Historical Biology, Vol. 15, pp. 29-39
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Biostratigraphy and Palaeogeography of Late Ordovician and Early Silurian Chitinozoans from the Zagros Basin, Southern Iran

MOHAMMAD GHAVIDEL-SYOOKI

Exploration Division, National Iranian Oil Company, P. O. Box 1065, Tehran, Iran

Investigation of 200 surface samples from the Kuh-e-Faraghun area of the Zagros Basin has permitted recognition 42 chitinozoan taxa, upon which six successive assemblage zones are based. Assemblage zones I-IV occur in the Late Ordovician Seyahou Formation and IV-VI occur in the Early Silurian Sarchahan Formation. The chitinozoans *Plectochitina persica* sp. nov. and *Plectochitina khosravii* sp. nov. are described from the Sarchahan Formation. A hiatus, encompassing the Middle and Late Silurian and possibly corresponding to the Caledonian Orogeny, is recognized between the Sarchahan Formation and the Faraghan Formation (Devonian).

Diverse chitinozoan and acritarch assemblages suggest a marine environment for the two formations. Comparison of chitinozoans from the Zagros Basin with those from other parts of the world indicates that the Zagros Basin was part of North Gondwanaland during the Late Ordovician and Early Silurian.

Keywords: Chitinozoans, Biostratigraphy, Palaeobiogeography, Late Ordovician, Early Silurian, Zagros Basin, Iran

INTRODUCTION

Chitinozoans from the Palaeozoic strata of the Iranian platform have received minimal attention since the discovery of the group by Eisenack (1931). This paper aims to demonstrate the utility of some diagnostic chitinozoan taxa in providing a powerful tool for chronostratigraphic and palaeobiogeographic use in the Ordovician-Silurian strata of the Zagros Basin, southern Iran.

The chitinozoan material reported and illustrated in this paper was isolated from shale, siltstone and sandstone by standard palynological procedures. This included treatment of the residues from each sample with 30 ml of saturated zinc bromide, to separate the organic residues from the inorganic materials, and screening of the organic residues through 20m nylon mesh sieves. Three microscope slides were prepared from each sample for palynological investigation. Slides used in this study are on file in the palaeontological section of the Exploration Division of the National Iranian Oil Company under the sample numbers MEK-115 to MEK-345.

STRATIGRAPHY

A thick Lower Palaeozoic sequence is well developed at Tang-e-Zakeen in Kuh-e-Faraghan, approximately 100 km north of Bandar Abbas city on the Persian Gulf (Figure 1). The sequence has previously been studied by several geolo-

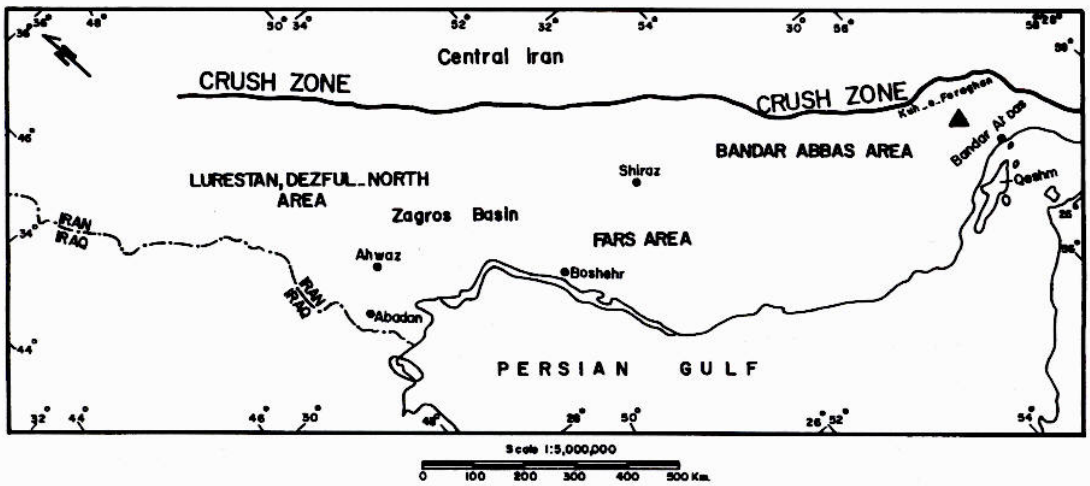

FIGURE 1 Locality map for the Kuh-e-Faraghun area in southern Iran

gists, but a complete stratigraphic column had not been compiled, nor was a detailed study carried out on the sequence until 1985, when the author and M.E. Khosravi measured the section and sampled it for palynological and sedimentological studies. The sequence is 807 m thick and consists of clastic sediments and subordinate argillaceous limestone. This clastic sequence was called "Silurian Shales" until Ghavidel-Syooki and Khosravi (1995) proposed the names Seyahou Formation for the Late Ordovician and Sarchahan Formation for the Early Silurian parts of the sequence respectively.

The Seyahou Formation is 741 m thick, consisting mainly of variegated shale, siltstone, sandstone and subordinate limestone. The lowermost part of the Seyahou Formation consists of variegated sandy conglomerate, with alternating shale, siltstone and subordinate sandstone beds toward the top. The lower contact of the Seyahou Formation with older rock units is not clear at Kuh-e-Faraghan, but it is disconformable with the Early Ordovician Zard-Kuh Formation in the Zard-Kuh area (Ghavidel-Syooki, 1997). Its upper contact is conformable with the Early Silurian Sarchahan Formation. Sedimentary structures such as cross-bedding, graded bedding, symmetrical ripple-marks, micro-ripples and large concretions as well as trace fossils (trails, tracks and burrows) are common in the Seyahou Formation; it also contains straight nautiloids, brachiopods, graptolites, crinoids, bryozoans, acritarchs and cryptospores of early land plants. A shallow marine environment of deposition is suggested for the Seyahou Formation. To determine its geological age, a palynological study of the Seyahou Formation was carried out. Diagnostic acritarch species suggested a Late Ordovician age for this formation (Ghavidel-Syooki, 1997).

