Geological Quarterly, 2021, 65: 53
DOI: http://dx.doi.org/10.7306/gq.1622

Biostratigraphy and palaeoecology of the Dalichai Formation (Lower Cretaceous) based on calcareous nannofossils from the western Alborz Mountains (north-west Iran)

Rana SHIRI[1] and Fatemeh HADAVI[1, *]

[1] Ferdowsi University of Mashhad, Department of Geology, Faculty of Sciences, Mashhad, Iran

Shiri, R., Hadavi, F., 2021. Biostratigraphy and palaeoecology of the Dalichai Formation (Lower Cretaceous) based on calcareous nannofossils from the western Alborz Mountains (north-west Iran). Geological Quarterly, 2021, 65: 53, doi: 10.7306/gq.1622

Associate Editor: Michał Zatoń

We describe the biostratigraphy and palaeoecology of the Dalichai Formation based on calcareous nannofossils from the Guydagh section in the western Alborz Mountains, north-west Iran. The nannofossils are moderately to well-preserved, and 25 species belonging to 8 genera have been distinguished, representing the Early Berriasian to Late Hauterivian ages according to the CC1–CC4b biozones of Sissingh (1977). The recorded nannofossils are generally Tethyan and cosmopolitan, while the record of *Nannoconus inornatus*, a Boreal species, at the top of the section reflects the water mass connection between the Boreal and Tethyan domains during the Late Hauterivian. The records of *Nannoconus* spp., *Watznaueria* spp., and *Rhagodiscus asper* show that the sedimentary basin of the Dalichai Formation was located at low latitudes of the Tethyan realm with warm surface waters. Palaeoecologically, the findings represent a marine transgression and increasing depth, and the palaeoenvironmental conditions change from low-high mesotrophic (shown by the dominance of *W. britannica*) to oligotrophic (from the dominance of nannoconids), r- to K-strategy of life (from the dominance of nannoconids), and became increasingly stable (shown by the reduction of *W. britannica*) towards the top of the section.

Key words: Calcareous nannofossils, Dalichai Formation, Guydagh section, Lower Cretaceous, Tethyan and Boreal Domain, western Alborz.

INTRODUCTION

The sedimentary-structural zone of the Alborz, an E–W anticlinorium, includes the high regions of northern Iran (Aghanabati, 2004), connecting indirectly via the northwestern Khorasan Mountains to the Hindu Kush and the Pamir Plateau (Jafari, 2005). The Dalichai Formation is composed of well- to thin-bedded, greenish grey, marly, and partly sparry to sandy limestone with intercalations of marly shale (Stöcklin, 1971); it outcrops along the southern slopes of the Alborz Mountains (Aghanabati, 2004). The marine deposits of the Dalichai Formation are distinguished easily from the lacustrine/lagoonal deposits of the underlying Shemshak Formation and the overlying thick-bedded carbonate Lar Formation by its greenish-grey colour (Aghanabati, 2004). A middle-late Jurassic age has been determined based on the ammonite fauna (e.g., Erni, 1931; Lorenz, 1964; Dellenbach, 1964; Assereto et al., 1968; Stöcklin, 1971; Nabavi and Seyed-Emami, 1977; Alavi-Naini et al., 1982; Seyed-Emami et al., 1985, 1989, 1995, 2018; Schairer et al., 1991; Majidifard, 2004) and palynomorphs (e.g., Wheeler and Sarjeant, 1990; Sajadi et al., 2009; Ghasemi-Nejad et al., 2012; Dehbozorgi et al., 2013, 2018; Mafi et al., 2014; Hashemi Yazdi et al., 2018, 2020); however, the nannofossils indicate an Early Cretaceous age (Hadavi et al., 2015; Barsan Najjar et al., 2016; Shiri et al., 2019, 2020). The results described here are a continuation of nannofossil studies of the strata of the Guydagh section in the western parts of the Alborz Mountains.

MATERIAL AND METHODS

The Guydagh section (coordinates 37°16’ N, 46°16’ E) is 127 m thick and is located to the south-east of Maragheh in the western Alborz Mountains (north-west Iran) (Fig. 1). The base of the section starts with a very thin layer of siltstone which is overlain by alternations of thin layers of limestone and shale,

* Corresponding author, e-mail: fhadavi@um.ac.ir

Received: August 8, 2021; accepted: November 1, 2021; first published online: December 20, 2021

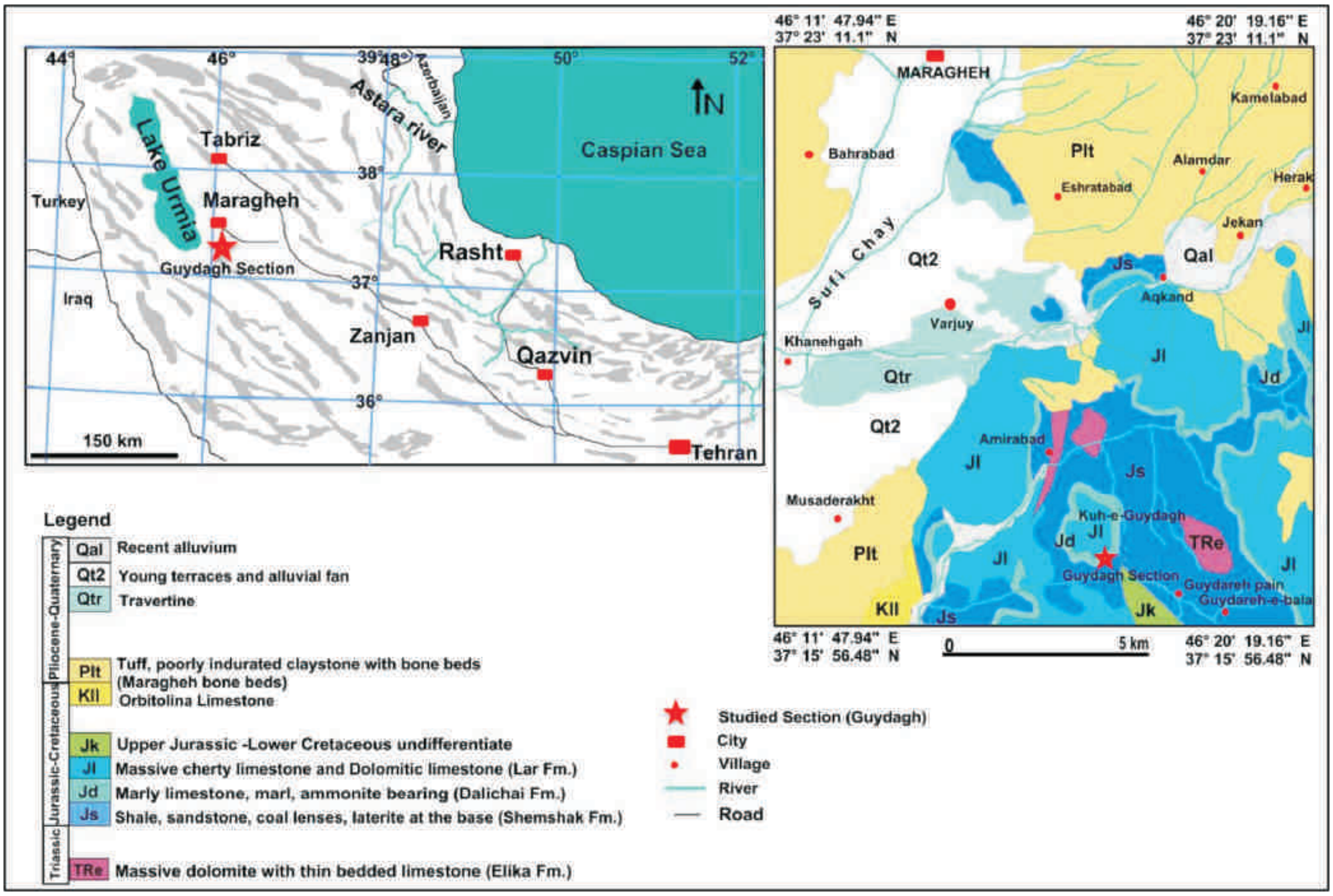

Fig. 1. Location of the Guydagh section on a geological sketch map and 1:100,000 geological map of Maragheh (Alavi-Naini and Shahrabi, 1975)

