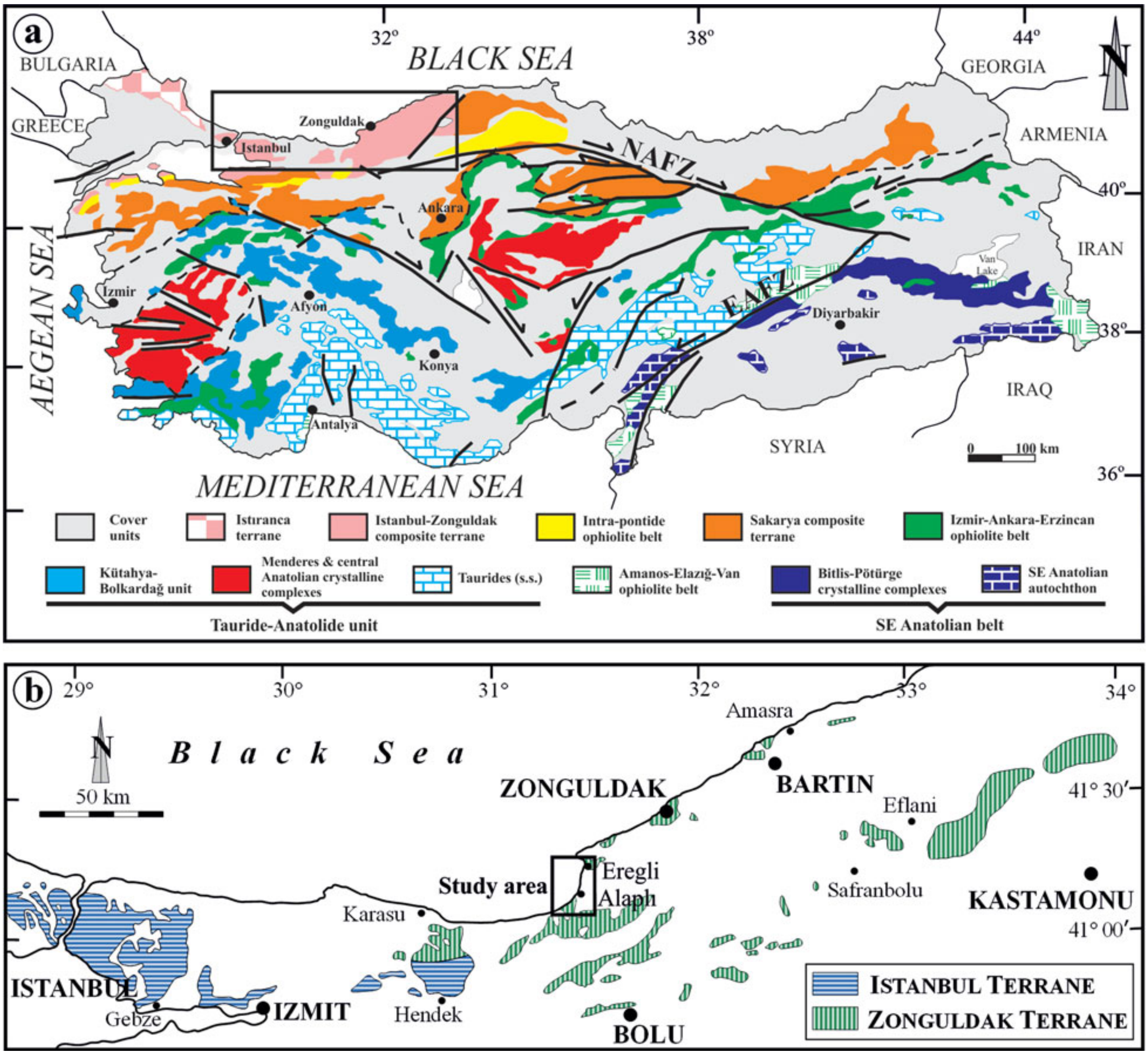

Figure 2. (Colour online) (a) The main tectonic units of Turkey and the position of the İstanbul and Zonguldak terranes (Göncüoğlu, Dirik & Kozlu, 1997). NAFZ – North Anatolian Fault Zone; EAFZ – East Anatolian Fault Zone. (b) The distribution of the Palaeozoic outcrops in the İstanbul and Zonguldak terranes (modified from Bozkaya, Yalçin & Göncüoğlu, 2012*b*).

3. The Alaplı Member of the Çakraz Formation

3.a. Lithostratigraphy

The recently determined succession of the Alaplı Member in Ereğli region and its conformable upper contact to the main body of Çakraz Formation (Ereğli Member) was not described or included in previous studies (e.g. Yazman & Çokuğraş, 1983; Altun & Aksay, 2002). Moreover, the Alaplı Member was considered as the equivalent of the upper Silurian black shales and Lower Devonian black limestones of the Yılanlı Formation.

In Ereğli area the Alaplı Member rests directly on the pre-Permian basement (Fig. 5). Locally, the contact is faulted. The lowermost part of the Alaplı Member includes an alternation of thin- to medium-bedded greenish-grey siltstones and sandstones with thin black mudstones, very rich in plant remains (Figs 5, 6a, b). The overlying part of the unit comprises thin-bedded violet and green laminated mudstone and green shale alternation at base and thin- to medium-bedded dark grey-black limestone with green-grey shale and siltstone interlayers at the top. The middle part of the member is represented by thin- to medium-bedded dark-grey grey-red-violet conglomerates with thin-bedded limestone, dolomitic limestone and shale interlayers (Fig. 6c, d). The black shales and limestones in this part are rich in organic matter and include miospore assemblages but lack any macrofossils (Fig. 6e, f). The pebbles of the conglomerates are mainly from the Kurtköy (Ordovician), Fındıklı (Silurian) and fossiliferous Upper Devonian – lower Carboniferous limestones of the Yılanlı formations (Fig. 6c, d). The conglomerates continue upwards as thin- to medium-bedded dark grey-black limestone with green-grey shale alternations. The uppermost part of the Alaplı Member is represented by thin-bedded black shale with siltstone interlayers. The black shales are very rich in organic

