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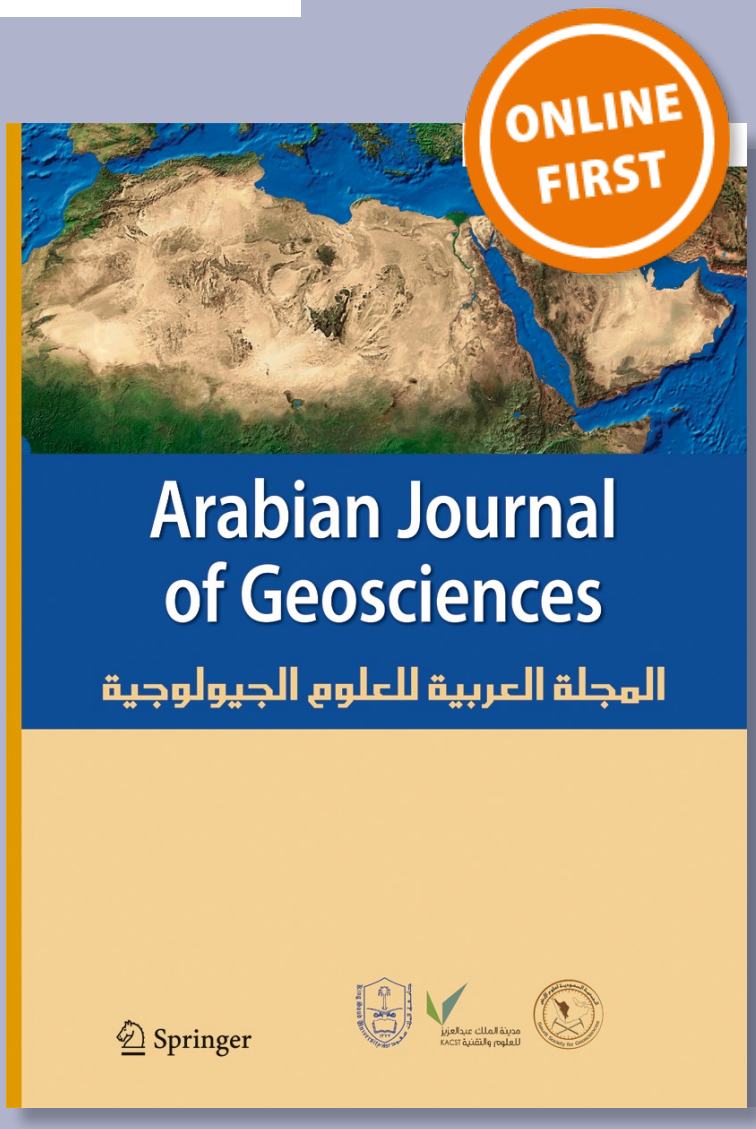

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ORIGINAL PAPER

Dinoflagellate cysts from the Upper Bajocian–Lower Oxfordian of the Dalichai Formation in Binalud Mountains (NE Iran): their biostratigraphical and biogeographical significance

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Abstract The Binalud Mountains of NE Iran represent the easternmost extension of the Alborz Range. After the Mid-Cimmerian orogenic event and rapid subsidence, the deep marine sediments of the Dalichai Formation were deposited. A well-preserved section of the formation was sampled for palynological purposes. The study revealed diverse and nearly well-preserved dinoflagellate cyst assemblages. Thirty-six dinoflagellate cyst species identified lead to identification of four biozones: *Cribroperidinium crispum* (Late Bajocian), *Dichadogonyaulax sellwoodii* (Bathonian to Early Callovian), *Ctenidodinium continuum* (Early to Late Callovian), and *Ctenidodinium tenellum* (Early Oxfordian) biozones. The close similarities of dinoflagellate cyst assemblages between Binalud Mountains, NE Iran, with those of Alborz Mountains (Northern Iran) during Middle Jurassic confirm the connection between two sedimentary basins during this time in Iran. Meanwhile, this biozonation corresponds largely to that established in Northwest Europe and reveals the marine connection between NE and North of Iran with Northwest Europe and the Northwestern Tethys during the Late Bajocian to Early Oxfordian.

Keywords Dinoflagellate cysts · Late Bajocian–Early Oxfordian · Binalud Mountains · Iran

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Introduction

A sequence of Jurassic marine strata, the Dalichai Formation, has been selected and sampled for palynological studies to conclude regarding age, stratigraphy, and palaeobiogeographic implications. The NE mountains of Iran, including the Kopeh-Dagh and Aladagh-Binalud deformation domains, comprise the northeastern boundary of the Iranian–Eurasia collision zone (Shabanian et al. 2010). The Binalud Mountains represent the easternmost extension of the Alborz Range (Seyed-Emami and Schairer 2011). Like other sedimentary basins of Iran, Jurassic strata are well exposed and preserved in the Binalud Mountains. After the Mid-Cimmerian Event, a renewed phase of rapid subsidence occurred across all of Northern Iran from the Late Bajocian onwards (Wilmsen et al. 2009), and subsequently deep marine sediments of the Dalichai Formation were deposited.

Petrology and geochemistry of the Binalud Basin have been discussed in some detail (Majidi 1981, 1983), while its tectonostratigraphy is studied comprehensively (Alavi 1979, 1991, 1992). Meanwhile, systematic studies on stratigraphy and ammonite contents of the Jurassic succession of the Binalud Mountains began in the 1990s as a part of the ongoing Iranian–German collaboration and resulted in a number of publications (Seyed-Emami et al. 1998; Schairer et al. 1999; Taheri et al. 2009; Wilmsen et al. 2009).

The present study shows that the Dalichai Formation is rich in terrestrial (spores and pollen grains) and marine palynomorphs (dinoflagellate cysts, acritarchs, and scolecodonts) and deals only with dinoflagellate cysts recovered from the formation.