and of calcareous shale and limestone, followed by marl and alternations of limestone and calcareous shale. In the section investigated, the lower boundary of the Dalichai Formation is conformable on the Shemshak Formation, and its upper boundary is transitional to the Lar Formation. Twenty-five samples taken from the section were prepared using smear slide techniques (Bown and Young, 1998), and then were examined under a light microscope (*Olympus BX51*) equipped with gypsum and quartz plates. The biostratigraphic data obtained was interpreted using Sissingh's (1977) biozonation (Fig. 2). Images of important nannofossils are illustrated in Figures 3–5. The relative abundances (%) of the nannofossil species were counted in 20 fields of view for each sample (Appendix 1* and Fig. 6). The graphics were drawn using *Surfer* software.

RESULTS

Twenty-five species belonging to 8 genera of calcareous nannofossils were identified from the Guydagh section (Appendix 2). Most of the species identified are from two families, the Nannoconaceae and Watznaueriaceae. The most important species of the Nannoconaceae family are: *Nannoconus bucheri*, *N. circularis*, *N. cornuta, N. dolomiticus, N. globulus* subsp. *globulus*, *N. inornatus, N. kamptneri* subsp*. kamptneri*, *Nannoconus* sp. 1, *Nannoconus* sp. 2, *Nannoconus* sp. 3, *N. steinmannii* subsp*. minor* and *N. steinmannii* subsp*. steinmannii.*

The dominant species of the Watznaueriaceae family are: *Cyclagelosphaera deflandrei*, *C. margerelii*, *Watznaueria barnesiae*, *W. biporta*, *W. britannica*, *W. fossacincta* and *W. rawsonii*.

Other nannofossils identified are: *Calcicalathina oblongata*, *Discorhabdus ignotus*, *Lithraphidites bollii*, *L. carniolensis*, *Rhagodiscus asper*, and *Umbria granulosa.*

BIOSTRATIGRAPHY AND DISCUSSION

The state of preservation of the calcareous nannofossils is moderate to good in the Guydagh section. Based on the first and last occurrence of the index and associated species, the

* Supplementary data associated with this article can be found, in the online version, at doi: 10.7306/gq.1622

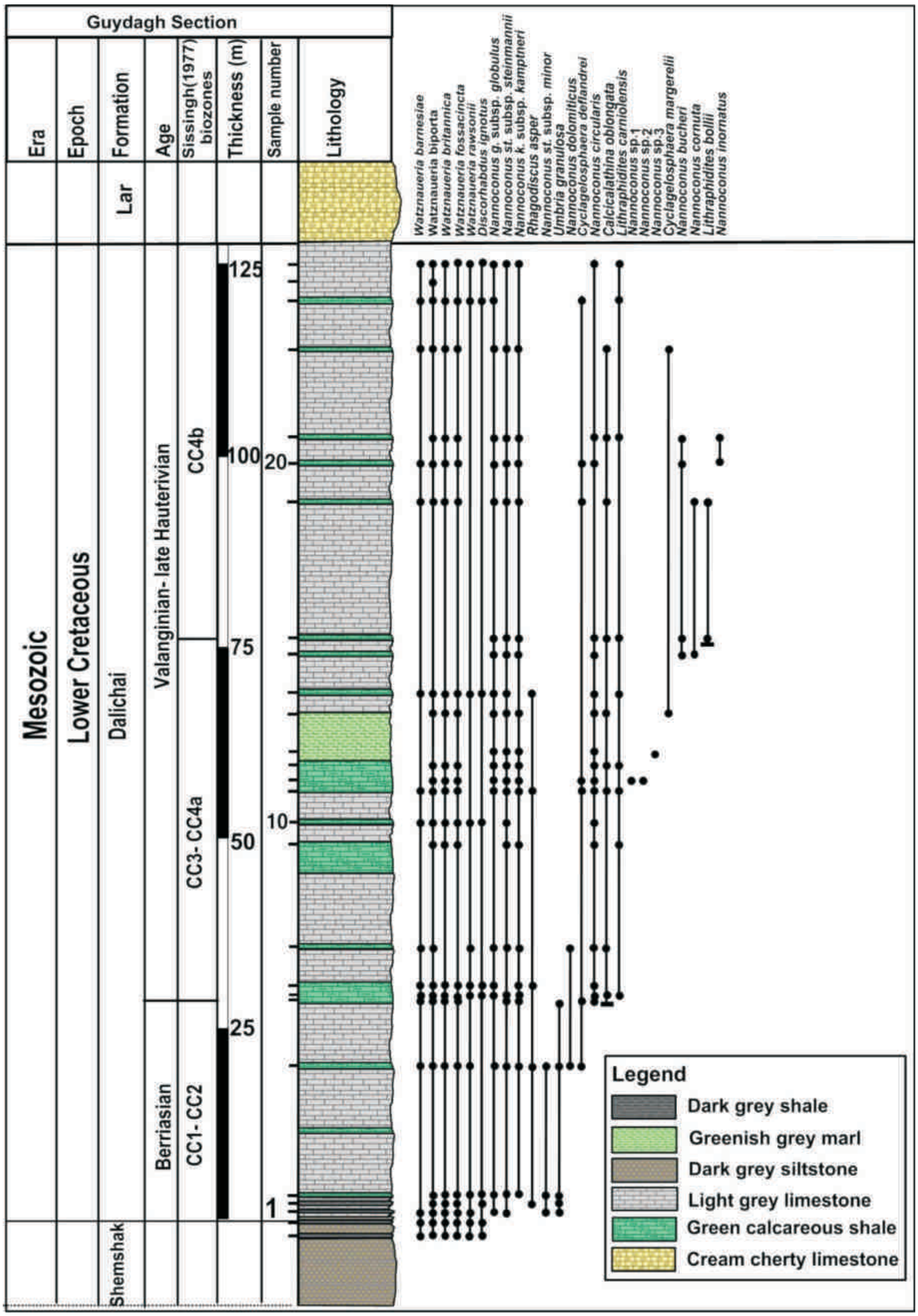

Fig. 2. Calcareous nannofossil zonation of the Dalichai Formation in the Guydagh section

