Research Journal of Environmental and Earth Sciences 4(12): 1052-1059, 2012
ISSN: 2041-0492
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Submitted: August 25, 2012 Accepted: September 24, 2012 Published: December 20, 2012

Devonian Miospores from Atiavi-1 Well in the Keta Basin, Southeastern Ghana

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Abstract: Miospore assemblages from the Atiavi-1 well in the Keta basin have been described to corroborate the upper Lower Devonian (Emsian) to lower Upper Devonian (Frasnian) age assigned to the lower section of the well based on chitinozoan and acritacrch assemblage by Anan-Yorke (1974). The study also assigns Uppermost Devonian (Strunian) age to the upper part of well with a diverse, well preserved and abundant assemblage of pteridophytic spores and phytoclasts which hitherto has not been dated. Observations from palynomorph distribution reflect a change from marine environment of deposition for the lower section to that of fluvio-deltaic or nearshore environment for the upper part in a humid climate. The palynomorophs are well preserved and thermal maturity is within the oil floor and wet-gas zone.

Keywords: Emsian, keta, miospores, phytoclast, strunian, Thermal Alteration Index (TAI)

INTRODUCTION

The Keta basin is a southward open monocline controlled by basement flexures and faults (Akpati, 1975). It is characterized by two sub parallel faults, the Fenyi-Yakoe and Adina faults which are generally regarded as the northeastern extensions of the Romanche Fracture Zone. The basin contains over 4400 m of Devonian to Recent non-marine and marine sediments (Akpati, 1978). The basin continues offshore beneath the continental shelf, where the thickness of the sediments may exceed 5000 m and include Mesozoic and Cenozoic deposits (Blundell and Banson, 1975). The Keta basin is one of the chains of Mesozoic and Tertiary sedimentary basins along the West African Gulf of Guinea. These basins lie parallel to the present coastline and are concentrated along mobile belts that were established in the Late Precambrian (Kennedy, 1965). The occurrence of these basins are attributed to the subsidence along the line of the Late Precambrian orogenic belt, that later marked the separation of the Africa and South America (Sutton, 1968). The occurrence of the Devonian sediments in the Keta basin could be reconciled with the reconstruction of the continents by Bullard *et al*. (1965) in that the sediments were deposited in an inland basin that later became inundated by the sea between Gedinnian and Givetian time (Saul *et al*., 1963).

The thirty seven samples processed contain a rich assemblage of miospores, chitinozoans and acritarchs. Previous work on biostratigraphic work on the Keta basin has been on the Mesozoic and Tertiary sediments of the Keta basin (Cox, 1952; Khan, 1970; Robertson Research International (RRI), 1984). Anan-Yorke (1974) studied the palynology of Atiavi-1 well in the Keta basin which penetrated Paleozoic sediments. He recognized a lower marine interval based on chitinozoan, acritarchs, spores and occasionally scoloecodonts and dated the sediments upper Lower Devonian (Emisian) -lower Upper Devonian (Frasnian) and an upper continental unit with predominant spores which was not studied.

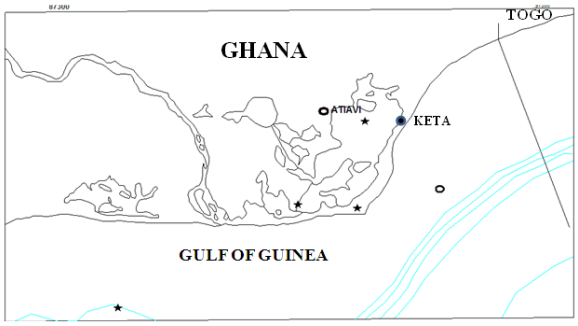

Fig. 1: Location map of Atiavi-1 well in the keta basin (modified after Aparicio (1984))

This study describes well preserved spore assemblages recovered from the Devonian strata in the Atiavi-1 (Fig. 1) to corroborate the age assigned to the lower section based on chitinozoan and acritacrch assemblage (Anan-Yorke, 1974). It also further assigns ages to the upper part of the well after comparison with similar assemblages used successfully in dating

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Devonian sediments in other parts of the world (Europe, North and South America, USSR and Australia).

