Dinoflagellate cysts from the Upper Triassic (Norian) of northeastern Iran

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ABSTRACT – Upper Triassic (Norian) strata of the Miankuhi Formation in northeastern Iran have been studied palynologically, revealing a diverse but poorly preserved association of dinoflagellate cysts. Based on representatives of the genera *Hebecysta*, *Heibergella*, *Rhaetogonyaulax* and *Sverdrupiella*, the strata are assigned to the middle of the *Hebecysta balmei* Zone with an inferred age of early Late Norian. The association shows similarities with assemblages from Australia, New Zealand, Indonesia, Northwest Europe, arctic Canada and Alaska, indicating an interconnection of warm Tethyan waters during the Late Triassic. The occurrence of *Sverdrupiella* species in the clastic, near-shore marine deposits of Miankuhi, and their presence in similar sedimentary facies world-wide, indicate that this genus was well adapted to clastic shallow-marine environments. *J. Micropalaeontol.* **27**(2): 125–134, November 2008.

KEYWORDS: *dinoflagellate, Miankuhi, Aghdarband, Triassic, Iran*

INTRODUCTION

Triassic rocks of the Aghdarband Group are believed to form the basement of the Kopet Dagh Range, which stretches for nearly 700 km in a WNW–ESE direction east of the Caspian Sea, and extends from the former USSR across northern Iran and into Afghanistan (Fig. 1). Kopet Dagh comprises a 5000–7000 m thick sequence of gently folded rocks of Middle Jurassic to Eocene age. The Triassic basement in this range is exposed only at a small location in the easternmost part of the country. Here, Triassic and Palaeozoic rocks are exposed over an area about 20 km long and 15 km wide, named the Aghdarband window (Triassic Aghdarband).

Strata of the Aghdarband window have been the subject of extensive field work, mapping and laboratory investigations (e.g. Seyed-Emami, 1971; Ruttner, 1983, 1984, 1988, 1991, 1993; Baud & Stampfli, 1989; Baud *et al.*, 1991; Boersma & van Konijnenburg-Van Crittert, 1991; Donofrio, 1991; Eftekharnezhad & Behroozi, 1991; Krystan-Tollmann, 1991; Krystyn & Tatzreiter, 1991; Oberhauser, 1991; Schonlaub, 1991; Siblik, 1991; Alavi *et al.*, 1997). Some studies have compared the Triassic rocks of the Aghdarband window with the Nakhlak strata in central-eastern Iran (Davoudzadeh *et al.*, 1981; Ruttner, 1984; Alavi *et al.*, 1997; Fig. 1), assigning both sequences to the southern part of Laurasia (Turan Plate). These authors consider the two deposits, which are now some 900 km apart, as belonging to a single sedimentary basin located on the margin of the Turan continent in northern Tethys. They also propose rifting and a 135° counter-clockwise rotation of the central-east Iranian microcontinent, a hypothesis supported by palaeomagnetic data (Soffel *et al.*, 1975; Soffel & Forster, 1980, 1984; Wensink, 1982, 1983; Schmidt & Soffel, 1984).

Marine microfossil groups, especially those influenced by provincialism and sensitive to the relevant environmental conditions, might be useful in determining the unity of these palaeosediments and palaeobasins. Dinoflagellate cysts represent one such group that arose during Triassic time.

The Triassic Aghdarband Group comprises the Sefidkuh, Nazarkardeh, Sina and Miankuhi formations. Of these, the Upper Triassic Miankuhi Formation, which consists mainly of shales, is lithologically the most suitable for palynological analysis. However, there are no previous published studies on the palynology of these shales. Indeed, the Miankuhi Formation appears to be otherwise barren of fossils, with the exception of an impoverished assemblage of benthic marine agglutinated foraminifera that reflects possibly adverse environmental conditions (Oberhauser & Prey in Ruttner, 1991, p. 47).

Samples were collected from shales of the Miankuhi Formation (Fig. 2) from a 170 m thick section in the vicinity (SE) of the village of Aghdarband (Fig. 1). The samples all contain dinoflagellate cysts. However, their state of preservation is poor owing both to corrosion and to the high degree of thermal maturation of the organic matter. The recorded specimens are variously torn, compressed, crumpled and folded. The corrosion is often accompanied by numerous impressions of pyrite or other crystals. Some specimens are so severely corroded as to remain only as ghosts. In spite of these difficulties, it has been possible to identify some specimens to generic and even tentatively specific levels, owing to their distinctive overall morphology. However, unequivocal identification to species level was not possible, as is often the case in marginal palynology (Traverse, 1972). The better-preserved specimens are illustrated on Plates 1–3.

The present study aims to report the occurrence of a relatively diverse suite of dinoflagellate cysts of the Miankuhi Formation, and to compare the dinoflagellate cyst association with contemporaneous assemblages from around the world to assess their palaeogeographical and palaeoenvironmental significance. This completes the first stage of a study to compare the palynology of the Miankuhi Formation with that of the Triassic strata at Nakhlak in central-eastern Iran (Fig. 1).

