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Oktay, B. and Wellman, C.H. (2019) Palynological analysis of Upper Ordovician to Lower Silurian sediments from the Diyarbakir Basin, southeastern Turkey. Review of Palaeobotany and Palynology, 263. pp. 28-46. ISSN: 0034-6667

https://doi.org/10.1016/j.revpalbo.2019.01.007

Palynological analysis of Upper Ordovician to Lower Silurian sediments from the Diyarbakir Basin, southeastern Turkey

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ABSTRACT

This paper reports on a palynological analysis of 41 core and 21 cutting samples from a well drilled through an Upper Ordovician-Lower Silurian sequence, belonging to the Bedinan and Dadas formations, of the Diyarbakır Basin of southeastern Turkey. The samples yield abundant and well-preserved marine palynomorphs (acritarchs, chitinozoans and scolecodonts) although non-marine palynomorphs (spores/cryptospores) are extremely rare or absent. The Upper Ordovician sediments of the Bedinan Formation have low organic content but contain abundant palynomorphs whereas the Lower Silurian sediments of the Dadas Formation have high organic content, dominated by amorphous organic matter, with relatively rare palynomorphs. Three chitinozoan assemblages are identified and attributed a late Katian (*merga* Biozone), Hirnantian (*moussegouda* Biozone) and Llandovery (*alargada* Biozone) age. Two acritarch assemblages are identified and attributed a Katian-Hirnantian and Llandovery (Aeronian-Telychian) age. The chitinozoan and acritarch age determinations are compatible and suggest that the Bedinan Formation is of Katian-Hirnantian age and is separated by an unconformity from the Dadas Formation that is of Llandovery (Aeronian-Telychian) age. These findings confirm the presence of an unconformity at the Ordovician-Silurian transition in the southeastern Turkey. Palynofacies analysis suggests that the Bedinan Formation accumulated on an offshore shelf that was initially well oxygenated but became increasingly anoxic, whereas the Dadas Formation accumulated in an offshore basin that was anoxic. Palynomorph assemblages recorded in the Bedinan and Dadas formations indicate northern Gondwana affinity.

Keywords: Ordovician, Silurian, acritarchs, chitinozoans, Bedinan Formation, Dadas Formation, Turkey.

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1. Introduction

This study examines chitinozoan and acritarch assemblages from Upper Ordovician and Lower Silurian sediments penetrated by a well in the Diyarbakır Basin, southeastern Turkey. The palynomorph assemblages comprise well preserved palynomorphs of low thermal maturity. This interval is of interest because other Lower Palaeozoic sequences of Northern Gondwana (Middle East, North Africa) are important targets for petroleum exploration. In general the lower Silurian organic-rich rocks ('hot shales') are excellent source rocks (Lüning et al., 2003) and glacial related rock sequences of the Upper Ordovician often form reservoirs (Le Heron et al., 2009).

The Diyarbakır Basin of southeastern Turkey is one of a number of early Palaeozoic basins on the North Gondwana platform. It includes a sequence mainly represented by siliciclastic sediments that are included in the Bedinan and Dadas formations. Unfortunately at present understanding of the subsurface geology of these deposits is poor and age dating of many of the sequences is insecure. Previous age assignments were mainly based on trilobites and graptolites (Paris et al., 2007). Macrofaunas were previously studied from the Taurus Range and Border Folds (Dean, 1967; Dean and Monod, 1990; Dean et al., 1999). Sarmiento et al. (1999) also described conodonts. However, extensive intervals of the succession are not well age-constrained because macrofaunas are sporadic in occurrence (Paris et al., 2007).

Very few palynological studies have been undertaken on the Lower Palaeozoic sequences of Turkey. Ordovician-Silurian acritarchs and chitinozoans have been described by Erkmen and Bozdogan (1979), Miller and Bozdogan (1989) and Steemans et al. (1996). Steemans et al. (1996) also reported on Ordovician and Silurian cryptospores and miospores. The Upper Silurian to Lower Devonian Dadas and Hazro formations were also studied palynologically by Fontaine et al. (1980) and Brocke et al. (2004). These studies may be considered alongside preliminary macrofossil data from both the Taurus Range and southeastern Turkey (Dean and Martin, 1992; Dean et al., 1993; Monod et al., 2003, Paris et al., 2004; Sancay and Dinc, 2012).

