First record of late Campanian paleoceanographic and paleoclimatic changes, Arabian Platform, Mazidag-Mardin area, SE Turkey

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Abstract: The sedimentology, geochemistry and paleontology of the pelagic upper Campanian Maastrichtian Bozova Formation in the "Mazidag" (Mazıdağ) - Mardin area, SE Turkey, reveal paleoceanographic and paleoecological changes for the first time. A 119.25 m-thick composite stratigraphic section is characterized by alternating marls, clayey limestones, shales, and black shales; no coarse clastic admixture or turbidite intercalations were recorded in the section. Biostratigraphic data indicate trends in productivity from the lower part and the middle part of the succession. The lower part of the section is characterized by alternating marls, clayey limestones, shales, and black shales; no coarse clastic admixture or turbidite intercalations were recorded in the section. Biostratigraphic data indicate the presence of the Radotruncana calcarata Zone, and the UC15de/UC16 nannofossil zones. Stable isotopes and elemental geochemical analyses have been carried out in the studied section. The isotope curves display similar patterns compared to reference curves from European and Chinese basins in the same interval. The prominent negative carbon isotope excursion determined in the upper interval can be correlated with the Late Campanian Event. Proxy elements display generally two relative rising - trends in productivity from the lower part and the middle part of the succession. The lower part of the section records relatively more dysoxic/anoxic conditions and coincides with common black shale beds. The presence of both diverse planktonic foraminifera and calcareous nannofossils in the studied interval indicates a fully marine, warm-water, low-latitude Tethyan oceanic environment. In addition, the plant fossils derived from the nearby land mass indicate that a tropical humid climate was similar to that in northeast Australia. Therefore, warm water, tropical humid atmospheric conditions developed in the studied area causing the rise in productivity, precipitation and transportation of plant debris into offshore environments.

Key-words:
• upper Campanian;
• paleoceanographic event;
• paleoclimate;
• plant fossil;
• Arabian Platform;
• SE Turkey

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Résumé : Premier enregistrement des modifications paléo-oceanographiques et paléo-climatologiques au Campanien supérieur, Plate-Forme Arabe, secteur de Mazidag-Mardin area, Turquie du sud-est.- La sédimentologie, la géochimie et la paléontologie des dépôts pelagiques d’âge Campanien supérieur à Maastrichtien de la Formation de Bozova illustrent pour la première fois les changements paléo-oceanographiques dans le secteur de Mazidagi-Mardin, Turquie du sud-est. La couche stratigraphique composite, épaisse de 119,25 m, est constituée d’alternances de marnes, calcaires marneux, argiles et argiles noires (“black shales”); un couple mélangé plus silicoclastique ou intercalation de turbidite n’a été observé dans cette coupe. Les données biostratigraphiques indiquent la présence de la Zone à Radotruncona calcara et des zones de nannofossiles UC15de/UC16. Les analyses géochimiques d’isotopes stables et d’éléments-traces ont été effectuées sur la coupe étudiée. Les courbes isotopiques résultantes montrent des variations similaires aux courbes de référence des bassins européens et chinois pour la même période. L’excursion principale négative en isotopes du carbone reconnue dans l’intervalle supérieur peut être corrigée avec l’Événement du Campanien supérieur. Les éléments-traces montrent de manière générale deux tendances haussières relatives de la productivité dans la partie inférieure et la partie moyenne de la succession lithologique. La partie inférieure de la coupe montre des conditions relativement plus dysoxiques/anoxiques et coïncide avec les niveaux habituels de “black shales”. La présence conjointe de foraminifères planctoniques et de nannofossiles calcaires diversifiés dans l’intervalle étudié indique un environnement marin océanique téthysien de basse latitude et d’eaux chaudes. De plus, les fossiles de plantes provenant de la masse continentale voisine indiquent un climat tropical similaire à celui de l’actuelle Australie nord-orientale. Par conséquent, des conditions atmosphériques tropicales humides et d’eaux chaudes se sont développées dans la zone d’étude provoquant une hausse de la productivité, des précipitations et le transport de débris végétaux jusqu’aux environnements marins du grand drapeau.

Mots-clés :
• Campanien supérieur ;
• événement paléo-oceanographique ;
• paléo-climat ;
• fossiles de plante ;
• Plate-Forme Arabe ;
• Turquie du sud-est

1. Introduction

The Late Cretaceous, especially late Campanian paleoceanogetic/paleoclimatic changes have been studied in various parts of the world by different methods to characterize the key transitional time from the mid-Cretaceous hot-hose to a cooler greenhouse climate state (Hu et al., 2012; Hay & Floegel, 2012). Most of the studies include chemoostratigraphic records such as those from the European basins (Jarvis et al., 2002, 2006). Lower and middle Campanian black shales and positive carbon isotope excursions in pelagic sequences are evidence of minor oceanic anoxic events (OAEs) in pelagic sequences from different parts of the world (Jarvis et al., 2002, 2006; Li et al., 2006; Wagreich, 2009; Locklair et al., 2011). These events correspond to the end of the OAE3 interval, which took place mainly during the late Coniacian-Santonian interval (Beckmann et al., 2005; Wagreich, 2009; Wagreich et al., 2012).