Geological setting

The section studied is located close to Fraizi village some 60 km northwest of Mashad (coordinates, E 58° 58′ 11.3″

and N 36° 29′ 52.7″, Fig. 1) and contains the Dalichai Formation under study here. The formation is a lithostratigraphically outstanding unit in the Binalud Mountains where it disconformably overlies the Upper Triassic to Lower–Middle Jurassic of the Shemshak Group (Seyed-Emami and Schairer 2011) and is in turn overlain by the massive and cliff-forming carbonates of the Lar Formation with a transitional boundary. The formation, with a thickness of 540 m, has been differentiated to some rock unit; the basal 215 m is composed of an alternation of gray shale and marl with abundant nodules and a few ammonites and bivalves, followed by 37 m of thick-bedded buffy sandstone with sedimentary structures (cross beds and graded bedding) and trace fossils (Zoophycus and Palaeodictyon) which are overlain by 153 m of alternations of dark gray shale and gray-greenish gray marl with intercalations of fine grain siltstone and calcareous siltstone in the upper part. This member contains some ammonites and sedimentary structures (cone-in-cone structures) and nodules. The remaining 35 m of the upper part is composed of greenish gray marl and gray shale with intercalations of thin-bedded light limestone with a few ammonites.

Methods and materials

Forty-eight rock samples were collected systematically from the formation under study and prepared in the palynology laboratory of the Geological Survey of Iran (Northeast Territory). The preparation method of Traverse (2007) was used. Cold hydrochloric (20 %) and hydrofluoric acids were used to dissolve carbonates and silicates, respectively. The residue was neutralized and centrifuged in $ZnCl_2$ with specific gravity (1.9 g/cm^3). The materials were then sieved using a 15-μm nylon mesh and mounted on microscope slides using liquid Canada balsam (Ghasemi-Nejad et al. 2012). Three slides were made from each sample and examined with a

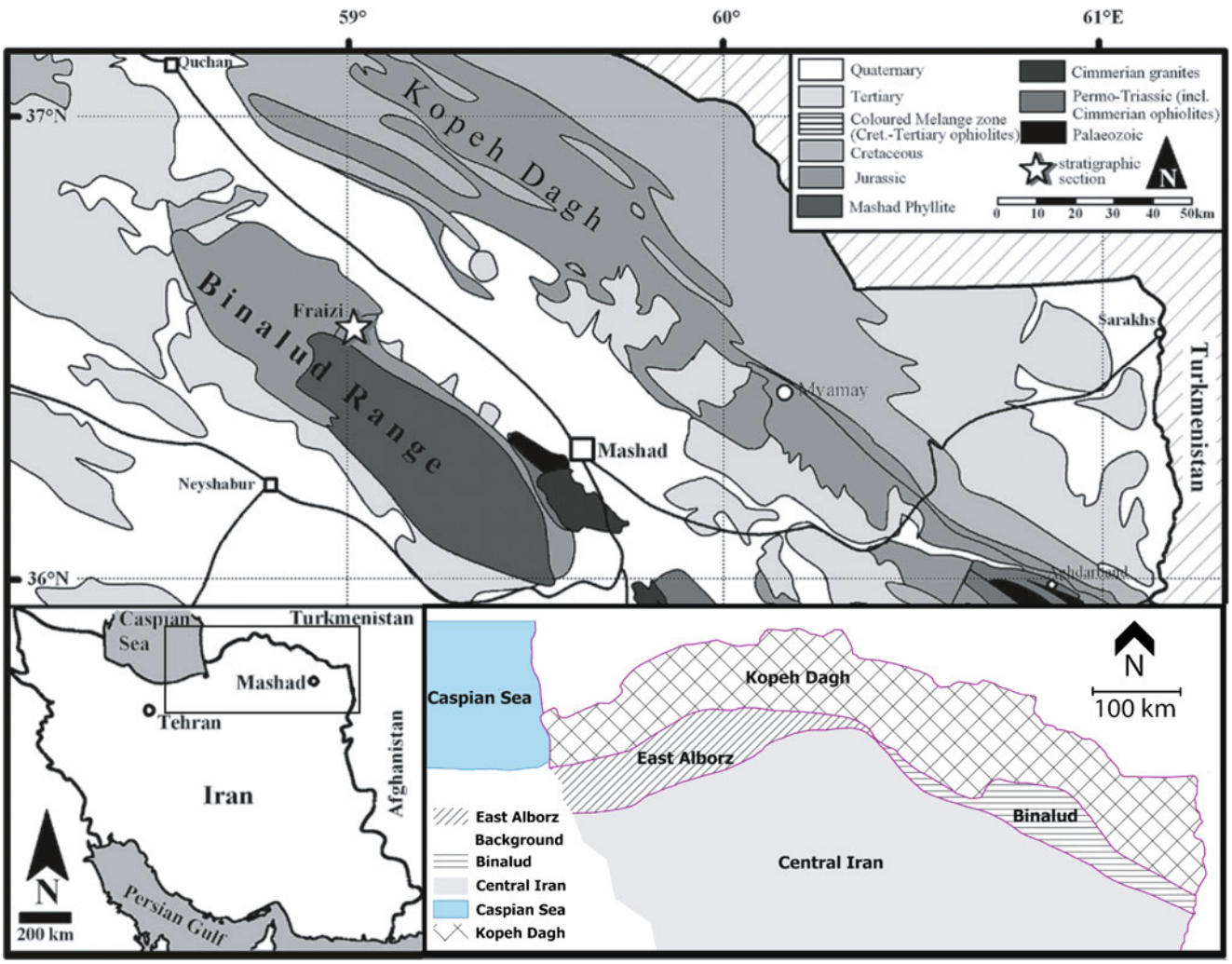

Fig. 1 Geographic overview showing the position of the Fraizi section (redrawn from Wilmsen et al. 2009)