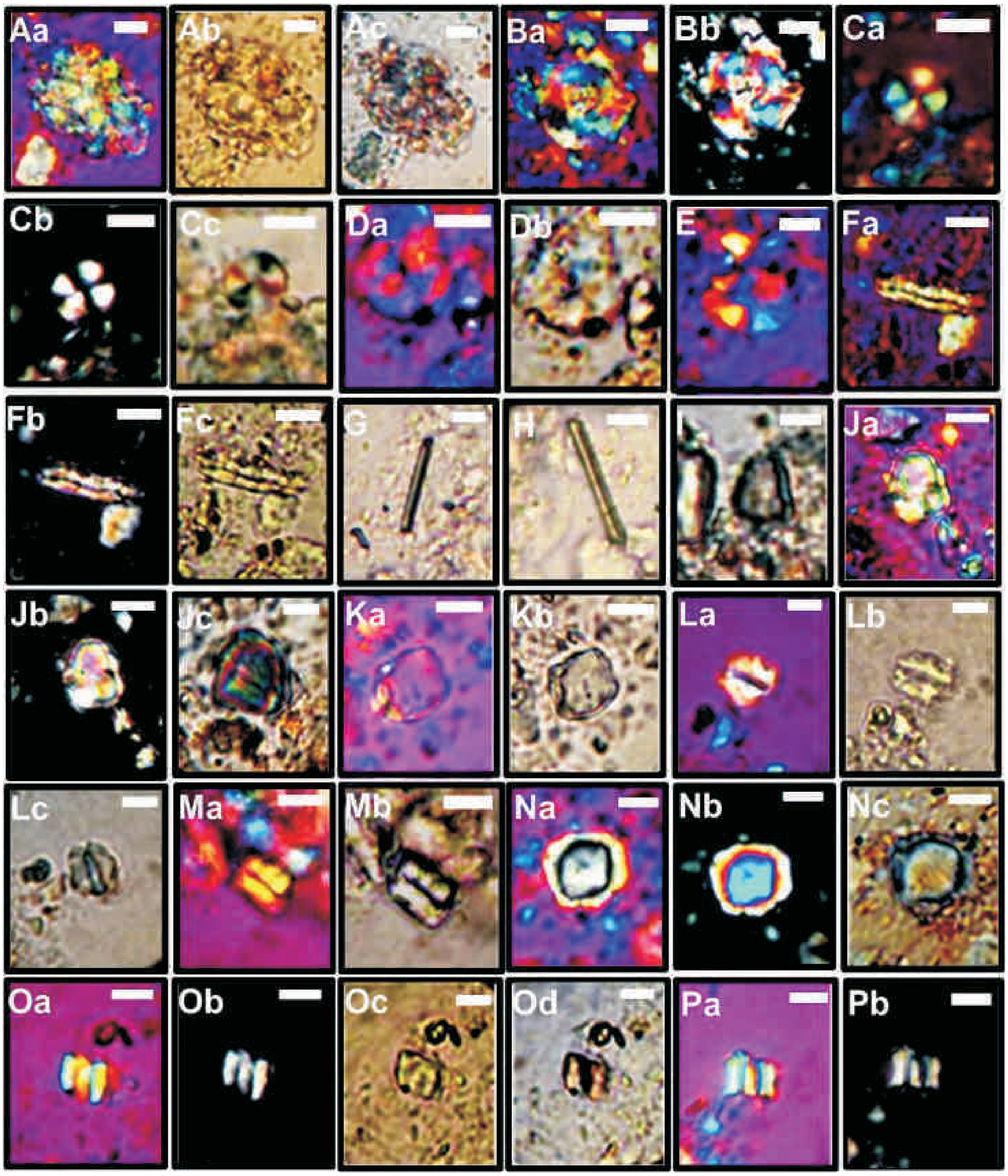

Fig. 3. Microphotographs of calcareous nannofossils from the Guydagh section (scale bars: 5 μm)

Aa–c – *Calcicalathina oblongata* (no. 5); **Ba, b** – *Cyclagelosphaera deflandrei* (no. 11); **Ca–c** – *Cyclagelosphaera margerelii* (no. 15); **Da, b, E** – *Discorhabdus ignotus* (no. 10) (proximal view), (no. 23) (distal view); **Fa–c** – *Lithraphidites bollii* (no. 4); **G, H**– *Lithraphidites carniolensis* (no. 6 and 13); **I, Ja–c** – *Nannoconus bucheri* (no. 17 and 21); **Ka, b** – *Nannoconus circularis* (no. 17); **La–c** – *Nannoconus cornuta* (no. 17); **Ma, b** – *Nannoconus dolomiticus* (no. 8); **Na–c** – *Nannoconus globulus* subsp. *globulus* (no. 13); **Oa–d, Pa, b** – *Nannoconus inornatus* (no. 20 and 21)

CC1–CC4b biozones were identified according to Sissingh's (1977) nannofossil biozonation (Fig. 2) as follows:

Nannoconus steinmannii and *Stradneria crenulata* Zone (CC1–CC2; undivided)

The CC1 biozone is defined as the interval between the first occurrence (FO) of *N. steinmannii* and the FO of *Stradneria crenulata* with a latest Tithonian to Early Berriasian age (Perch-Nielsen, 1985).

Fig. 4. Microphotographs of calcareous nannofossils from the Guydagh section (scale bars: 5 µm)

A – *Nannoconus inornatus* (no. 21); **Ba, b, Ca, b, Da–d** (top view) – *Nannoconus kamptneri* subsp. *kamptneri* (no. 17 and 12); **Fa–c** (top view) – *Nannoconus* sp.1 (no. 12); **Ga, b** (top view) – *Nannoconus* sp. 2 (no. 12); **Ha, b** (top view) – *Nannoconus* sp. 3 (no. 14); **Ia–c** – *Nannoconus steinmannii* subsp. *minor* (no. 3); **Ja–d** – *Nannoconus steinmannii* subsp. *steinmannii* (no. 3); **Ka–d** – *Rhagodiscus asper* (no. 1); **La–d** – *Umbria granulosa* (no. 1); **M** – *Watznaueria barnesiae* (no. 4)

R e m a r k s. – According to Perch-Nielsen (1985), the first appearance of *N. steinmannii* and *Lithraphidites carniolensis* indicates the base of the Cretaceous.

In the Guydagh section, the occurrence of *N. steinmannii* subsp. *steinmannii* in the first sample (~1 m from the base) and *L. carniolensis* in sample no. 6 (~30 m from the base) indicate the onset of the Berriasian.

The CC2 interval zone spans the FO of *S. crenulata* and FO of *C. oblongata* of Late Berriasian to Early Valanginian age (Perch-Nielsen, 1985).