Jarvis et al. (2002) correlated Campanian oceanographic changes based on carbon isotope events between successions in Tunisia, France and UK, and identified three events: (1) the positive Santonian-Campanian boundary event (SCBE), (2) the positive Mid-Campanian event (MCE), and (3) the negative late Campanian event. Jarvis et al. (2006) later depicted a carbon-isotope reference curve for the Cenomanian-Campanian interval in the English Chalk and indicated the mid-Campanian Event and the late Campanian Event (LCE) above the SCBE. Li et al. (2006) confirmed a 2 per-mil negative shift in the carbon curve in the upper Campanian pelagic limestone and marl successions from southern Tibet, China, and correlated this excursion to the LCE. In Turkey, the Campanian-Maastrichtian pelagic sequence in the Mudurnu-Goynuk basin, Sakarya Continent, has been studied by stable isotopes and elemental analyses. Aickin et al. (2015) indicated a negative carbon-isotope excursion in the upper Campanian G. havanensis biozone, above the R. calcara biozone, as also recognized by Wagreich et al. (2012). Voigt et al. (2012) discussed the global correlation of upper Campanian-Maastrichtian carbon-isotope stratigraphy and oceanographic events. They emphasized the presence of the Campanian-Maastrichtian Boundary Event (CMBE), which is a significant long-ranging negative carbon-isotope excursion with multiple peaks of about 0.3 to 1.0 per mil (Voigt et al., 2012), also recognized by Wendler (2013).

The Campanian record of the Arabian Platform, especially the sea-level fluctuations and the related deposits and facies have been dealt with by HAQ and Al-Qahtani (2005). They indicated a major flooding surface in the Campanian on the Arabian Platform, probably related to Late Cretaceous tectonic movements. HAQ (2014) indicated the presence of seven sequence boundaries in the Campanian. The late Campanian sea-level record according to HAQ (2014) is characterized by a sequence boundary and 100 m sea-level fall in the R. calcara biozone, and CC23a/UC 16 nannofossil biozones. This sequence boundary is over-
Figure 1: Simplified geological framework of Southeastern Turkey and generalised stratigraphic sequence for the Cretaceous carbonates in the Mardin-Mazıdağı region (SUNGURLU, 1974; YILMAZ et al., 2018).

lain by another higher sequence boundary at the G. aegyptiaca biozone. According to JARVIS et al. (2002) the LCE seems to coincide with an interval of sea-level fall; however according to a revised sea-level change curve and sequence boundary chart of Haq (2014), it seems to take place within the sea-level rise interval. ZAREI and GHASEMI-NEJAD (2015) indicated three Campanian sea-level falls as recorded in the Gurpi Formation on the Arabian Platform, southwest of Zagros, Iran.

Another distinct oceanographic event is the occurrence of phosphorites in Jordan (PUFAHL et al., 2003) and in Israel (EDELMAN-FURSTENBERG, 2009), related to oceanic upwelling, high productivity conditions and transgressions. The records of phosphate deposition and transgressive sequences were also observed in southeastern (SE) Turkey (BEER, 1966; CATER & GILLCRIST, 1994) with the deposition of a pelagic sequence and carbonate buildups on the Arabian Platform following transgression (ERKMEN & SADEK, 1981; ÖZER, 1993).

Southeastern Turkey is situated geologically along the northern part of the Arabian Plate and is bounded to the north and east by the Iran-Zagros-Bitlis suture zone (ALA & MOSS, 1979; FONTAINE et al., 1989). A thick Cretaceous sedimentary succession was deposited in this area (Fig. 1). This paper examines the Campanian succession on the Arabian Plate in southeastern Turkey using stable isotope and elemental geochemistry besides plankton biostratigraphy. The upper Campanian-Maastrichtian succession of southeastern Turkey is composed of various units (Figure 1), that reflect the intensive tectonic activity in northern parts of the region. However, carbonatesuccessions were deposited in protected shallow marine areas (ALA & MOSS, 1979; İŞBILIR et al., 1992). This condition continued up to the end of the Paleocene and thus, except for the marginal northern region, Şırnak, Mardin, and Gaziantep areas, no well-defined break is between the Mesozoic and Cenozoic successions (CATER & GILLCRIST, 1994).

This study provides new data for the upper Campanian-lower Maastrichtian interval in SE Turkey and discusses events and their correlations as recorded on the Arabian Platform. This study is the first application for this purpose in the Arabian Platform in SE Turkey.

2. Geological setting

During the Aptian-early Maastrichtian, southeast Anatolia lay on a shelf characterized by intrashelf basins, along the northern passive margin of the Arabian Plate (HÖRSTINK, 1970). The Upper Cretaceous (Campanian-Maastrichtian) sequences of the northern Arabian Platform in southeastern Anatolia are well preserved in surface and subsurface sections in SE Turkey (Fig. 1). These successions are very extensive and comprise mainly marine clastic and carbonate sedimentary rocks (HOŞGÖR & KOSTAK, 2012, MULAYIM et al., 2016).