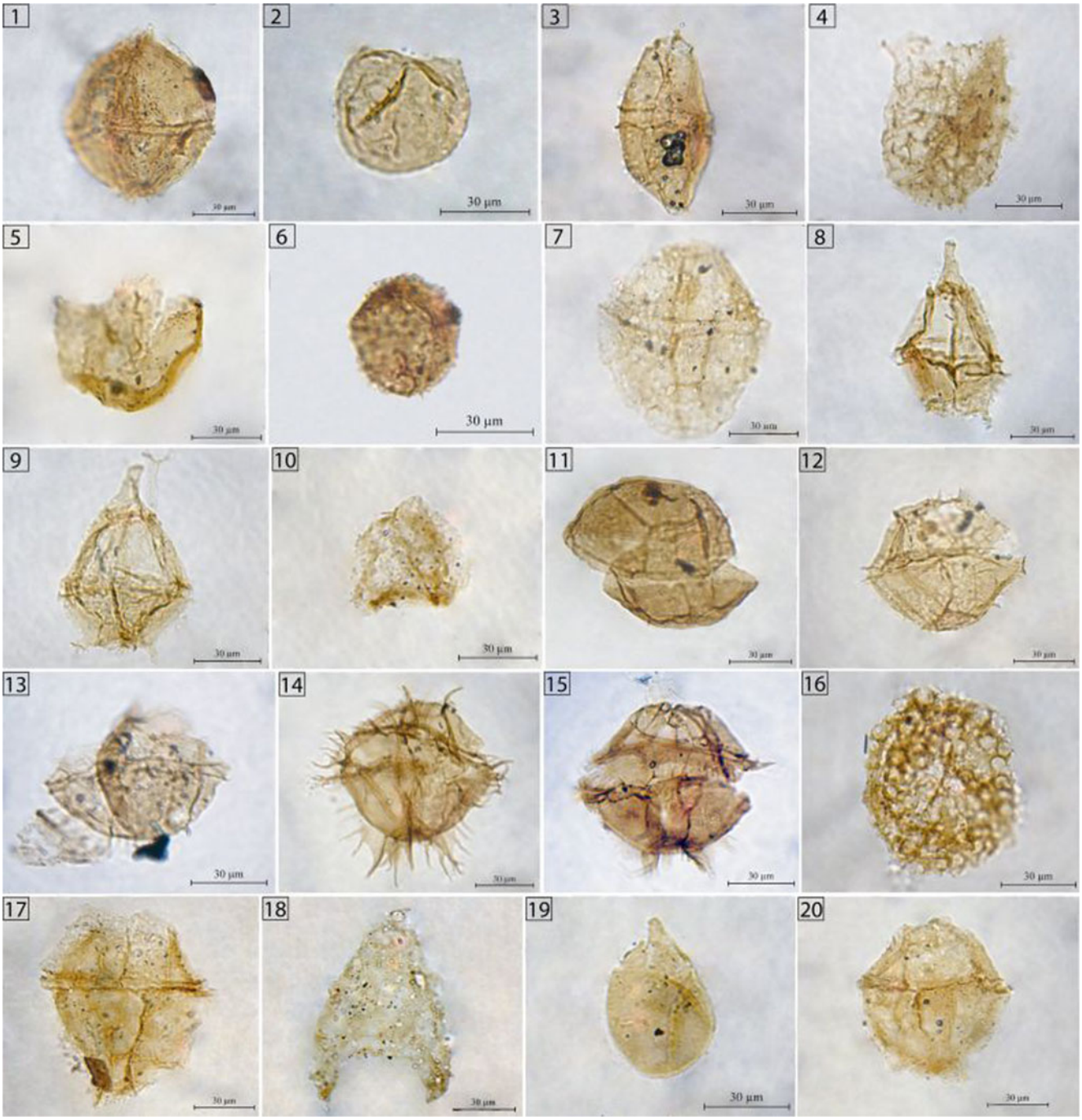

Fig. 2 Dinoflagellate cysts recorded from the Dalichai Formation in the Binalud Mountains, NE Iran. *1 Cribroperidinium crispum* (Wetzel 1967) Woollam and Riding 1983. sample 1, slide a. *2 Chytroeisphaeridia chytroeides* (Sarjeant 1962) Downie and Sarjeant 1965. sample 22, slide b. *3 Carpathodinium preda* (Beju 1971) Drugg 1978. sample 40, slide a. *4 Ellipsoidictyum reticulatum* (Valensi 1953) Lentin and Williams 1977, sample 12, slide c. *5 Escharisphaeridia pocokii* (Sarjeant 1968) Erkmen and Sarjeant 1980, sample 2, slide a. *6 Sentusidinium sparsibarbatum* Erkmen and Sarjeant 1980, sample 10, slide a. *7 Lithodina caytonensis* (Sarjeant 1959) Gocht 1976, sample 32, slide b. *8–9 Gonyaulacysta jurassica* (Deflandre 1938) Norris and Sarjeant 1965. *8* sample 24, slide a, *9* sample 92, slide a. *10 Nannoceratopsis raunsgaardii* Poulsen 1996. sample 10, slide a. *11 Mendicodinium groenlandicum* (Pocock and Sarjeant 1972) Davey 1979, sample 12, slide b. *12* and *13 Dichadogonyaulax sellwoodii* (Sarjeant 1975) Stover and Evitt 1978. *12* sample 12, slide b, *13* sample 70, slide a. *14* and *15*. *Ctenidodinium combazii* Dupin 1968. *14* sample 38, slide a, *15* sample 40, slide a. *16 V. ovulum* (Deflandre 1947) Eisenack 1963. sample 40, slide c. *17 Aldorfia aldorfensis* (Gocht 1970) Stover and Evitt 1978. sample 70, slide a. *18 Nannoceratopsis pellucida* Deflandre 1938. sample 38, slide b. *19 Pareodinia ceratophora* Deflandre 1947. sample 70, slide a. *20 Meiourogonyaulax caytonensis* (Sarjeant 1959) Sarjeant 1969. sample 60, slide c