MATERIALS AND METHODS

Thirty seven cutting samples from the Atiavi-1 well in the Keta Basin, between the interval 936-1524 m yielded moderate to well preserve and diverse palynomorphs. Laboratory preparations followed the standard techniques using hydrofluoric (40%) and hydrochloric acid (35-38%) to digest the carbonates and silica content of the sediments respectively and the release of organic matter from the rock matrix. The sample residue were strewn in elvanol and mounted on microscope slides in Canada balsam. The slides were studied using the Karl Zeiss Axiolab microscope fitted with a MC 80 Microscope camera.

RESULTS AND DISCUSSION

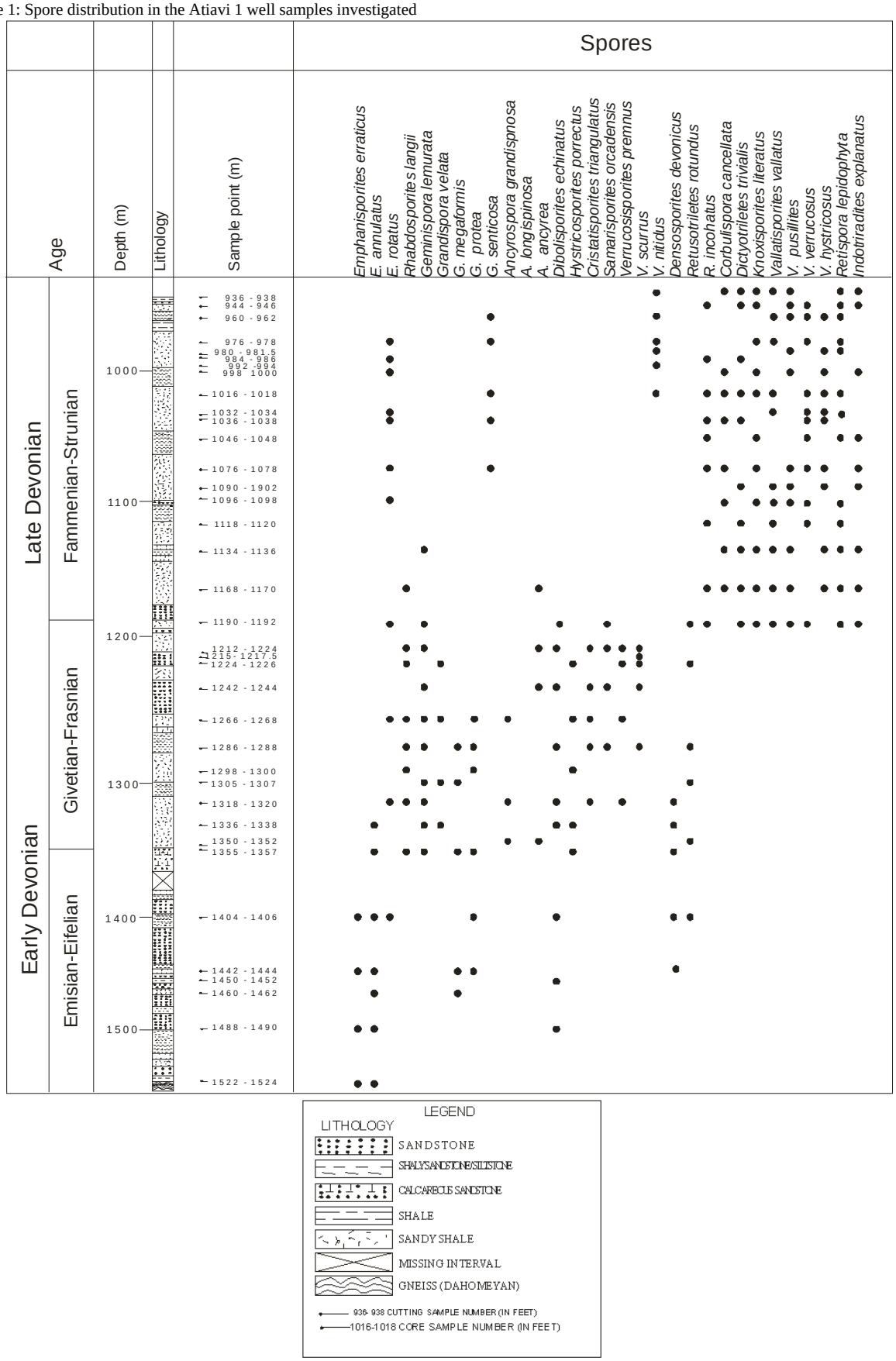
Stratigraphic significance of the miospores: Marine organic-walled microfossils (acritarchs and chitinozoans) are abundant in the lower sections of this sequence as noted by Anan-Yorke (1974). The overlying intervals are more continental/nearshore in nature with trilete spores and phytoclast being the dominant kerogen content (Table 1). They are well preserved, abundant and diverse. The presence and relative abundance of species such as *Emphanisporite*s spp, *Ancyropora* spp, *Hystricosporites* spp, *Verrucsisporites* spp, *Grandisporites* spp, *Rhabdosporites langii*, *Calyptosporites* spp, *Biharisporites* spp, *Auroraspora micromanifestus*, *Geminospora lemurata*, *Densosporites* spp. *Dibolisporites* spp show that miospore assemblage in the lower section of the Atiavi-1 well (1524-1224 m) originate in the Emsian to Frasnian age rocks. The upper sections (1192-936 m) contain elements typical of Upper Devonian (Fammenian-Strunian) age.