A detailed palynological analysis is desirable for: (i) determining the biostratigraphical age of the strata and improving stratigraphical correlation; (ii) enabling interpretation of palynofacies and palaeoenvironments. The main aim of this study is to present a preliminary palynological investigation of these deposits based on material from core and cutting samples from a well drilled through the Dadas and Bedinan formations.

2. Geological setting

The history of research on recognizing Palaeozoic rocks in Turkey begins in the second half of the 19th century when a large number of scientists began working on the stratigraphy and palaeontology of the Palaeozoic rocks of this region (e.g. Tchihatcheff, 1864; de Verneuil, 1869). The systematic mapping of these Palaeozoic rocks was primarily conducted by the Mineral Research and Exploration Institute of Turkey and the Turkish Petroleum Company, but also by some independent geologists (e.g. Tolun and Ternek, 1952; Ketin, 1966; Dean, 1967 to 2006; Kaya, 1973).

Turkey is composed of a number of continental fragments which were separated by ancient oceans until the Cenozoic. The continental fragments (terranes) and their remnants, such as ophiolites and accretionary prisms, subsequently came together to form Anatolia (Okay, 2008). Goncuoglu (2012) notes that Turkey is located in the centre of the Alpine orogenic belt and was formed by closure of at least three branches of the Neotethys Ocean between Laurasia in the north and Gondwana in the south.

Ketin (1966) divided Turkey into three main tectonic terranes (the Pontides, Anatolide-Tauride and Arabian Platform), but recently new findings have emended the classification of these continental fragments. It is now considered that Turkey consists of five main terranes connected by different suture belts. In northern Turkey there are three terranes: the Rhodope-Strandja, İstanbul-Zonguldak and Sakarya Terranes (together called the Pontides). In southern Turkey the Anatolite-Tauride terrane is separated from the Pontides by the Izmir-Ankara-Erzincan suture zone (Okay, 2008; Goncuoglu, 2012). The Pontides has Laurasian affinities while the Anatolite-Tauride terrane has Gondwana affinities. It is currently a controversial issue as to whether the Central Anatolian Crystalline Complex or the Kırsehir Massif is part of the Anatolite-Tauride terrane or an independent terrane (Okay, 2008). The Southeast Anatolian Autochthon is a northern continuation of the Arabian platform and resembles the Anatolite-Tauride terrane stratigraphically (Okay, 2008; Goncuoglu, 2012).

The Southeast Anatolian Zone in the south and the Bitlis Unit in the north are separated from each other by an active thrust that is a continuation of the Zagros fold and thrust belt (Goncuoglu, 2010). Pan-African basement and Palaeozoic–Cenozoic cover are the main components of the Southeast Anatolian Zone (Sungurlu, 1974). The basement complex is covered by arenite which is intercalated with shelf carbonates and Mid Cambrian aged nodular limestone (Schmidt, 1966; Sungurlu, 1974; Dean, 2006; Demircan and Gursu, 2009). Ordovician siliciclastic rocks are observed below the Upper Silurian-Upper Devonian succession with a depositional break occurring during the Early Silurian. Late Silurian-Late Devonian deposits are composed of continental clastics and limited marine sediments in the central part (Goncuoglu, 2010). Perincek et al. (1991), on the other hand, considers that the Ordovician rocks are covered by Upper Devonian-Lower Carboniferous coastal-shallow marine rocks in the eastern areas. The northern part of Gondwana was stable during the Late Palaeozoic resulting in intercalations of two units: Late Permian shelf carbonates and Triassic shallow marine deposits (Goncuoglu, 2010).

