Palynofacies analysis and paleoenvironmental interpretation of the Dalichai Formation, northeast of Semnan

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Abstract

Palynological and Palynofacies analysis combined with sedimentological studies have been performed on Dalichai Formation, northeast of Semnan, in order to define its paleoenviromental interpretation. Based on petrographic studies of organic matter, three palynofacies types were recognized as PF1, PF2, and PF3. PF1 is a characteristic of proximal shelf settings or basin. This palynofacies in the lower part of Dalichai Formation represents the shallowest environment because it is comprised almost exclusively of large black phytoclast while PF1 in limestone successions in the upper part of Dalichai Formation was deposited in distal setting under suboxic environment. This interpretation is supported by sedimentological and paleontological data. PF2 represents the lower and middle parts of the formation with high contents of brown wood and sporomorphs. In addition, it shows the presence of fluorescent amorphous organic matter and proximate dinocysts deposited in the open marine lagoon (the anoxicsuboxic environment) in agreement with general sedimentological observations. PF3 has a high diversity of dinocysts, combined with the terrestrial material. A diverse dinocyst assemblage is common in shelf environments, leading us to interpret a possible inner to middle shelf close enough to land to allow accumulation of terrestrially derived organic material.

Keywords: *Palynofacies, Depositional environment, Dalichai Formation, central Alborz*

Introduction

Combaz (1964) introduced the term palynofacies as "*the total complement of acidresistant particulate organic matter recovered from sediments by palynological processing techniques*". However, Tyson (1995) provided the most recent and widely used definition of the palynofacies term as "*the total particulate organic matter assemblage contained in a body of sediment thought to reflect a specific set of environmental conditions, or to be associated with a characteristic range of hydrocarbongenerating potential*". The latter definition can be used in paleoenvironment interpretation as well as in source rock evaluation and will be used here because it links palynofacies types to sedimentary sequences. Several palynological investigations have dealt with the paleoenvironmental interpretations of the Dalichai Formation (Wheeler and Sarjeant, 1990; Dehbozorgi *et al.*, 2013) However, there is still a lacking in use of detailed palynofacies analyses in interpreting paleoenvironmental settings. The present work aims to study the palynological facies of the Dalichai Formation with more detailed analyses of the percentage distribution of the palynological organic matter (POM) assemblages to infer the paleoecological settings in terms of depositional paleoenvironments. A 697m thick wellexposed section was chosen for this purpose

Geological setting

It is located on the mountain of Gavak, approximately 14 km northeast of Semnan (coordinates with E 53° 26´ and N35° 43´, Fig. 1), in the central part of Alborz mountains. The Balu section is the most complete section of this formation as it ranges from the upper Bajocian to the late Callovian and can be subdivided, from bottom to top, into eight members (Fig. 3). In the studied section, the Dalichai Fm. consists largely of an alternation of marls, marly limestones, and limestones and follows, after a discontinuity, on the dark, siliciclastic Shemshak Fm. and is overlain gradationally by the light and cliffforming carbonates of the Lar Formation (Fig.3). The formation contains a very rich ammonite fauna, sponge spicules, belemnites, bryozoans, bivalves, echinoderm debris, ostracods, benthic foraminifers, and the trace fossil Zoophycos.

Materials and Method

A detailed fieldwork and study of 35 thin sections, using a microscope, was done for identification of facies and sedimentary environment of the Dalichai Formation at the Balu section. The lithology, general microfacies characteristics, and environment interpretation of the Dalichai Formation at this locality is illustrated in Fig. 3. The results of study lead to the identification of 10 microfacies, deposited in river, beach, lagoon, and open marine environments. An absence of turbidite deposits, reefal facies, and gradual facies indicates that the Dalichai Formation was deposited on a carbonate ramp.

For palynofacies studies, 57 samples were collected every five meters from Balu section and prepared in the palynology laboratory of the Department of Geology of the University of Tehran using standard preparation method described by Travers (2007). The mineral matrix, carbonate, and silicates of the samples were removed using dilute hydrochloric acid (HCL 30%) and cold hydrofluoric acid (HF 40%), respectively. The remaining residue was then sieved through a 20 µm nylon sieve prior to mounting on slides.