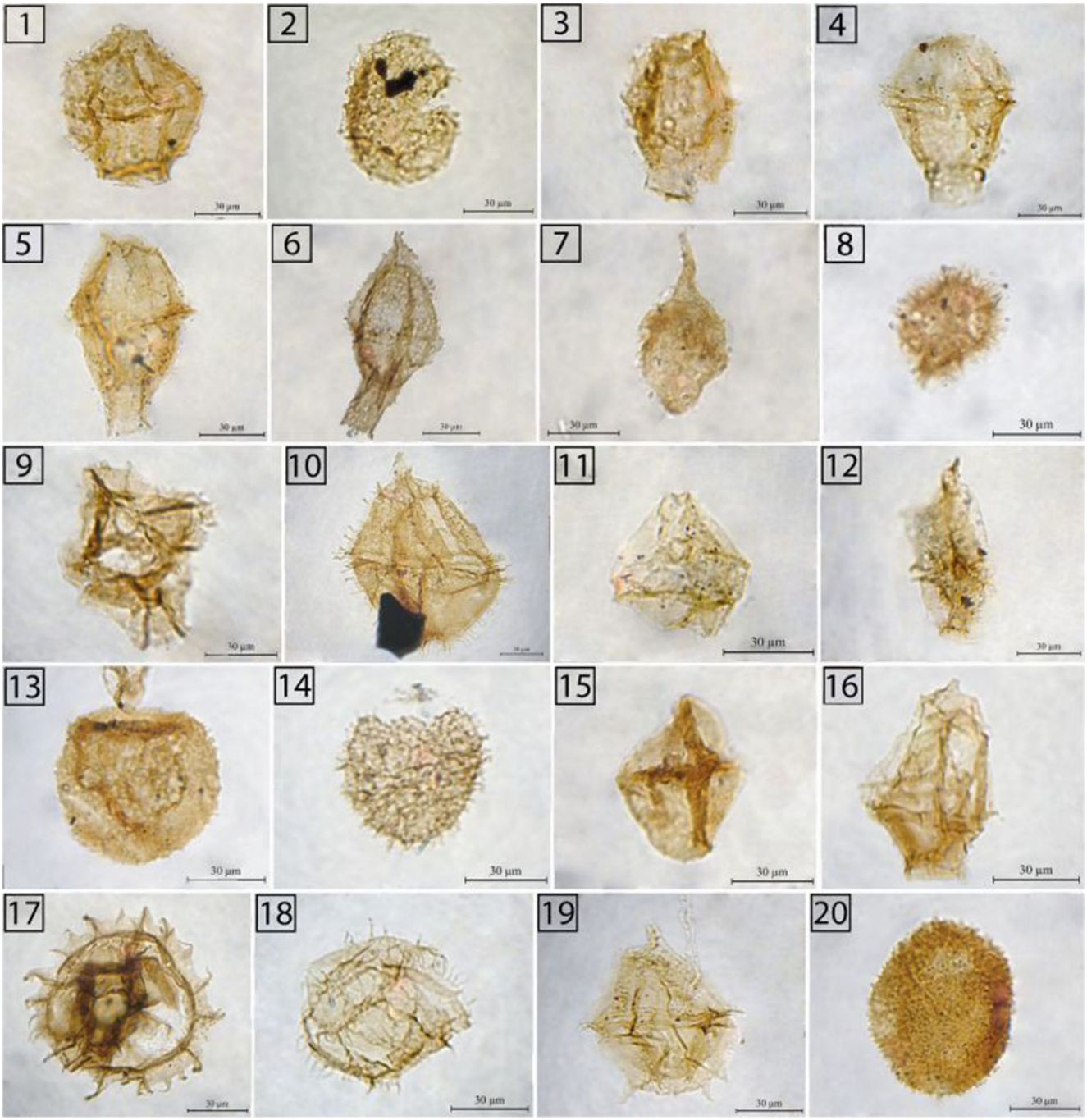

Fig. 3 *1 Leptodinium subtile* Klement 1960. sample 82, slide a. *2 Egmontodinium diminutum* Davies 1983. sample 74, slide a. *3 Stephanelytron scarburghense* Sarjeant 1961 emend. Stover et al. 1977. sample 66, slide a. *4 Meiourogonyaulax valensii* Sarjeant 1966. sample 70, slide b. *5 Tubotuberella dangeardii* (*Sarjeant 1968*) Stover and Evitt 1978emend. Sarjeant 1982. sample 92, slide b. *6 Tubotuberella apatella* (Cookson and Eisenack 1960) Ioannides et al. 1977. sample 70, slide a. *7 Pareodinia prolongata* Sarjeant 1959. sample 70, slide b. *8 B. pilosa* (Ehrenberg 1854) Courtinat 1989. sample 100, slide a. *9 Ctenidodinium continuum* Gocht 1970. sample 92, slide a. *10 Rhynchodiniopsis cladophora* (Deflandre 1938) Below 1981. sample 94, slide c. *11 Atopodinium prostatum* Drugg 1978 emend. Masure 1991. sample 88, slide a. *12 Endoscrinium asymmetricum* Riding 1987. sample 98, slide a. *13–14 Sentusidinium rioultii* (Sarjeant 1968) Sarjeant and Stover 1978. *13* sample 98, slide a, *14* sample 112, slide b. *15 Glossodinium bicuneatum* (Deflandre 1939) Loannides et al. 1977. sample 107, slide a. *16 Gonyaulacysta eisenackii* (Deflandre 1939) Gorka 1965 emend. Sarjeant 1982. sample 105, slide a. *17 Ctenidodinium ornatum* (Eisenack 1935) Deflandre 1938. sample 104, slide b. *18 Ctenidodinium tenellum* Deflandre 1938. sample 112, slide a. *19 Gonyaulacysta centriconnata*, Riding 1983. sample 104, slide a. *20 Tehamadinium konarae* Dedokova 1990. sample 112, slide b

binocular light microscope (Leitz) at ×40 magnification. The index dinocyst species were photographed and presented in Figs. 2 and 3. The slides are housed at the palynology laboratory of the Geological Survey of Iran (Northeast Territory).