GEOLOGICAL SETTING

The Triassic deposits at Aghdarband occur within the large WNW–ESE-trending Aghdarband syncline. To the south of this syncline, the Shahtutak Fault (Fig. 1) separates these Triassic
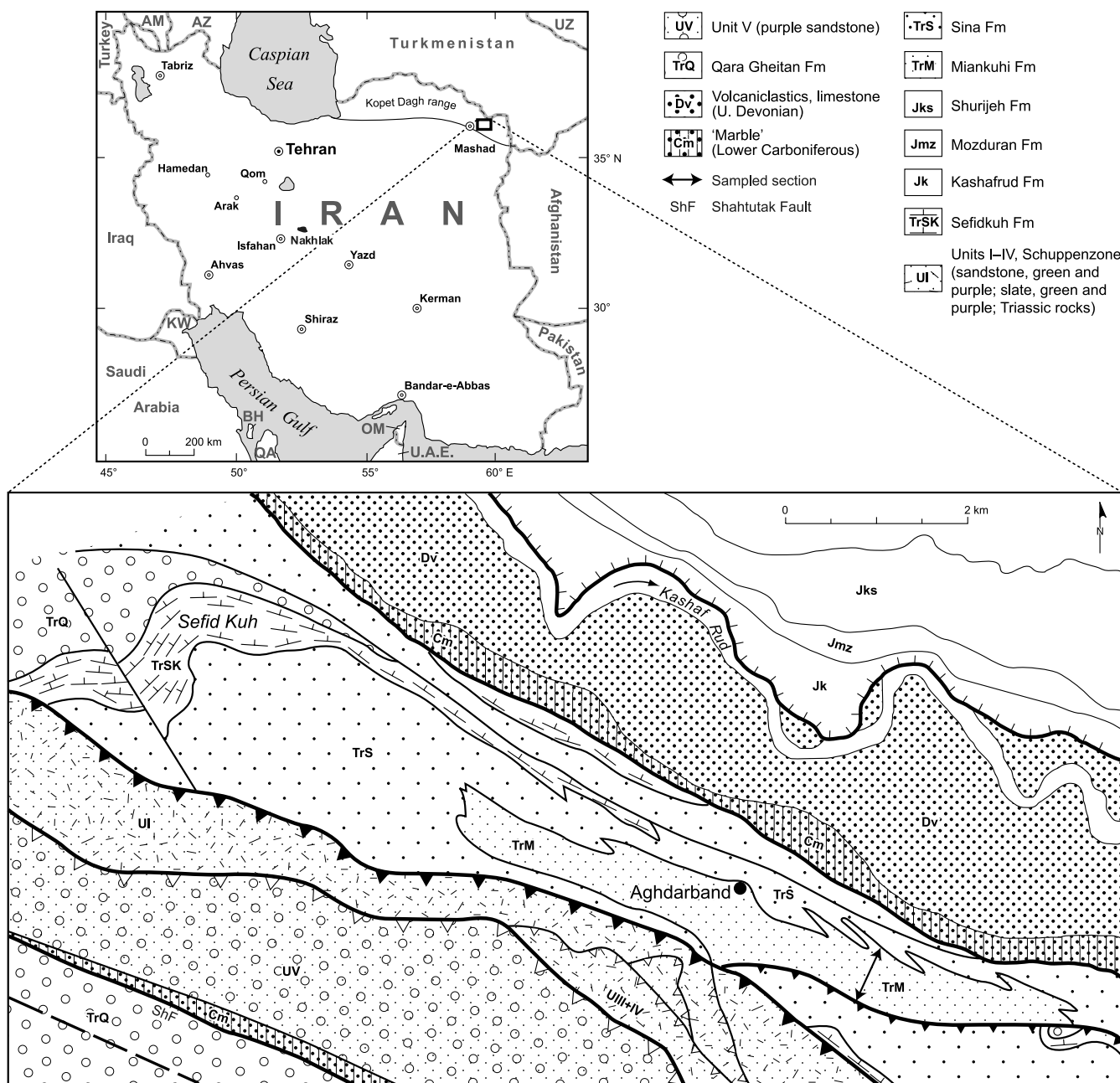
Fig. 1. Location of the studied section and geology of the Triassic Aghdarband window (redrawn from Ruttner, 1991). AM, Armenia; AZ, Azerbaijan; BH, Bahrain; KW, Kuwait; OM, Oman; QA, Qatar; UAE, United Arab Emirates.

rocks from a sequence exceeding 1000 m in thickness of unmetamorphosed shales, sandstones and conglomerates of brownish-red to greenish colour, which occupies nearly the entire southern half of the erosional window of Aghdarband (Ruttner, 1991). The Shahtutak Fault is thought to mark the southern edge of the Hercynian Turan plate, which would place Triassic deposition at Aghdarband on the southern margin of this plate (Ruttner, 1991; Alavi *et al.*, 1997).