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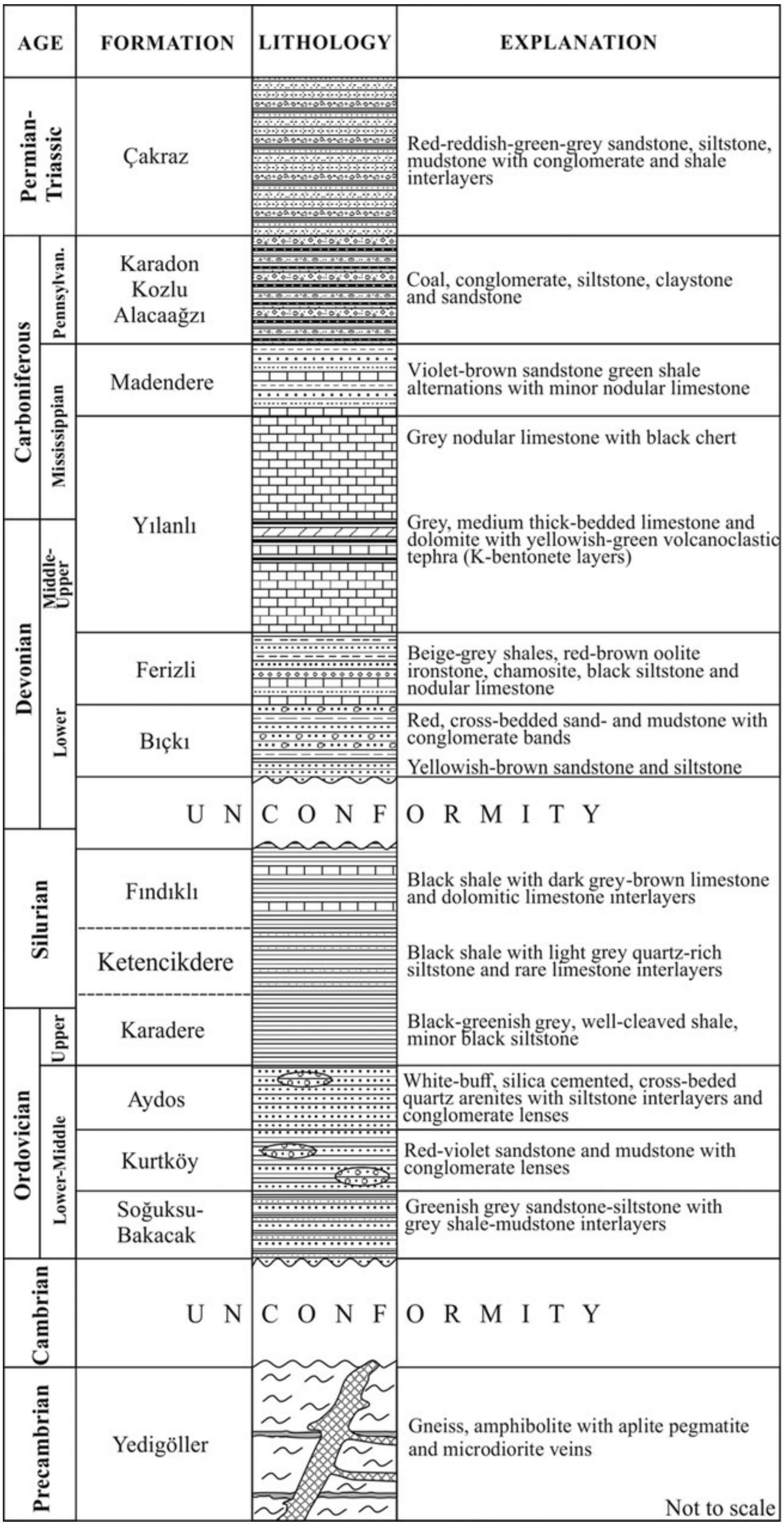

Figure 3. Generalized columnar section of the Zonguldak Terrane (Bozkaya, Yalçin & Göncüoğlu, 2012*b*).

matter but lack any macro- or microfossils (Fig. 6a). The occurrences of black shales (mainly laminated) are occasionally accompanied by pyritic shales.

The Alaplı Member of Çakraz Formation is conformably overlain by the Ereğli Member, which starts with the thin- to medium-bedded red-pink, grey, sandstone, mudstone and siltstone alternations with shale interlayers at the bottom (Fig. 6a). The upper part of member is represented by thin- to medium-bedded red-pink sandstone and siltstone alternations. The main body of the member is represented by an alternation of red, violet, occasionally massive, moderate- to thick-bedded

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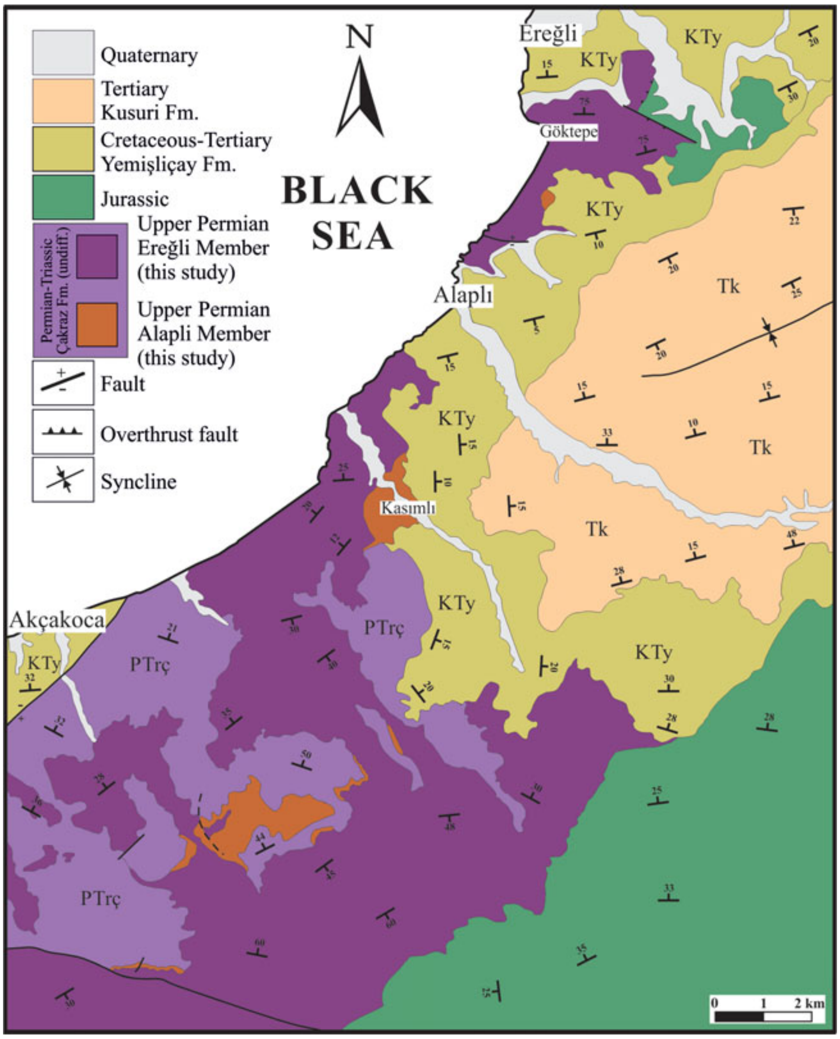