The Cretaceous sequences in the NW Mardin area are divided into seven formations (Fig. 2) composed mainly of limestones and dolomites with minor amounts of siliciclastic sequences (MULAYIM et al., 2016; YILMAZ et al., 2018; HOŞGÖR & YILMAZ, 2019). In the study area, basement rocks crop out close to Mazıdağı village and are characterized by Ordovician sandstone and shale (KELLOG, 1960; KURU, 1987). They are overlain by Mesozoic carbonates with an angular unconformity (SUNGURLU, 1974). The carbonate platform began to develop over the Areban Formation (Aptian; siliciclastic sandstones and mudstones) in the studied region and the main carbonate successions, both limestones and dolomites, start
Figure 2: Geological and location map of the Mazıdağı area (after Beer, 1966; Umut, 2011).

with the Sabunsuyu Formation (Albian). The limestones and dolomites of the Derdere Formation (Cenomanian-Turonian) overlie the Sabunsuyu Formation with an unconformity in the studied region. The Derdere is overlain unconformably by the Karababa Formation comprising limestones, cherty limestones, and dolomitic limestones of Coniacian to early Campanian age. The limestones of the Karaboğaz Formation (lower Campanian) overly the Karababa Formation with a disconformity (Fig. 1).

The upper Campanian-Maastrichtian Bozova Formation in the Mazıdağı area is characterized by clayey limestone and marl (Köylüoğlu, 1988; Çoruğ et al., 1997). The overlying Lower Germav Formation consists of calcareous mudstone-marl, and was deposited in relatively deeper, basinal conditions (Gater & Gillcrist, 1994) as evidenced by the presence of planktonic foraminifera, plant fragments, inoceramids, and ammonites in Campanian-Maastrichtian marls, shales and limestones (Yılmaz et al., 2018). The Bozova Formation on the Arabian Platform is the objective of this study. One two-part composite stratigraphic section has been measured in detail and sampled with high frequency (Fig. 2).

3. Materials and methods

A composite stratigraphic section of the Bozova Formation is composed of two parts and was sampled in detail (Fig. 3). The sections were tied directly to each other in the field by using the bed surfaces on both sides of the road cuts. Therefore, there is no gap in between. The section is about 119.5 m thick, and 46 samples were collected. The samples were collected in regularly measured intervals in stratigraphic order (Appendix 1) but GPS measurements were not recorded per each sample. Sixteen species of planktonic foraminifera from 40 samples were identified at the Middle East Technical University, Ankara, Turkey. Loose specimens of planktonic foraminifers were picked from the rock sample residues after washing with H$_2$O$_2$. The taxonomic criteria adopted for the identification of planktonic foraminifera are from Bölü et al. (1985).
Nannofossil biostratigraphy was carried out at the University of Vienna, Department of Geodynamics and Sedimentology. Eleven smear-slide samples were prepared from a small fragment of rock dropped into distilled water for separation and determination of calcareous nannofossils taxa. The residue was smeared onto a glass slide and fixed with Canada balsam. The samples were examined qualitatively under the polarizing light microscope (oil immersion, magnification 1000x) for nannofossil biostratigraphy.
Plant fossils were determined at the Department of Palaeontology National Museum Prague, Czech Republic. The plant fossil materials consist of twelve specimens, preserved as brown, gray, or black imprints. They are rare and slightly permineralised. The specimens were studied under a binocular microscope. Observations and photographs were made under oblique light. An Olympus CX31 polarizing microscope was used for microfossil determination, and the principles of microfossil analysis of Füçel (2004) have been followed.

Stable isotope C and O analyses were carried out on 45 samples by the ISO-Analytical Company, UK using Continuous Flow-Isotope Ratio Mass Spectrometry (CF-IRMS) (the ion source of a Europa Scientific, 20-20 IRMS) with He carrier gas on-line to Gas-Bench. Finely powdered bulk rock samples were reacted with phosphoric acid to obtain CO₂. CO₂ gas liberated from samples was then analyzed by Continuous Flow-Isotope Ratio Mass Spectrometry (CF-IRMS). The reference material used for the analysis was IA-R022 (Iso-Analytical working standard calcium carbonate, δ¹³C-PDB = -28.63 ‰ and δ¹⁸O-PDB = -22.69 ‰). IA-R022 has been calibrated with the NBS-18 (carbonatite, δ¹³C-PDB = -5.01 ‰ and δ¹⁸O-PDB = -23.2 ‰) and NBS-19 (limestone, δ¹³C-PDB = +1.95 ‰ and δ¹⁸O-PDB = -2.2 ‰). The samples have been normalized according to standards and cross checked with each other for quality control. Precision of the analyses is about 0.05 ‰ and the accuracy is about 0.1 ‰ for both oxygen and carbon.

Elemental analyses of 34 samples were carried out at the Acme Analytical Laboratories Ltd., Vancouver, Canada. The total major oxides and minor elements were recovered from 0.1 g powdered limestone/marl/mudstone/shale samples (<63 mm) and analyzed by ICP-emission spectrometry and ICP-mass spectrometry following a Lithium metaborate/tetraborate fusion and nitric acid digestion. Loss-on-ignition (LOI) was by weight-difference after ignition at 1000°C. Rare-earth and refractory elements were determined by ICP-mass spectrometry following a Lithium metaborate/tetraborate fusion and nitric acid digestion of a 0.1 g sample. In addition, a separate 0.5 g split was digested in Aqua Regia and analyzed by ICP-mass spectrometry to report the precious and base metals. Each analysis required 5g of sample and determination limits of the elements were 0.04% for SiO₂, 0.03% for Al₂O₃, 0.04% for Fe₂O₃, 0.01% for CaO, 0.01% for MgO, 0.01% for Na₂O, 0.04% for K₂O, 0.01% for MnO, TiO₂ and P₂O₅, 0.5 ppm for Ba, 0.1ppm for Cd, Cu, Mo, Ni and Pb, 1 ppm for Zn, and 5 ppm for V.