Lower Palaeozoic sedimentary rocks of southeastern Turkey are observed in many localities (Fig. 1). Southeastern Anatolia is located at the northern end of the Arabian Plate (Monod et al., 2003) and the tectonic evolution and sedimentary sequence of the region are controlled by the relative movements of the Arabian Plate and the Anatolian Continent with respect to one another. The Mardin-Kahta High, which was formed by the influence of these movements, separates Southeastern Anatolia into two sub-basins (the Akçakale Basin and Diyarbakır Basin) (Bozdogan and Erten, 1990).

The studied well is located in the province of Diyarbakır in the Diyarbakır Basin (Fig.1). The formations sampled through the well are the Bedinan and Dadas formations (Fig. 2 and 3).

2.1. Bedinan Formation

Steemans et al. (1996) stated that the thickness of this formation is 1500 m and the depositional environment is shallow marine and tidal-flat. Transgression is observed in the lower part of the formation whereas two successive regressions are observed in the upper part. The upper part of the sequence is comprised of dark green shales and sandstone (Bozdogan et al., 1994). According to Bozdogan et al. (1996) the lower part is composed of fossiliferous dark shales and siltstone, and the middle and upper parts are composed of sandstones and shales with local submarine lavas.

The Bedinan Formation is recognised at outcrop and in subsurface boreholes. It yields a rich benthic fauna and palynomorphs (Bozdogan et al., 1994; Steemans et al., 1996). The lower part of the formation is Sandbian (Carodoc) while the upper part is Katian-Hirnatian (late Caradoc-Ashgill) (Dean et al., 1981). The Bedinan Formation is unconformably overlain by the Dadas Formation and in some regions stratigraphical differentiation is apparent because of erosion that occurred after the Ordovician period (Steemans et al., 1996).

2.2. Dadas Formation

The thickness of the Dadas Formation varies from 100 to 400 m in the subsurface and it is exposed in Korudag and Dadas (Diyarbakir region) (Steemans et al., 1996). The formation is underlain by the Bedinan Formation and overlain by the Kayayolu and Hazro formations (Bozdogan et al., 1987). Ozdemir (2013) suggests that the Dadas formation is conformably overlaid by the Hazro Formation, and the lower boundary of the Dadas Formation is not exposed at the surface. However, it unconformably overlies the Bedinan Formation in the Kayayolu-2 well. The lower part of the Dadas Formation is composed overwhelmingly of anoxic organic-rich shale and limestone whereas the upper part of the formation is composed of sandstone and dolomite, which were deposited under high energy conditions in a shallow marine environment (Steemans et al., 1996). Bozdogan et al. (1996) suggests that the lower part of the formation represents an inner-shelf with low energy condition. Shallow marine deposits in the middle part and coastal deposits in the upper part are intercalated. Previous palynological studies suggest a mid Silurian to Early Devonian age for the formation (Bozdogan et al., 1987, 1994).

3. Materials and methods

Sixteen core and twenty-one cutting samples from the Upper Ordovician rocks and twenty-five core samples from the Lower Silurian rocks were selected. The core from the depth of 1808 to 1873.5 m penetrated 33.95 m of the Dadas Formation and 12.4 m of the underlying Bedinan Formation. Core samples were derived from the interval 1826.05-1873.4 m and cuttings were derived from the interval 1908-2362 m.

Samples were prepared in the palynology laboratory of the Turkish Petroleum Research and Development Centre. Standard HCI-HF-HCI palynological acid maceration techniques were applied prior to heavy liquid separation. No oxidation was needed. Samples generally yielded assemblages of abundant and well-preserved palynomorphs.

The prepared slides were examined using an OLYMPUS BH-2 microscope with specimen location recorded using an England Finder. Photographs of the specimens were obtained using a MEIJI, transmitted light microscope, with a digital camera that uses *Infinity Analyze* software. Counts for palynofacies analysis considered only palynodebris larger than 10 μm in diameter. All material (rock sample, residue, slides and digital images) are curated in the palynology laboratory of the Turkish Petroleum Research and Development Centre.