Palynology and palynostratigraphy

Dinoflagellate cysts were widely distributed during the Middle to Late Jurassic, and they do have the ability to act as excellent index fossils for this period of time. The content of

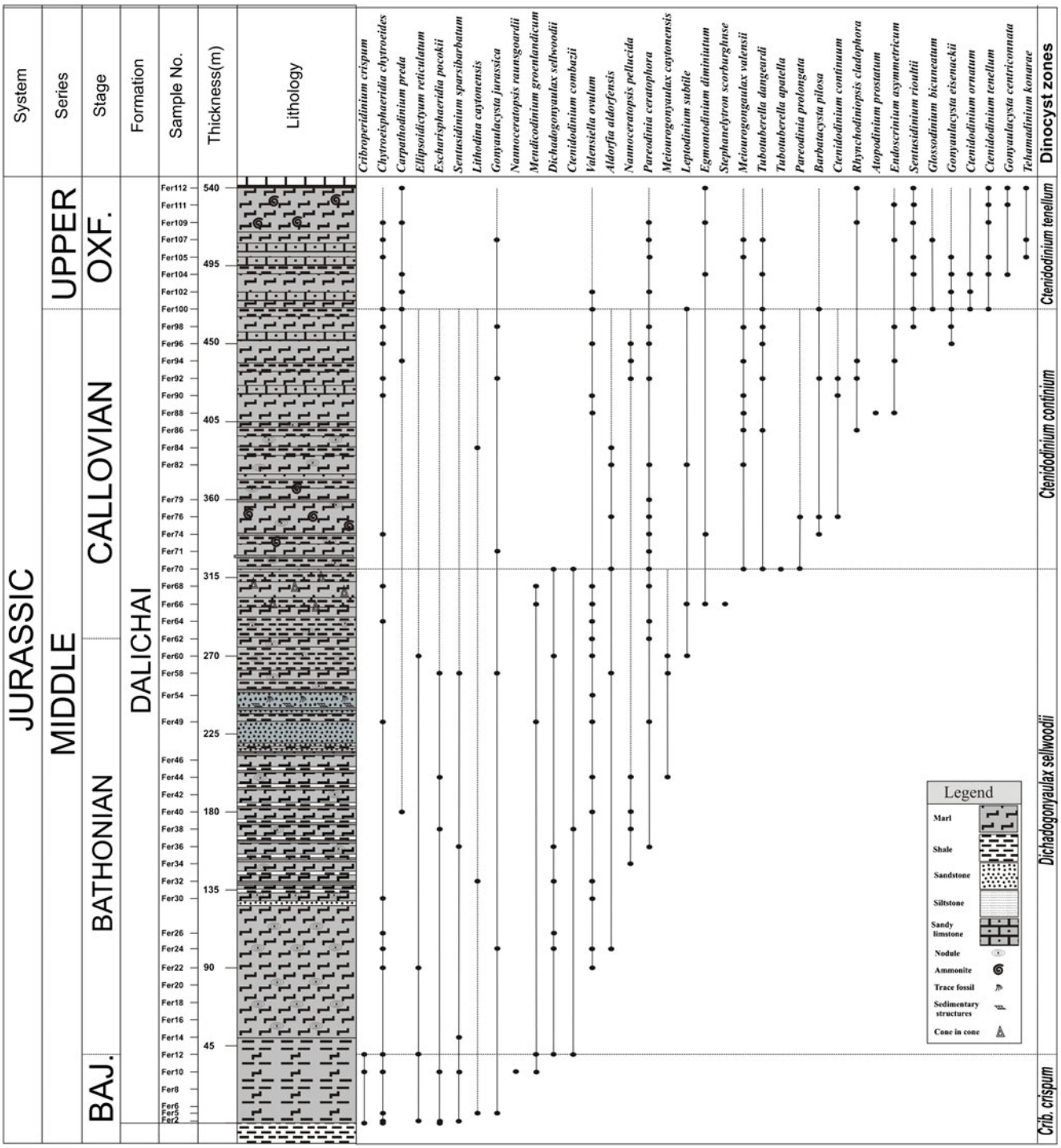

Fig. 4 Dinoflagellate cyst distribution and zonation throughout the Dalichai Formation, of NE Iran

our slides revealed that the Dalichai Formation is rich in terrestrial (spores, pollen grains, and wood tissues) and marine palynomorphs (dinoflagellate cysts, acritarchs, scolecodonts, and foraminiferal test linings). Thirty-six species of dinoflagellate cysts and five genera of acritarchs are recorded. The dinoflagellate cyst assemblage includes such forms as: *Aldorfia aldorfensis*, *Atopodinium prostatum*, *Barbatacysta pilosa*, *Carpathodinium preda*, *Chytroeisphaeridia chytroeides*, *Cribroperidinium crispum*, *Ctenidodinium combazii*, *Ctenidodinium continuum*, *Ctenidodinium ornatum*, *Ctenidodinium tenellum*, *Dichadogonyaulax sellwoodii*, *Egmontodinium diminutum*, *Ellipsoidictyum reticulatum*, *Endoscrinium asymmetricum*, *Escharisphaeridia pocokii*, *Glossodinium bicuneatum*, *Gonyaulacysta centriconnata*, *Gonyaulacysta eisenackii*, *Gonyaulacysta jurassica*, *Leptodinium subtile*, *Lithodina caytonensis*, *Meiourogonyaulax caytonensis*, *Meiourogonyaulax valensii*, *Mendicodinium groenlandicum*, *Nannoceratopsis pellucida*, *Nannoceratopsis raunsgaardii*, *Pareodinia ceratophora*, *Pareodinia prolongata*, *Rhynchodiniopsis cladophora*, *Sentusidinium sparsibarbatum*, *Sentusidinium rioultii*, *Stephanelytron scarburghense*, *Tehamadinium konarae*, *Tubotuberella apatella*, *Tubotuberella dangeardii*, *Valensiella ovulum* (Fig. 4).

Some Jurassic palynological investigations in the sub-Mediterranean realm are reported from Iberian Peninsula (Smelror et al. 1991), Libya (Thusu et al. 1985, 1988), Egypt (Aboul Ela and Mahrous 1990, 1997; El Beialy 1994, 1997, 2002; Ibrahim and El Beialy 1995, 2001; Mahmoud and Moawad 2000), Israel (Conway 1978, 1990), Iraq (Al-Ameri et al. 1999, 2011, 2013; Al-Ahmed 2006), and Iran (Ghasemi-Nejad et al. 2012).