The Sarchahan Formation, which is disconformably overlain by the Faraghan Formation, consists of laminated black shale with subordinate siltstone and sandstone and contains brachiopods, bryozoans, graptolites, acritarchs and miospores. The fauna and flora indicate an Early Silurian age for the Sarchahan Formation, which was deposited in a shallow marine environment (Ghavidel-Syooki, 1997).

SYSTEMATIC PALEONTOLOGY

Formal systematic classification of the entire microfauna is not presented here; two new chitinozoan taxa are described, and a few of the age-diagnostic taxa are illustrated from the abundant microflora. All illustrated specimens were extracted from sample number MEK-340, approximately 35 m below the top of the section, Sarchahan Formation, Zagros Basin, Iran; they are lodged with the Australian Museum, Sydney, Australia and are prefixed with AMF.

CHITINOZOA Eisenack, 1931
Plectochitina Cramer, 1964

Type species: *Plectochitina carminae* Cramer, 1964.

Plectochitina khosravii n. sp

Derivation of name: The species is named in honour of my friend and colleague Mohammad Ebrahim Khosravi, who measured the section and prepared the samples from the Sarchahan Formation.

Holotype: AMF 107988 (Figure 2, F-G)

Type stratum: *Plectochitina khosravii* ranges through the upper 10 m (levels 40–30 m of Figure 4) of the Sarchahan Formation (50 m thick); sample MEK-340. Llandovery (Early Silurian).

Diagnosis: *Plectochitina* with funnel-shaped body chamber, with indistinct shoulder; base slightly concave with rounded edge; neck long and cylindrical, grading with increasing diameter into a transparent and smooth collarette. Three appendices of variable size, of spongy tissue, continuous with the body chamber.

Measurements: Total length 375μ; chamber length 65μ, maximum width of chamber 80μ; neck length 310μ, width 24μ; appendix length 37μ, width 12.5μ. 10 specimens were measured.

Remarks: This species is similar to *Angochitina longicolla* Eisenack, 1959 (in Cramer, 1973, plate 1, figure 33), but the presence of three spongy appendices characterizes the new species.

Plectochitina persica n. sp

Derivation of name: Derived from the ancient name for Iran.

Holotype: AMF 107983. (Figure 3 C-G)

Type stratum: *Plectochitina persica* ranges through the upper 10 m (levels 40–30 m of Figure 4) of the Sarchahan Formation (50 m thick); sample MEK-340. Llandovery (Early Silurian).

Diagnosis: *Plectochitina* with a flask-shaped outline; appendices situated at the aboral pole only; appendices spongy and nodular, often anastomosing; neck subcylindrical to cylindrical and tapered toward body chamber; body chamber flask-shaped; collar transparent and flared; no prosome or other internal structures observed.

Measurements: Total length 65μ; length of chamber 40μ, width 43μ; length of neck 25μ, width 22.5μ; aperture diameter 20μ; appendices numerous and nodular, with the configuration of the anastomosing parts varying from specimen to specimen. 20 specimens were measured.

BIOSTRATIGRAPHY

From study of 200 samples from the Seyahou and Sarchahan Formations, six assemblage zones are here proposed, based on chitinozoans. Most samples contain well-preserved and abundant palynomorphs (chitinozoans, acritarchs, small trilete spores and scolecodonts), except for the lowermost samples of the Seyahou Formation (MEK-115 to MEK-125). In total, 42 chitinozoan species were identified; their stratigraphic distributions are plotted on Figure 4. The chitinozoan assemblage zones are discussed below in ascending stratigraphical order. The age ranges of these assemblage zones are supported at all levels by diagnostic acritarch taxa and at two levels by correlation with graptolite zones.