Figure 4. (Colour online) Geological map of the study area and the distribution of the Alaplı Member in the Ereğli and Alaplı regions (modified from Aydın *et al*. 1987). Undiff. – undifferentiated.

conglomerate, sandstone, siltstone and mudstone with mud cracks, rain drops and cross-bedding. The uppermost part of the formation is typically a greenish-yellow-colored marl, siltstone and claystone alternation (Fig. 6a) (Altun & Aksay, 2002).

Late Cretaceous volcanic and volcanoclastic rocks unconformably overlie the Çakraz Formation in the Ereğli area (Fig. 6a) (e.g. Altun & Aksay, 2002).

3.b. Depositional features

The Alaplı Member, described here for the first time in detail, is represented by sandstone shale alternation at the base, conglomerates with limestone, dolomitic limestone interlayers at the middle and shale with siltstone interlayers at the top. The predominantly fine-grained character of the lithofacies, mainly the occurrences of laminated mudstones associated with shales and sands with abundant plant material, represents the deposits of lacustrine deltas formed at lake margins, which were related to the river systems (Newell, Tverdokhlebov & Benton, 1999; Cassinis, Durand & Ronchi, 2007; Newell *et al.* 2010; Opluštil *et al.* 2013). The limestone levels in between conglomerates and the overlying units in the Alaplı Member probably represent lacustrine carbonates deposited in shallow lakes. The association of poorly sorted conglomerates in the middle part of the succession with shale interlayers indicates a possible influx of the river channel to the lacustrine system. It is probable that the Alaplı Member and underlying units were deposited in an interior continental basin that was closed to the marine shelves and deposited in a broad range of fluvial and lacustrine environments. This is also supported by the lack of any marine macro- or microfossils in the formation.

3.c. Palynological data and age

The upper Permian sediments from the Ereğli area in north Turkey is scarcely represented in outcrop and still very little studied. From four samples (Fig. 5) taken from the freshest outcrops, only two samples (10-AK-13 and 10-AK-19) contain relatively

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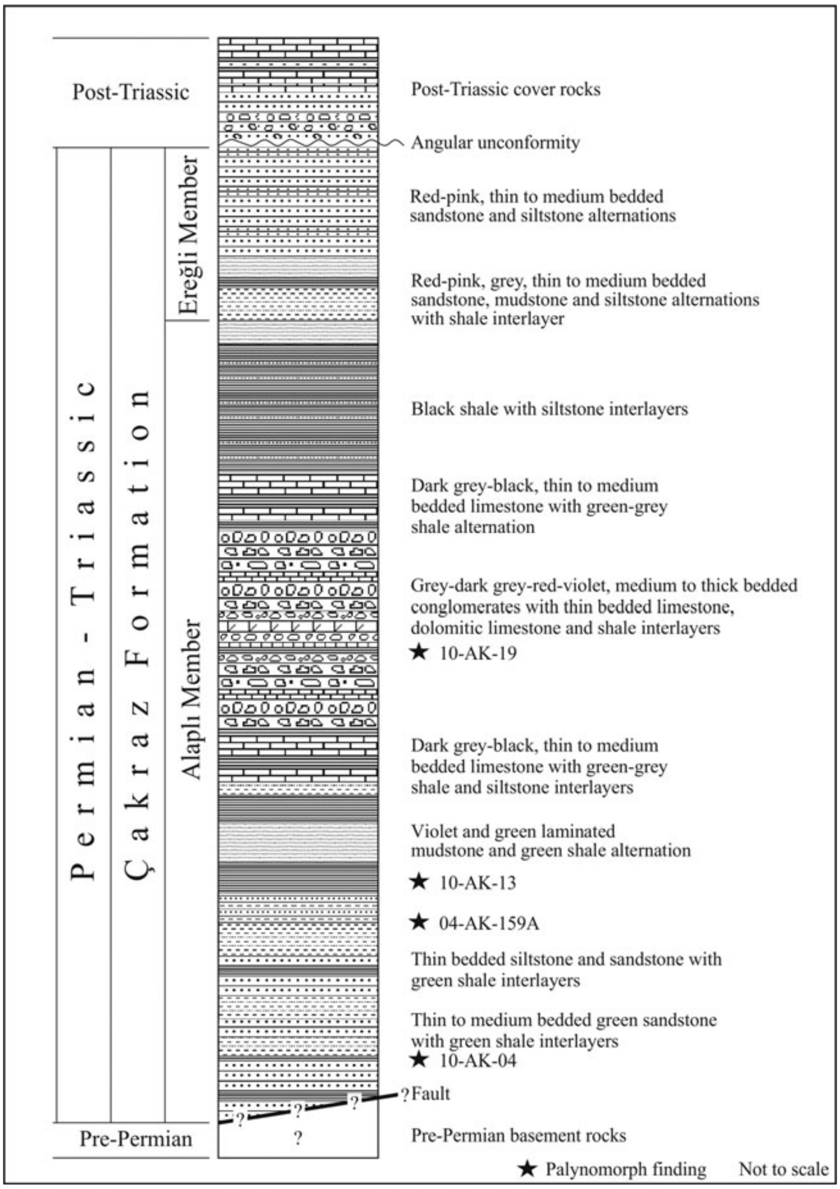

Figure 5. Generalized lithostratigraphic section of the Çakraz Formation in Ereğli area.

well-preserved material for palynological determination and illustration.