The Triassic sequence of the Aghdarband window comprises four formations that together form the Aghdarband Group. The lowest of these is the Sefidkuh Formation, which is an alternation of thickly bedded to massive yellowish limestone and thinly (centimetre) bedded light grey to bluish-grey limestone. It is late Scythian (Olenekian Stage, Spathian Substage) in age based on conodonts (Donofrio, 1991). This formation is overlain by thin-bedded cherty limestones of the Nazarkardeh Formation in the type section, and by an ammonite-bearing sequence of beds consisting of nodular limestone interbedded with tuffaceous marl and sandstones in the more southerly part of the area. The age of the Nazarkardeh Formation and its lateral equivalents is Aegean–Bithynian (early Anisian to early middle Anisian Stage) according to evidence from conodonts (Donofrio, 1991) and ammonites (Krystyn & Tatzreiter, 1991).
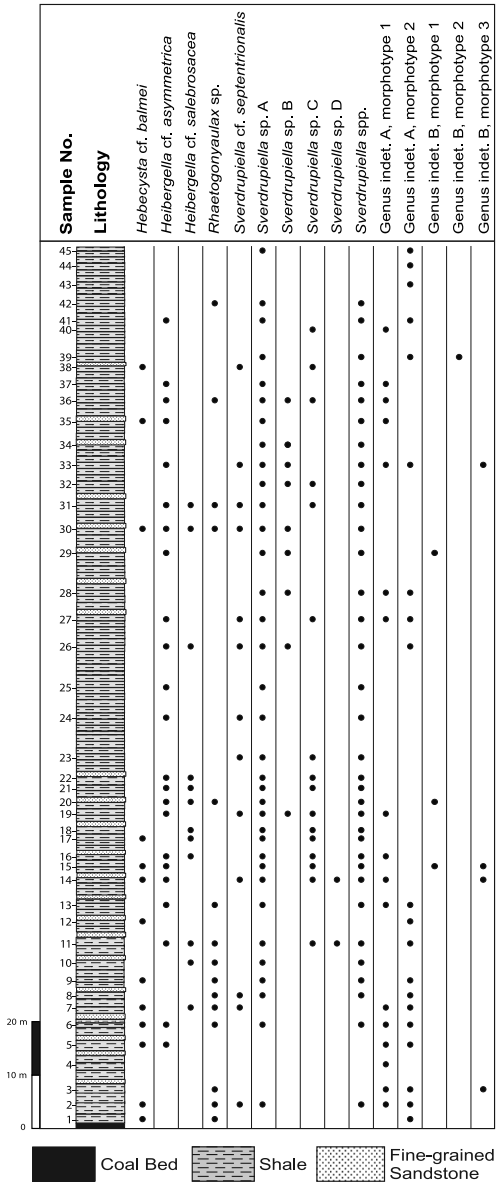
Column headers of the distribution chart (Fig. 2):

Sample No.; Lithology; *Hebecysta* cf. *balmei*; *Heibergella* cf. *asymmetrica*; *Heibergella* cf. *salebrosacea*; *Rhaetogonyaulax* sp.; *Sverdrupiella* cf. *septentrionalis*; *Sverdrupiella* sp. A; *Sverdrupiella* sp. B; *Sverdrupiella* sp. C; *Sverdrupiella* sp. D; *Sverdrupiella* spp.; Genus indet. A, morphotype 1; Genus indet. A, morphotype 2; Genus indet. B, morphotype 1; Genus indet. B, morphotype 2; Genus indet. B, morphotype 3

Legend: Coal Bed; Shale; Fine-grained Sandstone

Scale: 20 m, 10 m, 0

Fig. 2. Lithology of the Triassic (Norian) Miankuhi Formation, Aghdarband, and distribution of dinoflagellate cysts.

