Palynomorphs' response to sea-level fluctuations: a case study from Late Cretaceous – Paleocene, Gurpi Formation, SW Iran

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Abstract

Statistical studies on Palynology contents of Late Cretaceous to Paleocene age Gurpi Formation in a surface section in Zagros Basin, SW Iran indicate changes in abundance, species diversity, ratio of Spiniferites to Cyclonephelium (S/C), palynological marine index (PMI) values and organic facies. These palynological variations clearly reflect fluctuations in relative sea-level and depositional environment and can be used for recognition and differentiation of systems tracts and key horizons such as flooding surfaces and sequence boundaries. Dramatic increase in PMI, dinoflagellate species diversity and S/C ratio associated with sedimentary facies parameters indicate a marine transgressive systems tract while, a reduced species diversity, lower S/C ratio and PMI value along with increase in abundance of phytoclasts and degraded land-plant materials are characteristics of marine regression. The variation trends of the palynological parameters when consecutive indicate a complete cycle of relative sea-level change. Abundance of Spiniferites, Achomosphaera, Areoligera, and Cleistosphaeridium species and presence of peridiniacean dinoflagellate cysts show a warm Tethyan, upper bathyal to middle shelf environment of deposition for the Gurpi Formation. The nine depositional sequences identified here can be correlated to the global third-order sea-level cycles. The main regional sequence surfaces like K180 (maximum flooding surface) in the Late Cretaceous sequences (68Ma) in northeast of Arabian Plate are recognizable here.

Keywords: *Palynomorph, Sea-level fluctuation, Gurpi Formation, SW Iran*

Introduction

Composition and quantity of the palynofacies in marine palaeoenvironments are directly related to sea-level changes (Downie *et al.*, 1971; Goodman, 1979; Partridge, 1976; Habib & Miller, 1989; Gorin & Steffen, 1991; Steffen & Gorin, 1993; Blondel *et al.*, 1993; Tyson, 1993, 1995; Bombardiere & Gorin, 2000; Carvalho *et al.*, 2006). Terrestrially derived organic matter, marine to terrestrial palynomorph ratio, amount of recycled palynomorphs, and depositional organic facies are the main palynological parameters for reconstruction of sea level curves (Eshet *et al.*, 1988, 1992; Habib & Miller, 1989; Gregory & Hart, 1992; Habib *et al.*, 1992; Moshkovitz & Habib, 1993). The background models for palynofacies in sequence stratigraphic context that are integrated herein for the distribution of organic matter in different systems tracts have been taken from Steffen and Gorin (1993) and Tyson (1995).

Lowstand systems tracts (LSTs) are typically indicated by palynofacies that contain abundant, often comparatively, large phytoclasts and numerous spores and pollen grains that are not very well preserved, suggesting that they have been partly oxidized (Habib *et al.*, 1992; Moshkovitz & Habib, 1993; Carvalho *et al.*, 2006). Black, charcoalified, woody detritus are commonly important component of such palynofacies. By contrast, transgressive systems tracts (TSTs) are frequently associated with palynofacies in which dinoflagellate cysts are more important components whereas the assemblage of miospores and phytoclasts are less frequent and varied (Habib *et al.*, 1992; Huan & Habib, 1996; Helenes & Somoza, 1999; Carvalho *et al.*, 2006). Highstand systems tracts (HSTs) may contain a significant component of AOM, with dinoflagellate cysts being the most numerous of the palynomorphs recovered (Prauss, 1993; Steffen & Gorin, 1993; Helenes & Somoza, 1999; Carvalho *et al.*, 2006).

The Gurpi Formation has been studied extensively in terms of lithostratigraphy and biostratigraphy (e.g. James & Wynd 1965; Wynd 1965; Wells 1968; Sampo 1969; Setudehnia 1972, 1978; Stoneley 1974, 1990; Zahiri 1982; Motiei 2003; Ghasemi-Nejad *et al.*, 2006; Darvishzadeh *et al.*, 2007) but there is no record of any palynofacies-based stratigraphy. Therefore, the overall objective of this study is a detailed study of depositional sequences and their relation with sea-level cycles using palynofacies associations, total organic content and natural gamma ray log variations.

Geological setting and stratigraphy

The Zagros basin was developed in the Late Cretaceous due to the fore-deep subsidence ahead of the continental closure along the Zagros suture zone (Ziegler, 2001; Alavi, 2004). Most of the basin margins and structural highs of the northeastern Arabian Plate were covered by the Tethyan Ocean (Zeigler, 2001; Sharland *et al.*, 2001; Motiei, 2003; Alavi 2004; Haq & Al-Qahtani, 2005) during the Late Cretaceous to Paleocene. The initially developed basin was strongly asymmetric (Koop & Stoneley, 1982), with the deepest part along the northeastern side and a broad shallow marine shelf that prevailed to the southwest. Because of this, thickness of the Gurpi Formation increases dramatically towards the northeast in the Zagros Basin (Bahroudi & Talbot, 2003).

The Gurpi Formation in the studied area as the upper part of the AP9 mega-sequence corresponds with the Late Campanian to basal part of the AP10 mega-sequence (Sharland *et al.*, 2001). The AP10 mega-sequence coincids to the Late Danian in the northeast Arabian Plate (Sharland *et al.*, 2001). The sedimentary succession coincides to the global supercycles of UZA-4 and TA-1 reported by Haq *et al.*, (1988) which belong to the Late Cretaceous/ Paleocene (80-58.5 Ma). On the other hand, the widespread erosion and hiatuses recorded in the Gurpi Formation are coinciding with hiatuses of known eustatic sea-level changes reported by some authors (Haq *et al.*, 1987; Li *et al.*, 1999). During Maastrichtian through Early Paleocene time, an upwelling system existed in the southeastern Tethys (Kolodny, 1980; Parrish & Curtish, 1982; Almogi-Labin *et al.*, 1990, 1993; Eshet *et al.*, 1994; Ziegler, 2001), resulted in accumulation of thick sequences of organic-rich, relatively deep marine shales and argillaceous lime mudstones in the Zagros Oil province in southwest Iran.