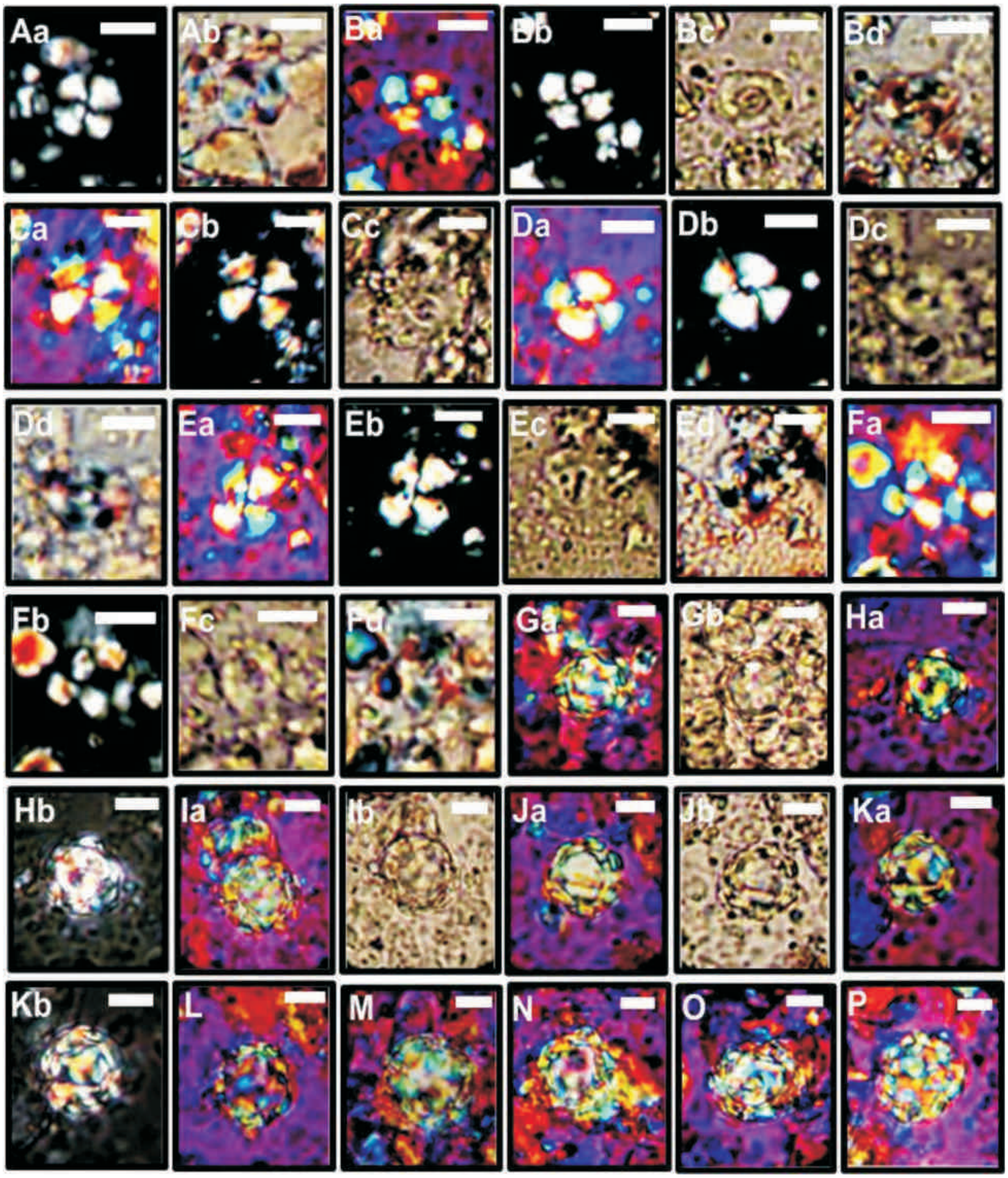

Fig. 5. Microphotographs of calcareous nannofossils from the Guydagh section (scale bars: 5 μm)

Aa, b – *Watznaueria barnesiae* (no. 4); **Ba–d** – *Watznaueria biporta* (no. 11); **Ca–c, Da–d** – *Watznaueria britannica* (no. 1); **Ea–d** – *Watznaueria fossacincta* (no. 15); **Fa–d** – *Watznaueria rawsonii* (no. 4); **Ga–P** – coccosphere

R e m a r k s. – In the Geological Time Scale 2012, the CC2 biozone is of Early to Late Berriasian age (Ogg and Hinnov, 2012).

The first presence of *C. oblongata,* showing the upper boundary of the zone, was recorded in sample no. 5 (~30 m from the base). Due to the lack of *Stradneria crenulata*, the CC1 and CC2 biozones were merged as CC1–CC2; therefore, the first 30 m of the section (alternations of shale, limestone, and calcareous shale) is attributed to a CC1–CC2 biozone and an Early Berriasian age is attributed to the base of the section.

Calcicalathina oblongata and *Cretarhabdus loriei* Zone (CC3–CC4a; undivided)

The CC3 interval zone is defined by the interval from the FO of *C. oblongata* to the FO of *Cretarhabdus loriei*, and is Late Valanginian in age (Perch-Nielsen, 1985).

R e m a r k s. – In the Geological Time Scale 2012 (Ogg and Hinnov, 2012), the FO of *C. oblongata* indicates the base of the CC3 zone, showing the beginning of the Valanginian. In the Guydagh section, the FO of *C. oblongata* indicates the beginning of the CC3 zone and the start of the Valanginian Age.

The CC4 interval zone spans between the FO of *C. loriei* and the LO of *Speetonia colligata* of the Late Valanginian to Early Hauterivian ages (Perch-Nielsen, 1985).

R e m a r k s. – *C. loriei* and *S. colligata* were not found in the samples, but according to Applegate and Bergen (1988), the FO of *L. bollii* divides the CC4 biozone into two subzones of CC4a and CC4b. They considered that the CC4a subzone is the interval from the FO of *Eiffellithus striatus* to the FO of *L. bollii,* and that the CC4b subzone is an interval from the FO of *L. bollii* to the LO of *S. colligata.*

The FO of *L. bollii* was recorded in sample no. 18 (~76 m from the base). Considering the lack of *C. loriei* and *S. colligata*, the boundary between the CC3 and CC4 biozones is not clear and these two biozones are merged as CC3–CC4a. Due to the first record of *C. oblongata* in sample no. 5 (~30 m from the base of the section), a thickness of 46 m (alternations of calcareous shale and limestone) indicates the beginning of CC4b and the beginning of the Hauterivian Age. In the present study, the interval from 76 m to the end of the section includes the CC4b biozone, comprising 50 m of alternating calcareous shale and limestone. Due to the presence of *N. inornatus* (with an age of Late Hauterivian-Barremian), a Late Hauterivian age is suggested for the upper part of this section (Fig. 2).

PALAEOECOLOGY AND CORRELATION

Thermophilic species such as *Nannoconus* spp., *Watznaueria* spp., and *Rhagodiscus asper* (Erba, 1987, 1992; Mutterlose, 1991) are common in samples from the Dalichai Formation, representing relatively warm surface water (Mutterlose et al., 2005).

Nannoconids first appeared at the Jurassic-Cretaceous boundary (Bown et al., 2004). *Nannoconus* is a major component of Tithonian-Barremian deposits (Busson and Nöel, 1991; Erba, 1994; Bersezio et al., 2002; Bornemann et al., 2003; Erba and Tremolada, 2004). Nannoconids are believed to have adapted to life below the photic zone (Erba, 1994; Herrle, 2003) (~80–200 m) and have a K-strategy lifestyle in low-turbulence environments (Mutterlose et al., 2005). They are affected by nutricline depth (Erba, 1994; Herrle, 2003). High abundances of nannoconids probably demonstrate increased productivity in the lower photic zone (Mutterlose et al., 2005). Busson and Nöel (1991) considered that nannoconids were dinoflagellate calcite cysts, grew in clean water, were inhibited by detrital input, and their abundance was inversely related to the abundance of other coccoliths because nannoconids were poisoned the surface waters, killing coccolithophores, planktonic foraminifers, radiolarians, and some benthic organisms (Erba, 1994).

