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# STRATIGRAPHY AND PALYNOLOGY OF THE UPPER TRIASSIC NAYBAND FORMATION OF EAST-CENTRAL IRAN

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*Abstract*. A palynological study of the Nayband Formation (central eastern Iran) has been carried out in order to review and update its stratigraphic framework. In its type locality the formation crops out on the southern flank of Nayband Mountain, about 200 km south of Tabas. It consists of a thick, mixed siliciclastic-carbonate sequence subdivided into four members; in ascending order: the Gelkan Member (mainly shales and silstones), the Bidestan Member (marls, siltstones with minor sandstones and fossiliferous limestones), the Howz-e-Sheikh Member (sandstones and siltstones), and the Howz-e-Khan Member (sponge and coral dominated reefs alternating with marls and sandstones). Three palynological assemblages have been recognised; in ascending order: a) an assemblage characterised by the presence of *Annulispora folliculosa* and *A. microannulata* which allows the Gelkan Member and most of the Bidestan Member to be assigned an early Norian age; (b) an assemblage marked by the first occurrence of *Polycingulatisporites mooniensis,* which indicates the upper part of the Bidestan Member is mid-late Norian; c) an assemblage containing *Classopollis chateaunovi* in association with *Retitriletes austroclavatidites, Gliscopollis meyeriana, Limbosporites lundbladii, Rugaletes awakinoensis* and *Callialasporites dampieri* that allows the Howz-e-Sheikh Member to be assigned a Rhaetian age.

The presence of some Eurasian and/or cosmopolitan forms in the Rhaetian microflora reflects the position of the Iranian plate on the southern margin of Eurasia.

*Riassunto*. L'analisi palinologica della Formazione di Nayband (Iran centro-orientale) ha permesso di ricostruire in dettaglio la stratigrafia di questa potente successione sedimentaria affiorante lungo il fianco meridionale della catena montuosa di Nayband, 200 km circa a Sud di Tabas. La formazione é costituita da una successione mista carbonatico-silicoclastica, suddivisa in quattro membri, che dal basso verso l'alto sono: il Membro di Gelkan (principalmente costituito da argille e siltiti), il Membro di Bidestan (marne, siltiti e rare intercalazioni di arenarie e calcari fossiliferi), il Membro di Howz-e-Sheikh (arenarie e siltiti) e il Membro di Howz-e-Khan (calcari con patch reefs a predominanti spugne e coralli alternati a marne ed arenarie). Sono state riconosciute, dal basso verso l'alto, tre associazioni palinologiche: a) un'associazione contenente *Annulispora folliculosa* e *A. microannulata* che permette di datare il Membro di Gelkan e gran parte del Membro di Bidestan al Norico inferiore; b) un'associazione caratterizzata, nella parte superiore del Membro di Bidestan, dalla prima comparsa di *Polycingulatisporites mooniensis* riferibile al Norico medio-superiore; c) un'associazione contenente *Classopollis chateaunovi*, *Retitriletes austroclavatidites, Gliscopollis meyeriana, Limbosporites lundbladii, Rugaletes awakinoensis* e *Callialasporites dampieri* che permette di assegnare il membro di Howz-e-Sheikh al Retico.

La presenza nella microflora retica di alcuni elementi ad affinità euroasiatica e/o cosmopoliti riflette la posizione della placca iraniana lungo il margine meridionale dell'Eurasia in questo intervallo di tempo.

## Geological setting and stratigraphy

The Upper Triassic Nayband Formation (Nayband Fm.) is one of the most important geological units that outcrops in parts of central eastern Iran. It consists mostly of alternating shales, sandstones and carbonate sediments and is more than 2220 m thick in its type locality, on the southern flank of the Kuh-e-Nayband (Nayband Mountain), about 20 km north-west of Naybandan village and 220 km south of Tabas (Fig. 1) (Brönniman et al. 1971; Seyed-Emami 1971; 2003; Kluyver et al. 1983; Senowbari-Daryan 2003).

The Nayband Fm. overlies Middle Triassic carbonate deposits of the Shotori Formation disconformably

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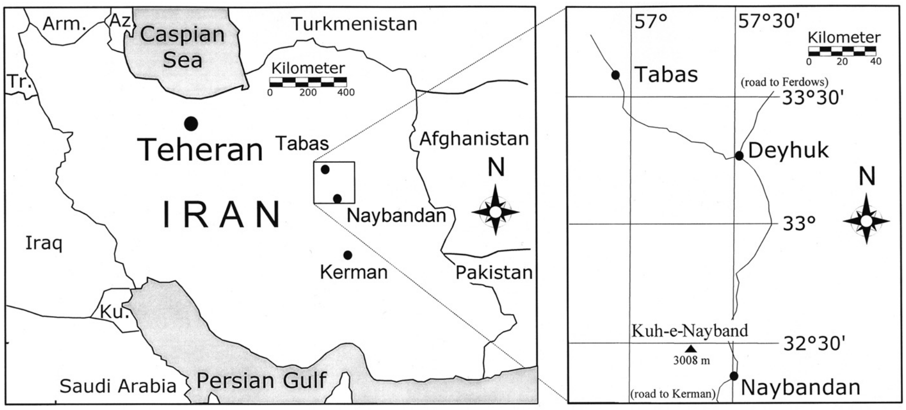


Fig. 1 - Location map. Arm: Armenia; Az: Azerbaijan; Ku: Kuwait; Tr: Turkey.

and underlies the Shemshak Formation (Kluyver et al. 1983; Seyed-Emami 2003). It has been variously dated as Early Triassic to Rhaetian (Douglas 1929), Ladinian to Rhaetian (Seyed-Emami 1971) and Late Triassic (Brönniman et al. 1971; Senowbari-Daryan et al. 1997).

The present palynological study has been carried out in a section close to the type section of the formation (Fig. 1).

Four members have been recognised within the Nayband Fm. (Brönniman et al. 1971; Kluyver et al. 1983; Senowbari-Daryan et al. 1997); in stratigraphic order these are:

a) Gelkan Member: this corresponds to the Lower Sandstone Shale Member in Brönniman et al. (1971). It is about 800 m thick and consists of dark grey-green shales and siltstones, locally with intercalated sandstones. Only bivalve bioclasts were found in thin coquina intervals in the lower part of the member (Brönniman et al. 1971; Kluyver et al. 1983).

b) Bidestan Member: this corresponds to the Middle Limestone Shale Sandstone Member in Brönniman et al. (1971). It is about 600 m thick and consists of calcareous shales and siltstones, fossiliferous limestones and minor sandstones. Limestones contain some sponge- or coral dominated biostromal reefs. *Heterastridium*-bearing marls and limestones are also present (Brönniman et al. 1971; Kluyver et al. 1983; Senowbari-Daryan et al. 1997). Brönniman et al. (1971) recorded the type level of the benthic foraminifer *Miliolipora cuvillieri* at the junction of this member with the overlying Howz-e-Sheikh Member. Other typically Upper Triassic benthic foraminifera were found at several levels within the member, both in association with and without *M. cuvillieri*. Brönniman et al. (1971) assigned this member to the Norian. Poorly preserved plant impressions (*Equisetites* sp.) have been recorded in an outcrop west of Kuh-e Nayband (Brönniman et al. 1971; Kluyver et al. 1983).

c) Howz-e-Sheikh Member: this is about 500 m thick and consists of fine to medium grained sandstones alternating with dark-green silty calcareous shales that grade upwards to siltstones. The upper boundary of this member is placed at the base of the first coral limestone bed of the overlying Howz-e-Khan Member. A few plant remains and some not diagnostic shell fragments were found (Brönniman et al. 1971; Kluyver et al. 1983).