The Nazarkardeh Formation is overlain by the Sina Formation, a sequence of rocks reportedly 400 m to 700 m thick, whose lower part comprises tuffaceous sandstone, limestone, marlstone and marl, and whose upper part comprises green tuffaceous shales, a fossiliferous marl bed (Faqir Marl Bed) and few layers of sandstone and conglomerate. The ammonoid fauna of the Faqir Marl Bed is characterized by a dominance of the genus *Romanites*, representing the *Frankites regoledosus* Zone of the upper Ladinian Stage (Krystyn & Tatzreiter, 1991). Moreover, the presence of the bivalve *Daonella lommeli* in shales of the upper parts of the formation suggests a latest Ladinian age. However, the topmost part of the formation is proven to be of early Carnian age (late Cordevolian Substage) based on an assemblage of radiolarians and sponge spicules recorded from a siliceous limestone immediately below the superjacent Aghdarband Coal Bed (Donofrio, 1991).
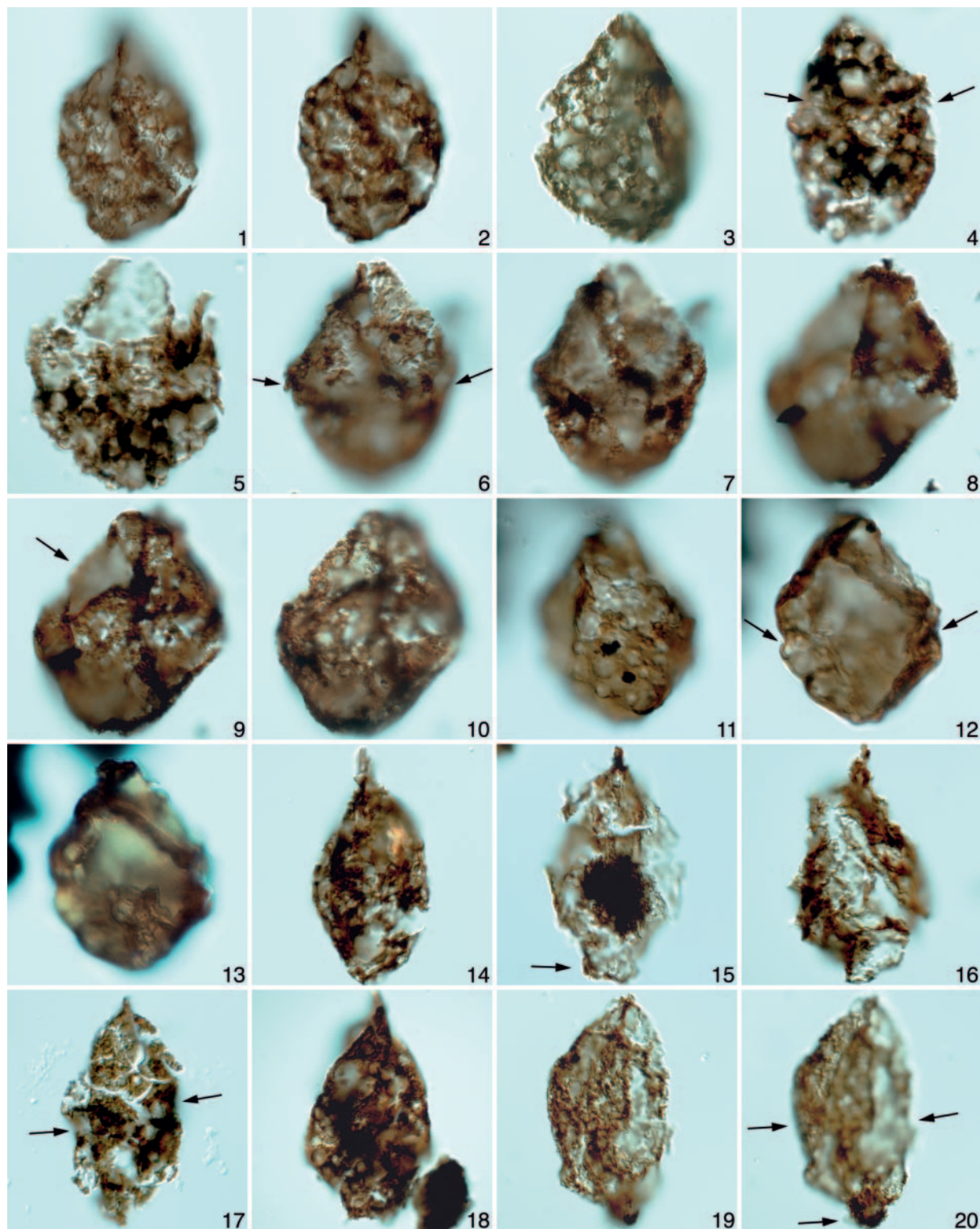
The Aghdarband Coal Bed represents the lowermost part of the overlying Miankuhi Formation. This formation forms the core of the Aghdarband syncline and consists of a monotonous sequence of brown-coloured shales with intercalations of siltstones and fine-grained sandstones. They are 200 m thick in the core of the Aghdarband syncline. The shales are marine, as indicated by the presence of an impoverished assemblage of agglutinated benthic foraminifera reported from a single sample (Oberhauser & Prey in Ruttner, 1991, p. 47). The shales were considered previously to be non-marine because of the apparent absence of fossils (Ruttner, 1983, 1984, 1988).

The coal seam is generally about 1 m thick and is the main reason for many mining and geological activities in the Aghdarband region. The coal seam marks the beginning of a new phase of deposition, with the tuffaceous sandstone and shales below the seam marking the end of volcanic activities. A considerable stratigraphic gap including the upper Carnian and possibly the lower part of the Norian (Ruttner, 1991) separates this new phase of sedimentation from the subjacent Sina Formation. This hiatus is reflected by the presence of layers of conglomerate and coarse sandstone underneath the coal bed in most parts of the Aghdarband window (Ruttner, 1991). Plant fossils were the only age indicators found so far in the shales and sandstones in and immediately above the coal bed. Boersma & van Konijnenburg-Van Crittert (1991) reported the following taxa: *Neocalamites* sp., *Taeniopteris* sp., *Podozamites paucinervis*, *Podozamites* sp., *Carpolithes* cf. *cinctus* and *Sphenobaiera* sp. Dominance of the genus *Podozamites* and presence of the Norian genus *Sphenobaiera* led these authors to conclude a probable Norian age for the base of the Miankuhi Formation. Palynological studies were also attempted but the recorded palynomorphs were inconclusive as they were strongly carbonized (Boersma & van Konijnenburg-Van Crittert, 1991).

The shales of the Miankuhi Formation are the youngest deposits affected by the early Cimmerian orogeny (Ruttner, 1991). The Cimmerian structures are covered unconformably either by the black shales of the Kashafrud Formation (Bajocian) in most parts, or by a white sandstone forming the base of a black shale sequence (named the Ghal'eh Qabri Shales) of Rhaetian age (Boersma & van Konijnenburg-Van Crittert, 1991).

UPPER TRIASSIC MARINE PALYNOLOGY

The earliest Mesozoic dinoflagellate cysts are recorded in the Middle Triassic, and taxonomic diversity remained relatively low until the Early Jurassic (Stover et al., 1996). It is therefore not surprising that few reports of dinoflagellate cysts exist from marine sequences of Carnian and Norian age. These include: arctic Alaska (Wiggins, 1973), arctic Canada (Fisher & Bujak, 1975, Bujak & Fisher, 1976), New Zealand (Wilson & Helby, 1986; Helby & Wilson, 1988), Australia (Helby et al., 1987a), Southern Europe (Wiggins, 1973; Hochuli & Frank, 2000) and Iran (Ghasemi-Nejad et al., 2004). In northwestern Europe deposits of Carnian to Norian age are exclusively continental, and the oldest dinoflagellate cysts are assigned to the *Rhaetogonyaulax rhaetica* Zone of Rhaetian age, which was a time of marine transgression over parts of Europe. The base of this zone was placed at the base of the Rhaetian Stage (Morbey, 1978). However, there is disagreement regarding the international

Explanation of Plate 1.