4. Biostratigraphy and age

4.1. Chitinozoan Assemblages

Three chitinozoan assemblages (CA1 to CA3) have been defined within the interval 2362 to 1826.05 m (Figs 4 and 5). In the interval of 1930-2362 m the oldest Chitinozoan Assemblage 1 is observed and is assigned a late Katian age. The overlying Chitinozoan Assemblage 2 from 1870.3-1912 m is assigned a Hirnantian age. The youngest Chitinozoan Assemblage 3 is identified in the sequence from 1826.05 to 1857.5 m and is assigned a Llandovery (Aeronian-Telychian) age.

4.1.1. Chitinozoan Assemblage 1 (1930-2362 m)

CA1 is assigned to the *merga* Biozone. It is characterized by the total range of *Ancyrochitina merga* as well as the diversity and abundances of Ancyrochitininae (Paris, 1990). *Armoricochitina nigerica*, *Calpichitina lenticularis, Conochitina dolosa, Cingulachitina* sp., *Cyathochitina* sp. and *Desmochitina minor* are present, and *Plectochitina* cf. *sylvanica* appears with *Rhabdochitina magna*. The upper boundary of CA1 is identified by the sharp disappearances of *A. merga* and other Ancyrochitininae species. This may correspond to the first phase of the end-Ordovician (Hirnantian) extinction at the base of *extraordinarius* graptolite biozone (Harper et al., 2013). The lower boundary of CA1, on the other hand, cannot be determined because the last downhole occurrence of *A. merga* is not observed in these samples. However, an early *nigerica* Biozone is likely from the depth of 2162 m downward if we consider the possibility that caving is responsible for the presence of *A. merga* in the samples from 2184-2186, 2352-2354 and 2360-2362 m (Fig. 4). There is clear evidence for caving in some of the cuttings samples which complicates biostratigraphical interpretation. For example, from the depth of 1908 m downward caved Silurian chitinozoans (*Angochitina macclurei*) and acritarchs (*Cymbosphaeridium pilar*, *Cymbosphaeridium* sp. 1, *Dictyotidium dictyotum*, *Deflandrastum millepiedi*) are present in cutting samples (Figs 4 and 6). Consequently, based on potential caving within CA1, the *merga* and *nigerica* Biozones are not confidently separated in this well. Chitinozoan species like *Hyalochitina fistulosa* and *Belonechitina robusta* which have their FAD earlier (see Paris et al., 2007 and Paris, 1990) have not been recorded in the studied interval. Thus there is no age control to identify an age older than late Katian and consequently this zone is assigned to the late Katian (Fig. 5).

4.1.2. Chitinozoan Assemblage 2 (1870.9-1912 m)

CA2 is similar to CA1 and is characterized by typical Late Ordovician species including *Armoricochitina nigerica*, *Calpichitina lenticularis, Conochitina dolosa, Euconochitina* cf. *moussegoudaensis* and *Desmochitina minor*. However, it differs from the underlying biozone CA1 due to the absence of *A. merga*. This zone can be assigned to the *moussegoudaensis/oulebsiri* Biozone based on the occurrence of *Euconochitina moussegoudaensis* (Thusu et al., 2013). These authors suggested that the *moussegoudaensis* Biozone starts with the FAD of *E. moussegoudaensis* with this taxon possibly ranging through the Ordovician-Silurian boundary in southeast Libya. However, *E.* cf. *moussegoudaensis* identified in this study ranges through this zone as well as CA1. Based on the discussion above, and the uncertainty of the age assignment of *E. moussegoudaensis*, this zone is cautiously assigned a Hirnantian age (as discussed by Thusu et al. 2013) (Fig. 5).

Diagnostic Hirnantian species (e.g. *Spinachitina oulebsiri* and *Tanuchitina elongata*) are absent in this assemblage, which may be a consequence of unfavourable environments for Hirnantian taxa. During the second phase of the end-Ordovician mass extinction the climate drastically changed from cooling to warming, causing the melting of major ice caps, sea level rise and widespread anoxia (Harper et al., 2013). Melt water and invasion of continental shelves by anoxic bottom waters during this transgression may have created unfavourable brackish and/or anoxic environments excluding certain Hirnantian chitinozoan taxa (as discussed by Melvin, 2014).