d) Howz-e-Khan Member: this consists of sponge or coral dominated reefs alternating with calcareous shales, marls and fine-grained sandstones. In the sampled area it is about 450 m thick, but the reefal limestones change in facies and thickness to the west of the type section (Brönniman et al. 1971). This member has yielded a rich macrofauna (Kluyver et al. 1983) of inozoid sponges (Senowbari-Daryan et al. 1997), corals (Brönniman et al. 1971), echinoderms, brachiopods and gastropods (Nützel & Senowbari-Daryan 1999). In the section south of Kuh-e-Nayband the member has a characteristic Triassic bivalve fauna including *Catella, Mysidiella, Rhaetavicula, Cassianella, Indopecten, Newaagia, Serania, Umbrostrea, Healeya, Costatoria, Gruenwaldia, Myophoricardium, Palaeocardita* and *Vietnamicardium* (Hautmann 2001; pers. comm. M. Hautmann 2002, Würzburg). Upper Triassic benthic foraminifera were recorded from this member by Brönniman et al. (1971). On the basis of the above paleontological content a Late Triassic (Norian-Rhaetian) age was suggested for this member.

The depositional setting of the Nayband Fm. was interpreted as linked to the transgressive regime that followed uplift during the mid-Late Triassic (Kluyver et al. 1983). The beginning of the transgression is recorded by the Gelkan Member which was deposited in a paralic environment, with sandstones and shales derived from a source area probably located to the east and northeast. The transgression resulted in the establishment of a marine environment, characterised by a reduced siliciclastic supply and an increase in carbonate sediments. The abundance of silty and shaly intervals in the Howz-e-Sheikh Member reflects a renewed increase in clastic sedimentation, which prevented or reduced carbonate production. The facies and thickness of the Howz-e-Khan Member record conditions favourable

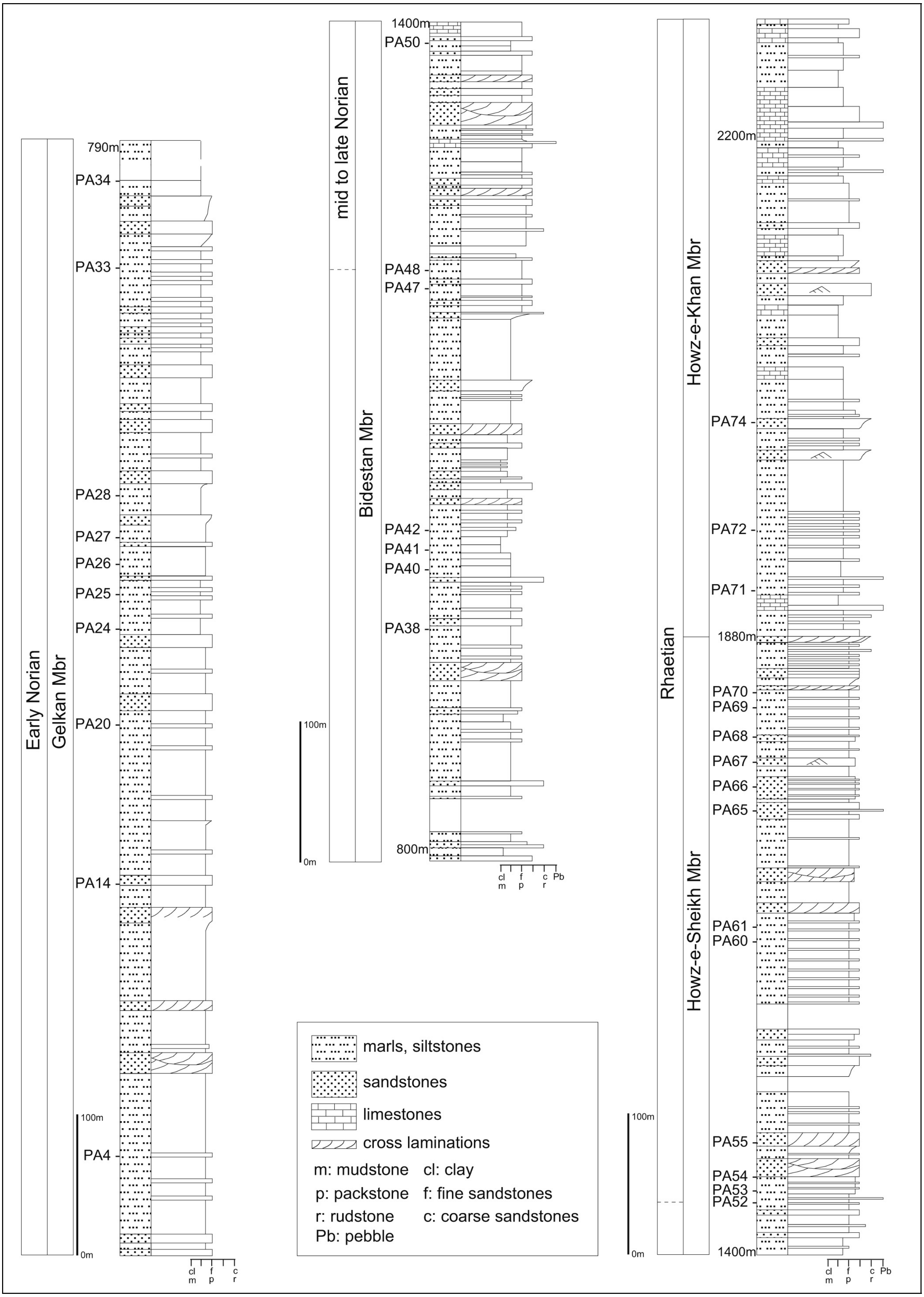


Fig. 2 - Schematic stratigraphic log of the Nayband Formation.

for carbonate production, and the deposition of reefal limestones.

### Palynological data

Palynological residues were prepared using standard techniques. Palynological slides are deposited at the Dipartimento di Scienze della Terra, Perugia University. A total of 74 samples were processed and 32 proved palynologically productive (Fig. 2); about 46 genera and 70 species were recorded (Fig. 3).

The preservation of the palynomorphs is not very good, being affected by medium to high thermal maturity and by degradational processes. However, we consider that the assemblages, even if not well preserved, are significant in providing new biostratigraphic evidence for the age of Nayband Fm.

#### Gelkan Member

The palynomorph assemblages of the Gelkan Member contain dark specimens, often broken and badly preserved, especially in the lower part of the member. In the lowest productive samples (PA 4, PA 14, Fig. 2), the only recognisable forms are *Cycadopites* sp., *Alisporites* sp., *Equisetosporites* sp., *Calamospora* sp., *Guthoerlisporites cancellosus*, *Deltoidospora toralis* and *Retitriletes* sp. (Fig. 3). Higher samples, from PA20 to PA26 (Fig. 2), yielded better preserved and more diverse microfloras, with successive appearances of new taxa such as *Annulispora folliculosa, Striatella seebergensis* (Pl. 1, fig. 5), *Microreticulatisporites fuscus* and *Camarozonosporites rudis* (Fig. 3).

In the upper part of the member, from PA27 to PA34, (Fig. 2) there are successive appearances (Fig. 3) of *Annulispora microannulata* (Pl. 1, figs. 1, 2), *Foveogleicheniidites atavus* (Pl. 1, fig. 9), *Limatulasporites limatulus* (Pl. 1, figs. 6, 7), *Densoisporites psilatus* and *Dictyophyllidites harrisii* (Pl. 1, fig. 3).