4. Lithology and facies

Lithology and microfacies descriptions were based on field observations and petrographic analysis. Sedimentary structures observed were used to determine the depositional environments. At the base of the lower part of the section, alternating clayey limestone is overlain by alternating marl and black shale (Figs. 3-4.b-c,e). In this first alternation of clayey limestone and marl, the association of plant fragments, relatively abundant inoceramid shells, pyrite and relative abundance of bioturbation was remarkable (Fig. 3: samples 44-46; Fig. 4.a). Another clayey limestone - marl alternation is present at the top of the lower part of the section. At the ultimate top, clayey limestones become dominant (Fig. 4.h). Bioturbation is not intensive throughout the whole section. In this second interval of intercalated clayey limestone and marl ammonites are relatively abundant. Along the section, these relative abundance zones are indicated as I (inoceramids) and A (ammonites) to display their positions along the section (Fig. 3). Black shales are laminated, silty (Fig. 4.e) and rarely bioturbated.

Alternating clayey limestone, marl and shale characterize the bottom of the upper part of the section (Fig. 4.c,g). Clayey limestones are thicker than the marls and increase in thickness compared to the lower part of the section. Alternating thin clayey limestone and marl are present in the topmost part of the section. Clayey limestone and marl include pyrite, fine bioturbation, relatively abundant plant fossils and fragments (Fig. 4.d,f) marked with P in the section log (Fig. 3). Some plant fossils are also present towards the top of the section, but they stratigraphically disappear at the top (Fig. 3). The topmost part of the section displays lighter colors and does not include any plant fossils, ammonites, inoceramids, or pyrite. Transported shallow water benthic foraminifers or calcareous turbiditic facies or coarse siliciclastic intercalations have not been observed throughout the studied section.

Lithofacies analyses are parallel with the field observations and are cross-checked with petrographic examinations under the microscope (Fig. 5). The following types of facies were identified, and petrographic compositions are explained:

Shale: Shales are generally laminated and silty. Gray, light grey and blueish grey shales alternate with clayey limestones in the lower part of the section.
Figure 5: Photomicrographs of the microfacies recognized in Mazıdağı section. Small white bar is 100 micron scale for all, a) marl with planktonic foraminifera and plant fossil (p: planktonic foraminifera, m: micrite) (sample 5), b) bioturbated silty marl (p: planktonic foraminifera, m: micrite, pt: pyrite, g: glauconite) (sample 13), c) silty black shale with microb turbation (b: microb turbation traces, o: organic matter linings, s: silt) (sample 16), d) laminated clayey limestone (wackestone) with pyrite and glauconite (pt: pyrite, ptpl: planktonic foraminifera filled with pyrite, gl: glauconite, m:micrite) (sample: 15), e) clayey limestone with planktonic foraminifera (packstone-wackestone) (m: micrite, p: planktonic foraminifera) (sample 18), f) gray silty calcareous shale (lmts: laminated silt, m: matrix) (sample 24).

Marl: Marls are generally greyish to beige-colored, thin bedded and silty (Fig. 5.a-b). Generally, marls are more common in the bottom and the top of the section. In some intervals, tiny bioturbation structures are in the marls. Plant fossils and fragments are also observed in the field. Ma-
Arkhangelskiella cymbiformis (Gartnerago sEN) is characterized by common genera like fossils are the biostratigraphic index species that define biozones. Plant fossil identifications helped to understand the paleoecological and paleogeographic conditions in the studied region.

**Black shale**: Thin-bedded black shales are mainly observed in the mid part of the section. They are silty, laminated and rarely bioturbated (Fig. 5.c). Matrix of the black shale facies is generally composed of quartz silt, organic matter, clay, and micritic carbonate (Fig. 5.c). Microbial structures observed petrographically are filled by micritic calcite (Fig. 5.c).

**Clayey limestone**: Thin-beded light grey to beige-colored clayey wackestone to packstone alternate with marls and shales throughout the section. Ammonites and inoceramids are present and planktonic foraminifera are abundant. Micro-scale disseminated pyrite is in matrix and fills the chambers of planktonic foraminifera (Fig. 5.d-f). Fine-grained disseminated glauconite is also in clayey limestone facies together with pyrite.

**5. Biostratigraphy and paleontology**

Planktonic foraminifera and calcareous nannofossils are the biostratigraphic index species that define biozones. Plant fossil identifications helped to understand the paleoecological and paleogeographic conditions in the studied region.

**CALCAREOUS NANNOFOSILS**

The nannofossil assemblages are characterized by common genera like Watznaueria, Rectecapsa, Cribrasperaerella, Chiastozygus, Lithophidites, Micula, and Microhrabudus. The common dominating presence of Watznaueria barnesae, and the lack or low amount of cold or cooler water species like Ahmuellerella octoradiata, Gartnerago spp., Kamptnerius magnificus, and Arkhangelskiella cymbiformis (e.g., Lees, 2002; Thibaut & Gardin, 2006, 2010; Thibaut et al., 2015) attests to a fully marine, warm-water, low-latitude Tethysian oceanic environment.