Dinoflagellate cysts from the Miankuhi Formation, Aghdarband. Various magnifications. An England Finder reference follows the sample and slide reference for each specimen. All photomicrographs are interference contrast images. **figs 1–4.** Possible representatives of the *Hebecysta–Heibergella* plexus: it is unclear whether the reticulation represents wall surface ornament or preservational pitting: **1, 2,** specimen at upper and lower focus respectively, sample 35, slide A, L30/1, length 72 μm; **3,** specimen at upper focus; sample 14, slide A, M38/0; length 49 μm; **4,** specimen at lower focus, arrows indicate cingulum; sample 9, slide B, M35/4; length 55 μm. **fig. 5.** *Hebecysta* cf. *balmei*, mid-focus showing apparently the style of archaeopyle illustrated by Below (1987) modified by tearing; sample 12, slide A, J31/4; length 50 μm. **figs 6–10.** *Heibergella* sp., showing low positive sculptural

definition of the Rhaetian Stage and the position of its base (Ogg, 2005; Kuerschner *et al.*, 2007). The global distribution of Upper Triassic dinoflagellate cysts is discussed by Palliani & Buratti (2006).

MATERIALS AND METHODS

Forty-five samples were collected from shales of the Miankuhi Formation (Fig. 2). Field work and sampling was conducted by MZ with help provided by the Geological Survey of Mashhad, Iran. Rock samples were first crushed into small pieces of about 2 mm and washed and dried. The samples were then placed in HCl (10%) for 24–48 hours to dissolve the carbonates, neutralized with distilled water, and treated with HF (50%) to dissolve the silicates. The residue was neutralized again and boiled in 10% HCl to remove any precipitates, and then centrifuged in a zinc chloride solution (specific gravity 1.9) to separate heavy minerals. Residues were sieved using a 15 μm nylon mesh, and strew mounted onto microscope slides using Canada balsam as the mounting medium.

The microscope slides were studied under a Leica DM 2500 light microscope, and selected specimens were photographed using a Leica DMR microscope and DFC 490 camera (Plates 1–3). The slides are housed in the Geology Department of the University of Tehran.

The stratigraphical occurrences of identified taxa are plotted by presence or absence (Fig. 2), the poor preservation of assemblages precluding the possibility of obtaining reliable counts of specimens. From five to 30 specimens were recorded on each slide.

The taxonomic methodology used requires comment because specimens are corroded and have undergone strong thermal alteration, and the finer morphological features – including details of tabulation – are usually not preserved. Identifications therefore rely mostly on shape, size and length/width ratio. This is achievable, with the appropriate experience, because dinoflagellate cysts had not significantly diversified by Norian times (about 25 species world-wide), thereby limiting the number of potential species to identify. Species-level identifications are nevertheless tentative, given the preservational state of the material.

PALYNOLOGY OF THE MIANKUHI FORMATION

Slides are dominated with dark brown, large, mostly elongate and angular wood particles, including tracheidal phytoclasts, with subordinate angular black particles (Pl. 3, figs 13, 14). Cuticular tissue is also present. Spores and pollen grains are recorded rarely (less than 5% of the total number of particles) and dinoflagellate cysts are present sporadically (up to 5–10% of the total number of particles). Amorphous organic matter

(AOM) is not recorded, or only rarely present in a few slides. The presence of dinoflagellates implies a marine environment, while the dominance of wood particles suggests near-shore deposition. The rarity of AOM is consistent with a shallow-marine, near-shore depositional environment for the Miankuhi Formation.

The palynomorphs are medium dark brown to almost black in colour, depending on wall thickness. This degree of thermal maturation corresponds to about five to six on the thermal alteration scale (based on palynomorph colour; Batten, 1996), and is equivalent to a vitrinite reflectance (R_o) value of about 1.2–2.0 (Batten, 1996). It indicates that the Miankuhi Formation is thermally late-mature to overmature and no longer has much potential to generate oil but may have generated gas. This assessment is consistent with the coal at the base of the formation, which is bituminous in rank (Ruttner, 1991).

In addition, the palynomorphs are corroded extensively and many specimens show angular pits and cavities due to the growth of diagenetic minerals.

DINOFLAGELLATE CYST ASSEMBLAGES

The dinoflagellate cysts of the Miankuhi Formation can be assigned to a single association characterized by a species diversity that is relatively high, considering its age and in comparison with assemblages from other parts of the world. Specimens are assigned to four previously described genera and two indeterminate genera.