Among marine palynomorphs, the dinoflagellate cyst *Suessia swabiana* (Pl. 2, fig. 16) appears at PA28 (Figs. 2, 3).

#### Bidestan Member

The palynological content of this member is richer and more diverse (Fig.3), with the following successive stratigraphic appearances:

– *Kyrtomisporis niger* (Pl. 1, fig. 8), *Uvaesporites verrucosus* (Pl. 1, fig. 4), *Lycopodiacidites rugulatus*, *Limbosporites denmeadi* and other accessory elements (Fig. 3), from PA38 to PA47.

– *Polycingulatisporites mooniensis* (Pl. 1, fig. 10), *Chasmatosporites apertus* (Pl. 1, fig. 11), *Lunatisporites acutus* (Pl.1, fig. 12) and *Callialasporites* sp. from PA48 to PA50.

#### Howz-e-Sheikh Member

This member is marked by significant new occurrences of taxa such as:

– *Classopollis chateaunovi* (Pl. 1, fig. 14), *Acanthotriletes ovalis, Retitriletes austroclavatidites* (Pl. 2, fig. 3), *Densoisporites velatus*, *Gliscopollis meyeriana* (Pl. 1, fig. 17), *Alisporites australis* (Pl.1, fig. 16), *Rugaletes awakinoensis* (Pl. 1, figs. 19, 20), *Araucariacites australis* (Pl. 2, fig. 5) and *Limbosporites lundbladii* (Pl. 2, fig. 1) from the base of this member (PA52) to PA61 (Figs. 2, 3).

– *Callialasporites dampieri* (Pl. 2, figs. 9, 10) at PA65 and *Striatella jurassica* (Pl. 2, fig.12) at PA69 (Figs. 2, 3).

Acritarchs (*Veryhachium* sp. and *Micrhystridium* sp.) (Pl. 2, figs. 17, 18) become more abundant and consistently present in the middle-upper part of this member, together with foraminifera test linings (Fig. 3; Pl. 2, figs. 19, 20).

#### Howz-e-Khan Member

This member yielded less diversified palynological assemblages that consist largely of elements present in the underlying members (Fig. 3).

### Stratigraphic distribution of selected taxa

In this section, the age-significant taxa and their ranges, based on occurrences in independently dated successions elsewhere, are discussed in order to determine the chronostratigraphic and palaeobiogeographic value of the Iranian palynological assemblages.

*Annulispora folliculosa* is a characteristic element of the latest Ladinian – early Norian (*A. folliculosa* zone) in New Zealand. The FAD (First Appearance Datum) of *Annulispora microannulata*, which marks the late Carnian-early Norian *A. microannulata* subzone (de Jersey & Raine 1990) occurs in the upper part of this zone. This miospore is a significant accessory element in middle Carnian-lower Norian assemblages from eastern Australia (*Craterisporites rotundus* Zone; de Jersey 1975) and in Carnian-lower Norian assemblages from Western Australia (Dolby & Balme 1976). In the northern hemisphere *A. folliculosa* has been reported in lower Norian successions of Svalbard (Bjærke & Manum 1977; Smith 1982), and from younger strata (late Rhaetian) in Luxembourg and France (Schuurman 1977; 1979). It has been also recorded in Poland (Orlowska-Zwolinska 1983), from Carnian to Rhaetian strata, and from middle to upper Norian strata in New Caledonia (de Jersey & Grant-Mackie 1989).

The first appearance of *Polycingulatisporites mooniensis* is, like that of *P. crenulatus,* a useful marker