The oldest productive intervals (1357-1524 m) contain a variety of azonate miospores, the proximal radial ribbed forms (*Emphanisporites*) including the species *E. rotatus*, *E annulatus*, *E. erraticus*, rare zonate spores and *Dibolisporites* spp, *Dictyotriletes* spp. These assemblges are typically of Emsian rocks and are comparable with Emsian microfloras from Algeria (Jardine and Yapaudjian, 1968), Libya (Paris *et al*., 1985; Massa and Moreau-Benoit, 1976), Saudi Arabia (Breuer *et al*., 2005), Czeckoslovakia (McGregor, 1979). Also present in the assemblage are large zonate spores and pseudosaccate forms and also spores possessing distinctive processes with bifurcate termination and also some considerable number of species from the previous level. The following species are important in the assemblage, *Ancyrospora ancyrea* (Plate 3, Fig. G), *A. longispinosa*, *Hystricosporites* spp, *Grandispora* spp, *Rhadosporites langii*, *Auroraspora* spp, *Verrucosisporites scurrus*, *Cristatisporites* spp, *Samarisporites* spp, Grapnel-tipped spores, *Ancyrospora* spp (*A. ancyrea*, *A. grandispora*, *A. longispinosa*), large camerate spores including *Auroraspora* spp, *Grandispora* spp, *Calyptosporites* spp. *Rhabdosporites langii*, *Densosporites devonicus* have been reported as characteristic of the Middle Devonian Eifelian stage (Richardson, 1974; Marshall and Fletcher, 2002; Marshall, 1988; Richardson and McGregor, 1986). According to Richardson (1974) *Rhabdosporites langii* has not been recorded below the Eifelian. In Euramerica *R. langii* has a widespread distribution from the lower part of the Eifelian to the Givetian/Frasnian boundary (Hartkoff-Fröder and Streel, 1993). Ville de Goyet *et al*. (2007) have recorded *A. ancyrea*, *R. langii*, *G. velata* and *V. premnus* from Eifelian-Givetian samples from Ronquieres, Belgium and borehole A1-69 from Libya. Ghavidel-Syooki (2003) reported the presence of *V. premnus*, *R. langii*, *E. rotatus* and *G. velata* which characterized his Spore zone IV from Zagros basin in southern Iran and assigned an Eifelian-early Givetian age to the zone. The absence of *G. lemurata* delimits the age of this interval to Emsian-Eifelian, since it is reported that the species makes its first appearance at the Eifelian/Givetian boundary (Loboziak *et al*., 1991a; Streel and Loboziak, 1994; Streel *et al*., 1987).