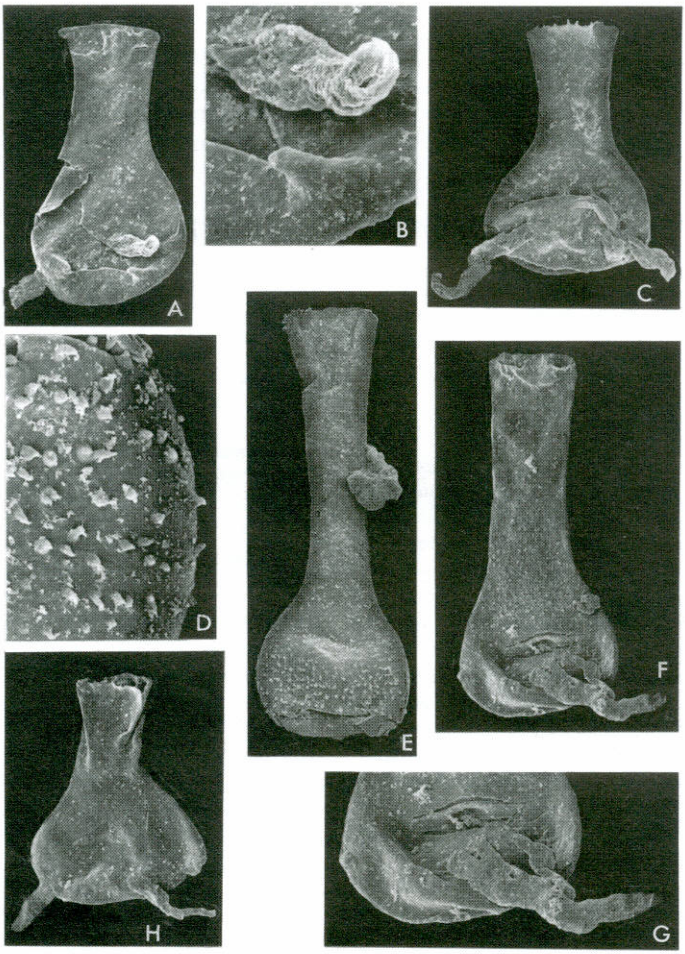

FIGURE 2 Chitinozoans from the Sarchahan Formation, Early Silurian (Llandoverian) of the Zagros Basin, Iran. **A-C, H**: *Plectochitina paraguayensis* Wood & Miller, 1991. **A-B**, AMF 107984: **A**, × 400; **B**, enlargement of spongy appendix, × 1500; **C**, AMF 107985, × 400; **H**, AMF 107986, × 400. **D-E**: *Angochitina macclurei* Paris and Al-Hajri, 1995. **D-E**, AMF 107987; **E**, × 350; **D**, enlargement of ornamentation, × 1700. **F-G**: *Plectochitina khosravii* n. sp. **F-G**, AMF 107988; **F**, × 350; **G**, enlargement of complex appendix, × 480

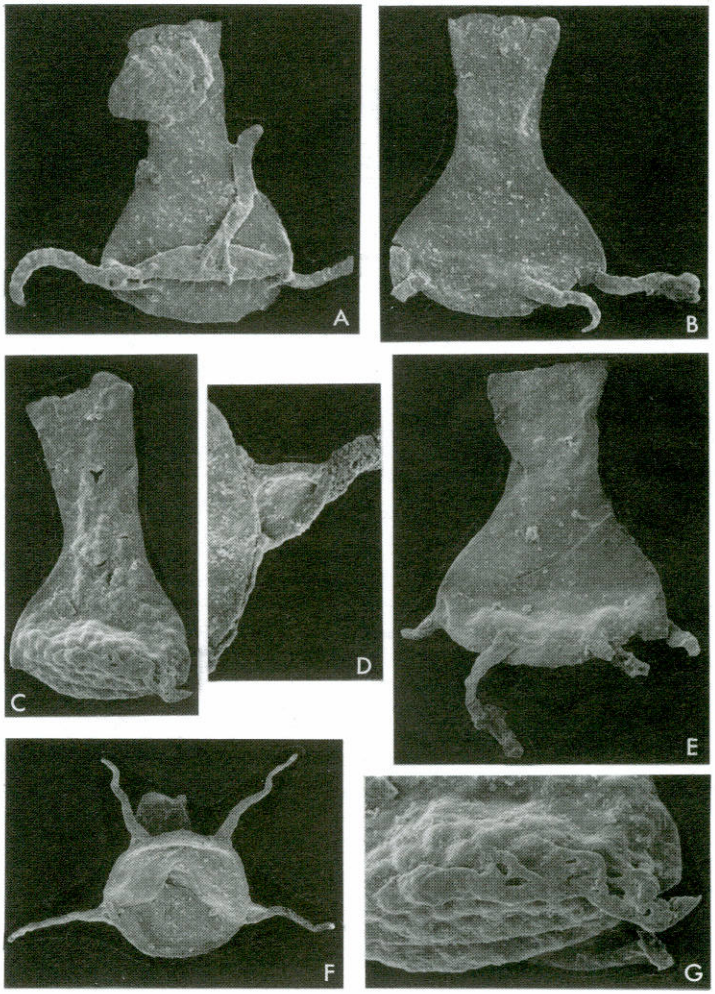

FIGURE 3 Chitinozoans from the Sarchahan Formation, Early Silurian (Llandoverian) of the Zagros Basin, Iran. **A-B, D-F**: *Plectochitina pseudoagglutinans* (Taugourdeau, 1963). **A**, AMF 107979, × 400; **B**, AMF 107980, × 400; **E**, AMF 107981, × 400; **D, F**, AMF 107982: **F**, × 400; **D**, enlarged detail of structure of the spongy appendix, × 1300. **C, G**: *Plectochitina persica* n. sp., AMF 107983. **C**, × 350; **G**. enlargement of nodular spongy appendix, × 850