4.1.3. Chitinozoan Assemblage 3 (1826.05-1857.5 m)

CA3 is characterized by the occurrence of *Angochitina* sp., *Bursachitina* sp., *Lagenochitina navicula*, *Pterochitina deichaii* and *Conochitina* cf. *alargada*. It is cautiously assigned to the *alargada* Biozone in which *C. alargada* (=*C. edjelensis alargada*) is dominant. This biozone is defined by the concurrent range of *C. alargada* and *Plectochitina paraguayensis* (Paris et al., 1995). Verniers et al. (1995) showed that the age range of *C. alargada* extends from the mid to late Aeronian. Paris et al. (2015) suggest that the *alargada*

Biozone is found in the early Aeronian sediments of Arabia, although specimens referred to as *C.* cf. *alargada* extend up into the Telychian in this region (Paris et al. 2015). One of the accompanying species in CA3 is *P. deichai* that is present in low numbers in this Biozone. Another accompanying chitinozoan in this assemblage is *L. navicula*, which was reported from the Llandovery of northeast Brazil by Grahn et al. (2005). It is worth emphasising that *Angochitina macclurei* has been found as caving within the 1930-2290 m interval. The occurrences of these taxa suggests that the *macclurei* (early Telychian) Biozone is likely present within or above the cored interval (see Paris et al., 2015). Based on the discussion above and the occurrence of *C.* cf. *alargada* this assemblage is assigned an Aeronian-Telychian age (Fig. 5).

4.2. Acritarch Assemblages

Two acritarch assemblages have been identified (AA1-AA2). Acritarch Assemblage 1 is older and recovered from the Bedinan Formation and Acritarch Assemblage 2 is younger and recovered from the Dadas Formation (Fig. 6).

4.2.1. Acritarch Assemblage 1

This assemblage is mainly composed of *Villosacapsula setosapellicula, Orthosphaeridium bispinosum*, *Orthosphaeridium chondrododora, Multiplicisphaeridium irregulare, Orthosphaeridum quadrinatum, Ordovicidium elengatulum, Orthosphaeridum ternatum, Dactylofusa striata, Dactylofusa platynetrella, Leiofusa litotes, Baltisphaeridium cf. latiradiatum, Baltisphaeridium longispinosum, Veryhachium subglobosum* and *Veryhachium lairdi* (Plates 4-8).

O. bispinosum, O. chondrododora, O. quadrinatum B. cf. *latiradiatum* were previously reported from Caradoc (Sandbian-Katian) sediments of Britain (Turner, 1979), but these taxa can also extend into the Ashgill (Katian-Hirnantian) (Vecoli and Le Herisse, 2004, Le Herisse et al., 2015). Although *Dactylofusa striatogranulata* (Plate VI, 9) can extend from the Late Ordovician into the Lower Silurian (see Jardiné et al., 1974, Le Herisse et al., 2015) it was restricted to the uppermost Ordovician (1870.9 m herein) in the study of Vecoli and Le Herisse (2004). However, *Dactylofusa platynetrella* (Plate V, 9) is not only restricted to the Hirnantian sediments (Vecoli and Le Herisse, 2004). It can be found in the Katian sediments recovered from the well (1870.9-2042 m). *D. platynetrella* were also recorded from the

Katian and Hirnantian sequences of northern Iran with occurrences of *Villosacapsule setosapellicula, Orthosphaeridium elengatulum, Dactylofusa striata* (Ghavidel-Syooki et al., 2011).

V. subglobosum, V. lairdi and *V. setosapellicula* were previously documented both from the Sarah and Qasim formations of the central Saudi Arabia (Le Herisse et al., 2015). These taxa are observed in the Hirnantian and Katian parts of the Bedinan Formation. *V. subglobosum* and *V. setosapellicula* in the Hirnantian sediments are distinctly higher than those in the Katian part of the Bedinan Formation. *O. chondrododora, M. irregulare, O. quadrinatum, O. elengatulum, O. ternatum* and *V. setosapellicula* were reported from the early mid Katian sediments of Oman (Droste, 1997). However, *M. irregulare, O. quadrinatum, O. elengatulum* are restricted to the Hirnantian in this study (Fig. 6). Previously, many Late Ordovician indicative acritarchs were recorded from the southeastern part of Turkey (Paris et al., 2007; Steemans et al., 1996). Furthermore, *L. litotes* (Plate V, 10) documented from the Caradoc-Ashgill (Katian) boundary of northeast Kansas (Wright and Meyers, 1981) is observed here through the late Katian-Hirnantian of the Bedinan Formation.