Dark gray to gray marly shales, marls and marly limestones of the Gurpi Formation generally overlay the Ilam Formation disconformably and are overlain by the Pabdeh Formation conformably. The basal contact of the formation is generally marked by an erosional surface, locally associated with ferrogenus conglomerates, composed of carbonate clasts that represent a hiatus of approximately 4 to 15 my (Stoneley, 1990). Palaeontological data (Wynd, 1965) suggest that the erosional unconformity at the basal boundary represents a hiatus of about 10 my at the type section. In contrast, the top boundary is generally gradational with the Pabdeh Formation.

The Gurpi Formation was sampled at Daniel Section where consists of a sedimentary succession with a thickness of 337 m, spanning the Late Campanian to Paleocene. The section is located about 145 km northwest of Ahwaz city in southwest Iran and about 25 km northwest of Izeh city (Fig. 1).

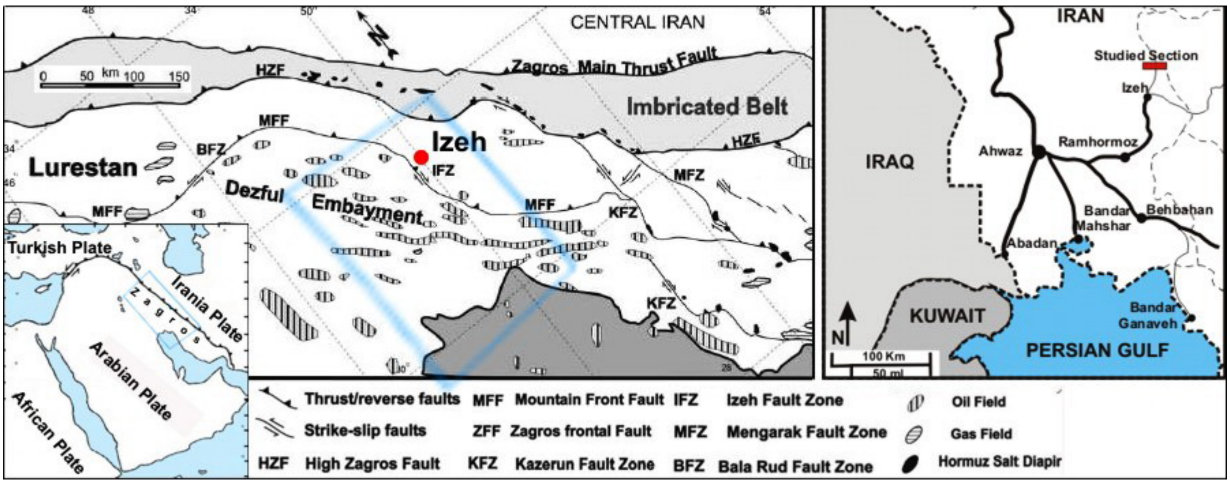

Figure 1: Geographic setting and location map of the measured section.

In this section, the Gurpi Formation overlies the Ilam Formation by a paraconformity and is conformably overlain by purple clayey shales and marls of the Pabdeh At the middle part of the section, the Gurpi Formation comprises a carbonate member (Emam Hassan Member), which expands well throughout the Zagros Basin and shows distinctive lateral facies variations. In the studied area, this member consists of thin-bedded pelagic and hemipelagic marls and argillaceous lime mudstones with planktonic foraminiferal assemblages (Wynd, 1965). This member has a gradational contact with the underlying strata making them practically indifferentiable except for their lithologic color. The upper part of the formation is assigned to the Danian, while the middle and lower parts to the Maastrichtian and late Campanian respectively (Ghasemi-Nejad *et al.*, 2006; Darvishzadeh *et al.*, 2007).

Materials and methods

Sampling and laboratory analysis

In the field, Natural gamma-ray was also measured using a SURVEY mode in GR-130 portable gamma for the section in 0.10 m interval. A total of 164 rock samples were collected from the section at a sample spacing of about 2m intervals, except for the interval between sample Gu-115 and Gu-116 spanning the K/Pg where sample spacing is about 10 cm. The section was carefully exmined for lithological changes and any evidence of stratigraphic discontinuities in the field. A total of 96 samples were used for thin section preparation from marly limestones and hard resistant shaley marl samples to achieve further evidence of microfossils, and to aid sedimentological descriptions (Fig. 2). All samples were processed for palynofacies investigation based on the technique proposed by Wood *et al.*, (1996).