Geminispora lemurata (Plate 1, Fig. M, N) appears in level 1355 m and together with some forms in the previous levels, including *Rhabdosporites langii*, *Ancyrospora* spp, *Densosporites devonicus*, *Emphanisporites* spp, *Dibolisporites echinatus*, *Cristatisporites* spp,*Grandispora* spp, *Auroraspora* spp. constitute the assemblages within the level 1355-1192 m which are elements characteristic of the Givetian-Frasnian age.

The abundance of Geminospora *lemurata* in most samples is significant or important as this zonal taxon has its inception at the base of the Givetian or in the uppermost Eilfelian (Loboziak *et al*., 1991a; Streel and Loboziak, 1994). Streel *et al*. (1987) reports that *G. lemurata* characterizes the Interval Zone Lem. Near the Eifelian/Givetian bouudary in the Ardenne-Rhenish region. According to Marshall (1996a), the redefinition of the Global Stratigraphic Section and Point (GSSP), sees the first occurrence of *G. lemurata* at the base of the Givetian and has been described as the most useful spore marker which can be used in the terrestrial sediments to locate the base of this stage. Playford (1983) intimated that the species is very abundant at the Givetian/Frasnian boundary and that the possible vertical range can be stated no more precisely than Givetian to late Frasnian. It has been recorded in the northwestern Canada where it reaches its peak within the Lower Fammenian (Braman and Hills, 1992). *Geminospora lemurata* has been recorded together with other forms which support late Givetian-Frasnian age

Table 1: Spore distribution in the Atiavi 1 well samples investigated



such as *Rhabdosporites langii*, *Cristatisporites triangulatus*, *Ancyrospora langii*, *Contagisporites optivus*. This assemblage is akin to late Givetian-Frasnian spore assemblage reported from the Old Red Sandstone sequences of the Walls Group (Marshall, 2000) and Eday Group of Orkney (Marshall, 1996b), Fair Isle (Marshall and Allen, 1982), S.E Shetland (Allen and Marshall, 1981) and East Orkney Basin (Marshall, 1996a), Orcadian Basin (Marshall *et al*., 1996) and South Portugueses zone (Lake *et al*., 1988). Ville de Goyet *et al*. (2007) have also reported *G. lemurata*, *R. langii*, *A. ancyrea*, *Samarisporites triangulatus*, *Aneurospora greggsii and Chelinospora concinni* from the Givetian-Frasnian. Loboziak *et al*. (1991a) clearly demonstrated that the first occurrence of *G. lemurata* is within the *Ensensis-obliquimarginatus* conodont standard Zone and very close to the first occurrence of *Polygnathus ensensis ensensis* and *P. hemiansatus*, which are the best candidate levels of the Eifelain/Givetian boundary proposed by the Subcomission on Devonian Stratigraphy.

Upper Devonian miospores (Fammenian-Strunian) have been recorded in the interval (1190-936 m). They are characterized by the presence of *Retispora lepidophyta* (Plate 2, Fig. K), *Indotriradites explanatus*, *Vallatisportites* spp, *Verrucosisporites* spp, *Dictyotriletes triavialis*, *Corbulispora cancellata*, *Lophozonotriletes* spp etc. The distribution of the miospores can be divided into the spore zonation schemes for the Upper Devonian identified in Western Europe and British Isles (Higgs and Streel, 1984; Higgs *et al*., 1988) especially and the former USSR (Avchimovitch *et al*., 1988).