Pollen and spores from the rocks were recovered by dissolving in hydrofluoric acid, in nitric acid (40 %) and zinc chloride, then cleared in potassium hydroxide (5 %). The maceration material (in Geological Institute, Sofia) was mounted in glycerin jelly, or only jelly, for microscopic study. The dark colour of the spores and pollen can be used to assess the degree of thermal alteration that organic material in sediments has been subjected to. The dominant study material is generally poorly preserved palynomorphs.

The palynological assemblage of the samples include various taxa (48 pollen grains and spores). The common genera such as *Lueckisporites* and other species and genera such as *Limitisporites lepidus*, *Vitreisporites* sp., *Cedruites* sp., *Platysaccus* sp., *Vittatina persecta*, *Illinites* sp., *Striatites* cf. *ovalis*, *Hamiapollenites* sp., *Lunatisporites* sp., *Jugasporites* sp., *Falcisporites* sp., *Alisporites* sp., *Striatopodocarpites* sp., *Nuskoisporites* sp. and *Protohaploxypinus* sp. are depicted in Figure 7.

The entire sequence is characterized by the dominance of striate bisaccate genera that includes *Striatites*, *Striatopodocarpites*, *Striatopollenites* and taneiate taxa as *Lueckisporites* and *Lunatisporites*. The palyno-assemblage (Fig. 7) is also described by specimens from the genera *Limitisporites lepidus*, bisaccate form genera *Cedruites* sp., *Lueckiesporites* sp., *Illinites* sp., spores (*Verrucosisporites*), cf. *Alisporites* sp., *Jugasporites* sp., *Limitisporites* sp., *Striatopodocarpites* sp., *Nuskoisporites* sp., *Protohaploxypinus* sp. and genus *Vittatina*.

International palynological correlations are not well established for the Permian at present. The palynological zonal scheme (Fijalkowska, 1994; Stephanson, Osterloff & Fılatoff, 2003) used by several authors (Jin *et al.* 1994; Utting *et al.* 1997; Hochuli *et al.* 2010;

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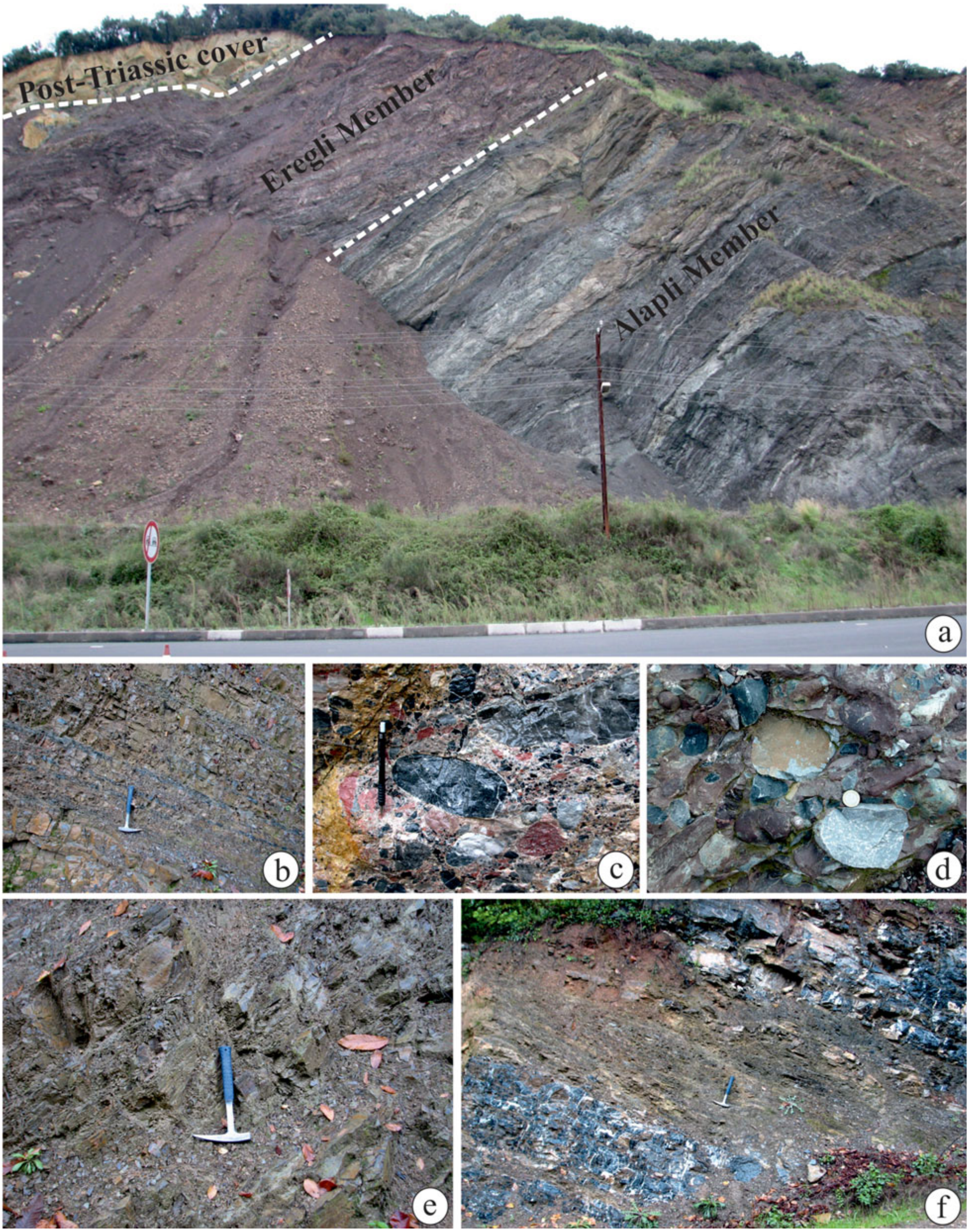

Figure 6. (Colour online) Field photos of the Çakraz Formation from the Ereğli and Alaplı regions. (a) General lithological characteristics of the Alaplı and Ereğli members and the contact between them and their post-Triassic cover (near to Erdemir Beach, Ereğli district); (b) alternation of thin- to medium-bedded greenish-grey siltstones and sandstones with thin black mudstones; (c, d) thin- to medium-bedded dark-grey grey-red-violet conglomerates; (e, f) organic-matter-rich black shales and limestone levels which include miospore assemblages. Photograhs (b–f) were taken on road between Oluce and Kasımlı districts.