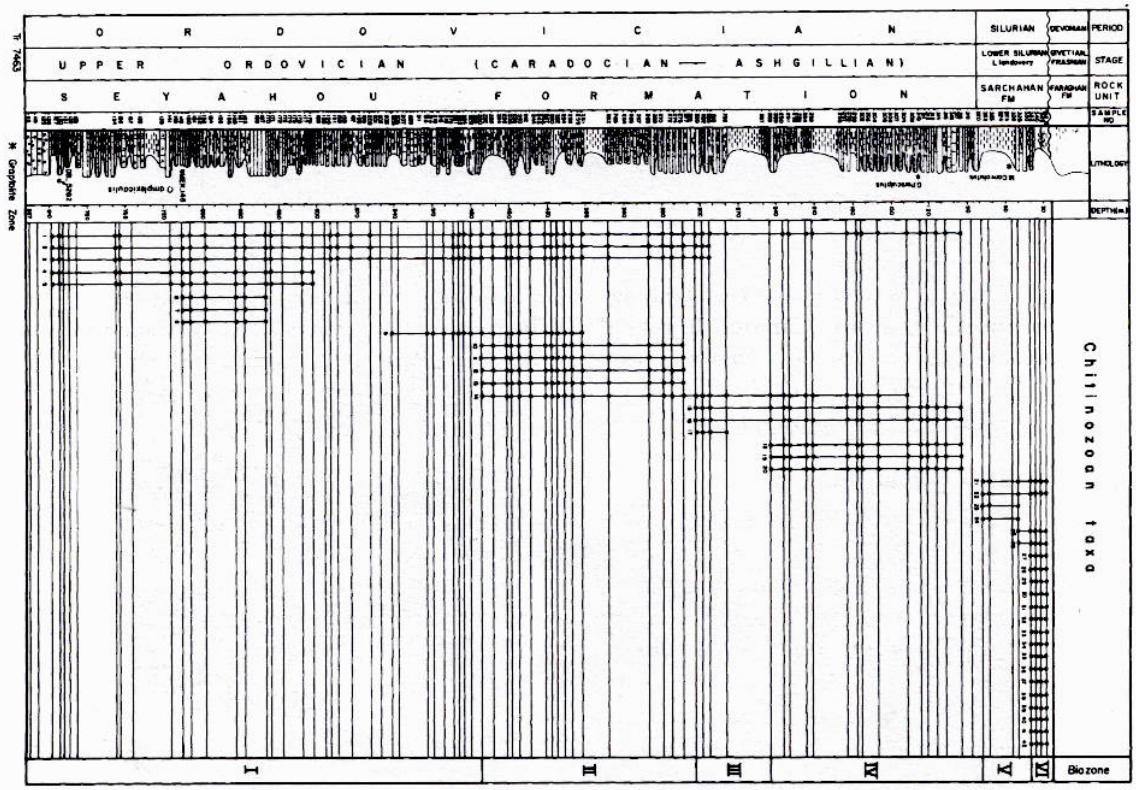

FIGURE 4 Stratigraphic distribution of selected chitinozoan species from the Late Ordovician and Early Silurian strata in the Zagros Basin, southern Iran. Numbers refer to the following taxa: **1**, *Desmochitina minor* forma *typica*; **2**, *Belonechitina micracantha typica*; **3**, *Belonechitina capitata*; **4**, *Cyathochitina jenkinsi*; **5**, *Cyathochitina campanulaeformis*; **6**, *Rhabdochitina usitata*; **7**, *Belonechitina hirsuta*; **8**, *Spinachitina* cf. *cervicornis*; **9**, *Angochitina* n. sp.?; **10**, *Acanthochitina barbata*; **11**, *Lagenochitina baltica*; **12**, *Lagenochitina* sp.; **13**, *Cyathochitina* sp. aff. *C. fistulosa*; **14**, *Calpichitina lenticularis*; **15**, *Cyathochitina ontariensis*; **16**, *Armoricochitina nigerica*; **17**, *Tanuchitina* sp. aff. *anticostiensis*; **18**, *Plectochitina sylvanica*; **19**, *Jenkinochitina lepta*; **20**, *Ancyrochitina merga*; **21**, *Lagenochitina* cf. *inflata*; **22**, *Cyathochitina caputoi*; **23**, *Ancyrochitina laevaensis*; **24**, *Spinachitina* cf. *fragilis*; **25**, *Plectochitina* sp. aff. *nodifera*; **26**, *Plectochitina pseudoagglutinans*; **27**, *Plectochitina saharica*; **28**, *Pterochitina* cf. *deichai*; **29**, *Plectochitina paraguayensis*; **30**, *Plectochitina* sp. aff. *carminae*; **31**, *Plectochitina persica* n. sp.; **32**, *Plectochitina khosravii* n. sp.; **33**, *Ancyrochitina ramosaspina*; **34**, *Ancyrochitina convexa*; **35**, *Ancyrochitina tomentosa*; **36**, *Conochitina edjelensis*; **37**, *Angochitina macclurei*; **38**, *Ancyrochitina ancyrea*; **39**, *Conochitina* sp.; **40**, *Ancyrochitina* sp.; **41**, *Spinochitina* sp.; **42**, *Cingulochitina* sp.

Chitinozoan Assemblage Zone I

This assemblage zone includes strata from 808–470 m. It is characterised by *Belonichitina capitata* (808–292 m); *Cyathochitina jenkinsi, C. campanulaeformis* (808–603 m); and *Rhabdochitina usitata, Belenochitina hirsuta* and *Spinachitina* cf. *S. cervicornis* (705–640 m). The basal part of this formation (MEK-11 to MEK-125) is barren. The zone might be divided at 710 m based on the appearance of *R. usitata, B. hirsuta* and *S.* cf. *S. cervicornis*, but this distinction would probably be of only local significance.

Some of the chitinozoan species from this zone have been shown to range from Llanvirn through early Caradoc strata in England (Jenkins, 1967), Sweden (Laufeld, 1967), the United States (Jenkins, 1970), southwestern Europe (Paris, 1981), Canada (Achab, 1984) and Saudi Arabia (McClure, 1988; Al-Hajri, 1995).

Spinachitina cf. *S. cervicornis* of the Seyahou Formation is similar to *Spinachitina* sp. A (Achab, 1984) from the Trenton Formation, which is consistent with an early Late Ordovician age for this assemblage zone, although *Spinachitina* sp. A occurs in the middle to late Caradoc strata. In general, this chitinozoan assemblage zone corresponds to the *Belonechitina* sp. B / *Pistallichitina* cf. *capitata* Biozone in Saudi Arabia (Al-Hajri, 1995). Therefore, this chitinozoan assemblage zone is assigned to the early Caradoc. In regard to biogeography, *Cyathochitina jenkinsi* has been reported from Middle Ordovician sediments of Saudi Arabia (McClure, 1988) and the Middle Ordovician (early Caradoc) of Northern Gondwanaland and Laurentia (Paris, 1996).

This zone also contains many index acritarch taxa including *Orthosphaeridium ternatum, Baltisphaeridium perclarum, Ordovicidium elegantulum* and *Gogonisphaeridium antiquum* which support the early Caradoc age for this chitinozoan assemblage zone.