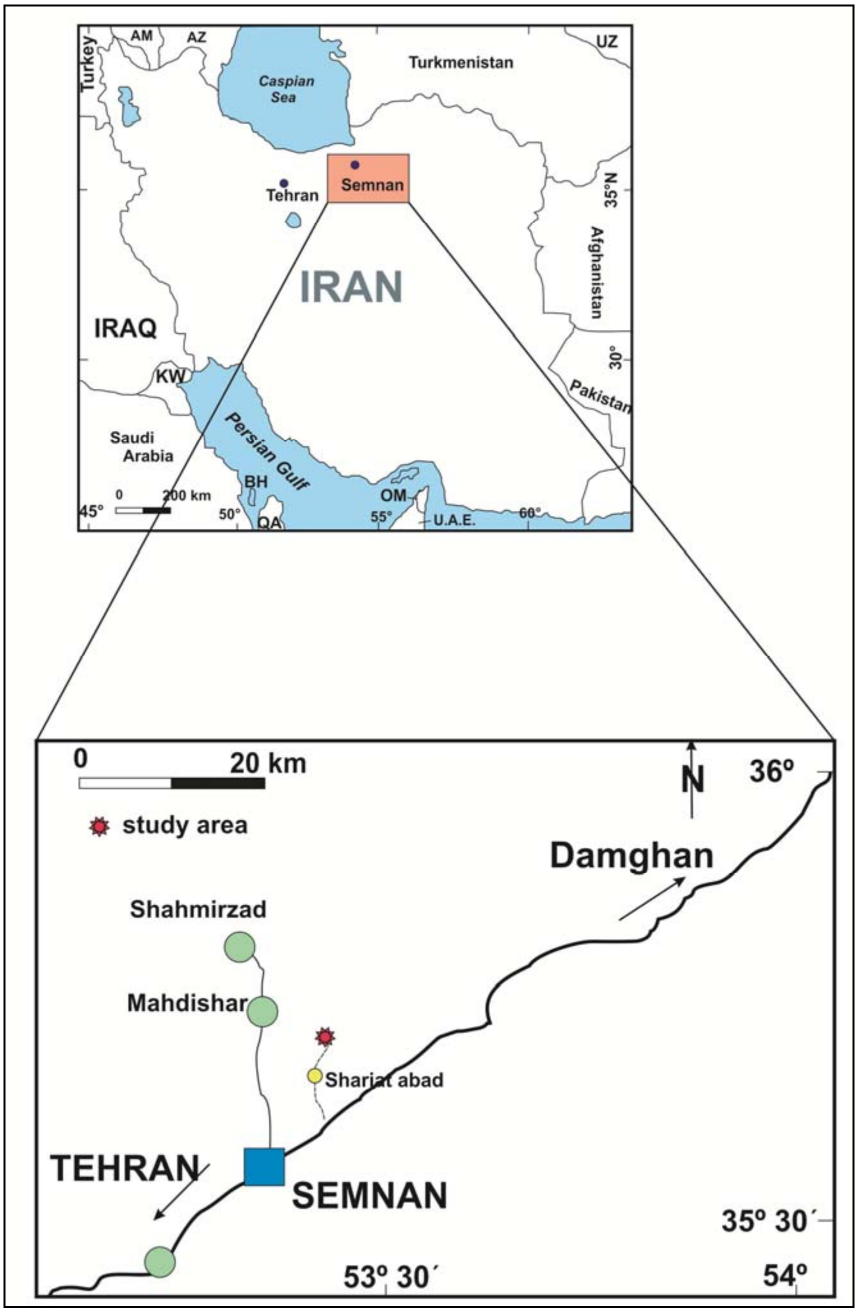

Figure 1. Location map of Dalichai Formation at the section study

Next, 500 particles were recorded for each sample using transmitted light microscopy as is necessary for differentiation of palynofacies type and the paleoenvironmental interpretations (Tyson, 1987, 1993, 1995). The palynofacies analysis is based on the percentage frequency of different POM constituents categorized by Tyson (1995). The percentage of each palynomaceral component is derived from the total POM frequencies. However, the species richness and percentage of dinoflagellate cysts morphotypes were obtained from the total dinoflagellate cysts frequencies.