| Early Norian | | | | | | | | | | | | | | | mlN | | Rhaetian | | | | | | | | | | | | | | | age | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gelkan Member | | | | | | | | | | Bidestan Mbr | | | | | | | Howz-e-Sheikh Member | | | | | | | | | | | | H-e-K | | | members | |
| PA4 | PA14 | PA20 | PA24 | PA25 | PA26 | PA27 | PA28 | PA33 | PA34 | PA38 | PA40 | PA41 | PA42 | PA47 | PA48 | PA50 | PA52 | PA53 | PA54 | PA55 | PA60 | PA61 | PA65 | PA66 | PA67 | PA68 | PA69 | PA70 | PA71 | PA72 | PA74 | samples | |
|*|*| | | |*| |*|*|*| | | |*|*| |*| | | | | | | | | | | | | | | |*Cycadopites* sp.| |
|*|*| | | | | | | | | | | | |*| | | | | | | | | | | | | | | | | |*Alisporites* sp.| |
|*| | | | | | | | | | | | | | | | | | | | | | | | | |*| | | | | |*Equisetosporites* sp.| |
|*| | | | | |*|*| | | | | | | |*| |*|*|*| | | | | | | | | |*| | |*Calamospora* sp.| |
| |*| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |*Guthoerlisporites cancellosus*| |
| |*| | | | | | | | | | | |*|*|*| | | | | | | | | | | |*| | |*| |*Deltoidospora toralis*| |
| |*| | | | | | | | | | | | |*| | |*| | | | |*| | | |*| | | | | |*Retitriletes* sp.| |
| | |*| | | | |*| |*| | | |*|*|*|*|*| | |*|*| |*| | | | | | | | |*Annulispora folliculosa*| |
| | |*|*| | | | | | | | | | | | | | | | | | | | | | | | | | | | |*Kraeueselisporites* sp.| |
| | |*|*| | | | | |*|*| | |*| | | | | | | | | | |*| |*|*| | | |*|*Stereisporites* sp.| |
| | | |*| |*| | | | |*| | |*|*|*|*|*| |*| |*|*|*| | |*|*| |*| | |*Striatella seebergensis*| |
| | | |*| | | | | | | | | | | |*| | | | |*| |*|*|*| | | | | | | |*Camarozonosporites rudis*| |
| | | |*|*| |*| | | | | | | | | | | | |*| |*|*| | | | | | | | |*Microreticulatisporites fuscus*| |
| | | |*| | | | | | | | | | | | | | | | | | | | | | |*| | | | | |*Calamospora mesozoica*| |
| | | |*| | | | | |*| | | | | | | | | | | | |*| | | | | | | | |*Converrucosisporites* sp.| |
| | | |*| | | | |*| | | | |*| |*| | | | | | | |*| | | | | | | | |*Deltoidospora* sp.| |
| | | |*| | | | | | | | | | |*| | | | | | | | | | | | | | | | | |*Concavisporites umbonatus*| |
| | | | |*| | | | | | | | |*| | |*| | | | | |*| |*| |*| | | |*| |*Acanthotriletes varius*| |
| | | | |*|*| | | | | | | | | |*| | | | | | | | | | | |*| | | | |*Ovalipollis pseudoalatus*| |
| | | | |*| |*|*| |*| | |*| |*| |*| | | | | | | | | | | | | | | |*Concavisporites* sp.| |
| | | | | |*|*|*| | | | | | | |*| |*| |*| | | |*| | | | | | | | |*Baculatisporites* sp.| |
| | | | | |*|*| | | | | | |*| |*|*| | | | | | |*|*|*|*|*| | | |*|*Conbaculatisporites mesozoicus*| |
| | | | | | |*|*| | | | | | | | | | | | | | | | | | | | | | | | |*Rogalskaisporites* sp.| |
| | | | | | |*| | | | | | | | | | | | | | | | | | | | | | | | | |*Foveogleicheniidites atavus*| |
| | | | | | |*|*| | | | | | | | | | | | | | | |*| | | | | | | | |*Annulispora microannulata*| |
| | | | | | |*| |*| | | | |*| | | | | | |*| | |*|*| | | |*|*| | |*Limatulasporites limatulus*| |
| | | | | | |*| | | |*| |*|*| |*| | | | | | | | | | | | | | | | |*Densoisporites psilatus*| |
| | | | | | | |*| | | | | | | | | | | | | | | | | | | | | | | | |*Aratrisporites macrocavatus*| |
| | | | | | | |*| | | |*| | | |*|*|*|*|*|*|*| | | | |*|*|*| |*|*|*Dictyophyllidites harrisii*| |
| | | | | | | |*| | | | | |*| |*|*| | |*| |*|*| |*|*|*|*|*| | | |*Deltoidospora directa*| |
| | | | | | | |*| | | | | |*|*|*|*| |*| | | |*|*|*| | | | | |*| |*Araucariacites* sp.| |
| | | | | | | | |*| | | |*| | |*| |*| |*| | | | | | | | | | | |*|*Cycadopites follicularis*| |
| | | | | | | | | |*| | | | | | | | | | | | | | | | | | | | | | |*Stereisporites stereoides*| |
| | | | | | | | | |*| | | | |*| | | | | | | | | | | | | | | | | |*Osmundacidites wellmanii*| |
| | | | | | | | | | |*| | | | | | | | | | | | | | | | | | | | | |*Converrucosisporites cameronii*| |
| | | | | | | | | | |*| |*| | |*| | | | | | | | | | | | | | | | |*Annulispora* sp.| |
| | | | | | | | | | | |*| | | | | | | | | | | | | | | | | | | | |*Alisporites robustus*| |
| | | | | | | | | | | |*| |*| |*|*|*| | |*|*| | |*| | | | | | | |*Kyrtomisporis niger*| |
| | | | | | | | | | | |*| | | |*| | | | | | | | | | | | | | | | |*Uvaesporites verrucosus*| |
| | | | | | | | | | | | |*|*| |*| |*| | | | | | | | | | | | | | |*Aratrisporites* sp.| |
| | | | | | | | | | | | |*| | | | | | | | | | | | | | | | | | | |*Rugulatisporites* sp.| |
| | | | | | | | | | | | |*| | |*| | | | | | | | | | |*| | | | | |*Limbosporites* sp.| |
| | | | | | | | | | | | | |*| | | | | | | | | | | | | | | | | | |*Todisporites minor*| |
| | | | | | | | | | | | | |*| | | | | | | | | | | | | | | | | | |*Gliscopollis* sp.| |
| | | | | | | | | | | | | |*| | | | | | | | | | | | | | | | | | |*Lycopodiacidites rugulatus*| |
| | | | | | | | | | | | | |*| | | | | | | | | | | | | | | | | | |*Monosulcites* sp.| |
| | | | | | | | | | | | | |*| | | | | | | | |*| | | |*| | | | | |*Kyrtomisporis* sp.| |
| | | | | | | | | | | | | |*| |*|*| | |*|*| | | | |*| | | | | | |*Inaperturopollenites* sp.| |
| | | | | | | | | | | | | |*| | | |*| | | |*| | | | | | |*| | | |*Punctatisporites leighensis*| |
| | | | | | | | | | | | | |*| |*| | |*|*| | | |*| | |*| | | | | |*Baculatisporites comaumensis*| |
| | | | | | | | | | | | | |*| |*| | |*|*|*|*|*|*|*| |*| | | | | |*Dictyophyllidites mortonii*| |
| | | | | | | | | | | | | |*| | |*| | | | | |*|*| | | | | | | |*|*Dictyophyllidites* sp.| |
| | | | | | | | | | | | | | |*| |*|*| |*| | | | | | |*|*| | | | |*Limbosporites denmeadi*| |
| | | | | | | | | | | | | | |*|*| | | |*| | | | | | | | | | | | |*Chasmatosporites* sp.| |
| | | | | | | | | | | | | | |*| | | | | | | | |*| | | | | | | | |*Trachysporites asper*| |
| | | | | | | | | | | | | | | |*| | | | | | | | | | | | | | | | |*Lunatisporites acutus*| |
| | | | | | | | | | | | | | | |*| | | | | | | | | | | | | | | | |*Equisetosporites steevesi*| |
| | | | | | | | | | | | | | | |*| | | | | | | | | | | | | | | | |*Laevigatosporites* sp.| |
| | | | | | | | | | | | | | | |*| | | | | |*| | | | | | | | | | |*Trachysporites sparsus*| |
| | | | | | | | | | | | | | | |*| |*| | | | | | | | | | | | | | |*Alisporites similis*| |
| | | | | | | | | | | | | | | |*| | | | | | | | | | | | | | | | |*Chasmatosporites apertus*| |
| | | | | | | | | | | | | | | |*| | | | | | | | | | | | | | | | |*Cosmosporites* cf. *elegans*| |
| | | | | | | | | | | | | | | |*|*|*| | | | | | | | | | | | | | |*Vitreisporites pallidus*| |
| | | | | | | | | | | | | | | |*| | | | |*| | |*| | | |*| | | | |*Polycingulatisporites mooniensis*| |
| | | | | | | | | | | | | | | | |*| | | |*| | | |*| | | | | | | |*Callialasporites* sp.| |
| | | | | | | | | | | | | | | | |*| | | |*| | | | | | | | | | | |*Aratrisporites fimbriatus*| |
| | | | | | | | | | | | | | | | |*| | | | | | | | | | | | | | | |*Chordasporites* sp.| |
| | | | | | | | | | | | | | | | |*| | | | | | | | | |*| | | | | |*Anapiculatisporites* sp.| |
| | | | | | | | | | | | | | | | |*|*|*|*|*| | | |*| | | | | | | |*Punctatisporites* sp.| |
| | | | | | | | | | | | | | | | | |*| | | | | | | | | | | | | | |*Cycadopites crassimarginis*| |
| | | | | | | | | | | | | | | | | |*| | | | | | | | | | | | | | |*Trachysporites* sp.| |
| | | | | | | | | | | | | | | | | |*|*| | |*|*|*| | | | | | | | |*Acanthotriletes ovalis*| |
| | | | | | | | | | | | | | | | | |*|*| | | | | | | | | | | | | |*Classopollis chateaunovi*| |
| | | | | | | | | | | | | | | | | | |*| | | | | | | | | | | | | |*Annulispora punctus*| |
| | | | | | | | | | | | | | | | | | |*|*| | | | | | | | | | | | |*Retitriletes gracilis*| |
| | | | | | | | | | | | | | | | | | |*| | | | | | | | | | | | | |*Foveogleicheniidites* sp.| |
| | | | | | | | | | | | | | | | | | |*|*|*| | |*| | | | |*| | | |*Conbaculatisporites baculatus*| |
| | | | | | | | | | | | | | | | | | |*| | | | | | | | | | | | | |*Stereisporites* cf. *lunaris*| |
| | | | | | | | | | | | | | | | | | |*| | | | | | | | | | | | | |*Todisporites major*| |
| | | | | | | | | | | | | | | | | | |*| | | |*| | | | | | | | |*|*Retitriletes austroclavatidites*| |
| | | | | | | | | | | | | | | | | | |*|*| |*| | | | | | | | | | |*Anapiculatisporites dawsonensis*| |
| | | | | | | | | | | | | | | | | | | |*| | | |*| | | | | | | | |*Calamospora tener*| |
| | | | | | | | | | | | | | | | | | | |*| | | | | | | | | | | | |*Stereisporites antiquasporites*| |
| | | | | | | | | | | | | | | | | | | |*| | |*|*| | | |*| | | | |*Densoisporites* sp.| |
| | | | | | | | | | | | | | | | | | | | |*| | | | | | | | | | | |*Densoisporites velatus*| |
| | | | | | | | | | | | | | | | | | | | |*| | | | | | | | | | | |*Converrucosisporites rewanensis*| |
| | | | | | | | | | | | | | | | | | | | |*| | | | | | | | | | | |*Apiculatisporites* sp.| |
| | | | | | | | | | | | | | | | | | | | |*| | | | | |*| | | | | |*Alisporites australis*| |
| | | | | | | | | | | | | | | | | | | | |*| | | | | | | | | | | |*Apiculatisporites otapiriensis*| |
| | | | | | | | | | | | | | | | | | | | |*| | | | | | | | | | | |*Kyrtomisporis speciosus*| |
| | | | | | | | | | | | | | | | | | | | |*| | |*|*| |*| | | |*| |*Verrucosisporites* sp.| |
| | | | | | | | | | | | | | | | | | | | |*| |*| | | | | | | | | |*Gliscopollis meyeriana*| |
| | | | | | | | | | | | | | | | | | | | | | |*| | | | | | | | | |*Rugaletes awakinoensis*| |
| | | | | | | | | | | | | | | | | | | | | | |*| | | |*|*| | | |*|*Araucariacites australis*| |
| | | | | | | | | | | | | | | | | | | | | | |*| | | | | | | | | |*Limbosporites lundbladii*| |
| | | | | | | | | | | | | | | | | | | | | | |*| |*| | | | | | | |*Densosporites fissus*| |
| | | | | | | | | | | | | | | | | | | | | | |*| | | | | | | | | |*Dictyophyllidites atraktos*| |
| | | | | | | | | | | | | | | | | | | | | | | |*| | | | | | | | |*Baculatisporites oppressus*| |
| | | | | | | | | | | | | | | | | | | | | | | |*|*| | |*| | | | |*Callialasporites dampieri*| |
| | | | | | | | | | | | | | | | | | | | | | | |*| | | | | | | | |*Ischyosporites* sp.| |
| | | | | | | | | | | | | | | | | | | | | | | | | | |*| | | | | |*Rewanispora foveolata*| |
| | | | | | | | | | | | | | | | | | | | | | | | | | |*|*| | | | |*Osmundacidites fissus*| |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |*| | | | |*Densosporites cavernatus*| |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |*| | | | |*Striatella jurassica*| |
| | | | | | | |*| | | | | | | | | | | | | | | | | | | | | | | | |*Suessia swabiana*|mar. elem.|
| | | | | | | | | | | | | | | | | | | | | |*|*|*|*|*|*|*| | |*|*|acritarchs| |
| | | | | | | | | | | | | | | | | | | | | | | |*| | | | | | | | |foraminiferal lining| |