Finally, two horizons from this interval (MEK-146 and DB-5282) yielded graptolites identified by Dr Barrie Rickards (pers. comm. 1997) as *Orthograptus amplexicaulis*, indicating a Late Ordovician, *clingani* zone (Caradoc) to *anceps* zone (Ashgill) age.

Chitinozoan Assemblage Zone II

This zone has a thickness of 165 m (from 470–305 m) and is marked by the appearance of the chitinozoans *Cyathochitina* sp. aff. *fistulosa, Calpichitina lenticularis, Lagenochitina baltica* and *Acanthochitina barbata*. These species occur in the Seyahou Formation from 470–305 m (Figure 4). Most of the chitinozoan species of this assemblage zone have been recorded from the Late Ordovician of the Baltic area (Eisenack, 1931, 1962, 1965, 1968), south-central Sweden (Grahn, 1981), northern Estonia (Grahn, 1984), England (Jenkins, 1967), Algeria (Taugourdeau and de Jekhowsky, 1960), Libya (Molyneux and Paris, 1985), the United States (Jenkins, 1970; Grahn and Bergstrom, 1984), southwestern Europe (Paris, 1981), Canada (Achab, 1984) and Saudi Arabia (McClure, 1988; Al-Hajri, 1995).

C. lenticularis is the most important species for correlation, as it suggests a correlation with the *C. lenticularis* zone (middle Caradoc) of Al-Hajri. However, the presence of *Acanthochitina barbata* with *C. lenticularis* suggests the succeeding zone in the Saudi scheme, that of *C.* sp. aff. *fistulosa* (late Caradoc), implying a gap in the succession. The presence of a gap is also suggested by *L. baltica*, which Paris used to indicate the basal part of the Ashgill, in his scheme for northern Gondwanaland.

Abundant diagnostic acritarch species in this zone, including *Veryhachium subglobosum, V. reductum, Villosacapsula setosapeliculla* and *Orthosphaeridium inflatum*, together with the associated chitinozoans, support a middle-late Caradoc age for this assemblage zone.

Chitinozoan Assemblage Zone III

This zone makes up a thickness of 60 m of the Seyahou Formation, ranging from 305–245 m. Its base is defined by the appearance of *Cyathochitina ontariensis, Tanuchitina* cf. *anticostiensis, T.* sp. and *Armoricochitina nigerica*. These species have been recorded from Ashgill strata of Libya (Molyneux and Paris, 1985), the Nigerian Sahara (Bouche, 1965), Saudi Arabia (Al-Hajri, 1995), Morocco (Elaoud-Debbaj, 1984), northern Gondwanaland (Paris, 1990) and the United States (Jenkins, 1970).

Based on the presence of *A. nigerica* and *C. ontariensis*, the zone corresponds to the *Armoricochitina nigerica* biozone of Al-Hajri (1995), and the *A. nigerica* biozone erected for the northern Gondwanaland realm (Paris, 1990). Thus an early Ashgill age is indicated.

Many index acritarch species occur with the chitinozoans of this assemblage zone including *Orthosphaeridium insculptum, Orthosphaeridium inflatum, Veryhachium subglobosum* and *Actinotodissus crassus*, indicating an Ashgill age for this

part of the Seyahou Formation (Ghavidel-Syooki, 1997). The latest Ordovician (late Ashgill) *persculptus* graptolite zone has been recognised in the upper part of the Seyahou Formation by Rickards, Wright and Hamedi (1997).

Chitinozoan Assemblage Zone IV

This assemblage zone has a thickness of 160 m, from levels 245–85 m. It is defined by the first appearance of *Plectochitina sylvanica, Jenkinochitina lepta* and *Anchyrochitina merga*. This zone corresponds to the *A. merga* zone (late Ashgill) proposed by Al-Hajri (1995) for Saudi Arabia and the same zone recognised by Paris for northern Gondwanaland. The topmost Ordovician zone recognised by these authors has not been recognised in southern Iran.

Chitinozoan Assemblage Zone V

This assemblage zone is characterised by the absence of Ordovician taxa and the appearance of Early Silurian forms such as *Spinachitina* cf. *fragilis* and *Anchyrochitina levaensis*. The lower boundary of this zone is defined at the base of the Sarchahan Formation. The zone encompasses 40 m of black shale, from 80–40 m.

The index species are *Spinachitina* cf. *fragilis, Anchyrochitina levaensis, Lagenochitina* cf. *inflata* and *Cyathochitina caputoi*. The first two species are confined to the lower 30 m of the zone. The ranges of the last two species extend into the overlying zone VI (Figure 4), up to about the 50 m level. The first two species have been recorded from the early Llandovery (Rhuddanian) strata of Libya (Molyneux and Paris, 1985), Estonia (Nestor, 1994), Saudi Arabia (McClure, 1988; Paris *et al.*, 1995) and Baltica and northern Gondwanaland (Paris, 1996). The assemblage corresponds to the *Spinachitina fragilis* biozone of the Qalibah Formation in Saudi Arabia (Paris *et al.*, 1995) and the *Anchyrochitina levaensis* biozone of the lower part of the Ohne and Varbola Formations in Estonia (Nestor, 1994). Verniers *et al.* (1995) have also indicated a Rhuddanian (lowest Silurian) age for this *fragilis* biozone. Therefore, this age is attributed to the assemblage zone.

Index acritarch species in this assemblage zone include *Dactylofusa estillis, Dactylofusa horrida, Dacteriocradus monterrosae, Geron guerillerus* and *Dactylofusa maranhensis*, which have been recorded from the Llandovery of Sweden (Le Herisse, 1989), Saudi Arabia (Le Herisse *et al.*, 1995), Libya (Molyneux and Paris, 1985), Czechoslovakia (Dufka, 1992) and USA (Cramer, 1970; Cramer and Diaz, 1972; Miller and Eames, 1982).