Results of palynofacies analysis

The paleoenvironmental interpretations presented in this part are mainly depending on the semiquantitative palynofacies characteristics of selected constituents of the palynological matter, which are known to have a paleoenvironmental significance. The changes in the palynofacies composition in the Balu section and the AOM-palynomorph- phytoclast (APP) ternary plot (Fig. 2) reveal three palynofacies types in the Dalichai formation of the study outcrop as follows:

Palynofacies 1 (PF1)

This palynofacies (samples 15 and 47-57) is dominated by black terrestrial elements (70-100%) with subsidiary AOM (0-10%) and no marine palynomorph (Fig. 2 and 3; Pl. I).

Palynofacies 2 (PF2)

PF2 is the most widespread palynofacies in the Dalichai succession (representing about 54% of the samples). This palynofacies is characterized by abundant of phytoclast (avg >46%), frequent AOM (10 to 40%) and frequent sporomorph (19%), whereas the marine palynomorphs are represented by rare (<15%) dinoflagellate cysts (Fig. 2 and 3; Pl. 1).

Palynofacies 3 (PF3)

This palynofacies is characterized by terrestrial elements (48-88 %) with subsidiary AOM (10-46 %) and marine palynomorphs (125%) (Fig. 2 and 3; Pl. 1).

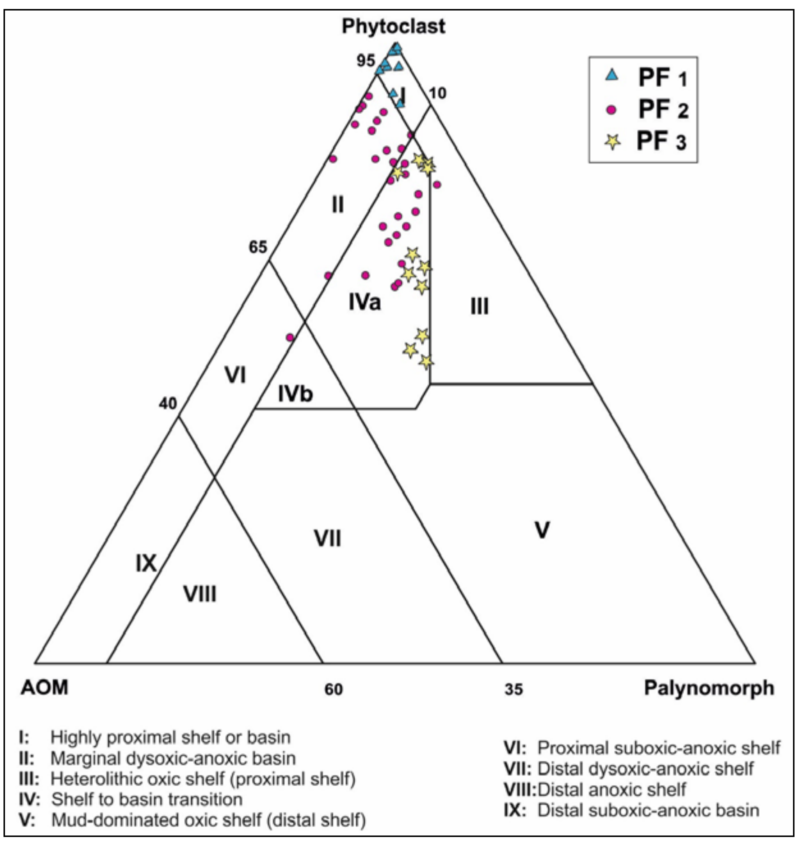

Figure 2. Location of the studied samples of Dalichai Formation at the Balu stratigraphic section on Tyson ternary diagram (Tyson, 1993)

Dinoflagellate cyst assemblages

Organicwalled dinoflagellate cysts occur in sediments deposited in a wide spectrum of environments ranging from nearshore through oceanic facies. Therefore, the distribution of fossil dinoflagellate cysts, which usually reflects the distribution of their motile stages, serves as a tool for paleoenvironmental reconstruction (Tyson, 1995; Riding and Hubbard, 1999; Williams, 1992). Variation in ratios of chorate dinocysts to proximate and cavate presented in this paper constitutes a part of a multidisciplinary study aimed to reconstruct the sedimentary environment of these deposits (GhasemiNejad, 2001; Sarjeant *et al.*, 1987; Tschudy, 1969). In addition, abundance (the number of all dinocyst taxa counted from two slides) and a simple diversity index (the number of species of dinocyst counted from two slides) were calculated (Powell, 1992; Batten, 1996) (Fig. 3; Pl. 1).