The Genus *Hebecysta* is represented by *Hebecysta* sp. cf. *H. balmei* Stover & Helby, 1987, emend. Below, 1987 (Pl. 1, fig. 5); and *Heibergella* is represented by *Heibergella* sp. cf. *H. asymmetrica* Bujak & Fisher, 1976 (Pl. 1, figs 11–13) and *Heibergella* sp. cf. *H. salebrosacea* Bujak & Fisher, 1976 (Pl. 3, figs 1–5). The Genus *Sverdrupiella* includes *Sverdrupiella* sp. cf. *S. septentrionalis* Bujak & Fisher, 1976 (Pl. 2, fig. 7) and the informally designated *Sverdrupiella* sp. A (Pl. 2, figs 5, 6), *Sverdrupiella* sp. B (Pl. 2, figs 8, 9), *Sverdrupiella* sp. C (Pl. 2, figs 10–12), and *Sverdrupiella* sp. D (Pl. 2, figs 13–15), which are differentiated on shape, size and length/width ratio. The Genus *Rhaetogonyaulax* is represented by an unidentified but characteristic species recorded sporadically as *Rhaetogonyaulax* sp. (Pl. 2, figs 3, 4).
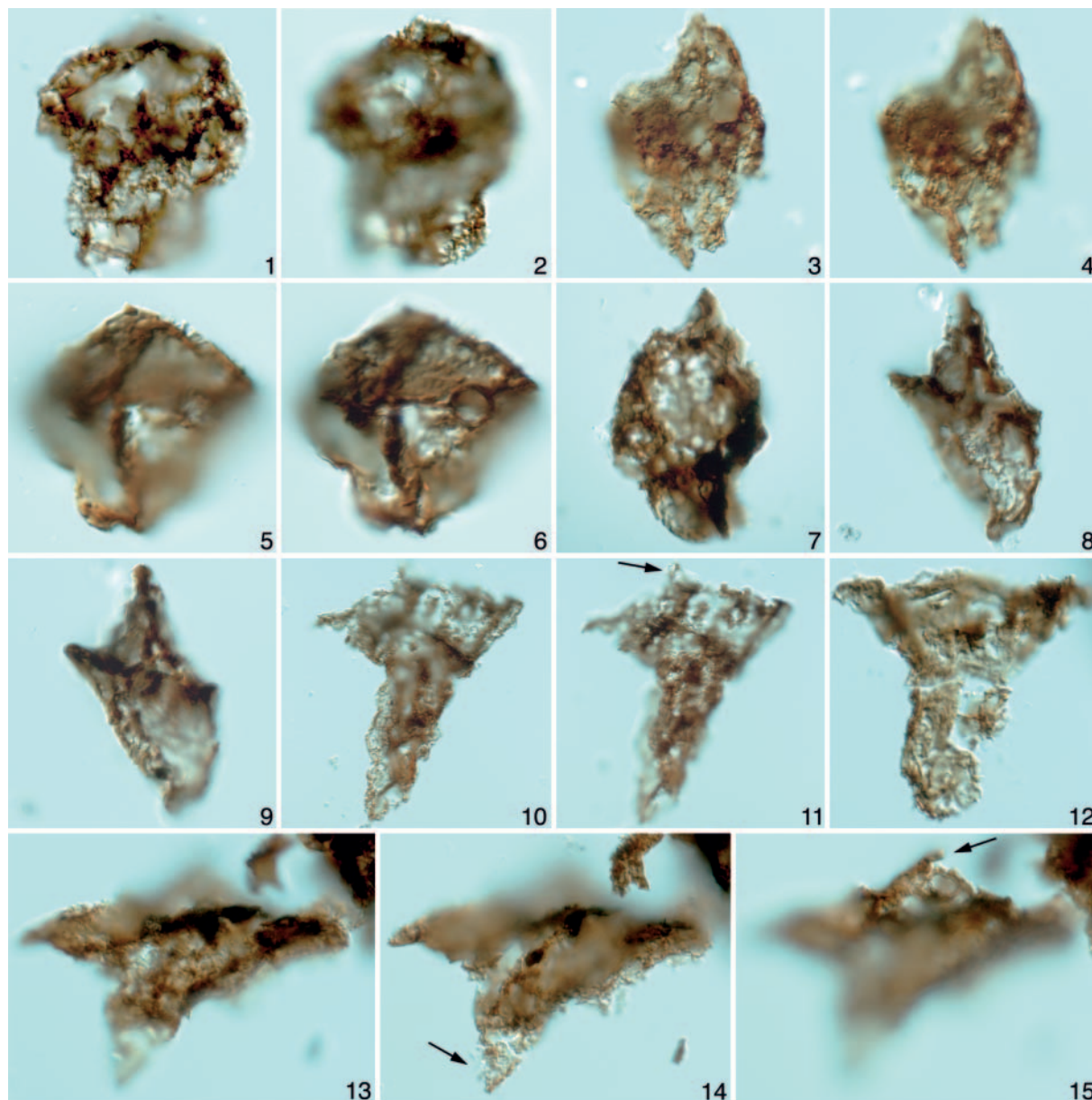
Of the two indeterminate genera recorded, one is differentiated into two morphotypes (Genus indet. A, morphotypes 1 and 2) and the other into three (Genus indet. B, morphotypes 1–3). These taxa are described informally in the comments on selected taxa, below, together with *Sverdrupiella* spp. A–D.

DISCUSSION AND COMPARISON

The Genus *Sverdrupiella*, which occurs sporadically through the studied section, has been reported from Norian strata of arctic

Canada, Alaska, New Zealand, Australia and Indonesia. Helby *et al.* (1987b, p. 151) believed that the pattern of distribution of the genus reflects a 'warm water circum-Pacific distribution with a northern extension along the arctic edge of North America'. The recorded association from the Miankuhi Formation, characterized by the presence of *Sverdrupiella* species, is quite similar to the association recorded from arctic Canada. The other genera, *Heibergella*, *Hebecysta* and *Rhaetogonyaulax*, have been recorded similarly from arctic Canada.

PALAEOENVIRONMENTAL AND PALAEOECOLOGICAL INTERPRETATION

The depositional environment of the Shublik Formation, Alaska, in which *Sverdrupiella* was recorded from the Middle to

Explanation of Plate 3.