Watznaueria species with an inferred r-strategy of life (Street and Bown, 2000; Lees et al., 2004) are abundant in the Guydagh section. But they are sharply reduced in the upper parts of the section, where nannoconids of K-strategy are more abundant. This lack of *Watznaueria* in the upper parts of the section may be due to the toxicity of the nannoconids. The inverse relationship between the abundance of nannoconids and *Watznaueria* species is quite evident in the abundance patterns of the Guydagh section (Fig. 6).

R. asper, W. barnesiae and *L. carniolensis* are Lower Cretaceous cosmopolitan species; in addition, *Nannoconus* spp.*, C. oblongata* and *L. bollii* are Tethyan nannofossils (Mutterlose, 1992) recorded from the Dalichai Formation.

The nannofossils identified are mainly Tethyan and cosmopolitan, but there is a considerable presence of Boreal taxa in the section. *N. inornatus* is an indicator of high latitudes (Boreal) and of Late Hauterivian age (Svobodová et al., 2011), which has been recorded in the Guydagh section. The presence of Boreal nannofossils among the Tethys realm nannofossil assemblages reflects the ancient biogeography and biological changes between the Boreal and Tethys realms. The presence of species from both realms may indicate water mass exchange between them (Vulc, 2008). The occurrence of index species from the Boreal realm in the samples from the Dalichai Formation reflects the connection between these two realms in the Early Cretaceous.

The pattern of the relative abundance of calcareous nannofossils along with the zonation of the Guydagh section is shown in Figure 6. These patterns, together with the nannofossils identified in the section studied, were used to interpret the palaeogeographical conditions of the Dalichai Formation.

There is an inverse relationship between water depth and abundance of *W. barnesiae* (Thierstein, 1976). The relative abundance of this species in the CC1–CC2 zone increases upwards in the Guydagh section, indicating decreasing water depth; then, it decreases and reaches zero, indicating increasing water depth, except for a brief decrease in depth at the top of the section.

Moreover, *N. steinmannii* subsp. *steinmannii, N. kamptneri* subsp. *kamptneri*, *N. globulus* subsp. *globulus* and *N. circularis*, with a markedly increasing upwards trend from the beginning to the end of the section, indicate increasing water depth from the base to the top of the section.

Nannofossil assemblages with a high frequency of *W. britannica* indicate marked changes in environmental conditions and a high input of detrital materials to the basin (Kędzierski, 2012). The markedly oscillating decreasing trend in the relative abundance of *W. britannica* indicates increasing stability of environmental conditions from the base to the top of the section.

Calcareous nannofossils are good indicators of surface water fertility. Two distinct groups were identified for the fertility index: a low fertility group with *Eiffelithus* spp., *Prediscosphaera* spp. and *Lithraphidites* spp., and a high fertility group with *Zeugrhabdotus* spp., *Biscutum* spp. and *Thoracosphaera saxea* (Mandur, 2016).

W. barnesiae, recorded in samples from the Dalichai Formation, is an indicator of warm temperatures and low fertility conditions (Thibault and Gardin, 2010). In the Cretaceous, the genera *Watznaueria* is considered as an indicator of oligotrophic to eutrophic fertility levels (Corbett and Watkins, 2013). In general, *W. barnesiae* prefers oligotrophic conditions and low-fertility waters (Herrle, 2003; Watkins et al., 2005; Hardas and Mutterlose, 2007). High-fertility species were not observed in the section studied, while low-fertility species such as *W. barnesiae, L. carniolensis*, and *L. bolli* did occur.

Pittet and Mattioli (2002) considered that *W. britannica* species are very abundant in low-to-high mesotrophic conditions (Kędzierski, 2012), while nannoconids show oligotrophic conditions (Mutterlose et al., 2005). Therefore, a change from

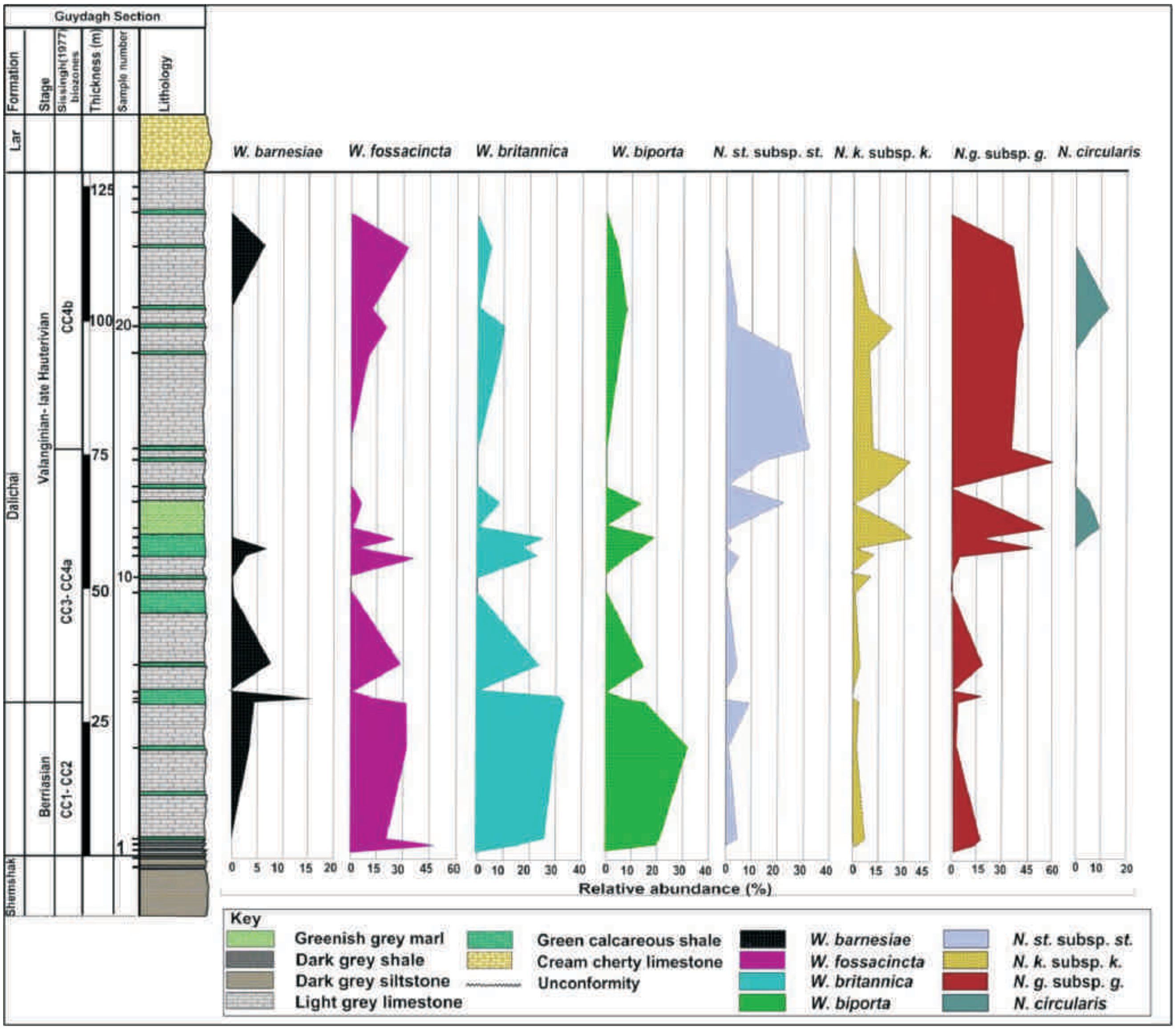

Fig. 6. The relative abundance of some common palaeogeographical index nannofossil species and the nannofossil zonation of the Guydagh section

low-high mesotrophic (due to the dominance of *W. britannica*) to oligotrophic (due to the dominance of nannoconids) conditions is suggested from the base to the top of the section.