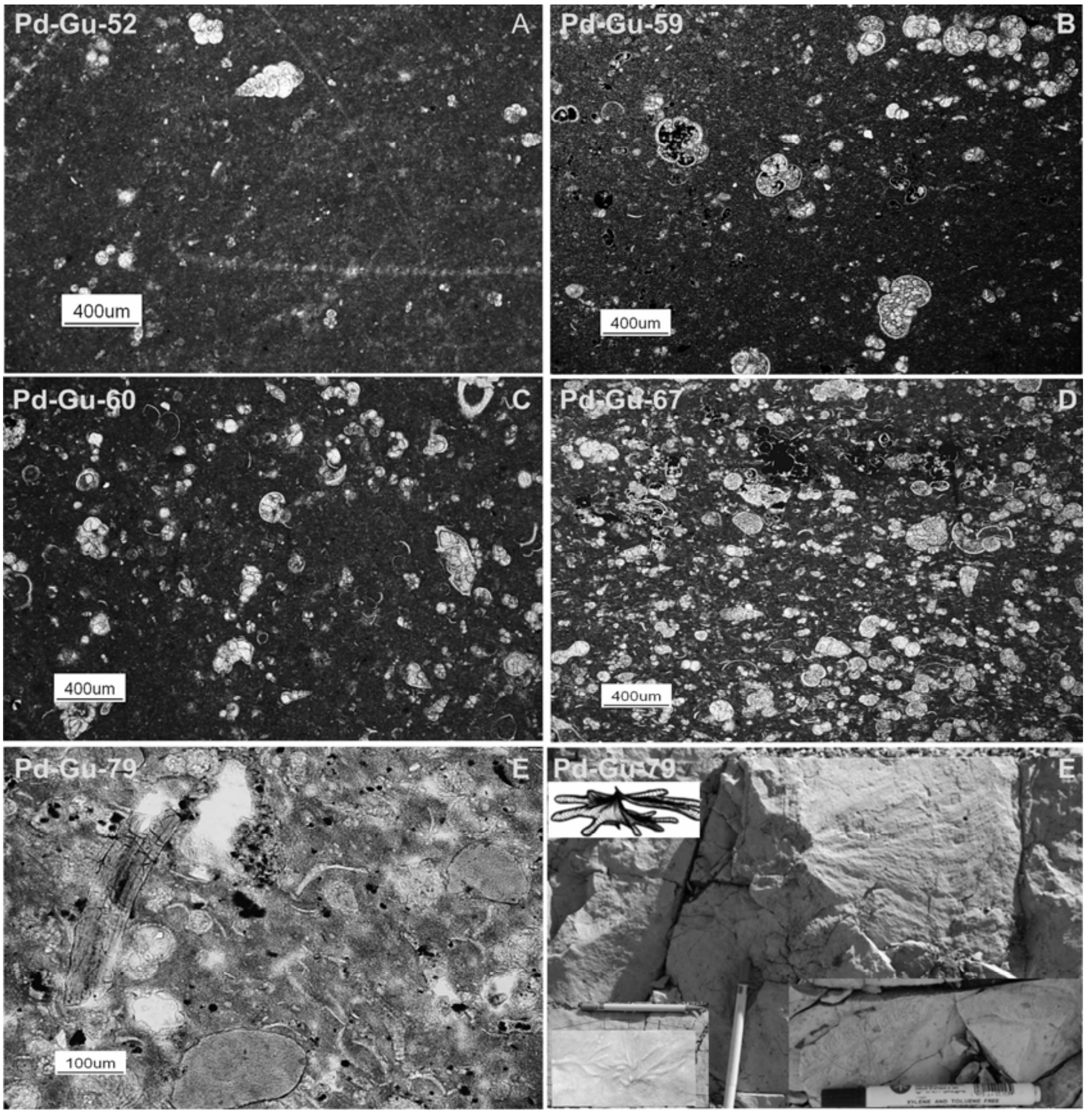

Figure 2: Identified different microfacies types (A-D), mineralogical composition (E), and the main ichnofacies (F) in the studied section. Pelagic Foraminifera Mudston (A), Wackeston (B), Wackeston/Packstone (C), and Packstone (D). Glauconite and phosphatic particles (E) and Zoophycos ichnofacies (F).

Residues after HCl and HF treatment were sieved on 20 μm filters. Heavy liquid separation (using ZnCl2) was carried out on all samples, and five slides were prepared from each sample. At least three slides per sample were scanned until approximately 200 palynodebris specimens were identified and counted. The identified and counted specimens were grouped in: dinoflagellate cysts, indeterminate marine algae, foraminiferal linings, sporomorphs, and brown to black wood debris. Opaque matter was not counted as this group may include inorganic mineral grains. Dinoflagellate cysts are the most common palynomorphs in most of the samples. Additionally, a total of 25 powdered bulk samples underwent standard analytical methods of Espitalie *et al.*, (1986) using Rock-Eval II plus TOC module for determination of Total Organic Carbon (TOC), Tmax, OI, and HI values.

Sedimentary facies

Microscopic studies and field descriptions of lithology, sedimentary structures, and trace fossils were used to identify the main sedimentary facies. The recognized facies are; 1) Gray marls and argillaceous limestones containing minor debris of planktonic and rare benthic foraminifera (foraminiferal mudstones, Fig. 2A), 2) Dark gray to gray marls and marly shales with some planktonic and rare benthic foraminifers (foraminiferal wackestones, Fig. 2B), 3) Gray fossiliferous marls and shaley marls containing abundant planktonic and rare benthic foraminifera (foraminiferal wackestones/packstones, Figs. 2C-D), and 4) Light gray to cream marls interbedded with marly limestones containing abundant oxidized minerals and glauconite and phosphatic particles (Fig. 2E) characterized by common trace fossils (e.g. Zoophycos ichnofacies, Fig. 2F).

Palynofacies

Some of the main parameters which can be proposed for analysis of sea level fluctuations in the organic rich facies are; the amount of terrestrially derived organic matter (Posamentier & Vail, 1988; Roberts & Coleman, 1988; Leithold & Bourgeois, 1989), the marine to terrestrial palynomorph ratio (Gregory & Hart, 1992), the ratio of recycled palynomorphs (Eshet *et al.*, 1988a, b), depositional organic facies (Habib & Miller, 1989; Habib *et al.*, 1992; Edet & Nyong, 1993), and dinoflagellate species diversity (Habib & Miller, 1989; Habib *et al.*, 1992; Moshkovitz & Habib, 1993). In this study, the abundance and diversity of marine palynomorphs, Palynological Marine Index (PMI), and Spiniferites/Cyclonephelium ratio (S/C) are used to determine sea level fluctuation and formation of transgression/regression cycles.