Paleoenvironmental interpretation

Studies of palynofacies are widely used for depositional and paleoenvironmental reconstruction (Tucker, 1988; Gorin and Steffen, 1991; Tyson, 1995; Batten *et al.*, 2005). Microfacies and palynofacies analyses make it possible to identify different depositional settings and obtain information on sedimentary environments (Tucker, 1988; Jaramillo and ObohIkuenob, 1999). Figure 2 and 3 show the ranges of the facies associations in this section. The following microfacies and palynofacies criteria of Balu section show:

Samples from PF1 (in the lower and upper part of Dalichai Formation) show a dominance of phytoclast on the ternary diagram (APP). According to the Tyson’s (1995) ternary plot (Fig. 2), the high percentages of black phytoclast are characteristic of proximal shelf settings or basin. This palynodebris component is usually attributed to oxidation, recycling, and in some cases forest fires (Gorin and Steffen, 1991; Jaramillo and ObohIkuenob, 1999). Samples 1 to 5 (with higher amounts of black debris) in the lower parts of Dalichai formation are interbedded with sandstones. These samples correspond with gravel and quartzarenite petrofacies and indicate the proximity of the depositional site to coastal condition. Besides, a high ratio of small equidimensional opaque phytoclasts in the upper part of Dalichai Formation (member 8) shows that this interval was deposited in distal setting under suboxic to oxic condition unsuitable for the preservation of organic matter in limestone successions. This interpretation is supported by sedimentological data and microfacies including Spicule Radiolaria Packstone, Pelecypoda Filament Radiolaria packstone, and Spicule Radiolaria mudstone (Fig.3).

Samples from PF2 located along the left side of the diagram are as a result of the higher relative abundance of palynodebris and amorphous organic matter and rare marine palynomorph. The plot of PF2 in the ternary kerogen of Tyson (1995) suggests the prevalence of suboxicanoxic to dysoxicanoxic conditions during deposition of the palynofacies, which is considered as the characteristic of the shelf to basin transition (Tyson 1996). A high percentage of brown wood and sporomorphs indicates strong terrestrial influx and deposition in proximal settings that are close to the parent land plants (Tyson, 1993). The override of pteridophyte spores over gymnosperm pollen grains in the sporomorph assemblage suggests deposition of PF2 in suboxic to anoxic nearshore settings. This conclusion is derived based on the ecological preference and reproduction rates of the sporeparent plants, as they thrive in swampy deltaic areas and are known to be less productive than the gymnosperm pollenproducing plants. In addition, pteridophyte spores have relatively limited transport efficiency in contrast to the more buoyant and easilytransported spheroidal pollen grains (Williams, 1992; Boggs, 2006; Tyson, 1995; Traverse, 2007). The dominance of cavate (avg. 35 %) and proximate (avg. 32 %) dinocysts such as *Nannoceratopsis pellucida*, *Nannoceratopsis gracilis*, *Ctenididinium combazii*, and *pareodinia ceratophora* show that this palynofacies has formed in open marine lagoon (the distal anoxicsuboxic environment), which is in agreement with general sedimentological observations and absent of ammonite (Tyson 1995; Boggs, 2006) (Fig. 3; Pl. 1).

Combining all information mentioned above and the frequent presence of small size quartz and pyrite and Miliolid benthic foraminifera in Peloidal Miliolida wackstone and Peloidal bioclastic wackstone microfacies in samples (511, 1732 and 3739) from the lower and middle part of Dalichai Formation suggests a lagoon environment. Moreover, an explanation that would justify the presence of open marine dinocysts in the suggested lagoon is that tidal currents of the tidal channel inlet of lagoons usually remove parts of the open marine sediments and fossils and then redistribute and concentrate them in the low energy area of the lagoons (Tyson, 1984, 1993; Boggs, 2006).