CORRELATION OF THE GUYDAGH SECTION (WESTERN ALBORZ) WITH OTHER SECTIONS OF THE DALICHAI FORMATION IN THE EASTERN AND CENTRAL ALBORZ

The biostratigraphy of Early Cretaceous calcareous nannofossils is a useful tool for correlating oceanic successions. In addition, calcareous nannofossils are an indicator in studies of the stratigraphy and geography of oceanic environments (Bown, 1998). The most important application of biostratigraphic studies is the correlation of successions based on index fossils. Calcareous nannofossils are considered as an accurate correlating tool, due to their high rate of reproduction and diversity, high abundance, and wide distribution (Bown and Young, 1998).

Examination of 4 sections of the Dalichai Formation in the eastern (Tepal, Talu, and Lavan sections) and central Alborz (Yonjezar section) also shows an Early Cretaceous age for this formation (Shiri et al., 2020). Correlation of the Guydagh section with these 4 sections was made in this study (Fig. 7). The Lavan section was excluded from this correlation, due to lack of zonal marker nannofossils.

Calcareous nannofossils identified in the Tepal, Talu, Yonjezar, and Guydagh sections show that the sedimentation of the sequences in these sections began simultaneously in the CC1 biozone of Berriasian age. The upper parts of the Tepal, Talu, and Yonjezar sections indicate the CC5 biozone of Early Barremian age, while the uppermost Guydagh section corresponds to the CC4b biozone of Late Hauterivian age. Variations in biozone thickness indicate sedimentation rates

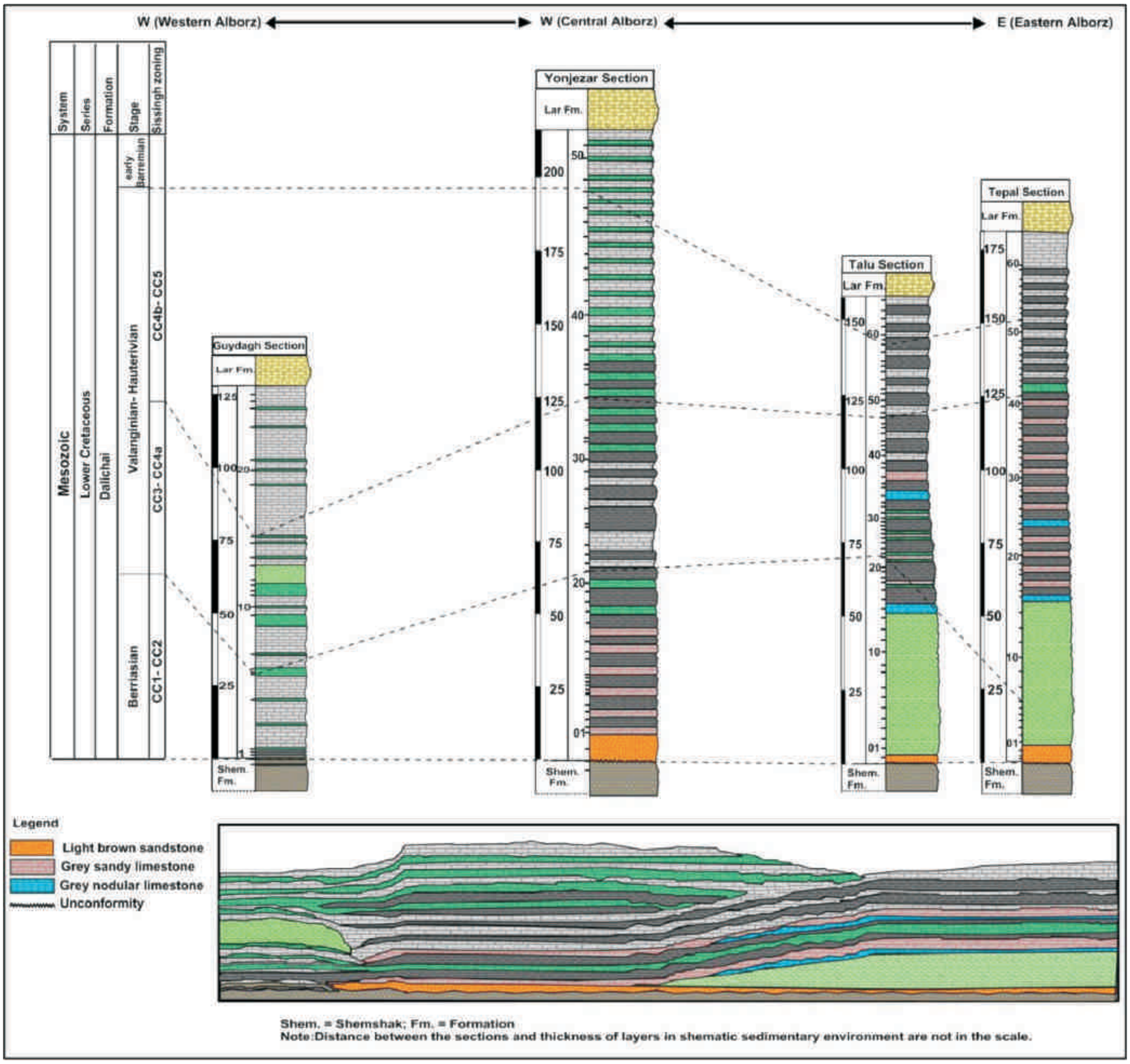

Fig. 7. Correlation of the Dalichai Formation in the western Alborz (Guydagh section) with the eastern and central Alborz sections (Shiri et al., 2020) based on calcareous nannofossils

For other explanations see Figure 2

(e.g., Kastens et al., 1987: p. 424; Reda et al., 2019). From east to west, the CC1–CC2 biozone increases in thickness and sedimentation rate from the Tepal to the Talu and Yonjezar sections and decreases in thickness and sedimentation rate from the Yonjezar to Guydagh sections. Also, the CC3–CC4a biozone shows a decrease in thickness and a decrease in sedimentation rate from the east to the west of the sedimentary basin of the Dalichai Formation. Toward the top of the Guydagh section, the thickness of the biozones shows a general increase, indicating an increase in sedimentation rate.

CONCLUSION

Calcareous nannofossils of the Dalichai Formation in the Guydagh section include 25 species belonging to 8 genera. The calcareous nannofossils identified demonstrate the CC1–CC4b biozones of Sissingh's (1977) zonation with an age of Berriasian-Late Hauterivian. Palaeogeographically, the Dalichai sedimentary basin of the Guydagh section was located at low latitudes of the Tethyan realm with warm surface water.

Palaeoecological interpretation of the formation in this section shows increasing depth and productivity and a shift from unstable to stable conditions, as well as a change from low-to-high mesotrophic to oligotrophic towards the top of the section due to a high relative abundance of *Nannoconus* spp. In general, the nannofossils recorded from the Dalichai Formation are mainly Tethyan and cosmopolitan, but the presence of the Boreal taxon *N. inornatus* reflects a connection between the Boreal and Tethyan domains in the Late Hauterivian.