Fig. 3 - Range chart of selected palynomorphs from the Upper Triassic Nayband Formation (central eastern Iran). H-e-K: Howz-e-Khan Member; mlN: mid to late Norian; mar. elem.: marine elements (acritarchs, dinoflagellate cysts, foraminifera lining).

in Upper Triassic successions. It marks the mid Norian in eastern Australia (Queensland), New Zealand (de Jersey 1974; Stevens 1981; de Jersey & Raine 1990) and New Caledonia (de Jersey & Grant-Mackie 1989).

*Classopollis* is the most characteristic, ubiquitous and abundant miospore in the Upper Triassic and Jurassic. Cheirolepidiacean cones yielding *Classopollis*-type pollen have been found in Germany, France, England, Iran and Argentina (Batten & Koppelhus 1996; Warrington 1996b). *Classopollis chateaunovi* has been reported from the Rhaetian and Hettangian in France (Reyre 1970), the Early Jurassic of Queensland (de Jersey 1973), the Jurassic of western Australia (Filatoff 1975) and the Early Jurassic of Tanzania (Hankel 1987). The *C. chateaunovi* Subzone of Filatoff (1975) has been considered the time equivalent of the *C. torosa* Zone (base of Hettangian to base of Toarcian) in western Australia (Helby et al. 1987), as well as in the North Sea Basin (Lund 1977).

The *Callialasporites dampieri* Superzone was assigned by Filatoff (1975) to the mid Toarcian-Kimmeridgian in western Australia but Helby et al. (1987) recognised the appearance of the *C. dampieri* microflora in the *Polycingulatisporites crenulatus* Zone (Norian? - Rhaetian-Hettangian) in eastern Australia. It has also been recorded in Hettangian strata near the equator (Reyre 1973).

Amongst the accessory miospores that occur with the above taxa, *Microreticulatisporites fuscus, Gliscopollis meyeriana, Acanthotriletes varius, Retitriletes austroclavatidites* and *Limbosporites lundbladii* are commonly recorded as post-Carnian elements in Upper Triassic successions from both the northern (Morbey 1975; Mostler et al. 1978; Pedersen & Lund 1980; Visscher et al. 1980; Guy-Ohlson 1981; Visscher & Brugman 1981; Achilles et al. 1984; Achilles & Schlatter 1986; Brenner 1986; Dybkjær 1991; Cirilli et al. 1994; Jadoul et al. 1994; Batten & Koppelhus 1996; Warrington 1996b; Buratti et al. 2000) and the southern (Stevens 1981; de Jersey & Raine 1990; Burger 1996; Martini et al. 2000) hemispheres. *Rugaletes awakinoensis* was recorded from Rhaetian successions of New Zealand (de Jersey & Raine 1990) and Indonesia (Seram) (Martini et al. 2004). *Striatella jurassica* and the cosmopolitan species *Araucariacites australis* are common in Rhaetian and Hettangian assemblages (Filatoff 1975; Lund 1977; Achilles 1981; de Jersey & Raine 1990; Dybkjær 1991; Batten & Koppelhus 1996).

The dinoflagellate cyst *Suessia swabiana* has been found in Rhaetian successions in Europe (Schuurman 1977; Morbey & Dunay 1978; Cirilli et al. 1994) and in the lower to middle Norian *Suessia listeri* zone of western Australia (Helby et al. 1987).

**Palynostratigraphy of the Nayband Formation**

On the basis of the stratigraphic ranges of the most age-significant taxa described in the previous section, the gradual upward diversification of the palynomorph associations throughout the Nayband Fm. allows the recognition of three distinct palynological assemblages, in ascending order:

a) lower Norian assemblage characterised by the presence of the miospores *Annulispora folliculosa* and *A. microannulata* together with important accessory taxa such as *Microreticulatisporites fuscus, Acanthotriletes varius, Camarozonosporites rudis, Lycopodiacidites rugulatus* and *Limbosporites denmeadi*. This assemblage also contains the dinoflagellate cyst *Suessia swabiana*;

b) a middle to upper Norian assemblage marked by the first occurrence of *Polycingulatisporites mooniensis*. A peculiar feature of lower and middle to upper Norian assemblages, which is also common to coeval associations of the southern hemisphere (i.e. Queensland and New Zealand, Helby et al. 1987; de Jersey & Raine 1990), is the frequent occurrence of cingulate spores with distal polar or circumpolar thickenings, such as *Polycingulatisporites*, *Annulispora* and *Limatulasporites*;

c) a Rhaetian assemblage characterised by the miospore *Classopollis chateaunovi* in association with *Retitriletes austroclavatidites, Gliscopollis meyeriana, Limbosporites lundbladii* and *Rugaletes awakinoensis*. *Callialasporites dampieri* and *Striatella jurassica* first occur in the upper part of this assemblage.