Species diversity is especially important in dinoflagellate palaeoecology. The main factors affecting dinoflagellate species diversity include nutrient supply, oceanic circulation, seasonal fluctuations and salinity changes (Habib & Miller, 1989; Habib *et al.*, 1992; Moshkovitz & Habib, 1993). Partridge (1976) suggested that relative sea level rise causes rapid increase in the number of dinoflagellate species, and that the occurrence of these dinoflagellate incursions can be used to interpret relative sea level changes. A high species diversity of dinoflagellate cysts indicates a marine shelf, whereas fewer species with a single dominant species in an assemblage represented coastal estuarine or brackish water environments (Wall *et al.*, 1977; May, 1980; Dale, 1983; Tocher & Jarvis, 1987; Edwards, 1989). Habib & Miller (1989) indicated that the significant increase in dinoflagellate species diversity associated with amorphous debris facies represents marine transgression, whereas a sharp drop in number of species reflects marine regression. The relationship between dinoflagellate species diversity and third-order cycles of relative sea-level change was proposed by Habib *et al.*, (1992).

The PMI that was proposed to support interpretation of depositional environments by Helenes *et al.*, (1998) is formulated as: PMI= (Rm/Rt+1) 100. In this formula, Rm is the richness of marine palynomorphs (dinocysts, acritarchs and foraminiferal test linings) and Rt is the richness of terrestrial palynomorphs (pollens and spores) counted per sample. This index reflects the tendency for farther offshore environments. The high values of PMI are interpreted as indicative of normal marine depositional conditions. As can be seen from the formula, when the samples are barren of marine palynomorphs, the PMI value is 100 (Carvalho, 2004). The PMI values of the studied samples show a wide range between 167 and 1600 (Fig. 3). The PMI increasing trend is generally corresponding to the transgressive events toward the maximum flooding surface.

Generally, cyst morphotypes with different length and complexity of processes have long been used for environmental interpretation (Vozzhennikova, 1965; Scull *et al.*, 1966; Williams, 1977; Tappan, 1980; Sarjeant *et al.*, 1987; Ghasemi-Nejad *et al.*, 1999).

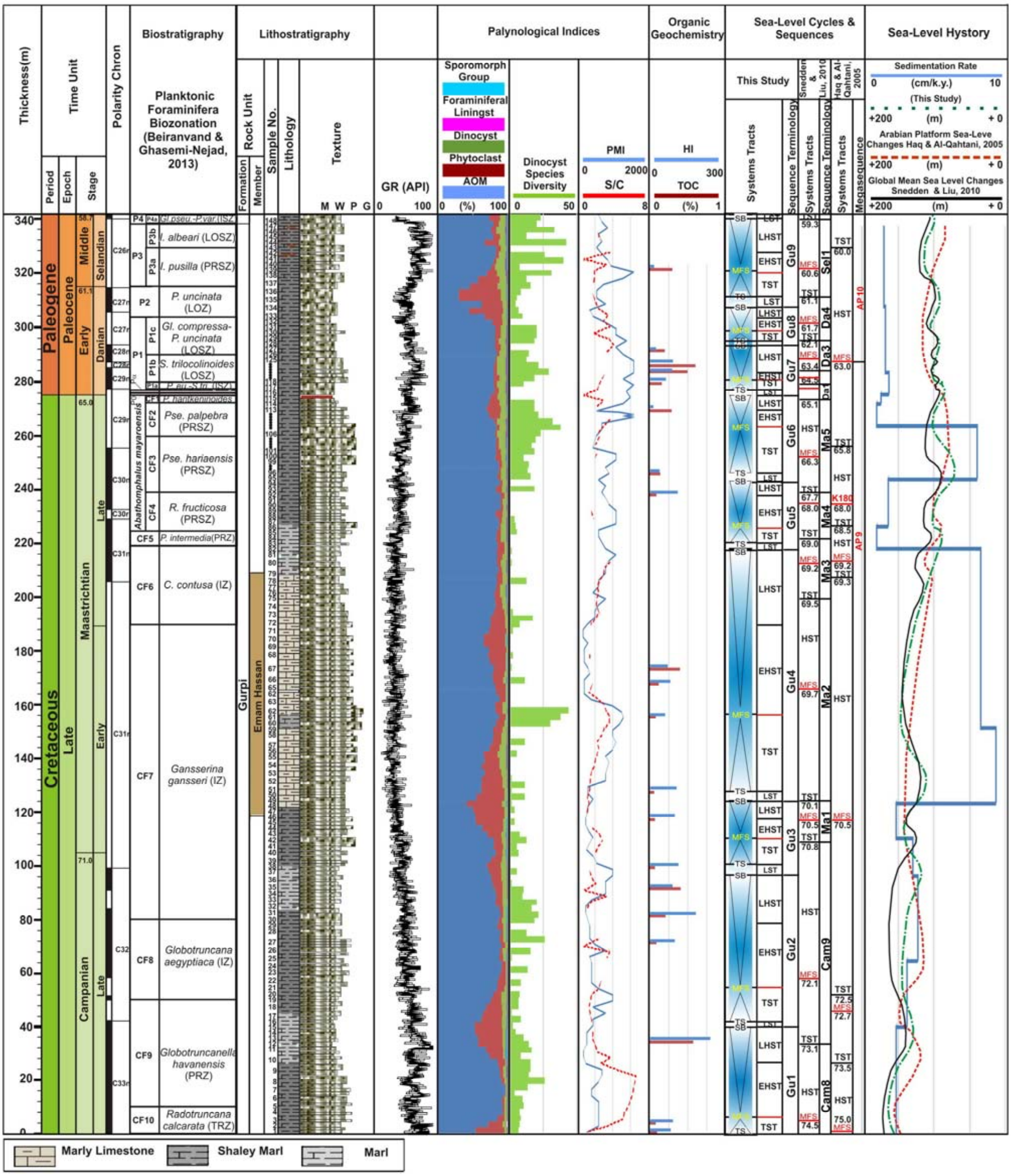

Figure 3: Lithologic column, gamma ray log, and correlation chart of palynological data to recognize sea-level changes and identify systems tracts corresponding to the regional and global sea-level cycles and systems tracts.