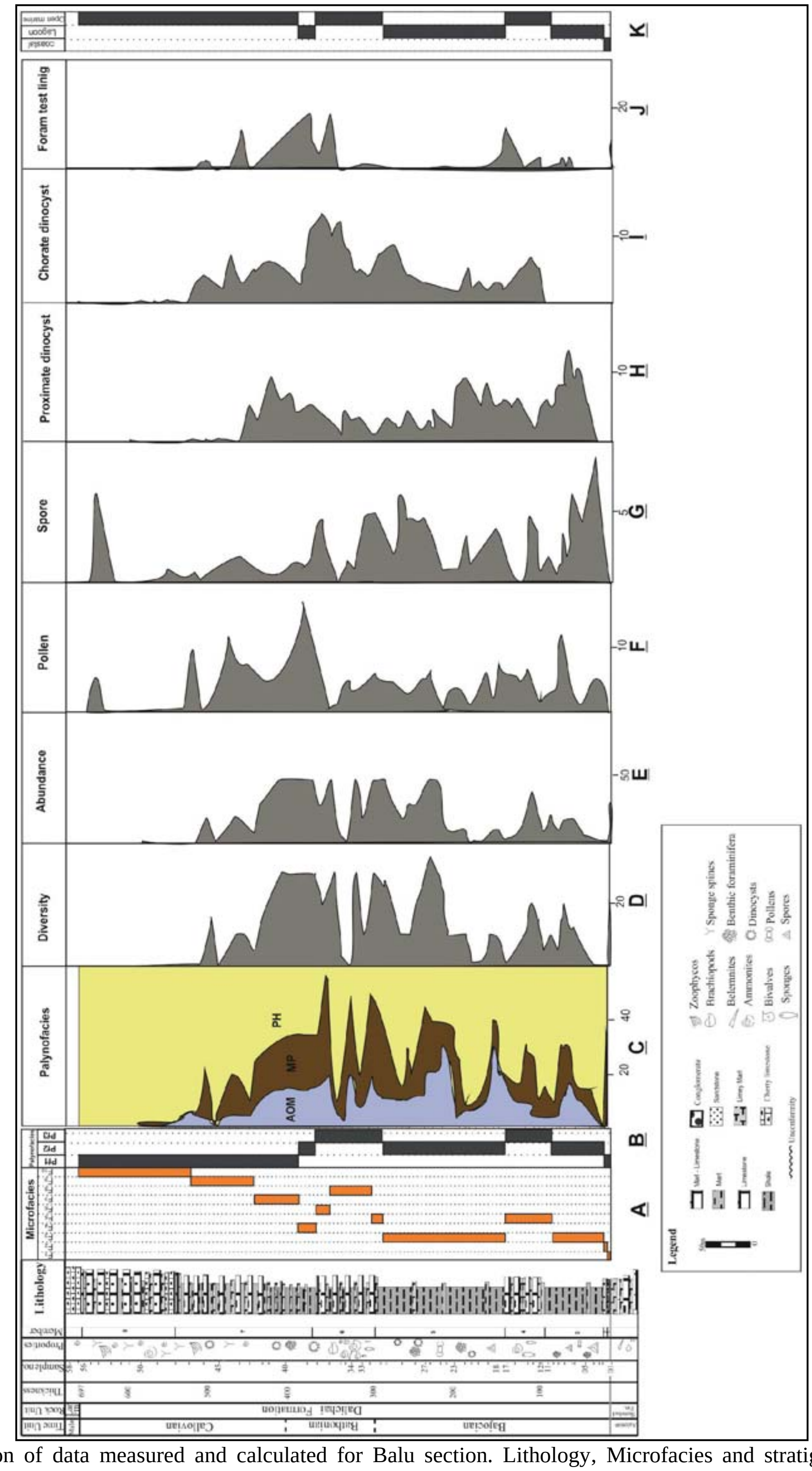

Figure 3. Presentation of data measured and calculated for Balu section. Lithology, Microfacies and stratigraphic distribution of Palynomorphs; A: Microfacies (F1: Gravel petrofacies; F2:Quartzanerait petrofacies; F3: Peloidal Miliolida Wackestone; F4: Peloidal bioclastic wackstone; F5: Benthic foraminifera peloidal echinoderm packstone; F6: Spicule Radiolaria wackstone, F7: Spicule Radiolaria mudstone, F8: Ostracoda Spicule Radiolaria Packstone, F9: Spicule Radiolaria Packstone; F10: Pelecypoda Filament Radiolaria packstone); B: associated palynofacies types (PF:1–3); C: percentage of Palynomorphs (AOM:amorphous organic matter, MP:marine palynomorphs, PHYTO: Phytoclast); D: Diversity: Diversity of dinoflagellate cyst species; E: abundance of dinoflagellate cyst species; F: abundance of pollen; G: abundance of spore; H, I: abundance of proximate and chorate of dinoflagellate cyst; J: foram test lining:Foraminifera test lining; K: interpreted paleoenviroments of Dalichai Formation recorded at Balu section.