Nannofossil biostratigraphy is based on assemblages by Perch-Nielsen (1985) and Burnett (1998). Samples from lower part of the Mazidaği section indicate an upper Campanian age throughout, with zones CC22-CC23a (Perch-Nielsen, 1985) and UC15de-UC16 (Burnett, 1998), respectively. The main nannofossil markers include Arkhangelskiella cymbiformis, Broinsonia parca parca and Broinsonia parca constricta (not found in all samples, Figs. 6-7), Ceratolithoides aculeus, Quadrum gothicum, Reinharttites levis, Tranolithus orionatus, Uniplanarius sissinghii, and Uniplanarius triditus. Biostratigraphic zone interpretation relies on the presence of both B. parca subspecies (last occurrence LO defines top UC16/CC23a), and Uniplanarius triditus (first occurrence FO defines base of UC15d/CC22). The absence of both Reinharttites anthroporus and Eiffellithus eximius (LOs define top of UC15/CC22) is notable but may relate to the poor preservation of the nannofossils. A single broken specimen of Eiffellithus eximius in sample 19 is regarded as reworked from older sediments. In addition, Opeculodinella operculata is present in most of the samples.

Samples from uppermost part of the Mazidaği section in principle show the same assemblage and marker species, with B. parca parca, B. parca constricta and Uniplanarius triditus, and thus are still in zones CC22-CC23a (Perch-Nielsen, 1985) and UC15de-UC16 (Burnett, 1998). The uppermost nannofossil sample of the section, sample 3, without specimens of the B. parca group, may indicate already the beginning of UC17/CC23b around the uppermost Campanian - lowermost Maastrichtian boundary (e.g., Burnett, 1998; Wagreich et al., 2009). However, the planktonic foraminifera data (see below) argues against such an interpretation. Also, additional samples from isolated outcrops around Mardin yielded an upper Campanian age, mostly CC22/23a and UC15de-UC16, and no indication of younger biostratigraphic ages.

**PLANKTONIC FORAMINIFERA**

Obtaining a precise distribution of the chronologically significant taxa made several resampling campaigns in the field necessary to supplement the information between significant samples. As a result of this procedure, the around 120 m-thick composite section was investigated with 40 samples. The graphic section logs (Figs. 6-7) are compiled from different sections at different scales, therefore these figures present sample-based correlation not scale-based correlation.

Planktonic foraminifera are mainly scattered occurrences and are low to moderately abundant assemblages along the section. Heterohelicids, muriocohedbergelids, and macroglobigerinellids are consistently present in substantial numbers, whereas the distribution of globotruncanids is more discontinuous throughout the section (Figs. 6-7). The globotruncanids are mainly represented in the low to moderately abundant assemblages including such as Contusotruncanita fornicata, G. bulloides, G. lapparenti, G. linneiana, G. orientalis, G. rosetta, G. ventricosa, Globotruncanita stuartiformis, and Radoetruncanita calcarata throughout the section (Figs. 6-7).

Although the marker species are in scattered occurrences, the conspicuous species found throughout this section and the LO and HO of R. calcarata define the temporal limits of the Radoetruncanita calcarata Zone (Wagreich et al., 2012). This zone is correlative with the lowermost part of the upper Campanian (Gradstein et al., 2012). In addition to this marker species, the presence of Globotruncanita ventricosa, Globotruncanita havanensis and Planoglobulina sp. supports the same chronostratigraphic interval (Figs. 6-7) (Gradstein et al., 2012). Finally, the combination of these taxa provides a possible middle upper Campanian interval.
In principle, the *Radotruncana calcarata* zone correlates globally to the UC15d/CC22 nannofossil zone (Wagreich et al., 2012). The nannofossils in the uppermost part of the section may already belong to UC16, although this is unlikely due to the continuous presence of *R. calcarata*. However, there may be a possible shift in the biozone calibration between planktonic foraminifera and nannofossils, related to the poor preservation of nannofossils and the possibility of reworking. Following the arguments for the *Radotruncana calcarata* zone, the section represents a short time interval of about 800 ka around 74 to 75 Ma (Wagreich et al., 2012).

**PLANT FOSSILS**

Fossil plant remains are fragments of shoots and leaves of a conifer assigned to the Araucariaceae. The plant remains are quite well preserved even showing details of cuticle, which indicates its clear affinity to the above-mentioned family. Araucarians are typically southern hemisphere conifers (Farjon, 2010). They are also well represented in the Mesozoic of the Southern Hemisphere (Krassilov, 1978; Andrichow-Colombo et al., 2018; for more details see Kvaček et al., 2019). However, in Jurassic and Cretaceous they occurred also in the Euro-Asian area (Bayer, 1983; Dolidenko & Orlovskaya, 1976; Harris, 1979; Stockey, 1980a, 1980b, 1982; Barale, 1981; Stockey et al., 1992, 1994; Ohsawa et al., 1995; Jung, 1996; Wang et al., 2006; Kunzmann, 2007a, 2007b). The plant fossils recovered from the Mazıdağı section (samples 10-14) were described in a separate study as *Araucaria rothwellii* (Kvaček et al., 2019).