The assemblages recorded from the Dalichai Formation are very similar to coeval Northern Iran and Northwest

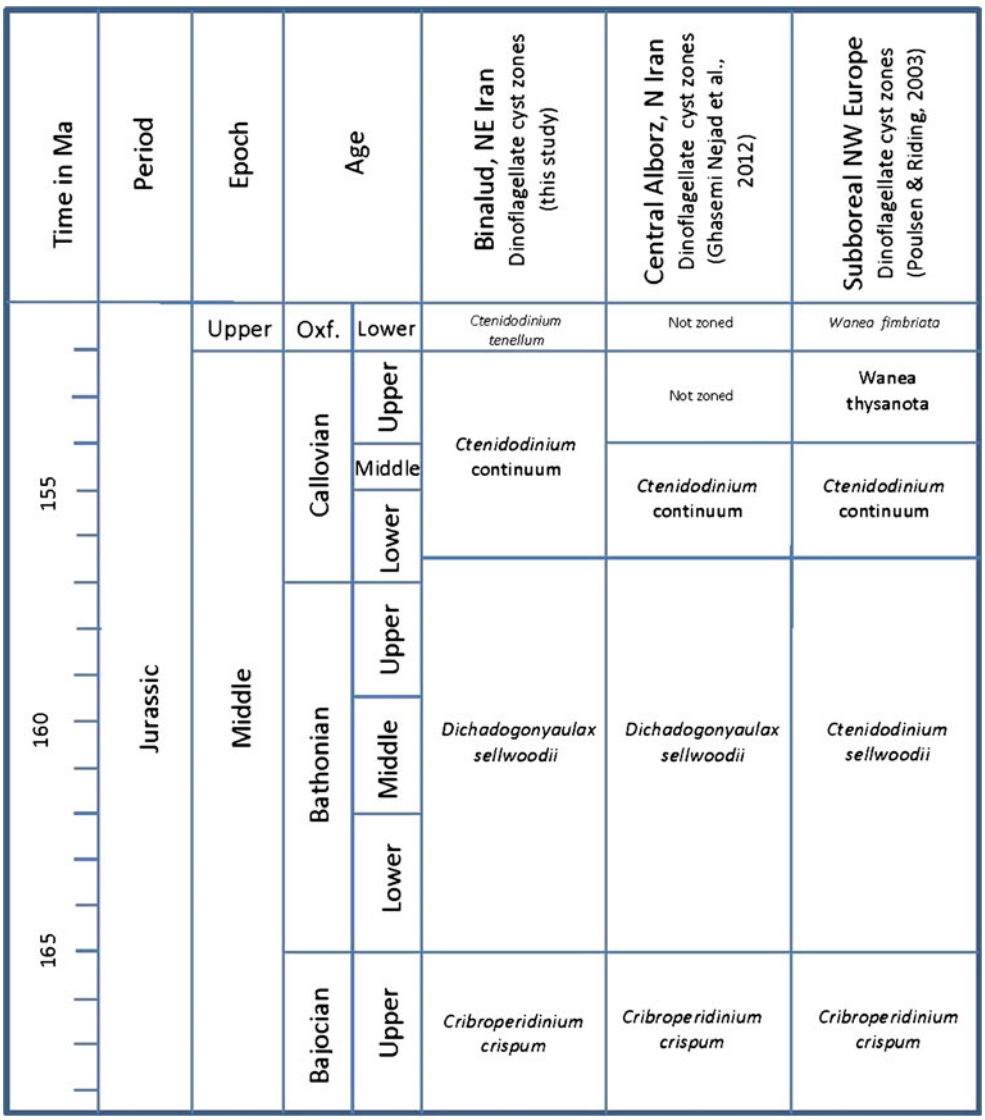

Fig. 5 Comparison and correlation of the Late Bajocian to Early Oxfordian dinoflagellate cyst zonation erected for the Dalichai Formation in Binalud with those of Northern Iran (Ghasemi-Nejad et al. 2012) and Northwest Europe (Poulsen and Riding 2003). Time in million years taken from Haq et al. (1987)

European populations. Based on the first and last appearances and abundance of the index species of dinoflagellate cysts and based on the standard zonation established for Northwest Europe and Northern Iran, a palynozonation was erected for the section studied. Three of the Northwest European (Woollam and Riding 1983; Riding and Thomas 1992; Poulsen and Riding 2003) and Alborz (Ghasemi-Nejad et al. 2012) palynozones are identified within the Dalichai Formation. These biozones are: *Cribroperidinium crispum* biozone for the late Bajocian, *Dichadogonyaulax sellwoodii* biozone for the Bathonian to Early Callovian, *Ctenidodinium continuum* biozone for the Early to Late Callovian, and *Ctenidodinium tenellum* biozone for the Early Oxfordian. The relationship of these biozones with the coeval dinoflagellate cyst biozones of Poulsen and Riding (2003) for sub-boreal Northwest Europe and Ghasemi-Nejad et al. (2012) for Northern Iran is discussed here and illustrated in Fig. 5. Moreover, we compared and correlated the Late Bajocian to Early Oxfordian dinoflagellate cyst zonation in the circum Mediterranean region with those of North and Northeast Iran (Fig. 6).

Cribroperidinium crispum total range biozone

This biozone encompasses 40 m of the base of the Dalichai Formation from samples 1 to 12. The zone differentiated here is equivalent to the *Cribroperidinium crispum* zone of Poulsen and Riding (2003) for sub-boreal Northwest Europe and *Cribroperidinium crispum* zone of Ghasemi-Nejad et al. (2012) for Northern Iran.

Characteristics

There are a few proximate dinoflagellate cysts in this zone. *Chytroeisphaeridia chytroeides* and *Escharisphaeridia pocokii* are abundant. *Carpathodinium preda*, *Ellipsoidictyum reticulatum*, *Gonyaulacysta jurassica*, *Lithodina caytonensis*, *Mendicodinium groenlandicum*, *Nannoceratopsis raunsgaardii*, and *Sentusidinium sparsibarbatum* first appear within this zone.

The ammonites *Cadomites* sp. and *Garantiana* sp. are recorded from the zone. These are considered to indicate an age of Late Bajocian for the zone.