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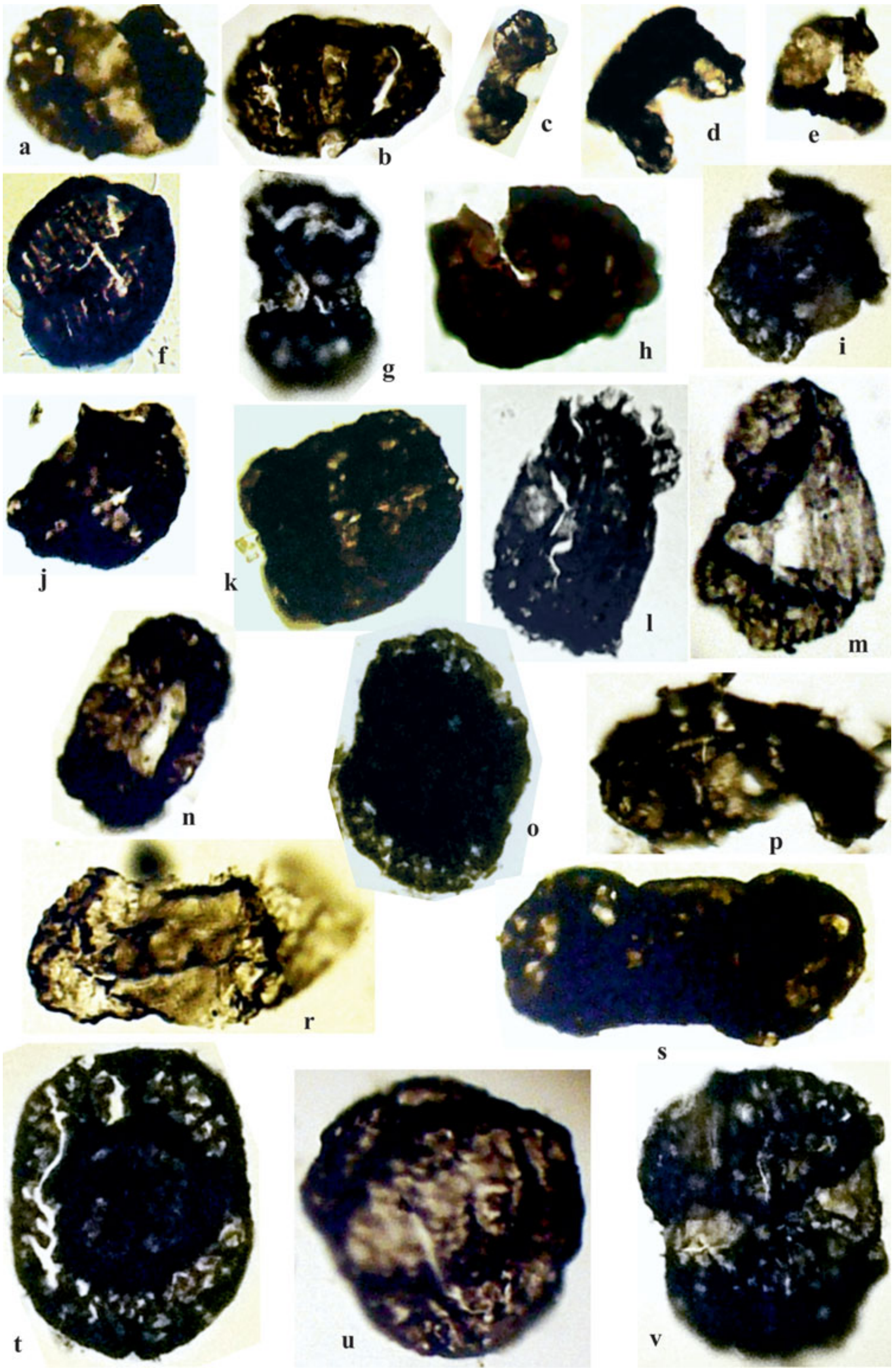

Figure 7. (Colour online) Selected palynological taxa from the Alaplı Member of the Çakraz Formation in the Alaplı-Ereğli region, NW Turkey. All magnifications ×700. (a) *Limitisporites lepidus* (Valts) Hart 1963, 10-AK-13; (b) *Limitisporites* sp., 10-AK-13; (c) ?*Vitreisporites* sp., 10-AK-19; (d) *Cedruites* sp., 10-AK-19; (e) *Platysaccus* sp., 10-AK-13; (f) *Vittatina persecta* Zauer 1960, 10-AK-13; (g) *Illinites* sp., 10-AK-13; (h) *Verrucosisporites* sp., 10-AK-13; (i) *Striatites* cf. *ovalis* Schaarschmidt, 1963, 10-AK-19; (j, k) *Lueckisporites* sp., 10-AK-19; (l) *Namiapollenites* sp., 10-AK-19; (m) *Lunatisporites* = *Taeniasporites* sp., 10-AK-19; (n) *Lueckisporites nyakapendensis* Hart 1963, 10-AK-13; (o) *Jugasporitres* sp., 10-AK-13; (p) *Falcisporites* sp., 10-AK-19; (r) ?*Alisporites* sp., 10-AK-19; (s) *Striatopodocarpites* sp., 10-AK-13; (t) *Nuskoisporites* sp., 10-AK-13; (u, v) *Protohaploxypinus* sp., 10-AK-13.

Stolle, Yalçin & Kavak, 2011) is based on many stratigraphic ranges of the forma genera.

The stratigraphic range of selected species such as *Lueckisporites*, *Alisporites*, *Lunatisporites* and *Hamiapollenites* (Fig. 7) allow the assemblage to be dated to the upper Permian rocks, and the same age was given to the studied formation at this locality.