Peteinosphaeridium nudum (Plate VII, 10) ranges through the Lower Ordovician and possibly Middle Ordovician rocks of northern Gondwana (Vecoli and Le Herisse, 2004) but it is observed at 1872.3 m, indicating probable reworking. *Peteinosphaeridium trifurcatum* is another long-ranging Ordovician acritarch from northern Gondwana (Vecoli and Le Herisse, 2004). *Peteinosphaeridium trifurcatum* subsp. *trifurcatum* (1872.8 m, Plate VII, 8) and *Baltisphaerosum christoferii* (1872.8 m, Plate VII, 12) is likely reworked here since these species were recorded from the Landeilo and Caradoc (Darriwilian-Katian) of Britain (Turner, 1979). *Baltisphaeridium annelieae* was documented from the Llandovery and lower Wenlock of Wales and the Welsh Borderland of Britain (Hill, 1974). However, in this study, *Baltisphaeridium annelieae*? (1870.9 m, Plate IV, 11) is observed in the Bedinan Formation. The range of this species is still debatable.

AA1 includes Silurian caved acritarchs such as *Cymbosphaeridium pilar*, *Cymbosphaeridium* sp., *Dictyotidium dictyotum*, *Onondagella* sp., *Deflandrastum millepiedi*, and *Pirea* sp.

Based on the above discussion, particularly regarding classical Late Ordovician (Sandbian-Hirnantian) acritarchs such as *Baltisphaeridium longispinosum, Baltisphaerosum onniensis, Veryhachium subglobosum*, *Veryhachium oklahomense, Villosacapsula* *setosapellicula* and *Leiofusa litotes,* AA1 and the Bedinan Formation is assigned to the Late Ordovician. LADs of *Stellechinatum celestum,* or earlier *Frankea* spp. and *Dicrodiacrodinium ancoriforme*, are not observed through the well. Therefore, a late Katian-Hirnantian age appears most likely rather than Sandbian-early Katian.

4.2.2. Acritarch Assemblage 2

AA2 is characterized by the existences of *Multiplicisphaeridium fisheri, Oppilatala eoplanktonica, Veryhachium wenlockium, Veryhachium europaeum, Domasia trispinosa, Dactylofusa striatifera, Visbysphaera dilatispinosa, Visbysphaera oligofurgata* and *Multiplicisphaeridium ramusculosum* (Plates 1-3). This suggests an Aeronian-Telychian age when considered together with the chitinozoan age designation. *M. fisheri* and *O. eoplanktonica,* reported from the early Silurian shales of Libya (Paris et al., 2012), indicates a Rhuddanian-Aeronian age. *M. fisheri* (1829-1857 m in this study), on the other hand, is found from the earliest Telychian to the latest Sheinwoodian (Loydell et al., 2013). The Aeronian-Telychian age interval is also consistent with the existence of *D. striatifera* (or *Eupoikilofusa striatifera*), which indicates an age no older than Rhuddanian (Paris et al., 2012). However, Loydell et al. (2013) suggested an extended age range (from Late Ordovician to earliest Devonian) for *Eupoikilofusa striatifera* (1857.5 and 1867.5 m in the Dadas and Bedinan formations respectively). In addition, occurrences of *D. striatifera* and *V. europeoum* are coincident with a Llandovery age (Thusu et al., 2013). Furthermore, occurrences of *V. dilatispinosa, V. oligofurgata, M. ramusculosum,*and *V. wenlockium*recorded in the Dadas-I Member suggest a Llandovery age (Hill, 1974).