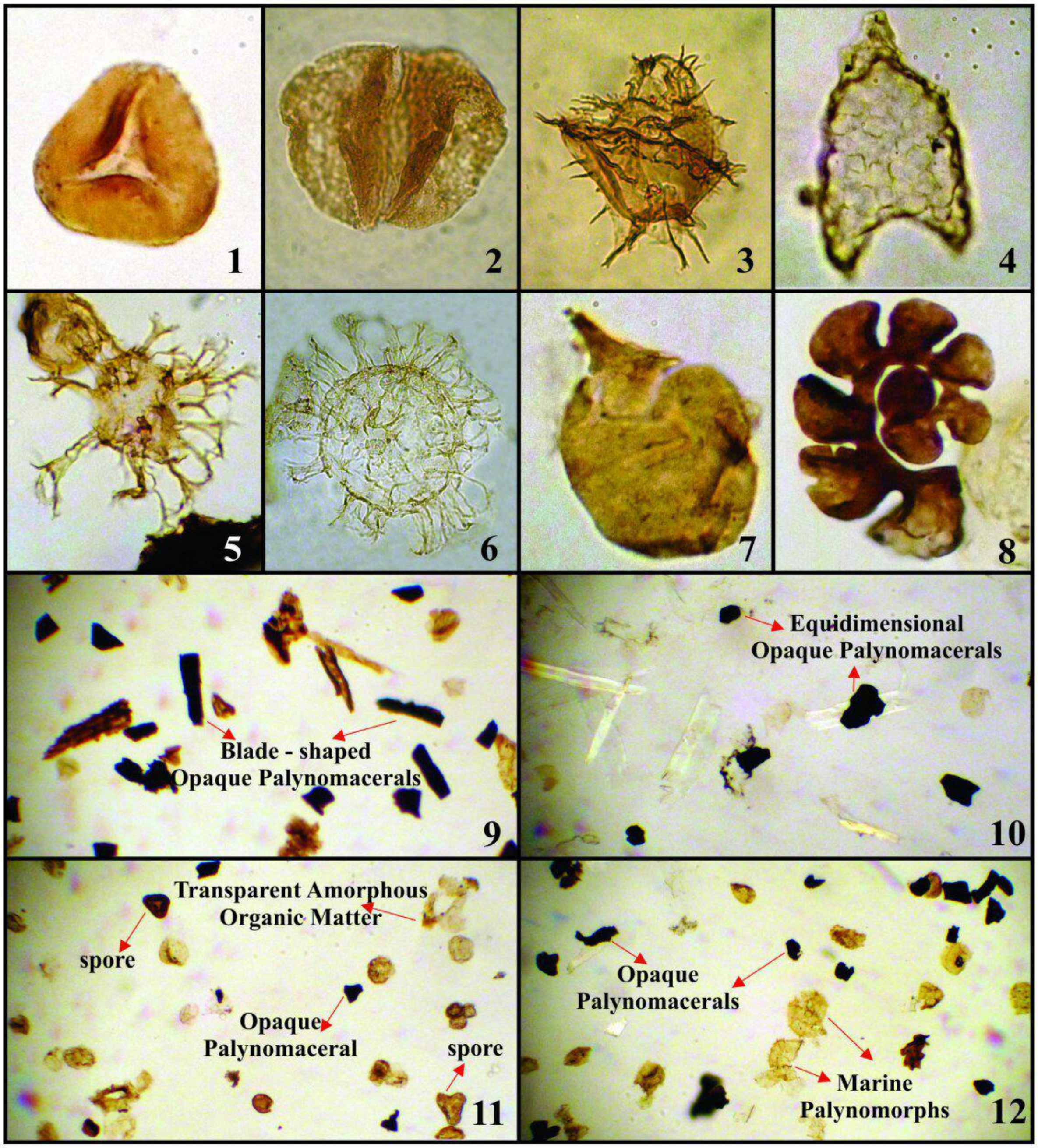

Plate I: 1-8: Palynomorphs from the Dalichai Formation. All images ×480. 1 *Dictyophyllidites harrisii* Couper, 1958; Proximal focus. 2: *Alisporites australis* de Jersey, 1962; Distal focus. 3: *Ctenidodinium combazii* Dupin, 1968. 4: *Nannoceratopsis pellucida* (Deflandre) emend. Evitt. 1961; 5, *Oligospheridium complex* (White) Davey & Williams, 1966. 6: *Systematophora penicillata* (Ehrenberg) Sarjeant, 1980. 7: *Pareodinia ceratophora* Deflandre, 1947. 8: Coiled foraminiferal test lining. (9-12): Photomicrographs of palynofacies types in the studied section. (Magnification X100). 9: Palynofacies (PF-1) dominated by brown and black wood, with subsidiary AOM,in the lower part of Dalichai Formation. 10: Palynofacies (PF-1) dominated by opaque degraded terrestrial elements in upper most of Dalichai Formation. 11: Palynofacies (PF-2) dominated by brown and black wood, with a diverse assemblage of miospores. 12: Palynofacies (PF-3) dominated by terrestrial elements with subsidiary AOM and marine palynomorphs.

An absence of reefal facies, anhydrite, and dolomite confirm this condition. A further development of distal low energy settings is suggested for the upper part of PF2 (samples 2732), considering the moderate increase in transparent AOM, marine palynomorph and diversity of dinocyst, abundance of pollen, where these pollen grains are known to have increased in percentage frequency in a shelfal direction (Hughes & MoodyStuart, 1967; Habib, 1979).

Samples from PF3 located along the right side of the diagram are as a result of the higher relative abundance of marine palynomorph and amorphous organic matter. A decrease in the brown wood and abundance and species richness of marine palynomorph in comparison to that of PF1 and PF2 reflects more offshore settings (Jaramillo and ObohIkuenob, 1999; Gorin and Steffen, 1991). On the other hand, the gradual upward increase in foraminifera test lining, the high dominance of the chorate dinocysts (e.g. *Oligospheridium* and *Systematophora*), and decreases in ratios of the cavate and proximate cysts recorded from all samples of PF3 generally indicate development of strong marine transgression and deposition in an open marine environment (Williams, 1992; Riding and Hubbard, 1999; Tyson, 1993).Third palynofacies (PF3) has a high diversity of dinoflagellate cysts, combined with the terrestrial material. A diverse