Associations with dominant long and complex processes of chorate forms (such as Spiniferites, Achomosphaera, Oligosphaeridium, Hystrichosphaeridium, and Hystrichodinium) are considered to indicate open marine shelf environments (Davey & Rogers, 1975; Wall *et al.*, 1977; Brinkhuis & Zachariasse, 1988; Carvalho, 2006) whereas, associations of proximate cysts with short, stout and berbed-processes (such as Cyclonephelium, Exochosphaeridium, Cleistosphaeridium, and Micrhystridium) reflect more coastal to near shore restricted environments and slightly less saline condition (Brinkhuis & Zachariasse, 1988; Eshet *et al.*, 1992). The two major morphotype groups (Spiniferites and Cyclonephelium groups) are defined based on the similarity of morphology and ecological significance of widely-used dinoflagellate species. Optima of the Spiniferites group are in most cases associated with a sea-level high and/or low energy condition.

However, the Spiniferites/Cyclonephelium (S/C) ratio, as an additional evidence for palynologic response to sea-level changes, can reflect a more detailed, smaller-scale change of depositional environments than what species diversity alone can do (Habib & Miller, 1989; Habib *et al.*, 1992; Moshkovitz & Habib, 1993). In general, increasing the S/C ratio shows an increase in seaward direction and is a good indicator of environmental change in the offshore direction (Harland, 1973). The subsequent change (increase, and then decrease) of S/C ratio within depositional sequences, corresponding with a similar change of species richness are indicative of transgression-regression cycles. (Brinkhuis & Zachariasse, 1988; Carvalho, 2006).

Total organic carbon (TOC) values can be interpreted as a proxy for organic influx. Coincident increase in TOC and proportion of planktonic foraminifera in carbonaceous rocks is related to the fact that this group (mainly heterohelicids) is the main source of carbonate in the organic-rich shales and marls (Leine, 1986). Pyrolysis data for the studied section is presented in Fig. 3. These data indicate that total organic carbon (TOC) values are generally low and rarely exceed 0.5 wt.%, with average values about 0.23 wt.%.

Palynofacies based Interpretative Sea-Level Fluctuation

The main object of this study is consideration of the changes in abundance of palynological elements, dinoflagellate species diversity, palynological marine index (PMI), Spiniferites /Cyclonephelium ratio (S/C), and organic contents and their relations to depositional migration in response to sea level fluctuations. Composition of the main palynological elements (AOM, dinocyst, and foraminiferal test lining as marine palynomorphs and phytoclasts and sporomorphs as terrestrial components) for the studied section is given in Figs. 4-6. This composition is largely controlled by AOM and phytoclatst contents. The abundance of phytoclatsts varies from 0% to 50% throughout the formation (Fig. 3). The sharp increases (tips) in terrestrial contents reflect marine regressive intervals at the top of each retrogradational package. These intervals show relatively small marine phytoplankton component, and reflect the shift in the overall progradational pattern of the upper part of each depositional sequence. On the other hand, the abundance of 'AOM' in the sedimentary successions varies from 30% to 96%. The high percentage of AOM is generally resulted from a combination of good preservation (directly related to dysoxic–anoxic conditions) and low-energy environments throughout the succession. In contrast, decrease in terrestrial element input (phytoclasts and sporomorphs) is mostly related to deep marine depositional conditions and long transportation of the particles. However, plotting the data on the Tyson-type (Tyson, 1995) 'AAP' ternary diagram shows concentrations in palynofacies zones VIII and IX that indicate deep basin and stratified shelf sea deposits (Fig. 4). Figure 3 is clearly showing variation in abundance of palynological elements related to depositional systems tracts. These variations indicate that an increasing trend in marine elements from the transgressive surface to the maximum flooding events and inversely for phytoclasts and sporomorphs in each depositional sequence. Generally, the highest amount of marine elements belong to the maximum flooding events.

Dinoflagellate species diversity, along with the distribution of other organic matter, is closely related to marine transgression and regression resulting from changes in relative sea level (Carvalho *et al.*, 2006). Determination of dinoflagellate cysts species diversity in the studied section indicates values vary widely between 1 and 44 with an increasing trend during relative sea level rises (Fig. 3). Palynological trends are well presented by complete cycles of species richness. Most taxa recorded in the studied section are relatively long-ranging and widely distributed forms. The frequent appearance of some relatively cosmopolitan forms (e.g. *Odontochitina operculata*, *Cerodinium diebelii* and *Areoligera senonensis*) reflects open oceanic connection between the study area and marine basins during the Late Cretaceous-Paleocene. An increase in the number of species within the amorphous debris facies is considered to be the best palynological evidence for marine transgression.