The interval 1192-1136 m contains an assemblage which is rich and diverse in composition. It shows elements of the. *Retispora lepidophyta-Knoxisporites literatus* (LL) Biozone. These include *Retispora lepidophyta*, *Corbulispora cancellata*, *Grandispora senticosa*, *Vallatisporites pusillites* together with simple forms such as *Retusotriletes incohatus* and *Punctatisporites irrasus*. Most of the species mentioned above have also been reported in LL biozones elsewhere (Higgs and Streel, 1984; Higgs *et al*., 1988; Avchimovitch *et al*., 1988).

The *Retispora lepidophyta-Hymenozonotriletes explanatus* (LE) Biozone is recorded in the interval 1134-1018 m. It is characterized by *Retispora lepidophyta* which is a near-cosmopolitan miospore marker and recorded over a restricted interval of the uppermost Devonian (late Fammenian) (Marshall *et al*., 1996) and the zonal species *Indotriradites* (*Hymenozonotriletes*) *explanatus* and some species from the previous zone. *Dictyotriletes trivialis* appear for the first time together with other *Vallatisporites* specimens including the species *V. vallatus* and *V. verrucosus* and *V. hystricosus*. Elements of the LE biozone in the present study are similar to that observed in Western Europe including Britain and Ireland (Higgs and Streel, 1984; Richardson and McGregor, 1986; Higgs *et al*., 1988), Russia (Avchimovitch *et al*., 1988; Byvsheva *et al*., 1984), Brazil (Loboziak *et al*., 1991b).

The interval (1016-936 m) contains miospore assemblage that is characteristic of the *Retispora lepidophyta-Verrucosisporites nitidus* (LN). In this zone *Verrucosisporites nitudus* a characteristic miospore of this younger zone appears, which of course was absent in the preceding LE zone and thus allows one to restrict the LE biozone to the lowermost samples. *Retusotriletes incohatus* becomes abundant miospore in the assemblage with *Retispora lepidophyta* becoming less abundant as compared to that of the preceding LE zone. A significant number of species observed in the LE zone are present in the LN zone.

Miospore assemblage in this zone is comparable to those recorded in the LN zone in Western Europe and Ireland by Clayton *et al.* (1974), Higgs and Streel (1984), Higgs *et al*. (1988), Richardson and McGregor (1986), Dolby (1970), Higgs *et al*. (1992) and Vigran *et al*. (1999). It has also been recorded in Brazil (Loboziak *et al*., 1991b, 1992), Russia (Avchimovitch *et al*., 1988; Byvsheva *et al*., 1984), the *Retispora lepidophyta* Abundance Zone of Vigran *et al*. (1999) from Greenland and Sample 4 (The Horseshoe curve section) in Altoona, Pennsylvania, USA (Streel and Traverse, 1978).

The low representation in number of *Retispora lepidophyta* towards the upper levels of the well is an indication of the approach to the systemic boundary between Devonian and Carboniferous (LN/VI biozones) which is defined by the upper stratigraphic limit of *Retispora lepidophyta* (Playford, 1976; Avchimovitch *et al*., 1988; Richardson and McGregor, 1986; Higgs *et al*., 1992) and the first appearance of the conodont *Siphonodella sulcata* (Paproth and Streel, 1984; Paproth *et al*., 1991). From the section so far studied it is obvious that the VI zone which is characterized by the absence of *Retispora lepidophyta* is absent thus limiting the age of the well to the Uppermost Devonian (Strunian). From the age range of the palynomorphs, the sediments from the Atiavi-1 well is dated upper Lower Devonian (Emsian)-Uppermost Devonian (Strunian).