dinoflagellate cyst assemblage is common in shelf environments; in this case, we interpret a possible inner to middle shelf, which is close enough to land to allow accumulation of terrestrially derived organic material (Jaramillo and ObohIkuenob, 1999; Gorin and Steffen, 1991). This palynofacies occurs in benthic foraminifera peloidal echinoderm Packstone, Ostracoda Spicule Radiolaria Packstone, and Spicule Radiolaria Wackstone Microfacies which reflect an inner to middle shelf.

Conclusion

The overall composition of the palynofacial content in this study is combined with the sedimentological data from the sections and gives good grounds for paleoenvironmental interpretation. To assess depositional environment based on petrographic studies of organic matter, three palynofacies types (PF1, PF2, and PF3) were plotted on ternary AOMPhytoclastPalynomorph (APP).

The sediments from the lower part of the succession are characterized by continental to relatively shallow marine conditions with a high influx of terrestrial organic matter (PF1). The gradual upward increase in brown wood and sporomorphs and cavate dinocyst, as well as fluorescent amorphous organic matter, are evidence of suboxic to anoxic condition, which favored accumulation and preservation of organic matter in open marine lagoon. This interpretation is supported by sedimentological observation. A decrease in the brown wood and abundance and diversity of marine palynomorph of PF3 shows a significantly higher frequency than that recorded from the underlying PF2 and supports the more distal setting of PF3. A higher percentage of aquatic palynomorphs (mainly chorate dinocysts) and a palynofacies dominated by black opaque phytoclasts presumably represent periods of decreased supply of landderived material and a slower sedimentation rate. The diverse dinocyst association is dominated by *Oligospheridium* and *Systematophora* representatives is considered to be more typical of middle shelf environments with normal seawater salinity conditions. A high ratio of small equidimensional opaque phytoclasts in cherty limestone successions in uppermost of the Dalichai Formation (member 8) shows that this interval was deposited in distal setting under suboxic to oxic condition unsuitable for the preservation of organic matter. This interpretation is supported by sedimentological observation.

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