Based on macro- and micro-morphology *Araucaria rothwellii* was compared with 28 fossil species (Kvaček et al., 2019). It is most similar to *A. leifepanensis* from the Maastrichtian of Patagonia (Andrichow-Colombo et al., 2018), from which it differs in lacking a pronounced keel on the abaxial side of the leaf and attenuate leaf apices (Kvaček et al., 2019). Among modern species of *Araucaria*, the studied material is most similar to *Araucaria bidwillii*, which is the only representative of the Section *Bunya* growing in Queensland of North East Australia. It shows similar leaf morphology and arrangement of stomata (Stockey & Taylor, 1978).
Paleoecological remarks: Plant fossils occurring in marine sediments are of completely allochthonous origin. However, they indirectly represent vegetation and paleoclimate occurring on nearby dry land. In the studied outcrop five specimens assigned to a new species *Araucaria rothwellii* were excavated (KVAČEK et al., 2019). All species of *Araucaria* have prevailing distribution in the low mid-latitudes (KRASSILOV, 1978; KERSHAW & WAGSTAFF, 2001), in mesothermal to microthermal climates (PANTI et al., 2012). The studied material indicates that *Araucaria* was a common conifer of the northern Gondwana mesophytic vegetation. *A. rothwellii* represents a broad-leaved species that probably grew in more humid environments, while araucarioid plants with imbricate leaves of *Brachyphyllum obesum* type grew in more xeric areas (compare KVAČEK et al., 2018). Broad-leaved Araucariaceae are present in the Lower Cretaceous of Lebanon (POINAR & MILKI, 2001). The appearance of wood fiber inclusions, and spectroscopic studies of amber argue for Araucariaceae as sources of the Myanmar Albian-Cenomanian amber (POINAR et al., 2007).

The genus *Araucaria* is an important indicator of paleoenvironments (KRASSILOV, 1978). Therefore, closer identification of the fossil is helpful for more precise paleoenvironmental interpretations. Based on comparison of macro- and micro-morphology KVAČEK et al. (2019) concluded that the species is most similar to *Araucaria bidwillii*. *A. bidwillii* grows in tropical rainforests in North East Australia where the annual rainfall is greater than 1000 mm (FARJON, 2010). The species is able to tolerate temperatures ranging from -4°C to 40°C (HUTH, 2002). These climatic variables support paleoecological interpretations of a Campanian paratropical humid to sub-humid climate in the area where *A. rothwellii* occurred.

6. Geochemistry

STABLE ISOTOPES

Carbon isotope values range between a minimum of 0.57 ‰ and a maximum of 1.92 ‰ and δ18O values range between -4.23 ‰ and -3.45 ‰ (Appendix 1). Stable isotope analyses reveal that carbon and oxygen isotope values are not greatly affected by diagenesis. Cross plots of the values indicate a trend line with no correlation with $R^2 = 0.281$ (Fig. 8).
The carbon isotope curve displays a negative shift in the lower-mid part of the section of about 1.5 per mil change (sample 19), and then it turns into a positive shift with more than 0.5 per mil in the upper part of the section (Fig. 9). It stabilizes and then displays a negative shift at the top of the section. However, oxygen isotopes display a relatively smooth curve but fluctuate between narrow values. It has a 0.5 per mil shift in the upper part of the section (Fig. 9). This shift coincides with positive shift of the carbon isotope curve. The isotope curves are divided into 4 intervals to better correlate the minor details in between (Fig. 9). In interval one at the bottom of the section, both curves display a similar pattern, but carbon isotope values tend to decrease towards relatively more negative values. Both curves present a 0.5 per mil negative shift at the bottom of the section. In interval two, oxygen isotope values fluctuate with 0.5 per mil and the curve displays a relatively smooth pattern. However, carbon isotope values change by more than 2 per mil; the curve shows a positive shift at the bottom of interval two and above it is a negative shift of more than 2 per mil at the top of the interval (Fig. 9).

In interval three, a positive carbon isotope shift of around 1 per mil is at the bottom and above it fluctuates around 0.5 per mil. However, oxygen isotopes present a negative shift with 0.5 per mil at the bottom and then display a positive 0.5 per mil shift at the top of the section. In interval four, both curves are relatively smooth at the bottom and mid parts of the interval. However, at the top of the interval a negative carbon shift is about 1 mil (Fig. 9). The oxygen curve varies about less than 0.5 per mil.

**ELEMENTAL GEOCHEMISTRY**

Generally, the oxide elements from bulk rock samples correspond to changes in isotope curves but at different magnitudes. Fluctuations in values of CaO, FeO, SiO₂, Al₂O₃, MgO, Na₂O, MnO, TiO₂, P₂O₅, Cd, Ba, Cu, Mo, Pb, Zn, and V throughout the section are herein used for interpretation such as Paleoproductivity (BURDIGE, 2006; TRIBOVILLARD et al., 2006; PAYTAN, 2009; LIGUORI et al., 2016), Hydrothermal and magmatic indicators (CHRISTENSEN et al., 1982; OWEN & OLIVARES, 1988; BURDIGE, 2006; DEMINA & GALKIN, 2016) and Redox indicators (BURDIGE, 2006; TRIBOVILLARD et al., 2006; McKAY et al., 2007; COLE et al., 2017; GOSWAMI et al., 2012) (Appendix 2).
Ca/Al fluctuates between 15% and 30% and displays two positive peaks in the middle part of the section. It decreases in the middle and at the top (Fig. 10). SiO$_2$ (10% to 18%) presents an opposite trend compared to CaO especially in the upper part of the section. Si/Al fluctuates between 22.5% and 28.5% (Fig. 10). Comparing Ca/Al and Si/Al curves, the lower part of the section shows an excess amount of Ca and Si compared to the upper part (Fig. 10).