The occurrence of *Callialasporites dampieri* (Fig. 3), considered by most authors to be indicative of Hettangian or younger age, suggests that the Rhaetian-Hettangian boundary should be placed within the upper part of the Howz-e-Sheikh Member, but the presence of Upper Triassic fossils within the overlying strata (Howz-e-Khan Member) implies that the first occurrence of *C. dampieri* is, in fact, in the Rhaetian.

The Norian microfloras from the Nayband Fm. have strong affinities with Gondwanan microfloras, particularly those of eastern Australia and New Zealand. The Rhaetian assemblages, still maintaining a strong affinity with southern hemisphere microfloras, show a gradual enrichment in cosmopolitan species recorded from both the northern and the southern hemispheres. However the composition of the Rhaetian microfloras differs considerably from that of typical European Rhaetian assemblages (Morbey 1975; Morbey & Dunay 1978; Schuurman 1979; Visscher et al. 1980; Visscher & Brugman 1981; Batten & Koppelhus 1996; Warrington 1996b). Also, the Rhaetian macroflora of northern Iran (Alborz), which is representative of the littoral south-

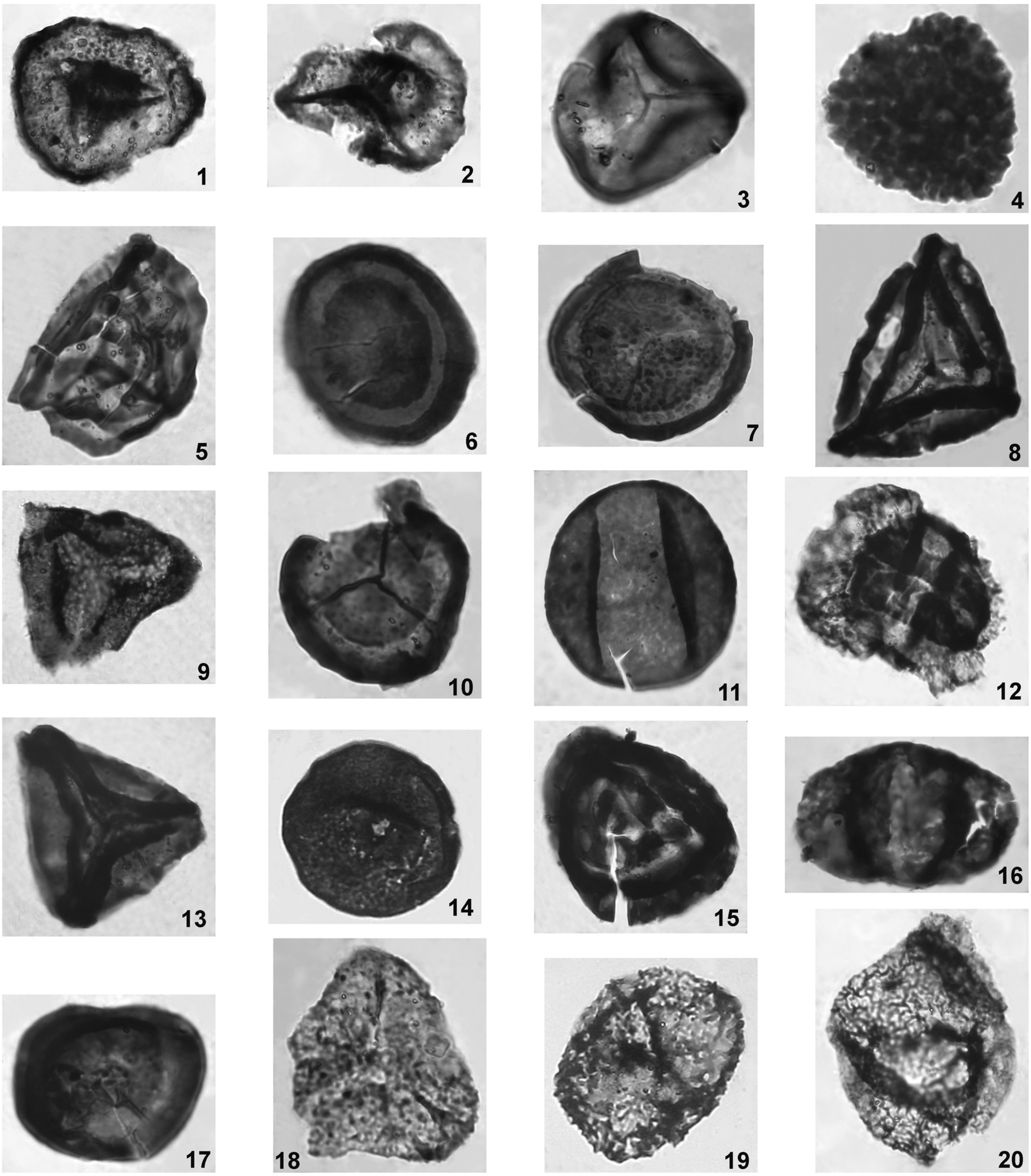


PLATE 1

Palynomorphs from the Upper Triassic Nayband Formation.
Figured specimens are held in the Dipartimento di Scienze della Terra, Perugia University.

Fig. 1 - *Annulispora microannulata* PA 27, E.F. (England Finder): H26-1, x1000; Fig. 2 - *Annulispora microannulata* PA 28 ipo, E.F.: K30, x1000; Fig. 3 - *Dictyophyllidites harrisii* PA 28, E.F.: T 39-2, x500; Fig. 4 - *Uvaesporites verrucosus* PA 40 ipo, E.F.: J42, x1000; Fig. 5 - *Striatella seebergensis* PA 26 ipo, E.F.: N40-2, x900; Fig. 6 - *Limatulasporites limatulus* PA 27ox ipo, E.F.: L41-4, x1000; Fig. 7 - *Limatulasporites limatulus* PA 33 ipo, E.F.: V50-4, x1000; Fig. 8 - *Kyrtomisporis niger* PA 42 ox ipo, E.F.: J43-4, x700; Fig. 9 -*Foveogleicheniidites atavus* PA 27 ox ipo, E.F.:F36-1, x700; Fig. 10 - *Polycingulatisporites mooniensis* PA 48 ox ipo, E.F.: W38-1, x1000; Fig. 11 - *Chasmatosporites apertus* PA 48 ipo2, E.F.: U49-4, x700; Fig. 12 - *Lunatisporites acutus* PA 48 ipo2, E.F.: S33-1, x900; Fig. 13 - *Dictyophyllidites harrisii* PA 48 ipo2, E.F.: K36-1, x500; Fig. 14 - *Classopollis chateaunovi* PA 52 ox ipo, E.F.: L 45-3, x1000; Fig. 15 - *Striatella seebergensis* PA 54 ox ipo, E.F.: D41-3, x900; Fig. 16 - *Alisporites australis* PA 55ox ipo, E.F.: N53-4, x600; Fig. 17 - *Gliscopollis meyeriana* PA 55ox ipo, E.F.: P49-4, x1100; Fig. 18 - *Microreticula-tisporites fuscus* PA 55ox ipo, E.F.: Y41-3, x1000; Fig. 19 - *Rugaletes awakinoensis* PA 61ox, E.F.: H49-4, x1000; Fig. 20 - *Rugaletes awakinoensis* PA 61ox, E.F.: W31-1, x1000.