Dinoflagellate cysts and palynofacies from the Miankuhi Formation, Aghdarband. Various magnifications. An England Finder reference follows the sample and slide reference for each specimen. All photomicrographs are interference contrast images, except for figs 13,14, which are in bright field illumination. **figs 1, 2.** *Heibergella* cf. *salebrosacea*, upper and middle focus respectively; sample 10, slide A, T61/3; length 40 µm. **figs 3, 4.** *Heibergella* cf. *salebrosacea*, upper and lower focus respectively; sample 16, slide A, R60/0; length 37 µm. **fig. 5.** *Heibergella* cf. *salebrosacea*, lower focus; sample 20, slide A, E25/0; length 54 µm. **figs 6, 7.** Genus indet. B, morphotype 1, middle and lower focus respectively, arrows indicate **6** antapical corona and **7** apical horn; sample 20, slide A, S41/4; length 46 µm. **figs 8, 9.** Genus indet. B, morphotype 2, upper and lower focus respectively, arrows indicate **8** trace of antapical corona and **9** cingulum; sample 39, slide A, L23/0; length 33 µm. **fig. 10.** Genus indet. B, morphotype 3, middle focus; sample 15, slide B, T40/3; length 44 µm. **figs 11, 12.** Genus indet. B, morphotype 3, upper and middle focus respectively; sample 14, slide A, W13/4; length 73 µm. **figs 13, 14.** Typical palynofacies showing dominance of woody phytoclasts: **13,** arrow indicating dinoflagellate cyst; sample 35 slide A, L30/0; width of photomicrograph 700 µm, length of dinoflagellate cyst 66 µm; **14,** sample 1, slide A, Z30/1, width of photomicrograph 650 µm.

Late Norian, has been interpreted as shelfal with detrital input (Detterman, 1970). Occurrences of *Sverdrupiella* in the Glenn Shale of east-central Alaska are also associated with clastic deposition (Helby *et al*., 1987b), and specimens were also recorded from clastic sequences in the Murihiku Supergroup of New Zealand (Wilson & Helby, 1986). Reports of the genus from Browse Basin, Australia are also from a clastic shallow-water sequence. The genus was recorded from the predomi-

nantly deltaic deposits of the Mungaroo Formation in the Carnarvon Basin, Australia (Helby *et al.*, 1987b), and finds of the genus from Indonesia are associated with shallow-water clastic deposits of the Kanikeh Formation (O'Sullivan *et al.*, 1985).

The Miankuhi Formation, which is the youngest formation of the Aghdarband Group, consists of shales, siltstone and subordinate sandstone. The coal bed at the base of this formation is autochthonous (Baud *et al.*, 1991) and marks the first clear phase of continental deposition for the group. Overlying the coal bed are about 6 m of coaly shales and sandstones, followed by a 170 m thick marine sequence of shales interbedded with sandstone. This succession indicates that after a break in deposition, sedimentation recommenced with a transgressive sequence of Middle to Late Norian age forming a shallow siliciclastic ramp (Baud *et al.*, 1991) with a coal seam at the base. The impoverished assemblage of agglutinated benthic foraminifera reported from the shale comprises *Ammodiscus* sp. (small-sized), *Reophax* sp., *Nodellum* sp., *Hyperammina* sp., *Ammobaculites* sp., cf. *Endothyra* sp., Saccaminidae (pinched), Trochamminidae, Textulariidae and fragments of Dendrophyrae, and possibly indicates adverse conditions (Oberhauser & Prey in Ruttner, 1991, p. 47). A similar shallow clastic environment was reported for the Shublik Formation of arctic Alaska (Detterman, 1970), the clastic strata of the Heiberg Formation, Sverdrup basin, arctic Canada, and for Australia and Indonesia. These occurrences indicate that *Sverdrupiella* was well adapted to shallow-marine clastic depositional environments.

DINOFLAGELLATE CYST ZONATION AND AGE ATTRIBUTION

The association, containing *Sverdrupiella* species, *Hebecysta* cf. *balmei* and *Heibergella* species, is characteristic of the *Hebecysta* (*Heibergella*) *balmei* Zone of Australia (Helby *et al.*, 1987a). The zone is defined as the interval from the lowest occurrence of *H. balmei* to the lowest occurrence of *Rhaetogonyaulax rhaetica*, with the accompanying species *Rhaetogonyaulax wigginsii*, *Wanneria listeri* and *Sverdrupiella* spp. in the middle of the zone (R. Helby, pers. comm., 2007), and was assigned a Late Norian age (Helby *et al.*, 1987a). Of the characteristic elements, *H.* cf. *balmei* is present throughout the Miankuhi Formation, and *Sverdrupiella* species are also present. *Wanneria listeri* was not encountered. The association therefore compares most closely with the middle part of the *Hebecysta* (*Heibergella*) *balmei* Zone, to which an age of early Late Norian may be assigned based on distribution data from Fisher & Bujak (1975), Wiggins (1976) and R. Helby (pers. comm., 2007). A Norian age is also supported by a similarity with dinoflagellate cyst assemblages from the Norian of arctic Canada (Bujak & Fisher, 1976) and Warepan Stage (Norian) of the Kaihiku Stream, South Otago, New Zealand (Helby & Wilson, 1988), and by the plant microfossils associated with the coal bed at the base of the Miankuhi Formation. *Rhaetogonyaulax rhaetica,* whose first appearance marks the end of the *H. balmei* Zone and ostensibly the beginning of the Rhaetian Stage (Brinkhuis *et al.*, 2006), was not recorded. This agrees with a pre-Rhaetian age for the assemblage. *Rhaetogonyaulax rhaetica* is present in Iran, having been recorded from the adjacent Alborz Basin (Ghasemi-Nejad *et al.*, 2004). Based on published information and the present study,

the *H. balmei* Zone can be identified world-wide from Australia, through the Middle East and southern Europe and into the Canadian arctic.