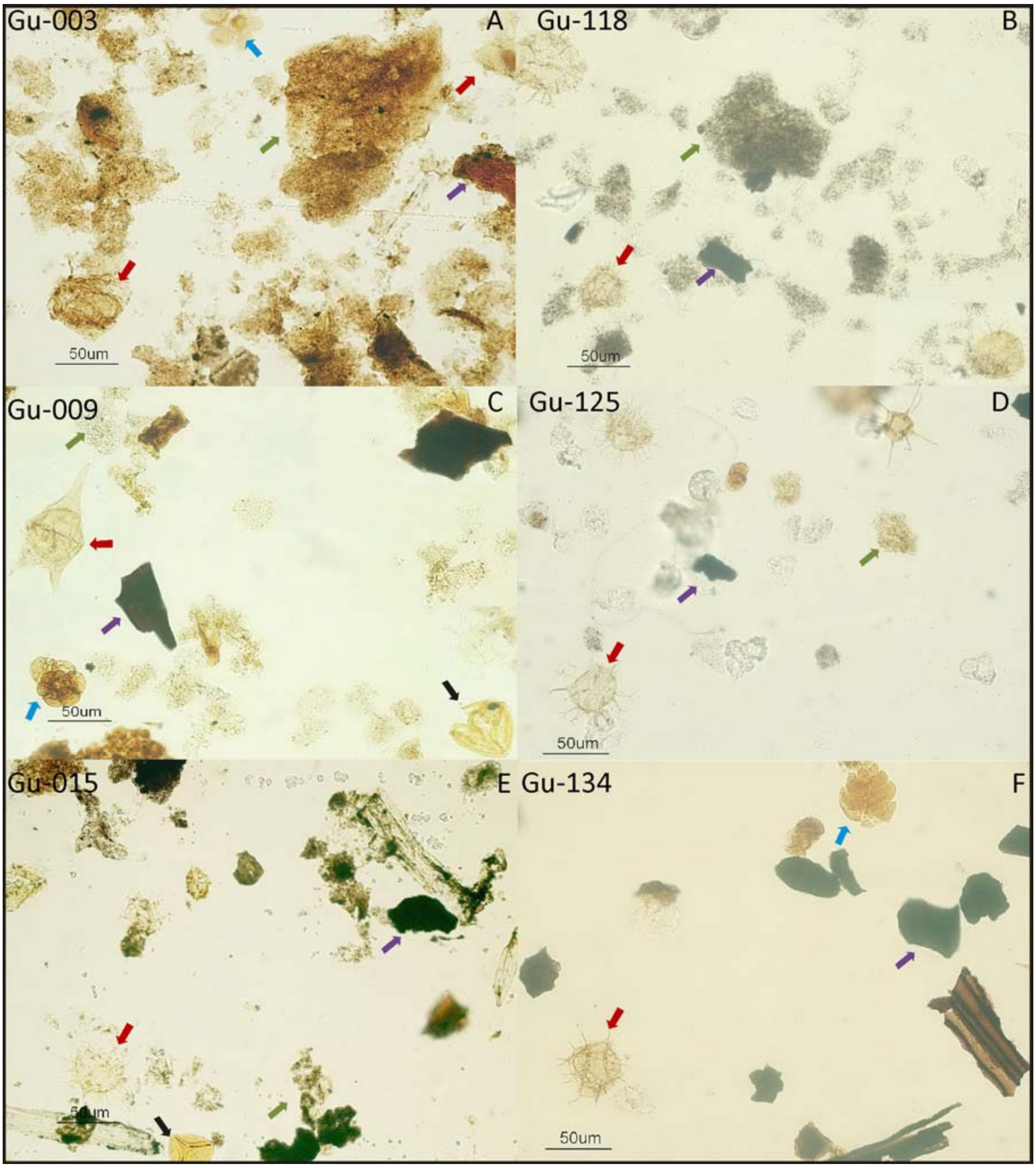

Figure 4: Examples of palynofacies and their components from successions of transgression-regression systems tracts. A and B indicate the transgressive stage palynofacies characteristics, C and D show highstand systems tract palynofacies characteristics and E and F indicate palynofacies characteristics of the regression systems tract.

In contrast, decrease in species diversity, together with an admixture of phytoclasts and amorphous debris, which represents a regressive interval, resulted from a still-stand or possible drop of sea level. These criteria have been represented in all depositional sequences identified throughout the section (Fig. 3).

In contrast to the third marine transgression which is characterized by the least species diversity (Fig. 3), the sixth marine transgression indicates the most dinoflagellate species diversity. Nevertheless, the most reduction in the species diversity was recognized in the regression stage of the fourth depositional sequence in the section (Fig. 3). The least changes in species richness occurs in the middle parts of the formation which corresponds to the early to late Maastrichtian and reflects a diminished effect of transgression and regression resulting from smaller fluctuations of sea level or possibly a further position offshore with continued transgression. A cyclic change in species diversity in response to marine transgression and regression is recorded in the sedimentary sequences (Fig. 3).