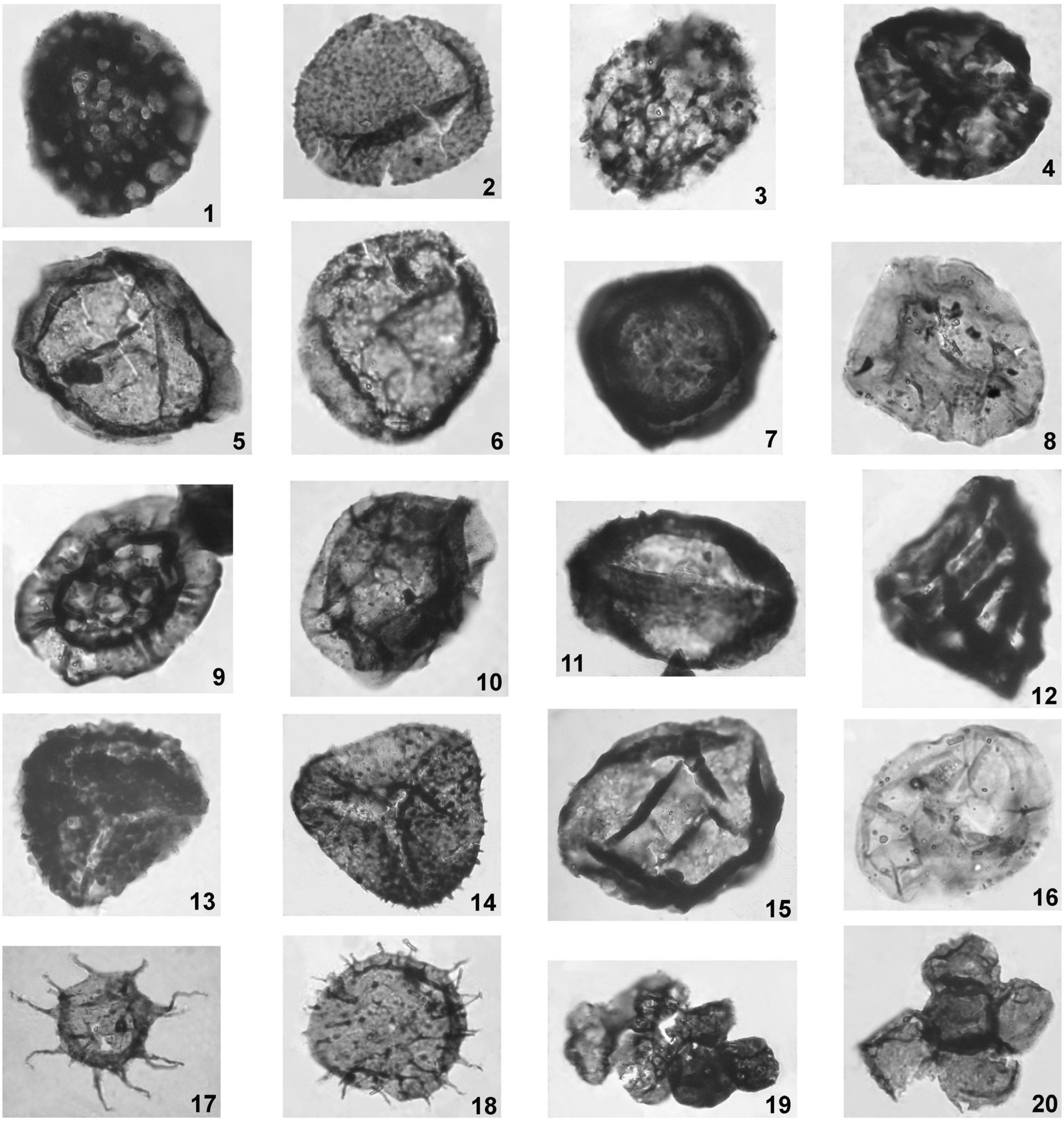


PLATE 2

Palynomorphs from the Upper Triassic Nayband Formation.
Figured specimens are held in the Dipartimento di Scienze della Terra, Perugia University.

Fig. 1 - *Limbosporites lundbladii* PA 61, E.F.: E36-1, x700; Fig. 2 - *Acanthotriletes ovalis* PA 65 ox, E.F.: T41-4, x700; Fig. 3 - *Retitriletes austroclavatidites* PA 61, E.F.: V51, x700; Fig. 4 - *Camarozonosporites rudis* PA 61ox, E.F.: U42-1, x700; Fig. 5 - *Araucariacites australis* PA 61 ox, E.F.: Q27-1, x600; Fig. 6 - *Araucariacites australis* PA 68, E.F.: P24-2, x600; Fig. 7 - *Limatulasporites limatulus* PA 65 ox, E.F.: V23, x1000; Fig. 8 - *Callialasporites* sp. PA 66 ipo, E.F.: G 46-4, x700; Fig. 9 - *Callialasporites dampieri* PA 69 ipo, E.F.: T 32, x600; Fig. 10 - *Callialasporites dampieri* PA 69, E.F.: H47-1, x600; Fig. 11 - *Ovalipollis pseudoalatus* PA 69, E.F.: S54-3, x600; Fig. 12 - *Striatella jurassica* PA 69, E.F.: G50-4, x1000; Fig. 13 - *Verrucosisporites* sp. PA55ox ipo, E.F.: L45-1, x1000; Fig. 14 -*Conbaculatisporites mesozoicus* PA 74, E.F.: Q 49-4, x900; Fig. 15 - *Araucariacites australis* PA 74, E.F.: P49-2, x600; Fig. 16 - *Suessia swabiana* PA 28 ipo, E.F.: O 26.3, x1000; Fig. 17 - *Micrhystridium* sp. PA 65 (2), E.F.: W30-3, x700; Fig. 18 - *Micrhystridium* sp. PA 65 (2), E.F.: L26-1, x1000; Fig. 19 - foraminiferal test lining PA 65 (2), E.F.: P48, x1000; Fig. 20 -foraminiferal test lining PA 65 (2), E.F.: W28-1, x1000.

west Pacific floristic province, shows a cosmopolitan character, being characterised by abundant tropical elements (Bennettitales, Matoniaceae, Marattiaceae) in association with forms characteristic of the Siberian province (Ginkgopsida, Dicksoniales, Nilssoniales, Coniferales) (Vozenin-Serra & Taugourdeau-Lantz 1985; Boersma & Van Konijnenburg-Van Cittert 1991; Schweitzer et al. 2000).

The southern microfloristic influence in Upper Triassic Nayband assemblages is the result of the geodynamic history of the Iranian Plate from Late Permian to Late Triassic-Early Jurassic times (Sengör 1979, 1984; Sengör & Hsu 1984; Warrington 1996a; Xingxue & Xiuyuan 1996; Besse et al. 1998). The influx of some northern taxa started from the Rhaetian, when the Iranian plate became a part of a continental margin, at the southern margin of Eurasia, after the Late Triassic collision (Seyed-Emami 2003). From Rhaetian times, the Iranian and southeast Asiatic macrofloras began to spread westwards towards Europe as the opening of Neo-Tethys created an important route for floral distribution, providing favourable conditions of humidity and temperature (Vozenin-Serra & Taugourdeau-Lantz 1985). The final stage of collision between Iran and Eurasia is marked by widespread molasse sediments (i.e. Nayband Fm., Shemshak Fm.), including continental coal-bearing sediments that also occur in nearby areas of Eurasia (Stampfli et al. 1991; Marcoux et al. 1993; Seyed-Emami 2003). Further evidence of the collision is the remarkable Upper Triassic floral affinity between Iran and Asia (Corsin & Stampfli 1977), the flora consisting, above all, of tropical and subtropical species.