D. trispinosa (1855-1847 m herein) was previously reported from the early Silurian of Iran and stratigraphic age range of *D. trispinosa* is known from the late Llandovery (Telychian) to early Ludlow (Ghavidel-Syooki et al., 2011). Assemblage of *D. trispinosa* with *D. bispinosa* is no older than the Telychian (Hill and Dorning, 1984). *D. bispinosa* was also previously recorded from a similar palaeogeographic region in the late Llandovery (Keegan et al., 1990). Moreover Wauthoz (2005) documented other *Domasia* species (*D. elongata*/*D. limaciformis*) attributed to the Aeronian-Telychian boundary. Based on this discussion and occurrences of *D. trispinosa* and *D. bispinosa* together at 1854 m the lower boundary of the Telychian can be attributed to this level.

5. Palaeoenvironmental interpretation

Palaeoenvironmental interpretation of the studied intervals is based on palynofacies analysis (based on 200 counts of palynomorphs and palynodebris).

The lower part of the Bedinan Formation has low organic yield but contains a high abundance and diversity of both acritarchs and chitinozoans. Land-derived spores/cryptospores are extremely rare. Amorphous Organic Matter (AOM) is present but not abundant (Table 1). The depositional environment is interpreted as an offshore, open marine, shallow shelf that was oxygenated. The presence of abundant animal remains supports this interpretation. The upper part of the Bedinan Formation has lower palynomorph abundance (but still yields acritarchs and chitinozoans with only very rare spores/cryptospores) and higher amounts of AOM (Table 1). The depositional environment is interpreted as an offshore, open marine, deeper water shelf that was anoxic. Changes in AOM amount in this formation may corresponds to the study of Harper et al. (2013) who suggested that the end Ordovician (Hirnantian) extinction comprised two discrete pulses with the second phase of this extinction linked to a remarkable transgression resulted from melting of ice caps following global warming. Steemans et al. (1996) suggested that the depositional environment of the Bedinan Formation was shallow marine to tidal-flat environment based on the sections they studied that contained relatively common land-derived spores/cryptospores. The studied well, however, is located in the eastern part of the basin and yields only extremely rare non-marine palynomorphs.

The Dadas Formation has high organic yield and is dominated by orange to brown AOM (up to 95%). However, palynomorphs are abundant and include relatively common sphaeromorphs, rare to relatively common acritarchs and chitinozoans, although spores/cryptospores are extremely rare (Table 2). This suggests that the deposits accumulated in an offshore, open marine, deep basinal environment that was anoxic. The presence of abundant pyrite associated with the AOM supports interpretation of anoxic conditions. An environment that is dominantly represented by AOM almost certainly reflects anoxic conditions, especially in areas far from the effect of terrestrial input (Batten, 1996). According to Steemans et al. (1996) the lower part of Dadas Formation consists of anoxic organic-rich shale and limestone, which is consistent with the interpretation herein.

6. Conclusions

Detailed palynological analysis of the Upper Ordovician to Lower Silurian sediments from a well in the Diyarbakır Basin, southeastern Turkey has enabled biostratigraphical age determination and palaeoenvironmental interpretation based on palynofacies analysis.

Three chitinozoan assemblages and two acritarch assemblages have been identified. Biostratigraphical evidence from both chitinozoans and acritarchs are compatible but due to a higher precision of taxon ranges the chitinozoan age determinations are considered more accurate than those based on acritarchs. Thus the Bedinan and Dadas formations are considered to be Katian-Hirnantian and Llandovery (Aeronian-Telychian) in age, respectively, and separated by an unconformity.

Palynofacies analysis suggests that the Bedinan Formation accumulated on an offshore, high productivity shelf that became increasingly less oxygenated, whereas the Dadas Formation accumulated in an offshore, anoxic, low productivity basin. The remarkable deepening following melting of ice cover during the second phase of end-Ordovician mass extinction may be responsible for the increasingly anaerobic conditions in the Bedinan Formation.

Acknowledgements

This study was undertaken at the University of Sheffield during research for a M.Biol.Sci. degree. We would like to thank Turkish Petroleum Corporation for providing material and permission to publish. We also thank Ken Dorning for taxonomic advice and Alain Le Hérissé and an anonymous referee who improved the manuscript considerably.

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