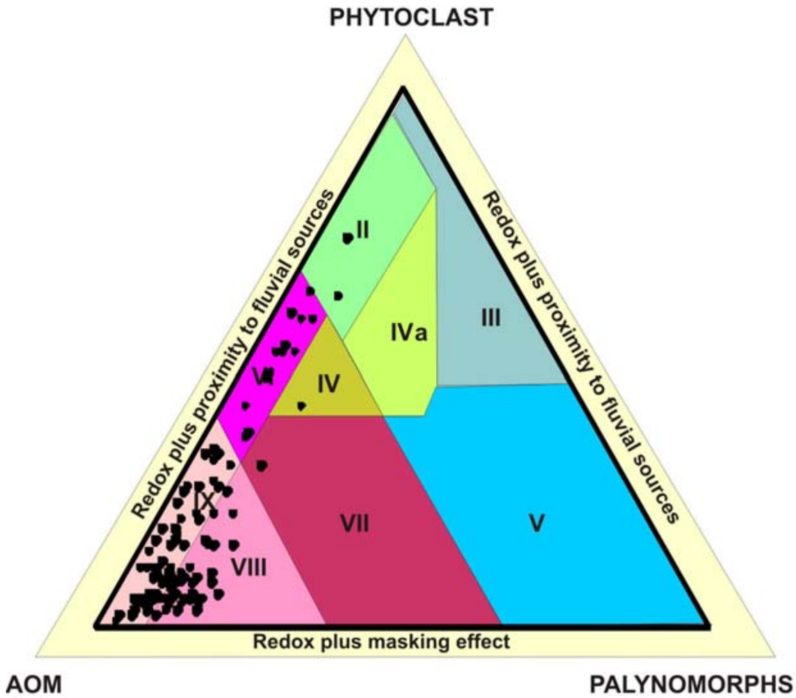

Figure 5: Tyson-type ternary diagram representing concentrations at IX and VIII zones that are showing deep basin and stratified shelf sea deposits for the Gurpi Formation.

Calculated Spiniferites/Cyclonephelium (S/C) ratio indicates that values vary widely between 0.5 and 7 with a normal increasing trend during relative sea level rises. The Spiniferites group is much more abundant than the Cyclonephelium group except in the lower part of the regression stage of the sequence-4. In most samples, the relative abundance of these two groups is inversely related. In compared with the Spiniferites and Cyclonephelium groups, Peridinioid group (cavate peridinioid cysts) remains less abundant throughout the section. The significant decrease in the S/C ratio, used as an additional evidence for palynologic response to sea level changes (Fig. 3), combined with a marked decrease in species diversity and relatively high concentrations of sporomorphs, suggest a period of marine regression. Inversely, the return of S/C values to a relatively high level at the lower stage of each depositional sequence together with abundant amorphous debris, occur at the beginning of marine transgressions. Nevertheless, the disproportionally lower S/C values in the fifth depositional sequence may not be explained just by sea level change. However, the subsequent changes (increase and then decrease) in S/C ratio among depositional sequences, corresponding with a similar change of species richness, are indicative of the transgression-regression cycles. The magnitude of changes in S/C ratio also represents, more or less, the scale of transgression and regression. Like species richness, the highest S/C ratio also occurs in the upper part of the transgressive intervals (Fig. 3). It is followed by decreasing, throughout the marine regression. This suggests that more open-marine assemblage of Spiniferites-type cysts increases more rapidly than the near-shore Cyclonephelium-type cysts during the expansion of shelf environments. In the studied section, the S/C ratio curve also shows a correspondence with that of species richness (Fig. 3). Sometimes, small changes in species diversity makes the S/C ratio a unique criterion that can be used to indicate transgressive and regressive pulses.