The assemblage from north Turkey is correlated with and indicates Zechstein assemblages which have been described from many European countries

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(see Visscher, 1971) and also in Bulgaria (Dimitrova, Petrunova & Yanev, 2006) and Turkey (Stolle, Yalçin & Kavak, 2011; Stolle, Yalçin & Kozlu, 2012). Important genera in the deposits with similar age are *Lueckisporites* (12 specimens of this genus), *Lunatisporites* and *Illinites-Limitisporites* complex. Other important genera include *Hamiapollenites*, *Protohaploxypinus*, *Alisporites* and *Podocarpites*. Taeniate and non-taeniate disaccates are dominant and include the species *Protohaploxypinus* spp. and *Striatopodocarpidites* spp.

At the end of the Permian Period, the worldwide collapse (Visscher *et al.* 2004) of the terrestrial and marine ecosystems resulted in major perturbation. The situation in the studied material suggests that conifers with large sacci (*Lunatisporites*, *Hamiapollenites*) were starting to dominate the flora. Reworked palynomorphs are identified in the maceration material as genera of early Carboniferous age and one specimen of Late Devonian age.

The established microflora is dominated by striate pollen grains, which would represent xerophytic floras mainly related to the Pteridospermaphyta. Other genera, such as *Alisporites*, *Vitreisporites* (two very dark, badly preserved specimens from different taxa), *Vittatina* and *Cycadopites*, could correspond to groups of Coniferophyta (Cordaitales and Coniferales) and Cycadophyta (e.g. Balme, 1995). Ornamented forms are mainly represented by *Verrucosisporites* and *Lucidisporites*, characteristic of a variety of late Palaeozoic ferns (Balme, 1995). *Nuskoisporites* conifers (Walchiaceae; *Ortiseia*), prepollen of the late Permian conifer species (Florin, 1927), was present in the samples only with one taxon. *Lueckisporites virkkiae* conifers (Majonicaceae; *Majonica*), known from the late Permian conifer *Majonica alpine* (Clement-Westerhof, 1987), includes two specimens. The assignable forms of *Voltziaceaesporites* conifers (family unknown; *Yuccites*), known from coniferous cones (*Willsiostrobus*), have also been described as *Alisporites* (Balme, 1970) and are seen in the assemblage with less well-preserved forms. *Jugasporites* (one specimen) conifers (probably Ullmanniaceae; genus unknown) forms are morphologically similar. Multitaeniate pollen Pteridosperms (Peltaspermales; family and genus unknown) identified form-genera include *Lunatisporites* and *Protohaploxypinus*. *Cycadopites* spp. cycads (family and genus unknown) monosulcate pollen is known from a variety of Palaeozoic and Mesozoic gymnosperms (Balme, 1995). Considering the megafossil record, late Permian and Early–Middle Triassic forms from Europe are likely to represent cycads (Balme, 1995). The disaccate striate, taeniate pollen is prominent for the assemblages of late Permian and Early Triassic age (Traverse, 1988).

The Tatarian period is characterized by a decrease in *Vittatina* and spore specimens (species of the Lycopsida). The dominant conifer taxa of the late Permian Euramerican floral realm became extinct at, or close to the Permian–Triassic (P-Tr) border. The long-ranging Carboniferous–Permian Walchiaceae also became extinct close to the P-Tr boundary (Poort *et al.* 1997) and *Cycadopites* and *Lueckisporites virkkiae* (it is easy to recognize this slightly diploxylonoid autline species, where sacci are less than semi-circular in shape) present with very common taxa belong to maceration material. In fact, after the P-Tr crisis the prepollen condition never appeared in gymnosperm evolution (Florin, 1927; Taylor & Taylor, 1993). On the other hand, the temporary reappearance of *Jugasporites* Leschik could indicate that the Ullmanniaceae survived outside Europe.

The early Permian Period is dominated by polyplicate pollen and the regular appearance of monosaccate pollen (Dimitrova *et al.* 2005). The late Permian assemblages of the studied material include bisaccate pollen and commonly appear in association with *Cycadopites* and *Lueckisporites virkkiae*, such as the forma species from NE Bulgaria (Dimitrova, Petrunova & Yanev, 2006) and Turkey (Dimitrova & Stolle, 2010).

Palynological assemblages from the rocks of the Alaplı Member in north Turkey are broadly synchronous throughout with similar interregional comparison of deposits within NW Turkey. Part of the Çakraz Formation with successions from Europe (Southern Alps, Germany) was correlated and discussed by Stolle (2014). This correlation also supports our conclusion that the studied deposits of the Çakraz Formation in Alaplı-Ereğli area are late Permian (Tatarian) in age.

4. Discussion

4.a. Regional geological correlation

There are some lithological differences in Çakraz Formation considering the regional distribution in Çamdağ, Zonguldak (Ereğli, Alaplı) and Çakraz areas of the ZT. The Çakraz Formation in the Çakraz-Amasra region is represented mainly by red sandstone and mudstones with green, grey mudstone and sandstone interlayers. Poorly sorted and grain-supported conglomerates represent the lowest stratigraphic level of the formation. The grain size decreases upwards from pebble to sand and mud to clay. The overlying deposits consist of red, reddish, purple sandstone, mudstone and shale (Güvenç *et al.* 1994; Alişan & Derman, 1995; Tüysüz, Aksay & Yiğitbaş, 2004; Gand *et al.* 2011) (Fig. 8). In Çamdağ region, the Çakraz Formation is composed of reddish sandstone and siltstone with fine-bedded claystones (Alişan & Derman, 1995; Gedik & Önalan, 2001; Stolle, 2014) (Fig. 8). In one locality only, a relatively thin conglomerate level was observed (e.g. Stolle, 2014). The Çakraz Formation in the Zonguldak-Ereğli area is represented by an alternation of red, violet, occasionally massive, moderate- to thick-bedded conglomerate, sandstone, siltstone and mudstone with mud cracks, raindrops and cross-bedding (Altun & Aksay, 2002). Generally, this part of the formation is overlain by the recently discovered Alaplı Member (Fig. 5).