Paleoenvironmental interpretation and thermal maturity: The paleoenvironmental interpretation has been based on the relative quantitative proportions of palynomorphs encountered in the sediments (Fig. 2). The Atiavi 1 well contains a lower section with marine elements (chitinozoa and acritarchs) which changes to continental/nearshore elements with abundant and diverse trilete spores in the upper sections of the well. The trilete spores mainly pteridophytes which inhabits

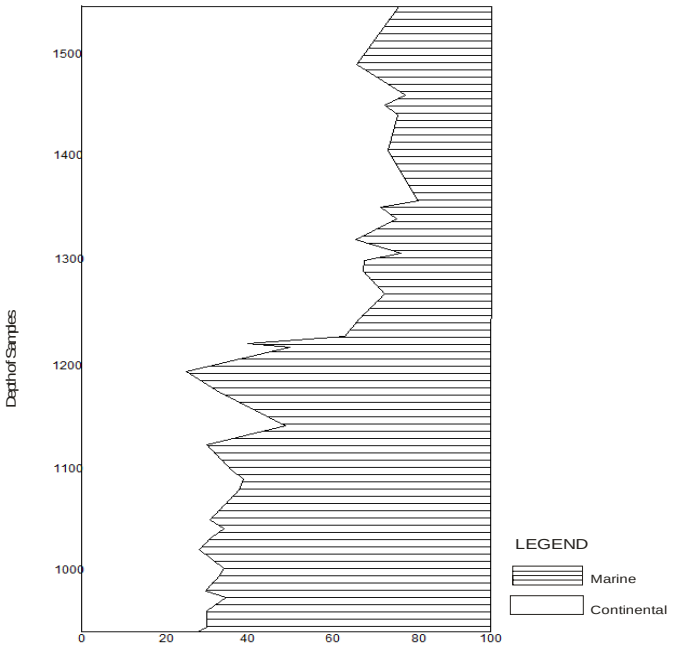


Fig. 2: Percentage frequency diagram of marine/continental ratio in Atiavi 1 well

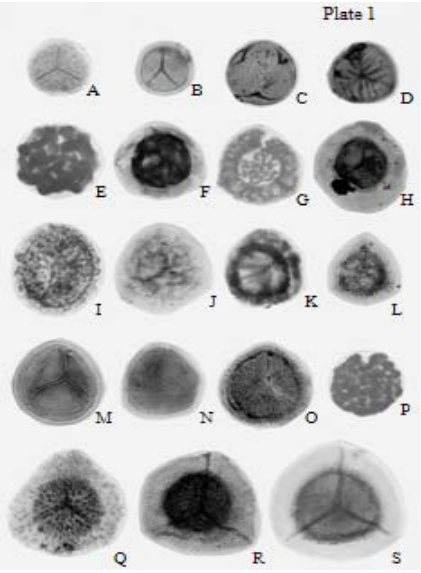


Plate 1: (All figure × 500)
(A) *Verrucosisporites nitidus*, (B) *Convolutiospora* sp., (C) *Retusotriletes rotundus*, (D) *Emphanisporites erraticus*, (E) *Corbulispora cancellata*, (F) *Rhabdosporites langii*, (G) *Vallastisporites pusillites*, (H) *Auroraspora micromanifestus*, (I) *Verrucosisporites scurrus*, (J) *Vallatisporites vallatus*, (K) *Emphanisporites annulatus*, (L) *Vallatisporites vallatus*, (M, N) *Geminospora lemurata*, (O) *Acinosporites* sp., (P) *Corbulispora cancellata*, (Q) *Grandispora libyensis*, (R) *Grandisporapermulta*, (S) *Grandisporavelata*