CONCLUSIONS

Dinoflagellate cysts and abundant woody phytoclasts together indicate a near-shore marine depositional environment for the shales of the Miankuhi Formation. The dinoflagellate cyst association shows close similarities with assemblages reported from Australia, New Zealand, Indonesia, Northwest Europe and arctic Canada and Alaska. This indicates a palaeogeographical relationship reflecting the extension of warm Triassic waters of Tethys across these areas, which occupied low palaeolatitudes at that time. Based on all of these occurrences it is clear that the genus *Sverdrupiella* was well adapted to clastic shallow-marine depositional environments. An age of early Late Norian is implied for the Miankuhi Formation based on the association recorded.

COMMENTS ON SELECTED TAXA

Genus *Sverdrupiella* Bujak & Fisher, 1976

***Sverdrupiella* sp. A (Pl. 2, figs 5–6).** Cysts are cavate and rhomboidal in shape, with the pericyst of almost equal length and breath. The epicyst is slightly shorter than the hypocyst and almost triangular in outline, with a rounded apex and convex sides. The cingulum is planar. Length is 38–50 μm, based on three specimens.

***Sverdrupiella* sp. B (Pl. 2, figs 8–9).** Cysts are biconical and semi-rhomboidal. The pericyst is longer than broad. The epicyst is shorter than the hypocyst and triangular in shape, terminating in a rounded apical horn. The hypocyst is triangular and broad. The cingulum is slightly helicoidal. Length is 49–57 μm, based on three specimens.

***Sverdrupiella* sp. C (Pl. 2, figs 10–12).** Cysts are cavate, with the pericyst much longer than broad, forming a triangular epicyst terminating in a small apical horn. The hypocyst is elongate, and semitabular to subconical. The cingulum is planar or slightly helicoidal. Length is 43–93 μm, based on two specimens.

***Sverdrupiella* sp. D (Pl. 2, figs 13–15).** Cysts are cavate, rhomboidal, with the pericyst much broader than long and flattened

apparently dorsoventrally. The epicyst is small and conical, terminating in a short apical horn. The hypocyst is longer, and acutely conical to subconical. The cingulum, sulcus and other tabulation were not seen. Length is 40–56 µm, width 47–68 µm, based on three specimens. This species appears not to have been reported previously.

Indeterminate genera

Genus indeterminate A, morphotype 1 (Pl. 1, figs 14–18). The epicyst is triangular to sub-triangular in outline and bears a small distinct apical horn. The hypocyst is of similar length or shorter than the epicyst, and vase-shaped or rounded in outline. The presence of a large antapical projection or carina is characteristic. The surface of the cyst wall is smooth or may bear small projecting elements. The cingulum is apparently planar or slightly laevorotary. However, neither cingulum, sulcus, nor other evidence of tabulation are recorded clearly, although traces of tabulation including the cingulum were interpreted on some specimens. An archaeopyle was not seen. Length is 56–78 µm, width 47–52 µm, based on five specimens. This morphotype appears not to have been reported previously.

Genus indeterminate A, morphotype 2 (Pl. 1, figs 19–20). Cysts are elliptical in outline, and a small distinct apical horn may be present. A characteristic antapical protuberance is present. The cyst wall is thin and the outer surface granulate. Neither cingulum, sulcus nor other evidence of tabulation are recorded clearly, although the trace of a planar cingulum was interpreted on some specimens. An archaeopyle was not seen. Length is 64–78 µm, width 34–40 µm, based on three specimens. This morphotype appears not to have been reported previously.

Genus indeterminate B (Pl. 3, figs 6–12). Cysts are cavate with an umbrella- or mushroom-like shape, presenting a conical or dome-shaped central body attached to a cylindrical corona that forms the distal end of the hypocyst as a unique feature. A small apical horn is always present. The tabulation, including cingulum and sulcus, was observed rarely, although this might be caused by the poor state of preservation. An archaeopyle was not observed. The outer surface of the cyst is smooth. The pericyst is longer than broad. The genus is somewhat similar to *Sverdrupiella* in outline but differs in having a corona at the distal end of the hypocyst and a dome-shaped outline. Length 33–73 µm, based on 11 specimens.

Three informal morphotypes are differentiated within this genus based on their shape and size.

- **Morphotype 1** (Pl. 3, figs 6, 7) is conical and relatively elongate with a small apical horn and a typical antapical corona. The outer surface of the cyst is smooth and lacks specific features. The corona is short and rounded. Length is 46–59 µm, based on two specimens.
- **Morphotype 2** (Pl. 3, figs 8, 9) has a small corona and the trace of a circular to slightly laevigatory cingulum. It is relatively short and has a stout apical horn. This morphotype appears to be the smallest, with a length of 33 µm.
- **Morphotype 3** (Pl. 3, figs 10–12) is differentiated by a long antapical corona and a semi-triangular cyst outline. A small

apical horn might also be present. Length is 44–73 µm, based on three specimens.

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