In the IT, the Permo-Triassic succession is known as the Kapaklı Formation (e.g. Özgül, 2012). The Kapaklı

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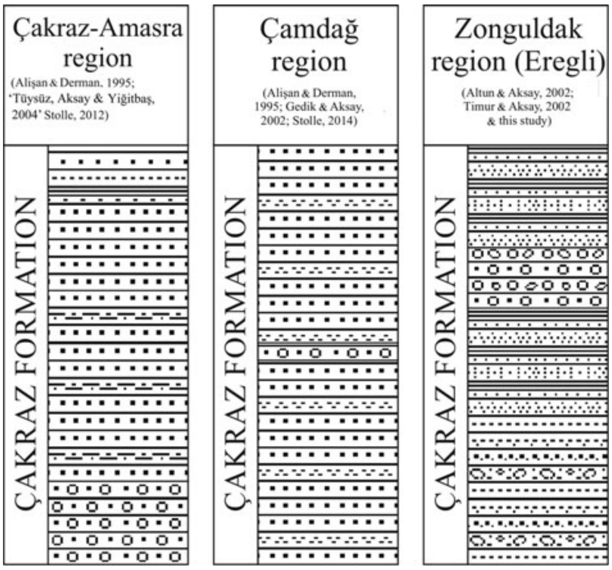

Figure 8. Generalized columnar sections of the Çakraz Formation in Çamdağ, Zonguldak (Ereğli, Alaplı) and Çakraz areas of the ZT, highlighting the lithological differences (Alişan & Derman, 1995; Altun & Aksay, 2002; Gedik & Aksay, 2002; Timur & Aksay, 2002; Tüysüz, Aksay & Yiğitbaş, 2004; Stolle, 2012, 2014).

Formation has been subdivided to several informal lithostratigraphic units by Altınlı (1968). The lowermost unit (Unit A) is up to 1000 m thick and consists of red, thick-bedded, poorly sorted conglomerates with large (5–30 cm) boulders. They are locally interbedded with olivine basaltic-andesitic lava flows. This unit has been compared with the Permian Verrucano facies of the Alps (e.g. Arthaber, 1915; Derman, 1997). Similar interregional comparison of deposits within NW Turkey and correlation of part of the Çakraz Formation with successions from Europe (Southern Alps; Germany) has been carried out and discussed by Stolle (2014), using data from the Camdag area.

Further NW in the Balkan area, the Permian system is well defined based on the sedimentary cycles (groups) which are separated by a marked unconformity (Yanev, 1981; Yanev, Maslarevic & Krstic, 2001). The first group, generally including upper Stephanian – lower Permian strata (Yanev, 2000; Yanev & Adamia, 2010), is characterized by lacustrine, fluvial and proluvial fan deposits as well as volcanic rocks. The second group of upper Permian deposits (?Tatarian to the P-Tr boundary) consists of deltaic and continental clastics and halite evaporates, which is limited to the southeastern part of the Moesian Terrane (Yanev, 1993; Yanev, Maslarevic & Krstic, 2001; Yanev & Adamia, 2010).

The lower Permian deposits of Bulgaria and Romania show molasse-type features in the Balkan, the Prebalkan, the Sredna Gora, the Kraishte, the south Carpathians, the Apuseni Mountains and the Carapelit Basin (Seghedi *et al.* 2001; Yanev, Maslarevic & Krstic, 2001). The Moesian and Scythian platforms, as well as in the Kraishte region, the upper Permian units are not typically molassic in character compared to the lower Permian parts of successions, which are mainly represented by continental and transitional facies units (Seghedi *et al.* 2001; Yanev, Maslarevic & Krstic, 2001). The sequences in Moesian and Scythian platforms are fault-related (tectonically controlled) and the deposition occurs in shallower grabens and half-grabens (Yanev, Maslarevic & Krstic, 2001; Yanev & Adamia, 2010). The similarity of the Permian deposits, mainly those of late Permian age in the Moesian Platform both in Romanian and Bulgarian parts, is caused by their mirrored position in the foreland of the Variscan chain. The other control on Permian sedimentation in Bulgaria and Romania is explained by active subaerial volcanism (the lower part of Rotliegend facies) for the former, and by bimodal volcanism, which continued during Triassic time, for the latter in the Moesian platform (Yanev, Maslarevic & Krstic, 2001).

The depositional environments of the Permian successions in both regions corresponds to a variety of continental environments such as fluvial, proluvial, playa, colluvial and alluvial-plain to palustrine, lacustrine, continental basin and sabkha conditions (Yanev, 1970, 1989; Seghedi *et al.* 2001; Yanev, Maslarevic & Krstic, 2001; Yanev & Adamia, 2010).

4.b. Changes in the depositional environment and age of the Çakraz Formation

Overall, there is general agreement over the deposition of the Çakraz Formation in a continental environment being mainly related to a fluvial system. The depositional conditions of Çakraz Formation in Çamdağ region is described by Alişan & Derman (1995) as continental and the depositional environment is proposed as river-channel and floodplain, possibly related to an alluvial fan with small lakes. This is also supported by the composition of the microfloras (mainly bisaccate pollen from hinterland conifers) of Stolle (2011) in Çamdağ region. Tüysüz, Aksay & Yiğitbaş (2004) provided a detailed lithological description of the Çakraz Formation in the Çakraz-Amasra region. In this area the base of the succession mainly consists of reddish conglomerates which are overlain by irregular braided fluvial sediments. Towards the top of the unit, more regular meandering river-floodplain sediments dominate. Gand *et al.* (2011) suggested a palustrine floodplain environment for the Cisuralian (early Permian) red-bed levels including mud cracks and raindrops from the Çakraz Formation near Çakraz village. The fluvial system and its sub-environments are assumed to be the depositional environment of Çakraz Formation in Gand *et al.* (2011), based on the horizons of Grancy (1938); this level is the equivalent of member p2 of Grancy (1938).