Chitinozoan Assemblage Zone VI

This assemblage occurs in the upper 26 m of the Sarchahan Formation (Figure 4). It is characterised by the chitinozoans *Plectochitina khosravii, P. persica, P. pseudoagglutinans, P. paraguayensis, P. saharica, P.* sp. aff. *carminae, Pterochitina* cf. *dechai, Conochitina edjelensis, Angochitina macclurei, Ancyrochitina ancyrea, A. convexa, A. ramosaspina* and *A. tomentosa*.

This zone does not correspond clearly with any in existing zonal schemes. There is some correspondence with the *C. alargada* / *P. paraguayensis* concurrent zone of the Saudi scheme (Paris *et al.*, 1995), although the presence of *C. edjelensis* and *P. pseudoagglutinans* may indicate the next zone, and *A. macclurei* the next zone again. The co-occurrence of *P. paraguayensis* and *A. convexa* suggests correlation with the *maennili* zone of Verniers *et al.*, (1995) but the co-occurrence of *P. pseudoagglutinans, C. edjelensis* and *P. saharica* suggests the next zone, the *alagada* zone of Verniers *et al.* (1995). The presence of *A. ramaspinosa, A. convexa* and *C. edjelensis* suggests a correlation with the *A. convexa* zone of Nestor (1994). Thus there is wide support for a gap in the sequence between Zone VI and the basal Rhuddanian zone V below it.

Acritarchs occurring in this assemblage zone include *Dactylofusa estillis, Oppilatala eoplanktonica, Cymatiosphaera imperfecta, Onondagaella*

asymmetrica, Dilatisphaera laevigata, Neoveryhachium carminae, Eupoikilofusa striatifera, Elektoriskos pogonius, Tunisphaeridium tentaculaferum, Leiofusa bernesgae, Pulvinosphaeridium sp. and *Moyeria* sp. These acritarchs have been recorded from the Llandovery sediments of Saudi Arabia (Le Herisse *et al.*, 1995), Sweden (Le Herisse, 1989), Libya (Hill *et al.*, 1985), the United States (Cramer, 1970; Cramer and Diez, 1972); Bolivia (Wood and Miller, 1997) and southern Iran (Ghavidel-Syooki, 1997). Moreover, there are many forms in this assemblage zone, such as planar *Coenobium* and *Synsphaeridium*, which are identical to those from the Llandovery of Saudi Arabia (Le Herisse *et al.*, 1995) and Bolivia (Wood and Miller, 1997).

Graptolites characteristic of the Aeronian (Llandovery) *leptotheca* and *convolutus* zones have been identified by Rickards *et al.* (1997) from the Sarchahan Formation at Kuh-e-Faraghun. From the sequence at nearby Kuh-e-Gahkum, they have identified the *convolutus* zone and the slightly younger but still Llandovery *sedgwickii* zone (Rickards and Wright, in prep.).

The chitinozoan species encountered in this assemblage indicate a middle-upper Llandovery (Aeronian-Telychian) age. Therefore, based on chitinozoans, acritarchs and graptolites, assemblage zones IV-V of the Sarchahan Formation are assigned to the Llandoverian. Consequently, Middle and Late Silurian sediments are believed to be absent, so a hiatus is inferred in the Zagros Basin of southern Iran for this interval.

PALAEOBIOGEOGRAPHY

Late Ordovician chitinozoans of southern Iran are broadly similar to those of the same age from widely separated areas within and outside Gondwanaland, as has also been shown for Saudi Arabia by Al-Hajri (1995). Many species from southern Iran such as *Cyathochitina fistulosa, Cyathochitina* sp. aff. *fistulosa, Jenkinochitina lepta, Armoricochitina nigerica, Calpichitina lenticularis, Ancyrochitina merga* and *Belenochitina micracantha typica* are common in the Late Ordovician of Saudi Arabia, the Algerian Sahara and Libya. Of twenty species from the Seyahou Formation, only *Calpichitina lenticularis, Cyathochitina* sp. aff. *fistulosa, Armoricochitina nigerica* and *Jenkinichitina lepta* have been found only in the Late Ordovician sediments of North Africa (Elaoud Debbaj, 1984; Molyneux and Paris, 1985; Oulebsir and Paris, 1995) and Saudi Arabia (McClure, 1988; Al-Hajri, 1995). The rest of the fauna has been recorded not only from the North Gondwana domain but also from Baltica and Laurentia (Paris, 1990, 1996; Achab *et al.*, 1992). Therefore, it is suggested that the chitinozoan assemblages of the Seyahou Formation of southern Iran are rather cosmopolitan.

Similarly, the rich and diverse chitinozoan assemblages of the Early Silurian Sarchahan Formation are comparable with contemporaneous assemblages from other parts of the world, exhibiting broad similarity with those from Saudi Arabia (McClure, 1988; Paris and Al-Hajri, 1995; Paris *et al.*, 1995), the Algerian Sahara (Taugourdeau and de Jekhowsky, 1960; Taugourdeau, 1962, 1963), Libya (Hill *et al.*, 1985) and, to a lesser extent, northwestern Spain (Cramer, 1967), Czechoslovakia (Dufka, 1992) and Florida (Cramer, 1973). In particular, some of the Early Silurian chitinozoans in the Sarchahan Formation, such as *Plectochitina saharica, P. pseudoagglutinans, P. paraguayensis, Cyathochitina* sp. cf. *caputoi, Ancyrochitina tomentosa, Ancyrochitina levaensis, Angochitina macclurei, Spinachitina* sp. cf. *fragilis*, and *Conochitina edjelensis*, also occur in northwestern Spain, Saudi Arabia, Algerian Sahara and Libya, suggesting that these regions were part of North Gondwanaland during the Early Silurian.