Acknowledgements. M. Kędzierski and an anonymous reviewer are thanked for comments and remarks which helped to improve the final version of the manuscript.

REFERENCES

Aghanabati, A., 2004. Geology of Iran. Ministry of Industry and Mines, Geological Survey of Iran.

Alavi-Naini, M., Shahrabi, M., 1975. Geological map of Maragheh. 1:100,000 series, Sheet 5265. Ministry of Industry and Mines, Geological Survey of Iran, Tehran.

Alavi-Naini, M., Hajian, J., Ahmadi, M., Bolourchi, H., 1982. Geology of Takab-Sain-Qaleh. 1:250,000 series. Geological Survey of Iran, Report no. 50: 1–99.

Applegate, J.L., Bergen, J.A., 1988. Cretaceous calcareous nannofossil biostratigraphy of sediments recovered from the Galicia Margin, ODP Leg 103. Proceedings of the Ocean Drilling Program, Scientific Results, **103**: 293–348.

Assereto, R., Barnard, P.D.W., Fantini Sestini, N., 1968. Jurassic stratigraphy of Central Elburz. Rivista Italiana di Paleontologia e Stratigrafia, **74**: 1–21.

Barsan Najjar, M., Hadavi, F., Notghimoghadam, M., 2016. Biostratigraphy of the Dalichai Formation based on calcareous nannofossils in Ferizi section (in Persian) (ed. A. Ghaderi). In: Collection of articles of the 10th meeting of Iranian Paleontological Society, 159.

Bersezio, R., Erba, E., Gorza, M., Riva, A., 2002. Berriasian-Aptian black shales of the Maiolica formation (Lombardian Basin, Southern Alps, Northern Italy): local to global events. Palaeogeography, Palaeoclimatology, Palaeoecology, **180**: 253–275.

Bornemann, A., Aschwer, U., Mutterlose, J., 2003. The impact of calcareous nannofossils on the pelagic carbonate accumulation across the Jurassic/Cretaceous boundary. Palaeogeography, Palaeoclimatology, Palaeoecology, **199**: 187–228.

Bown, P.R., 1998. Calcareous Nannofossil Biostratigraphy. Chapman and Hall; Kluwer Academic.

Bown, P.R., Young, J.R., 1998. Techniques (ed. P.R. Bown). In: Calcareous Nannofossil Biostratigraphy. Chapman and Hall, London.

Bown, P.R., Lees, J.A., Young, J.R., 2004. Calcareous nannoplankton evolution and diversity through time. In: Coccolithophores. From Molecular Processes to Global Impact (eds. H.R. Thierstein and J.R. Young): 481–508. Springer, Berlin.

Busson, G., Nöel, D., 1991. Les nannoconidés indicateurs environmentaux des océans et mers épicontinentales du Jurassique terminal et du Crétacé inférieur. Oceanologica Acta, **14**: 333–356.

Corbett, M., Watkins, K., 2013. Calcareous nannofossil paleoecology of the mid-Cretaceous Western Interior Seaway and evidence of oligotrophic surface waters during OAE2. Palaeogeography, Palaeoclimatology, Palaeoecology, **392**: 510–523.

Dehbozorgi, A., Sajadi, F., Hashemi, H., 2013. Middle Jurassic palynomorphs of the Dalichai Formation, central Alborz Ranges, northeastern Iran: Paleoecological inferences. Science China Earth Sciences, **56**: 2107–2115.

Dehbozorgi, A., Hashemi Yazdi, F., Sajadi Hazaveh, F., 2018. Palynostratigraphy and paleoenvironmental interpretation of the Dalichai Formation, at the Pol Dokhtar stratigraphic section, central Alborz. Applied Sedimentology, **6**: 35–48.

Dellenbach, J., 1964. Contribution á létude géologique de la region située á lest de Teheran (Iran). Ph.D. Thesis, Strasbourg Universite de Strasbourg.

Erba, E., 1987. Mid-Cretaceous cyclic pelagicfacies from the Umbri an-Marchean Basin: what do calcareous nannofossils suggest? International Nannoplankton Association Newsletters, **9**: 52–53.

Erba, E., 1992. Middle Cretaceous calcareous nannofossils from the Western Pacific (Leg 129): evidence for palaeoequatorial crossings. Proceedings of the Ocean Drilling Program, Scientific Results, **129**: 189–201.

Erba, E., 1994. Nannofossils and superplumes: the early Aptian “nannoconid crisis”. Paleoceanography and Paleoclimatology, **9**: 483–501.

Erba, E., Tremolada, F., 2004. Nannofossil carbonate fluxes during the early Cretaceous: phytoplankton response to nitrification episodes, atmospheric CO_2 and anoxia. Paleoceanography and Paleoclimatology, **19**: 1–18.

Erni, A., 1931. Découverte du Bathonien fossilifére dans l’Elbourz (Perse du Nord). Eclogae Geologicae Helvetiae, **24**: 165–166.

Ghasemi-Nejad, E., Sabbaghiyan, H., Mosaddegh, H., 2012. Paleobiogeographic implications of late Bajocian-late Callovian (Middle Jurassic) dinoflagellate cysts from the Central Alborz Mountain, northern Iran. Journal of Asian Earth Sciences, **43**: 1–10.

Hadavi, F., Moheghy, M.A., Ghadamgahi, M., 2015. Nannostratigraphy of Dalichai Formation in Naviya section of Kopet-Dagh Mountain Range in Iran. Journal of Nannoplankton Research, **35**: 42.

Hardas, P., Mutterlose, J., 2007. Calcareous nannofossil assemblages of Oceanic Anoxic Event 2 in the equatorial Atlantic: Evidence of an eutrophication event. Marine Micropaleontology, **66**: 52–69.

Hashemi Yazdi, F., Sajadi, F., Hashemi, H., 2018. Palynostratigraphy of the Middle Jurassic strata of central and eastern Alborz. Stratigraphy and Sedimentology Researches, **34**: 21–36.

Hashemi Yazdi, F., Bashiri, N., Sajadi, F., 2020. Palynofacies and Sporomorph EcoGroups-based paleoecology implications for the Dalichai Formation, Andariyeh, central Alborz. Stratigraphy and Sedimentology Researches, **36**: 39–59.

Herrle, J.O., 2003. Reconstructing nutricline dynamics of mid-Cretaceous oceans: evidence from calcareous nannofossils from the Niveau Paquier black shale (SE France). Marine Micropaleontology, **47**: 307–321.

Jafari, A., 2005. Geology of Iran, mountains and mountain names of Iran (in Persian). Gitashenasi Geographical and Cartographic Institute.

Kastens, K.A., Mascle, J., Auroux, Ch., Bonatti, E., Broglia, C., Channell, J., Curzi, P., Emeis, K. Ch., Glaçon, G., Hasegawa, Sh., Hieke, W., McCoy, F., McKenzie, J., Mascle, G., Mendelson, J., Müller, C., Réhault, J.P., Robertson, A., Sartori, R., Sprovieri, R., Torii, M., 1987. Site 652: Lower Sardinian margin. Proceedings of the Ocean Drilling Program, Initial Reports, Part A, **107**: 403–598.

Kędzierski, M., 2012. Calcareous nannofossils from the Bathonian (Middle Jurassic) ore-bearing clays at Gnaszyn as palaeoenvironmental indicator, Kraków-Silesia Homocline, Poland. Acta Geologica Polonica, **62**: 421–437.