Biostratigraphic and fossil data to help determine the age of the Çakraz Formation are rare. It was informally declared as Permo-Triassic in age by Altun & Aksay (2002), Gedik & Aksay (2002), Timur & Aksay (2002) and Tüysüz, Aksay & Yiğitbaş (2004). The age of the Çakraz Formation has also been proposed as early Permian (Grancy, 1938; Wedding, 1970), Permian (Tokay,

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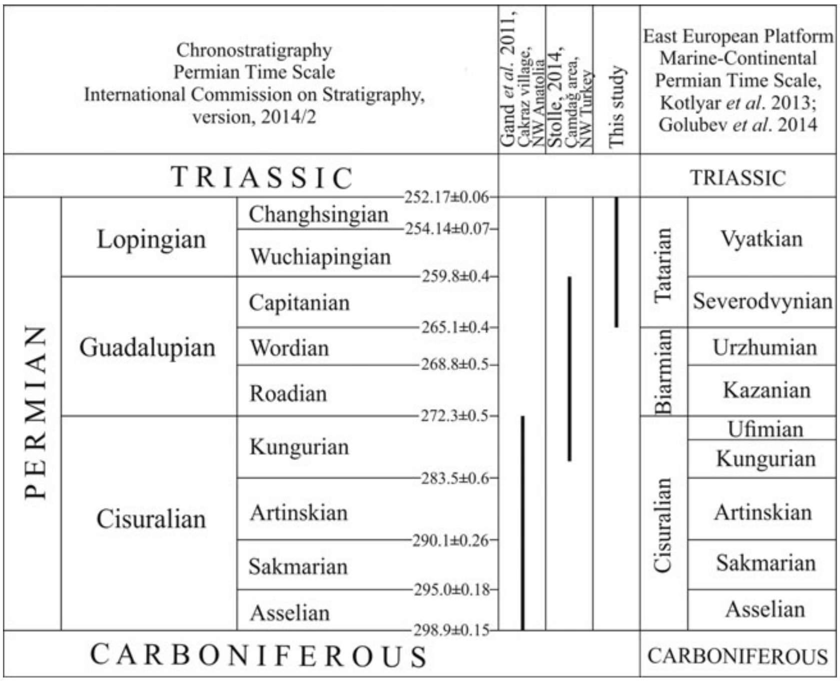

Figure 9. Stratigraphic ranges of the biostratigraphically investigated different parts of Çakraz Formation according to the previous studies of Gand *et al.* (2011), Stolle (2014) and this study.

1962), Triassic (Jongmans, 1939) and Permian-Triassic (Akyol *et al.* 1974; Kaya, Wiedmann & Kozur, 1986; Yergök *et al.* 1987) in previous studies. In Çamdağ region (NW Anatolia), Alişan & Derman (1995) dated the lake deposits of Çakraz Group as Late Triassic. The Çamdağ Formation, the equivalent of the Çakraz Formation in the Ereğli region, was dated as late Permian in age based on palynological findings. This study is the first palynological data revealed from the red beds of the Çakraz Formation.

Recently, Stolle (2011) studied the pollen-dominated assemblages of the Permian part of Çakraz Formation in Çamdağ region and indicated that the assemblages are characterized by a high proportion of *Lueckisporites*; the Çamdağ assemblage also shows similarities to the upper Permian successions of the palaeogeographically adjacent regions of northeastern Bulgaria and western Europe. Gand *et al.* (2011) have proposed a Cisuralian (early Permian) age for the Çakraz Formation near the Çakraz village (NW Anatolia), based on tetrapod footprints in the red beds of the lower part of formation (member p2) where coniferophyte *Walchia* (discovered by Grancy, 1938) was previously recorded. The finding of ichno- and macrofloral remains, together with the sedimentological data (mud cracks, raindrops), suggest a palustrine floodplain environment for these red-bed levels of the formation. Stolle (2014) has recently proposed an early Kungurian – Capitanian age for the palynomorph-bearing sections of the mainly reddish-coloured deposits of the Çakraz Formation in the Çamdağ region (NW Anatolia).

According to previously published results and this study, which mainly corresponds to the black shale, mudstone and a conglomeratic level in the middle part of the formation, the stratigraphic ranges of reddish-coloured Çakraz Formation are limited to Permian age (Fig. 9). A Cisuralian (Gand *et al.* 2011) age is reported from the tetrapod-footprint-bearing level in Çakraz region. Stolle (2014) recently specified an age range of late Cisuralian – Guadalupian (early Kungurian – Capitanian) for the palynomorph-bearing strata in Çamdağ region based on corelations with new palynological and radiometric data.

In brief, our recent findings from the succession, including miospores in black shale, and from mudstone from the south of Alaplı region (Fig. 9) suggest a Lopingian (Tatarian) age based on bisaccate pollen with the association of *Cycadopites* and some of the species including *Lueckisporites virkkiae*, *Falcisporites* sp. and *Alisporites* sp. The Russian name Tatarian was used for the equivalent of late Permian (Lopingian and partly Guadalupian) as proposed by Tverdokhlebov *et al.* (1997, 2005), Benton, Tverdokhlebov & Surkov (2004), Taylor *et al.* (2009), Kotlyar, Golubev & Sılantıev (2013) and Golubev *et al.* 2014 (Fig. 9).

5. Conclusions

The >1000 m thick organic-rich dark-coloured successions in the Zonguldak Terrane between Akçakoca and Ereğli, which were classified as being of early Palaeozoic (Ordovician–Devonian) age in previous studies, has been shown by palynological evidence to be late Permian (Tatarian) in age. The unit is the first finding of anoxic sediments of late Permian age in NW Anatolia. Because of its distinctive lithostratigraphy, the successions are described as a new lithostratigraphic unit and named the Alaplı Member of the Çakraz Formation.

The Alaplı Member is transitionally overlain by dysoxic, red, pink and violet sandstones and

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conglomerates with rare bands of silt- and mudstone and rare tuffaceous layers (Ereğli Member of the Çakraz Formation).

The black shales, mudstones and limestones of the Alaplı Member are very rich in organic matter but lack any macrofossils. The plant-bearing siliciclastics of the member yielded palynological assemblages including bisaccate pollen, and mainly appear in our studied section in association with *Cycadopites* and *Lueckisporites virkkiae* that are considered to indicate a late Permian (Tatarian) age. The overlying conglomerates in the middle part of the succession are dominated by pebbles of Kurtköy (Ordovician), Fındıklı (Silurian) and fossiliferous Yılanlı (Lower Devonian – lower Carboniferous) formations.

The Alaplı Member was very probably deposited in an intra-platformal basin that was closed to the marine shelves in a broad range of fluvial and lacustrine environments. Basins similar in age and depositional features are described from the East European Variscan Belt in Bulgaria and Romania, which were also developed in actively extending shallow-marine platforms on the NW Palaeotethyan margin at the end of the Permian Period.

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