## Conclusions

In comparison with conclusions based upon invertebrate faunas, the palynological study of Nayband Fm. provides improved dating of the formation and its members. The palynological assemblages indicate an early Norian age for the Gelkan Member and most of the Bidestan Member (up to 1225 m), a mid to late Norian age for the upper part of the Bidestan Member and a Rhaetian age for the Howz-e-Sheikh Member and at least the basal part of the overlying Howz-e-Khan Member. This new biostratigraphic information allows fairly detailed chronostratigraphic interpretations, especially for the Gelkan Member, the age of which has long been uncertain because of the lack significant fossils. The presence of Upper Triassic benthic foraminifera, frame builders and macrofauna in the Howz-e-Khan Member constrains the first occurrence of *Callialasporites dampieri* to the Late Triassic, at least at this palaeolatitude. The southern microfloristic influence in Upper Triassic Nayband assemblages is the result of the geodynamic history of the Iranian Plate from Late Permian to Late Triassic times when the plate became a part of a continental margin, at the southern margin of Eurasia.

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**Appendix: Author citations for species recorded from the Nayband Formation**

*Acanthotriletes ovalis* (Nilsson) Norris, 1965 (Pl.2, fig. 2)
*Acanthotriletes varius* Nilsson emend. Schuurman, 1977
*Alisporites australis* de Jersey, 1962 (Pl.1, fig. 16)
*Alisporites robustus* Nilsson, 1958
*Alisporites similis* (Balme) Dettmann, 1963
*Anapiculatisporites dawsonensis* Reiser & Williams, 1969
*Annulispora folliculosa* (Rogalska) de Jersey, 1959
*Annulispora microannulata* de Jersey, 1962 (Pl.1, figs. 1, 2)
*Annulispora punctus* (Klaus) Ashraf, 1977
*Apiculatisporites otapiriensis* de Jersey & Raine, 1990
*Aratrisporites fimbriatus* (Klaus) Playford & Dettmann, 1965
*Aratrisporites macrocavatus* Bjaerke & Manum, 1977
*Araucariacites australis* Cookson, 1947 (Pl.2, figs. 5, 6, 15)
*Baculatisporites comaumensis* (Cookson) Potonié, 1956
*Baculatisporites oppressus* (Leschik) Lund, 1977
*Calamospora mesozoica* Couper, 1958
*Calamospora tener* (Leschik 1955) Mädler, 1964
*Callialasporites dampieri* (Balme) Sukh Dev, 1961 (Pl.2, figs. 9, 10)
*Camarozonosporites rudis* (Leschik) emend. Klaus, 1960 (Pl.2, fig. 4)
*Chasmatosporites apertus* Nilsson, 1958 (Pl.1, fig. 11)
*Classopollis chateaunovi* Reyre, 1970 (Pl.1, fig. 14)
*Conbaculatisporites baculatus* Bharadwaj & Singh, 1964
*Conbaculatisporites mesozoicus* Klaus, 1960 (Pl.2, fig. 14)
*Concavisporites umbonatus* (Bolchovitina) Arjang, 1975
*Converrucosisporites cameronii* (de Jersey) Playford & Dettmann, 1965
*Converrucosisporites rewanensis* de Jersey, 1970

*Cosmosporites* cf. *elegans* Nilsson, 1958
*Cycadopites crassimarginis* (de Jersey) de Jersey, 1964
*Cycadopites follicularis* Wilson & Webster, 1946
*Deltoidospora directa* (Balme & Hennelly) Norris, 1965
*Deltoidospora toralis* (Leschik) Lund, 1977
*Densoisporites psilatus* (de Jersey) Raine & de Jersey in Raine et al., 1988
*Densoisporites velatus* Weyland & Krieger, 1953
*Densosporites cavernatus* Orlowska-Zwolinska, 1966
*Densosporites fissus* (Reinhardt) Schulz, 1967
*Dictyophyllidites atraktos* Stevens, 1981
*Dictyophyllidites harrisii* Couper, 1958 (Pl.1, figs. 3, 13)
*Dictyophyllidites mortonii* (de Jersey) Playford & Dettmann, 1965
*Equisetosporites steevesi* (Jansonius) de Jersey, 1968
*Foveogleicheniidites atavus* Raine in de Jersey and Raine, 1990 (Pl.1, fig. 9)
*Gliscopollis meyeriana* (Klaus) Venkatachala, 1966 (Pl.1, fig. 17)
*Guthoerlisporites cancellosus* Playford & Dettmann, 1965
*Kyrtomisporis niger* Bjaerke & Manum, 1977 (Pl.1, fig. 8)
*Kyrtomisporis speciosus* Mädler, 1964
*Limatulasporites limatulus* (Playford) Helby & Foster in Foster, 1979 (Pl.1, figs. 6, 7; Pl.2, fig. 7)
*Limbosporites denmeadi* (de Jersey) de Jersey & Raine, 1990
*Limbosporites lundbladii* Nilsson, 1958 (Pl.2, fig. 1)
*Lunatisporites acutus* (Leschik) emend. Scheuring, 1970 (Pl.1, fig. 12)
*Lycopodiacidites rugulatus* (Couper) Schulz, 1967
*Microreticulatisporites fuscus* (Nilsson) emend. Morbey, 1975 (Pl.1, fig. 18)
*Osmundacidites fissus* (Leschik) Playford, 1965
*Osmundacidites wellmanii* Couper, 1953
*Ovalipollis pseudoalatus* (Thiergart) Schuurman, 1976 (Pl.2, fig. 11)
*Polycingulatisporites mooniensis* de Jersey & Paten, 1964 (Pl.1, fig. 10)
*Punctatisporites leighensis* Playford & Dettmann, 1965
*Retitriletes austroclavatidites* (Cookson) Döring, Krutzsch, Mai & Schulz, 1963 (Pl.2, fig.3)
*Retitriletes gracilis* (Nilsson) Döring, Krutzsch, Mai & Schulz, 1963
*Rewanispora foveolata* de Jersey, 1971
*Rugaletes awakinoensis* de Jersey & Raine, 1990 (Pl.1, figs. 19, 20)
*Stereisporites antiquasporites* (Wilson & Webster) Dettmann, 1963
*Stereisporites* cf. *lunaris* (Rogalska) Lund, 1977
*Stereisporites stereoides* (Potonié & Venitz) Pflug in Thomson & Pflug, 1953
*Striatella jurassica* Mädler, 1964 (Pl.2, fig. 12)
*Striatella seebergensis* Mädler emend. Filatoff & Price, 1988 (Pl.1, figs. 5, 15)
*Suessia swabiana* Morbey emend. Below, 1987 (Pl.2, fig. 16)
*Todisporites major* Couper, 1958
*Todisporites minor* Couper, 1958
*Trachysporites asper* Nilsson, 1958
*Trachysporites sparsus* (Bharadwaj & Singh) Lund, 1977
*Uvaesporites verrucosus* (de Jersey) Helby in de Jersey, 1971 (Pl.1, fig. 4)
*Vitreisporites pallidus* (Reissinger) Nilsson, 1958.