Lees, J.A., Bown, P.R., Young, J.R., Riding, J.B., 2004. Evidence for annual records of phytoplankton productivity in the Kimmeridge Clay Formation coccolith stone bands (Upper Jurassic, Dorset, UK). Marine Micropaleontology, **52**: 29–49.

Lorenz, C., 1964. Die Geologie des Oberen Karaj-Tales (Zentral-Elburz), Iran. Ph.D. Thesis, University of Zürich.

Mafi, A., Ghasemi-Nejad, E., Ashouri, A., Vahidi-Nia, M., 2014. Dinoflagellate cysts from the upper Bajocian-lower Oxfordian of the Dalichai Formation in Binalud Mountains (NE Iran): their biostratigraphical and biogeographical significance. Arabian Journal of Geosciences, **7**: 3683–3692.

Majidifard, M.R., 2004. Biostratigraphy, lithostratigraphy, ammonite taxonomy and microfacies analysis of the Middle and Upper Jurassic of northeastern Iran. Ph.D. Thesis, der Bayerischen Julius Maximilians-Universität Würzburg, Würzburg.

Mandur, M.M., 2016. Late Cretaceous calcareous nannofossil biostratigraphy and paleoecology in the Northwestern Desert, Egypt. Arabian Journal for Science and Engineering, **41**: 2271–2284.

Mutterlose, J., 1991. Das Verteilungs- und Migrationsmuster des kalkigen Nannoplanktons in der borealen Unter-Kreide (Valangin-Apt) NW-Deutschlands. Palaeontographica (B), **221**: 27–152.

Mutterlose, J., 1992. Biostratigraphy and palaeobiogeography of Early Cretaceous calcareous nannofossils. Cretaceous Research, **13**: 167–189.

Mutterlose, J., Bornemann, A., Herrle, J.O., 2005. Mesozoic calcareous nannofossils – state of the art. Paläontologische Zeitschrift, **79**: 113–133.

Nabavi, M.H., Seyed-Emami, K., 1977. Sinemurian ammonites from the Shemshak Formation of North Iran (Semnan area, Alborz). Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, **153**: 70–85.

Ogg, J.G., Hinnov, L.A., 2012. Chapter 27, Cretaceous. In: The Geological Time Scale (eds. F.M. Gradstein, J.G. Ogg, M.D. Schmitz and G.M. Ogg): 793–853. Elsevier, Amsterdam.

Perch-Nielsen, K., 1985. Mesozoic calcareous nannofossils. In: Plankton Stratigraphy (eds. H.M. Bolli, J.B. Saunders and K. Perch-Nielsen): 329–426. Cambridge University Press.

Pittet, B., Mattioli, E., 2002. The carbonate signal and calcareous nannofossil distribution in an Upper Jurassic section (Balingen-Tieringen, Late Oxfordian, southern Germany). Palaeogeography, Palaeoclimatology, Palaeoecology, **179**: 71–96.

Reda, E.I., Gammal, M.H., Orabi, H., 2019. Coniacian-late Campanian planktonic events in the Duwi Formation, Red Sea Region, Egypt. Journal of Geology and Geophysics, **7:** 2.

Sajadi, F., Hashemi, S.H., Hashemi, F., 2009. Miospores-based palynostratigraphy of the Dalichai Formation at the Balu Section, North of Semnan (In Persian). Iranian Journal of Geology, **3**: 59–68.

Schairer, G., Seyed-Emami, K., Zeiss, A., 1991. Ammoniten aus der oberen Dalichai-Formation (Callov) östlich von Semnan (SE-Alborz, Iran). Mitteilungen Bayerischer Staatssammlung für Paläontologie und historische Geologie, **31**: 47–67.

Seyed-Emami, K., Schairer, G., Bolourchi, M.H., 1985. Ammoniten aus der unteren Dalichy-Formation (oberes Bajocium bis unteres Bathonium) der Umgebung von Abe-Garm (Avaj, NW–Zentraliran). Zitteliana, **12**: 57–85.

Seyed-Emami, K., Schairer, G., Alavi-Naini, M., 1989. Ammoniten aus der unteren Dalichai-Formation (Unterbathon) östlich von Semnan (SE-Alborz, Iran). Münchner Geowissenschaftliche Abhandlungen, A, **15**: 79–91.

Seyed-Emami, K., Schairer, G., Zeiss, A., 1995. Ammoniten aus der Dalichai-Formation (Mittlerer bis Oberer Jura) und der Lar - Formation (Oberer Jura) N Emamzadeh – Hashem (Zentralalborz, Nordiran). Mitteilungen der Bayerischen Staatssammlung für Paläontologie und Historische Geologie, **35**: 39–52.

Seyed-Emami, K., Raoufian, A., Zand-Moghadam, H., 2018. Late Bajocian and Bathonian (Middle Jurassic) ammonites from the Dalichai Formation north of Damghan (Alborz, North Iran). Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, **288**: 183–203.

Shiri, R., Hadavi, F., Sajadi Hazaveh, F., 2019. Biostratigraphy of the Dalichai Formation based on calcareous nannofossils in eastern Tethys Ocean (Tepal Section) (in Persian). Journal of Oceanography, **10**: 81–88.

Shiri, R., Hadavi, F., Sajadi Hazaveh, F., 2020. Biostratigraphy and palaeoenvironmental interpretation of the Dalichai Formation (Lower Cretaceous) in the eastern and central Alborz Mountains (North Iran) based on calcareous nannofossils. Geological Quarterly, **64** (3): 641–657.

Sissingh, W., 1977. Biostratigraphy of Cretaceous calcareous nannoplankton. Geologie en Mijnhouw, **56**: 37–65.

Stöcklin, J., 1971. Stratigraphic Lexicon of Iran, Part E: Central, North and East Iran. Geological Survey of Iran, Report no. 18.

Street, C., Bown, P.R., 2000. Palaeobiogeography of Early Cretaceous (Berriasian-Barremian) calcareous nannoplankton. Marine Micropaleontology, **39**: 265–291.

Svobodová, M., Švábenická, L., Skupien, P., Hradecká, L., 2011. Biostratigraphy and paleoecology of the Lower Cretaceous sediments in the Outer Western Carpathians (Silesian Unit, Czech Republic). Geologica Carpathica, **62**: 309–332.

Thibault, N., Gardin, S., 2010. The calcareous nannofossil response to the end-Cretaceous warm event in the Tropical Pacific. Palaeogeography, Palaeoclimate, Palaeoecology, **291**: 239–252.

Thierstein, H.R., 1976. Mesozoic calcareous nannoplankton biostratigraphy of marine sediments. Marine Micropaleontology, **1**: 325–362.

Vulc, A.M., 2008. Lower Cretaceous calcareous nannofossils from the Southern Apuseni Mountains, Romania. Studia UBB Geologia, **53**: 5–11**.**

Watkins, D.K., Cooper, M.J., Wilson, P.A., 2005. Calcareous nannoplankton response to the Late Albian oceanic anoxic event 1d in the western North Atlantic. Paleoceanography, **20**: 1–14.

Wheeler, J.W., Sarjeant, W.A.S., 1990. Jurassic and Cretaceous palynomorphs from the central Alborz Mountains, Iran: their significance in biostratigraphy and palaeogeography, Modern Geology, **14**: 267–35.