Dichadogonyaulax sellwoodii interval biozone

This biozone encompasses 280 m of the Dalichai Formation above the *Cribroperidinium crispum* zone (from samples 13 to 70). The *Dichadogonyaulax sellwoodii* zone (Riding and Thomas 1992) is equivalent to the *Ctenidodinium sellwoodii* zone of Poulsen and Riding (2003) for sub-boreal Northwest Europe and the *Dichadogonyaulax sellwoodii* zone of Ghasemi-Nejad et al. (2012) for Northern Iran.

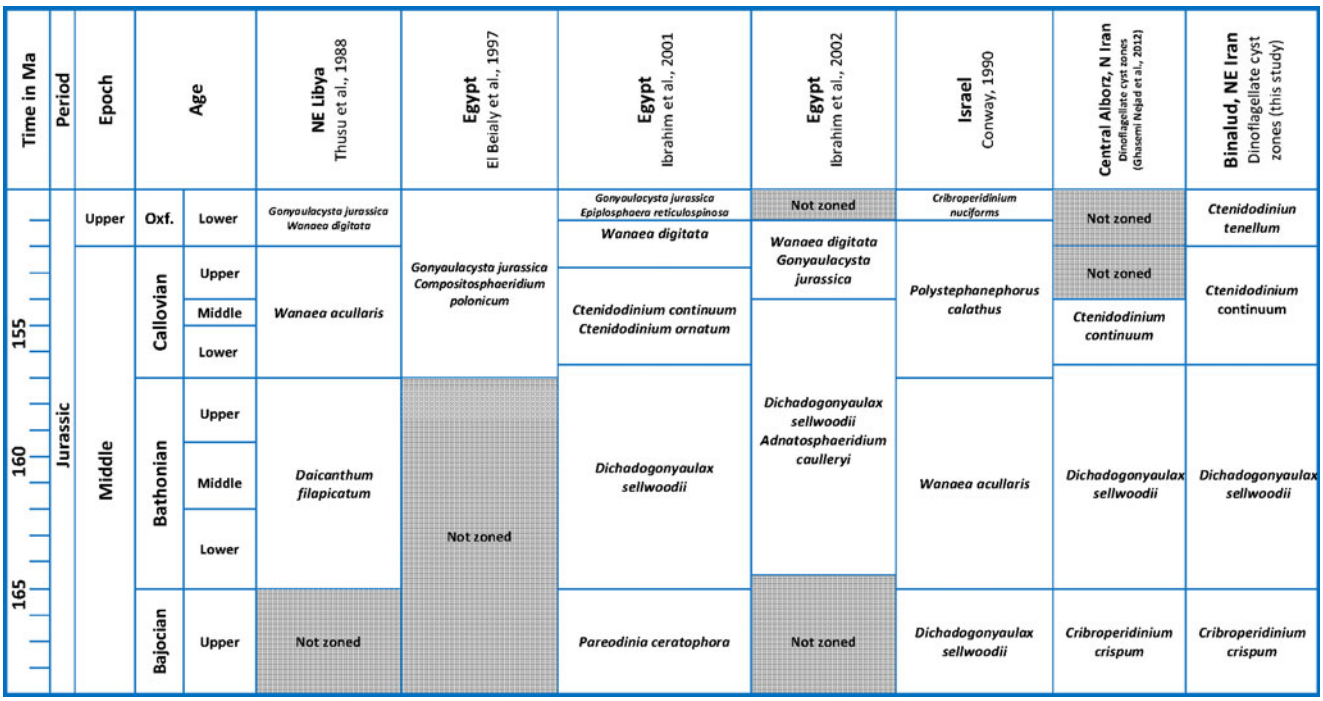

Fig. 6 Circum Mediterranean correlation of the Late Bajocian to Early Oxfordian dinoflagellate cyst zonation with those of the Northern Iran and Binalud Mountains (NE Iran). Time in million years taken from Haq et al. (1987)

Characteristics

The assemblages of dinoflagellate cysts are more diverse and with better preservation than the lower biozone. *Dichadogonyaulax sellwoodii* and *Ctenidodinium combazii* have their first appearances at the base of this zone. *Nannoceratopsis pellucida*, *Pareodinia ceratophora*, and *V. ovulum* are abundant in the zone. Common taxa include *Aldorfia aldorfensis*, *Egmontodinium diminutum*, *Leptodinium subtile*, *Meiourogonyaulax caytonensis*, *Nannoceratopsis spiculata*, *Stephanelytron scarburghense*, and *Pareodinia prolongata*. The ammonites *Morphoceras* sp. and *Homoeoplanulites* sp. are recorded from the zone. These are considered to indicate an age of Bathonian to Early Callovian for this zone.

Ctenidodinium continuum interval biozone

This zone encompasses 150 m of the Dalichai Formation above the *Dichadogonyaulax sellwoodii* zone (from samples 71 to 100) and is marked by the LAD of *Ctenidodinium combazii*. A slight change has been recorded in the upper boundary of the zone as the index species *Scriniodinium crystallinium* whose FAD marks the end of the zone in Britain (Riding and Thomas 1992), sub-boreal Northwest Europe (Poulsen and Riding 2003), and Northern Iran (Ghasemi-Nejad et al. 2012) has not been recorded. We therefore used the FAD of *Ctenidodinium tenellum* as the marker for the upper boundary of this zone. This species becomes abundant in the next interval.

Characteristics

There are many proximate and proximochorate dinoflagellate cysts recorded in this zone. Common taxa include *Carpathodinium preda*, *V. ovulum*, *Aldorfia aldorfensis*, *Nannoceratopsis pellucida*, *Pareodinia ceratophora*, *Ctenidodinium continuum*, *Leptodinium subtile*, *Egmontodinium diminutum*, *Tubotuberella apatella*, *Tubotuberella dangeardii*, *B. pilosa*, *Rhynchodiniopsis cladophora*, *Atopodinium prostatum*, and *Endoscrinium asymmetricum* in the uppermost part of this zone. *Glossodinium bicuneatum*, *Sentusidinium rioultii*, *Gonyaulacysta eisenackii*, and *Ctenidodinium ornatum* are seen.

The ammonites *Callotia* sp., *Hecticoceras* (*Rossiensiceras*) aff. *metomphalum*, and *Reineckeia anceps* are recorded from the zone. These are considered to indicate an age of Middle to Late Callovian for this zone.