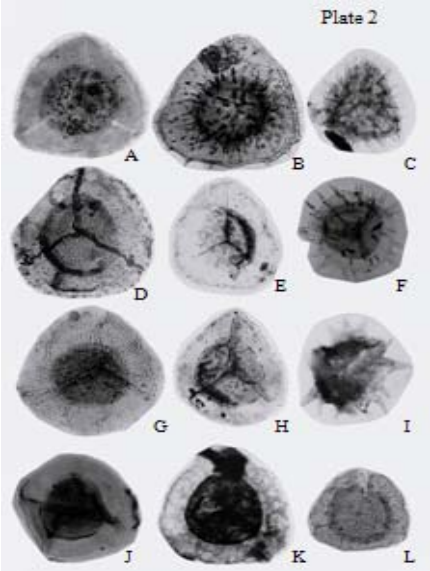


Plate 2: (All figures × 500)
(A) *Grandispora protea*, (B) *Grandispora megaformis*, (C) *Grandispora senticosa*, (D) *Grandispora mammilata*, (E) *Calyptosporites* sp., 1, (F) *Grandispora naumovii*, (G) *Grandisopora velata*, (H) *Calyptosporites* sp., 2, (I) *Ancyrospora melvillensis*, (J) *Rhabdosporites langii*, (K) *Retispora lepidophyta*, (L) *Calyptosporites microspinosus*

marshes and swamps in humid climates and structured/black phytoclasts are indicative of fluvio-deltaic environment in close proximity to the shoreline.

The color of the spore exines in transmitted light is medium orange to medium-dark brown. On a Thermal Alteration Index (TAI) scale of 4-6, this is equivalent to 0.5-1.2 which indicates peak maturity (oil floor and early wet-gas zone) (Alaug, 2011). In most samples the amorphous organic matter is low with the majority

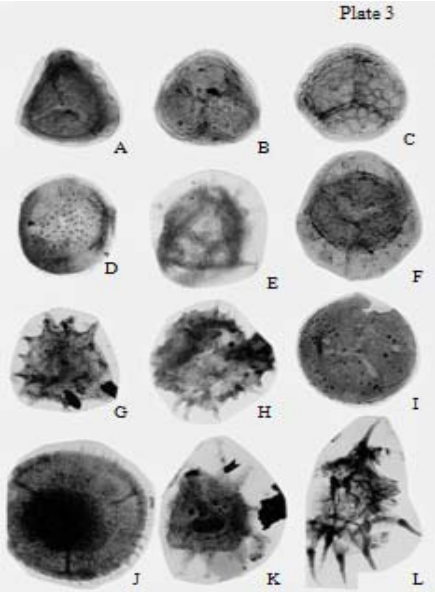


Plate 3: (All figures × 500)

(A) *Lophozonotriletes* sp., (B) *Acinosporites lindlarensis*, (C) *Reticulatisporites* sp., (D) *Dibolisporites echinatus*, (E) *Ancyrospora grandispinosa*, (F) *Calyptosporites velatus*, (G) *Ancyrospora ancyrea*, (H) *Grandispora* sp., (I) *?Baculatisporites* sp., (J) *?Biharisporites* sp., (K) *Ancyrospora longispinosa*, (L) *Hystricosporites porrectus*

composed of woody and coaly fragments with a low proportion of exinous fragments suggesting a low source-rock potential for liquid hydrocarbons.

CONCLUSION

The study of Devonian miospores from the Atiavi-1 well in the Keta basin allows the following conclusions:

- Miospores from the well indicate an age of upper Lower Devonian (Emsian) to uppermost Devonian (Strunian)
- The miospore zonation in the upper Devonian can be compared with the spore zonation scheme of Higgs *et al*. (1988) and Higgs and Streel (1984) recognized in Western Europe and British Isles
- From a palaeoenvironmental viewpoint, the distribution of palynomorphs (spores, chitinozoans and acritarchs) in the well indicate a lower marine interval (1524-1224 m) and an upper near shore or fluvio-deltaic interval (1192-936 m) in a humid climate
- Thermal maturity from spore color suggests a Thermal Alteration Index (TAI) within the oil floor and wet gas zone

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