However, Ti/Al and Zr/Al curves fluctuate between narrow limits and display relatively smooth curves with a small drop in the middle part (Fig. 10).

Paleoproductivity indicators like Cd/Al, Ba/Al, Fe/Al, Si/Al, P/Al, and Zn/Al (BURDIGE, 2006; TRIBOVILLARD et al., 2006; PAYTAN, 2009; LIGUORI et al., 2016) display generally different curve patterns (Fig. 12). Fe/Al shows a small fluctuation in the lower half and then slightly rises in the upper half of the section (Fig. 12). Ba/Al presents a rising trend with fluctuations in the lower half and then abruptly decreases in the middle part (Fig. 12). The pattern is similar in the upper part of the section. The Cd/Al and P/Al curves show a decreasing trend with fluctuations in the lower half of the section and a rise in the middle part (Fig. 12). The slopes of the curves decrease but fluctuate in the upper part of the section. However, the Si/Al ratio is totally different (Fig. 12). It decreases towards the middle part of the section and then becomes a slightly smooth curve in the upper half of the section. The Zn/Al curve displays a similar pattern to P/Al but abruptly rises in the middle part, followed by a slight decrease and a rise towards the top of the section.

Hydrothermal and magmatic indicators include Cr/Al, Co/Al, Cu/Al, Pb/Al, V/Al, Zn/Al, and Co/Al (CHRISTENSEN, 1982; OWEN & OLIVAREZ, 1988; BURDIGE, 2006; DEMINA & GALKIN, 2016). Each of these values decrease slightly in the lower half and then tend to rise in the upper half of the section (Fig. 13). Cr/Al presents a rising trend from bottom to top of the section with a gentle slope (Fig. 13). The V/Al curve indicates a slight decrease in the lower half of the section and then rises in the middle part of the section (Fig. 13). But it displays a relatively smooth curve with small fluctuations at the top of the section, resembling the Co/Al curve in a general pattern. The Pb/Al curve is very similar to that of Zn/Al (Fig. 13). The Cu/Al curve is nearly smooth with slight fluctuations in the lower part of the section.
Figure 8: Cross plot of C and O stable isotope values of the Bozova Formation, Mazıdağı section. Units are per mil.

It then abruptly rises in the middle part of the section (Fig. 13) and slightly rises with fluctuations in the upper part.

Redox indicators include Mo/Al, Mn/Al, TOTS, U/Al, and Mn/Al (Burdige, 2006; Tribovillard et al., 2006; McKay et al., 2007; Goswami et al., 2012; Cole et al., 2017). They decrease slightly in the lower half and increase in the upper half of the section (Fig. 14). TOTS values present a highly fluctuating pattern with higher values in the lower part of the section and decrease abruptly in the middle part (Fig. 14). In the upper half of the section, it shows high values also but the magnitude and frequency of the fluctuations are less than in the lower part. U/Al is relatively enriched in the lower part (Fig. 14). The Mo/Al curve displays high values and rising trend in the lower part and then an abrupt decrease in the middle part, whereas in the upper part of the section it has very low values and a relatively smooth curve. The Mn/Al curve decreases into the middle part and increases into the upper part (Fig. 14).

7. Discussion

The Campanian section in the region of SE Turkey has been studied for the first time in detail and with high-resolution. Paleoclimatological and paleoceanographical implications are detected from proxy data. Previous biostratigraphic studies in the region presented a lower resolution (Coruh et al., 1997). In the abundant plant fossil fragment zone in the studied section, the species are not diverse and physically not well preserved. Ammonite and inoceramid fossils were recorded for the first time in the study area. However, we were not able to identify the species for independent contribution to this study but will be presented in a future project.
Figure 9: C and O stable isotope curves of the Bozova Formation, Mazıdağı section. Numbered rectangular boxes refer to interval divisions. Units for C and O isotope values are per mil. Lithostratigraphic column is generalized for sample and facies comparison.
The δ¹³C and δ¹⁸O values do not appear to be strongly altered diagenetically by either the water-rock interaction or deep burial diagenesis (Hoefs, 2009; Bishop et al., 2014). Three main parts in the curve can be compared with the European (Jarvis et al., 2002) and Chinese carbon isotope curves (Li et al., 2006). The LCE in this section displays relatively a smaller magnitude compared to European curves. This may be related to first approach and lower resolution sampling of the LCE. Total thickness of the section is 119.25 m, which is a bit thicker than European sections. Voigt et al. (2010) indicated a Late Campanian Event (LCE) in the isotope curve from European shelves and the Pacific Ocean in the UC15d/e biozone. However, Perdriou et al. (2015) indicated the position of the LCE in UC15c in the North Sea. According to Chenot et al. (2016) the LCE is observed in the UC15d/e biozone in Paris Basin, Wagreich et al. (2012) reported the LCE directly above the Radotruncana calcara Zone in northwestern Tethys (Wagreich et al., 2012). Although, the position of this event is still not fully constrained, its relation to the Radotruncana
calcarata Zone and UC15cde is evident. Slight variations may be also due to regional and locally variable carbon isotope budgets but may also relate to lithostratigraphic/facies/diagenetic control/mask for the biostratigraphic appearance of the species in the stratigraphic section. The biozones in this study display the *Radotruncana calcarata* Zone and UC15cde, and the *Gansserina gansseri* Zone is not recorded here as in European sections. In addition to this, Voigt et al. (2010) indicated an "inoceramid acme" in the Maastrichtian of the Pacific Ocean. This study also found a regional inoceramid acme, but in a significantly lower biostratigraphic position, and it is not a real acme zone, but a kind of locally increased relative abundance. But its position is a subject of another study.
8. Conclusions