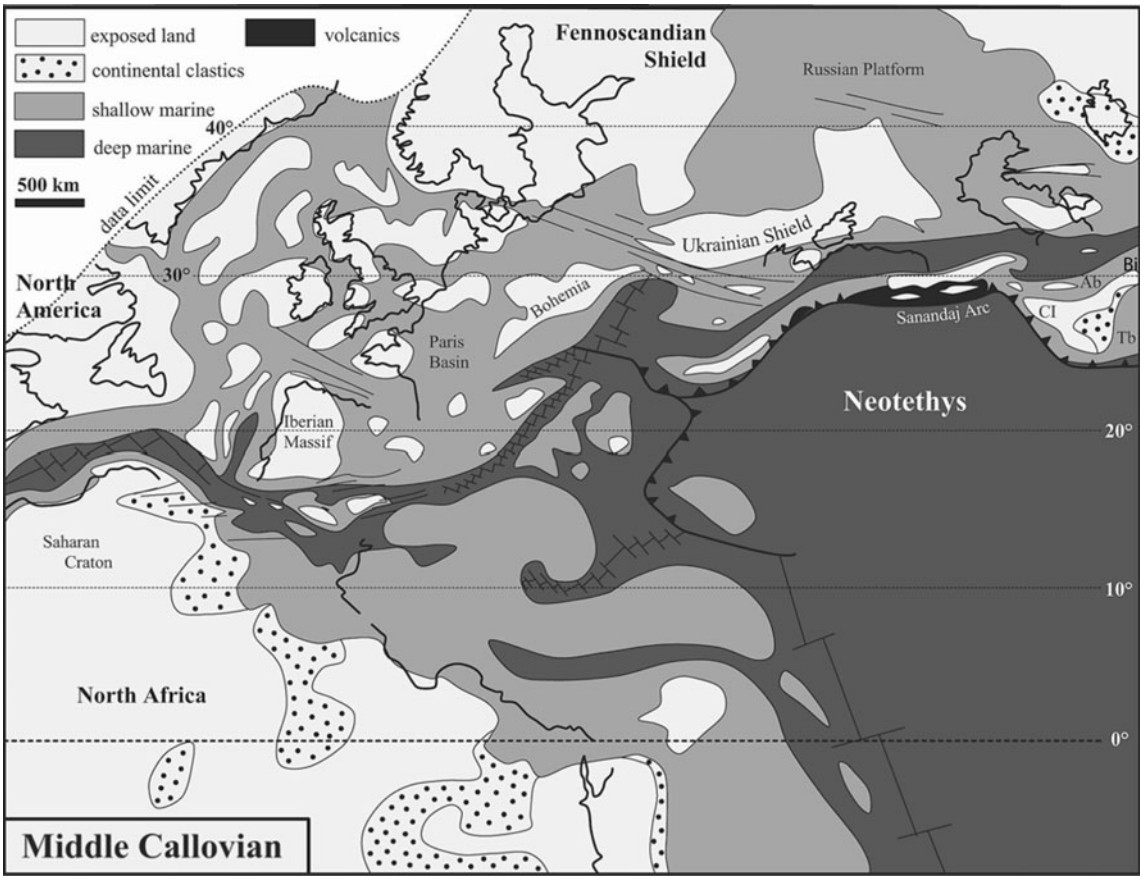

Fig. 7 Palaeogeographic map of the western Tethys region during the Middle Jurassic showing the position of Iran (adopted from Wilmsen et al. 2010). *Ab* Alborz, *CI* Central Iran, *Tb* Tabas Block, *Bi* Binalud

Ctenidodinium tenellum Acme biozone

This zone is locally defined as the interval above the *Ctenidodinium continuum* in which the species *Ctenidodinium tenellum* flourishes and continues up to the end of the Dalichai Formation. The zone encompasses from 470 to 540 m of the formation and represented by samples 102 to 112.

Characteristics

The dinoflagellate cyst assemblages are relatively diverse and with good preservation. The assemblages include: *Ctenidodinium continuum*, *Sentusidinium rioultii*, *Tehamadinium konarae*, *Gonyaulacysta eisenackii*, *Glossodinium bicuneatum*, *Endoscrinium asymmetricum*, *Rhynchodiniopsis cladophora*, *Tubotuberella dangeardii*, *Egmontodinium diminutum*, *Gonyaulacysta centriconnata*, *Pareodinia ceratophora*, *V. ovulum*, *Gonyaulacysta jurassica*, *Carpathodinium preda*, and *Chytroeisphaeridia chytroeides*.

Lower Oxfordian ammonites, e.g., *Perisphinctes* (*Decotomoceras*) *bifurcatus* and *Euaspideceras* aff. *douvillei*, are found in this interval confirming an age of Early Oxfordian for the zone.

Conclusion

Examination of the dinoflagellate cyst contents of the Dalichai Formation in Binalud Mountains, NE Iran, leads to the erection of four biozones. These include the *Cribroperidinium crispum* (Late Bajocian), *Dichadogonyaulax sellwoodii* (Bathonian to Early Callovian), *Ctenidodinium continuum* (Early to Late Callovian), and *Ctenidodinium tenellum* (Early Oxfordian) zones. The biozonation in this region is almost identical to that erected for Northern Iran (Ghasemi-Nejad et al. 2012) and Northwest Europe (Poulsen and Riding 2003). Besides, the recorded ammonoid families in this region including Phylloceratidae, Perisphinctidae, Reineckeidae, and Oppeliidae show a definite sub-Mediterranean character similar to other assemblages described from the Middle to Upper Jurassic of Northern Iran. The close similarities of dinoflagellate cyst assemblages between Binalud Mountains in NE Iran with those of the Alborz Mountains (Northern Iran) during Middle Jurassic confirm the connection between the two sedimentary basins during this time in Iran. Moreover, this biozonation corresponds largely to that established in Northwest Europe and reveals the marine connection between NE and N Iran with Northwest Europe and the Northwestern Tethys during the Late Bajocian to Early Oxfordian (Fig. 7).

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