CONCLUSIONS

Forty-two chitinozoan species occur in the Seyahou and Sarchahan Formations (Figure 4). Six

assemblage zones are recognised on the basis of these taxa. Zones I to IV are represented in the Late Ordovician (Caradoc-Ashgill) Seyahou Formation. Zones V and VI of the Sarchahan Formation are Early Silurian (Llandovery) in age.

Between the Sarchahan Formation (Early Silurian) and the Faraghan Formation (Devonian) a hiatus represents Middle and Late Silurian time.

Chitinozoans and acritarchs of both the Seyahou and Sarchahan formations show broad similarity with those recorded from the Arabian Peninsula, Algerian Sahara and Libya, indicating that the Iranian Zagros Basin, Saudi Arabia, Algeria and Libya occupied similar palaeolatitudes during the Late Ordovician and Early Silurian. The chitinozoans and acritarchs of the Seyahou and Sarchahan formations, with well-preserved ornamentation, processes and appendages, show remarkably little sign of transport. Extremely cold conditions may have prevailed during the Late Ordovician, as indicated by the low diversity of chitinozoan and acritarch faunas in the Seyahou Formation. However, this would appear to be contrary to the observation that diverse and abundant faunas are known from high latitude, cold water regions.

Fairly warm water conditions prevailed in the Zagros Basin in the Early Silurian, as indicated by the high diversity of chitinozoan and acritarch taxa in the Sarchahan Formation. The presence of *Pulvinosphaeridium* sp. in particular in the Sarchahan Formation further supports a warm climate for the Early Silurian of the Zagros Basin.

Acknowledgements

The author expresses his sincere appreciation to the management of the Exploration Division of the National Iranian Oil Company for permission to publish this paper, and to Professor Talent and Dr Wright for their invitation to attend the 1997 conference on Palaeobiogeography of Australasian Faunas and Floras. I am also grateful to Dr Theresa Winchester-Seeto and Professor Florentin Paris for constructive comments on an early version of this paper; to Dr Winchester-Seeto for critically checking identifications, providing SEM photographs of this material and assembling the figures illustrating the chitinozoans; to Dr Barrie Rickards for identifying graptolites; and to Dr. Tony Wright and Dr Winchester-Seeto for assisting with this manuscript.

References

Achab, A. (1984) Chitinozoaires de l'Ordovicien moyen de subsurface de l'Ile Anticosti. *Review of Palaeobotany and Palynology* **43**, 123–143.

Achab, A., Bertrand, R. and van Grootel, G. (1992) Chitinozoan contribution to the Ordovician and lower Silurian paleobiogeography. *Journal of Geology* **100**, 621–629.

Al-Hajri, S. (1995) Biostratigraphy of the Ordovician chitinozoans of northwestern Saudi Arabia. *Review of Palaeobotany and Palynology* **89**, 27–48.

Bouche, P. M. (1965) Chitinozoaires du Silurien du Djado (Sahara, nigérien). *Revue de Micropaléontologie* **8**, 151–164.

Cramer, F. H. (1964) Microplankton from three Palaeozoic formations in the province of Leon (northwest Spain). *Leidse Geologische Mededelingen* **30**, 254–361.

Cramer, F. H. (1967) Chitinozoans of a composite section of Upper Llandoverian to basal Lower Gedinnian sediments in northern Leon, Spain. *Bulletin de la Société Géologique de la Belgique* **75**, 69–129.

Cramer, F. H. (1970) Distribution of selected Silurian acritarchs. *Revista Espanola de Micropalenotologia* Numero extra, 203 pp.

Cramer, F. H. (1973) Middle and Upper Silurian chitinozoan succession in Florida subsurface. *Journal of Paleontology* **47**, 279–288.

Cramer, F. H. and Diez, M. del C. R. (1972) North American Silurian palynofacies and their spatial arrangement: Acritarchs. *Palaeontographica* **138B**, 107–180.

Dufka, P. (1992) Lower Silurian Chitinozoa of the Prague Basin (Barrandian Czechoslovakia) — preliminary results. *Review of Palaeobotany and Palynology* **35**, 1–10.

Eisenack, A. (1931) Neue Mikrofossilien des baltischen. Silurs, I. *Paläontologisches Zeitschrift* **13**, 74–118.

Eisenack, A. (1959) Neotypen baltischer Silur-Chitinozoen und neue Arten. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* **108**, 1–20.

Eisenack, A. (1962) Neotypen baltischer Silur-Chitinozoen und neue Arten. *Neues Jahrbuch für Geologie und Paläontologie, Abhandungen* **114**, 291–316.

Eisenack, A. (1965) Die Mikrofauna der Ostseekalke. 1. Chitinozoen, Hystrichosphären. *Neues Jahrbuch für Geologie und Paläontologie, Abhandungen* **123**, 115–148.

Eisenack, A. (1968) Mikrofossilien eines Geschiebes der Borkholmer Stufe, baltische Ordovizium, F2. *Mitteilungen der Geologischen Institut Hamburg* **37**, 81–94.

Elaoud-Debbaj, Z. (1984) Chitinozoaires ashgilliens de l'Anti-Atlas (Maroc). *Géobios* **17**, 45–68.

Ghavidel-Syooki, M. and Khosravi, M. E. (1995) Investigation of Lower Paleozoic sediments at Tang-e-Zakeen of Kuh-e-Faraghan and introduction of the Seyahou and Sarchahan Formations in the Zagros Basin. *Geological*

Survey of Iran, Geosciences Scientific Quarterly Journal **4** (14), 2–21.

Ghavidel-Syooki, M. (1997) Acritarch biostratigraphy of the Palaeozoic rock units in the Zagros Basin, Southern Iran. *Acta Universitalis Carolinae Geologica* **40**, 385–411.