The studied Upper Cretaceous pelagic succession in the Mardin-Mazidag area, SE Turkey on the Arabian Platform displays the lithological, chemical and paleontological characters of late Campanian oceanographic and climatic changes. The interbedded black shale, marl and clayey limestone, stable isotope changes, abundance of certain fossil groups at particular positions in the section exhibit considerable parallel fluctuations. Biostratigraphic investigations indicate the planktonic foraminifer *Radotruncana calcarata* Zone and the calcareous nannofossil zones UC15d and CC22 at around 74-75 Ma. Stable isotopic and elemental compositions display different patterns in lower, middle and upper parts of the section. The isotope curves are divided into four different intervals in the succession.
Each interval has its own characteristic features and potentially enable correlation with other successions. Carbon isotope excursions up to more than 2 per mil indicate that an oceanographic event is recorded in the carbon isotope curve in this succession. Productivity proxy elements indicate two relatively increasing trends in productivity, one in the lower part and the second in the middle part of the studied composite section. In the upper part productivity relatively decreased in general. Redox proxy elements reveal that the lower part of the section was more dysoxic/anoxic compared to the upper part. This coincided with the occurrence of black shales in the lower part and with a negative shift in the carbon isotope curve.
Figure 15: Comparison of the carbon stable isotope curve of the Bozova Formation, Mazıdağı section with UK (Jarvis et al., 2002) and China sections (Li et al., 2006). Green and yellow boxes and arrows are for comparison of rising and falling trends in different levels in isotope curves in between different regions. The red line indicates the position of the peak of the isotope excursion in the Late Campanian event.

Excess amounts of Ca/Al and Si/Al in the lower part of the section may support this interpretation of bottom waters oxygen. The Ti/Al, Zr/Al, TiO_2, and Zr curves indicate relatively more sediment influx compared to the lower part. Hydrothermal and magmatic proxy elements exhibit two relative rising trends in both upper and lower parts of the section. This suggests that sediment influx and volcanic/magmatic contribution might be mutually related. Proxy redox elements imply that the lower part of the section was more oxygen deficient compared to the upper part. This coincides with presence of common black shale occurrences in the lower part. Although there is slight a difference in biozones of the successions among different regions due to absence of index fossils, lithogenic and/or diagenetic controls, and local oceanographic variations, the carbon isotope curve patterns in the upper Campanian interval exhibit very similar patterns with the trends indicated by Jarvis et al. (2002, 2006) and Li et al. (2006), especially around the Late Campanian Event (Fig. 15). The carbon isotope excursions coincided with proxy element shifts and black shale occurrences in the same interval.

Oxygen and carbon isotope values display a more negative shift in intervals 3 and 4, following the Late Campanian Event (Figs. 10, 15). This shift can be linked to large scale palaeoclimate change. The presence of fully marine, warm-water, low-latitude Tethyan oceanic conditions were revealed by nanofossils and planktonic foraminifera and a tropical humid climate condition, which were similar to present-day conditions in northeastern Australia in terms of the fossil plants. These data support a generally warm palaeoclimate in northern Arabian Platform. During the Coniacian- Maastrichtian interval the Arabian Plate was on the Boreal-tropical paleogeographic and paleoclimatic belts by presence of laterites and some coal deposits (Boucot et al., 2013). Our record supports the presence of humid and warm conditions along the Arabian Plate in the studied area. In addition to this, Suarez et al. (2013) proposed intensive rainy conditions in the Artic Cretaceous continental environments in relation to its hydrological cycles and polar warming. This record indirectly supports the widening of humid belts and warming effect on Cretaceous flora. Identification of types of plant fossils recognized in the study can be a clue about palaeovegetation around the studied area in that time and can contribute to the understanding of the possible climatic conditions. The plant taxonomy of plant fragments as constituents of the pelagic deeper-marine formation, which are studied here for the first time in Turkey, indicate a humid hinterland and intense rainfall and flooding events to transport plant remains into the studied offshore region.

Acknowledgements

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tors for their comments and suggestions that thank the anonymous referees and Carnets' editors for their comments and suggestions that significantly helped improving the original manuscript.

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### Appendix 1

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