Grahn, Y. (1981) Ordovician Chitinozoa from the Stora Asbotorp boring in VästerGötland, south-central Sweden. *Sveriges Geologiska Undersokning, series C* **787**, 1–40.

Grahn, Y. (1984) Ordovician chitinozoan from Tallinn, northern Estonia. *Review of Palaeobotany and Palynology* **43**, 5–31.

Grahn, Y. and Bergstrom, S. M. (1984) Lower-Middle Ordovician chitinozoa from the southern Appalachians, United States. *Review of Palaeobotany and Palynology* **43**, 89–122.

Hill, P. J., Paris, F. and Richardson, J. B. (1985) Silurian palynomorphs. In *The Palynostratigraphy of Northeastern Libya*, edited by B. T. Thusu and B. Owen. *Journal of Micropalaeontology*, **4**, 27–48.

Jenkins, W. A. M. (1967) Ordovician chitinozoa from Shropshire, England. *Palaeontology* **10**, 436–488.

Jenkins, W. A. M. (1970) Chitinozoa from the Ordovician Silvan Shale of the Arbuckle Mountains, Oklahoma. *Palaeontology* **13**, 261–288.

Laufeld, S. (1967) Caradocian Chitinozoa from Dalarna, Sweden. *Geologiska Føreningens i Stockholm Førhandlingar* **89**, 275–349.

Le Herisse, A. (1989) Acritarchs et Kystes d' algues prasinophycees du Silurien de Gotland, Sweden. *Palaeontographica Italica* **76**, 57–302.

Le Herisse, A., Al-Tayyar, H. and Van der Eem, H. (1995) Stratigraphic and palaeogeographical significance of Silurian acritarchs from Saudi Arabia. *Review of Palaeobotany and Palynology* **89**, 49–74.

McClure, H. A. (1988) Chitinozoan and acritarch assemblages, stratigraphy and biogeography of Early Palaeozoic of northwest Saudi Arabia. *Review of Palaeobotany and Palynology* **56**, 41–60.

Miller, M. A. and Eames, L. E. (1982) Palynomorphs from the Silurian Medina Group (Lower Llandovery) of the Niagara Gorge, Lewistone, New York, U.S.A. *Palynology* **6**, 221–254.

Molyneux, S. G. and Paris, F. (1985) Late Ordovician palynomorphs. In *The Palynostratigraphy of Northeastern Libya*, edited by B. T. Thusus and B. Owen. *Journal of Micropaleontology* **4**, 11–26.

Nestor, V. (1994) Early Silurian Chitinozoans of Estonia and North Latvia. *Academia* **4**, 5–163.

Neville, R. S. W. (1974) Ordovician Chitinozoa from western Newfoundland. *Review of Palaeobotany and Palynology* **18**, 187–221.

Oulebsir, L. and Paris, F. (1995) Chitinozoaires Ordoviciens du Sahara Algerien (biostratigraphie et affinités paléogeographiques). *Review of Palaeobotany and Palynology* **86**, 49–68.

Paris, F. (1981) Les Chitinozoaires dans le Paléozoîque du Sud-Ouest de l'Europe (Cadre géologique Étude Systématique et Biostratigraphie). *Mémoire de la Société Géologique et Minéralogique de Bretagne, Rennes* **26**, 1–412.

Paris, F. (1990) The Ordovician chitinozoan biozones of the northern Gondwana Realm. *Review of Palaeobotany and Palynology* **66**, 181–209.

Paris, F. (1996) Chitinozoan biostratigraphy and paleoecology. In Palynology: Principles and Applications. *American Association of Stratigraphic Palynologists Foundation* vol. **2**, 531–552.

Paris, F. and Al-Hajri, S. (1995) New chitinozoan species from the Llandovery of Saudi Arabia. *Revue de Micropaléontologie* **38**, 311–328.

Paris, F., Verniers, J., Al-Hajri, S. and Al-Tayyar, H. (1995) Biostratigraphy and palaeogeographic affinities of Early Silurian chitinozoans from central Saudi Arabia. *Review of Palaeobotany and Palynology* **89**, 75–90.

Rickards, R. B., Wright, A. J. and Hamedi, M. A. (1997) Ordovician and Silurian graptolites from southern and East-Central Iran. *First Annual Conference of the Geological Society of Iran, Abstracts* p. 333–337.

Taugourdeau, P. (1962) Associations de Chitinozoaires dans quelques sondages de le region d'Edjelé (Sahara). *Revue de Micropaléontologie* **4**, 229–236.

Taugourdeau, P. (1963) Étude de quelques espèces critiques de chitinozoaires de la région d'Edjelé et complément B la fauna locale. *Revue de Micropaléontologie* **6**, 130–144.

Taugourdeau, P. and de Jekhowsky, B. (1960) Répartition et description des Chitinozoaires Siluro-Devoniens de quelques sondages de la C.R.E.P.S., de la C.F.P.A et de la S.N. Repal. au Sahara. *Revue de l' Institut Français du Pétrole* **15** (9), 119–126.

Verniers, J., Nestor, V., Paris, F., Dufka, P., Sutherland, S. and van Grootel, G. (1995) A global Chitinozoa biozonation for the Silurian. *Geological Magazine* **132**, 651–666.

Wood, G. D. and Miller, M. A. (1991) Distinctive Silurian chitinozoans from the Itacurubi group (Vargas Peña Shale) Chaco Basin, Paraguay. *Palynology* **15**, 181–192.

Wood, G. D. and Miller, M. A. (1997) Pre-Carboniferous Chlorophyta: New reports of Hydrodictyaceae, Sendesmaceae and Zygnemataceae. *Acta Universitalis Carolinae Geologica* **40**, 703–717.