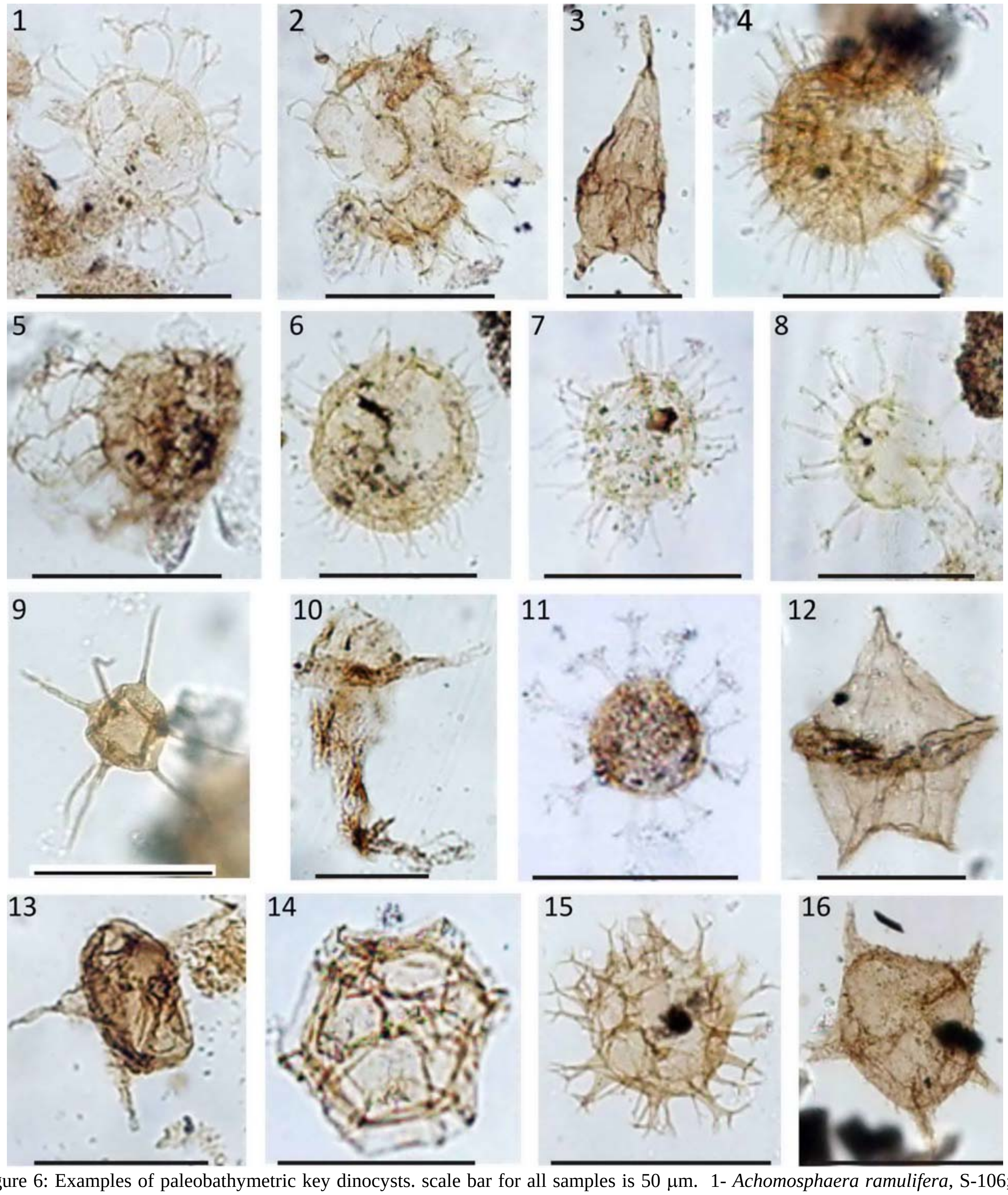

Figure 6: Examples of paleobathymetric key dinocysts. scale bar for all samples is 50 µm. 1- *Achomosphaera ramulifera*, S-106; 2-*Areoligera senonensis,* S-19; 3-*Cerodinium deibelii*, S-135; 4-*Cleistosphaeridium minus,* S-122; 5-*Glaphyrosista assamica*, S-146; 6-*Cleistosphaeridium ancyreum*, S-145; 7-*Exochosphaeridium phragmites*, S-114; 8-*Hystrichosphaeridinium bowerbankii*, S-12; 9-*Dorsennidinium aster*, S-125; 10-*Odontochitina operculata* , S-33; 11- *Oligosphaeridium pulcherrimum*, S-134; 12-*Phelodinium magnificum*, S-110; 13-*Phelodinium tricuspe*, S-112; 14-*Pterodinium cingulatum*, S-19; 15-*Spiniferites ramosus,* S-146; 16-*Wetzeliella astroides,* S-145.

Although, increase in TOC correlates with increase in water depth and transgressive stage of a cycle can also be recognized through the kerogen distribution (Hart *et al.*, 1994), but here the organic carbon and Rock-Eval pyrolysis data indicate that TOC values are generally low in the transgressive systems tracts and higher values recognized in late highstand systems tract (Fig. 3). The pyrolysis-data further suggest that all of the kerogens present in this interval are thermally immature, as indicated by the low to slightly elevated temperature maximum (Tmax) values (422–457 ^{o}C) and partially terrigenous source (Type III). However, the concentration of TOC in late highstand systems tract can probably be due to the minor sea level falls.

Discussion

The relative sea level changes interpreted based on palynofacies associations are represented in Fig. 3. Accordingly, whole nine depositional sequences can be identified throughout the Gurpi Formation. The basal depositional sequence of the section is separated from the underlain formation (Ilam Formation) by an unconformity which is marked by an erosional surface (Wynd, 1965; Stoneley, 1990). There is an increase in species richness up to the early highstand systems tract along the sequence (Fig. 3). Relatively high amounts of AOM and dinoflagellate cysts which are decreasing upward recorded in the lower part of the sequence (Fig. 3). This can be correlated with an increasing in phytoclast particles. The sequence boundaries here are marked by a major peak in abundance of phytoclast and the maximum flooding event is marked by a peak in AOM. The boundaries are also confirmed by gamma-ray profile observed.

The second pulse of relative sea level rise and marine transgression is supported by moderate values of the PMI and AOM. The upper boundary of the transgressive trend which is marked by a maximum flooding surface (mfs) is characterized by an abrupt decrease of phytoclasts and high abundances of dinoflagellate cysts, particularly of the genus Spiniferites. The upper boundary of the sequence is also marked by decrease in PMI and AOM values and an abrupt increase of phytoclasts. The third identified sequence (Gu3) was also confirmed well on the basis of palynofacies. A clear decrease in dinoflagellate cyst abundance is observed and the lowest peak of phytoplankton diversity occurs in the early HST of the sequence. In contrast, the abundance histogram of phytoclasts shows a slight increase upwards indicating the HST (Fig. 3). The AOM values are moderate to low.

The depositional sequence of Gu4 shows an abrupt lithological change at the base from shaley marls to dark gray marls and argillaceous limestones. It contains sedimentary cycles which are recognizable by decreasing upward PMI and AOM coinciding with increase in phytoclast abundance (Fig. 3). These cycles in the lower part of the sequence are characterized by moderate values of PMI, S/C and AOM that tend to increase upwards. The largest number of dinoflagellate species occurs in the peak transgression systems tract. The upper boundary of this systems tract which is marked by the peaks of dinoflagellates species diversity, PMI, S/C and AOM parameters indicating a MFS. Following this, decrease in PMI, S/C and AOM values simultaneous with increase in phytoclast particles show early highstand systems tract of the sequence (Fig. 3). Upper part of the sequence is poorly defined based on palynofacies analysis. However, this part of the sequence shows a slightly regressive trend upwards. This sequence which covers the Emam Hassan Member, corresponds to the sedimentary cycles of Ma2 and Ma3 defined by Snedden and Liu (2010), Fig. 3. It comprises the succession with highest rate of sedimentation (8-9.5 cm/k.y.).

The fifth sequence of the Gurpi Formation (Gu5) starts with a marine transgression which is supported by moderate values of the PMI and AOM (Fig. 3). A condensed section which is recognized based on glauconitic foraminiferal packstone microfacies, generally spans the uppermost part of the TST here. The upper boundary of the transgressive trend is marked by the most important maximum flooding (starvation) surface in the Late Cretaceous which is identified regionally (K180 of Sharland *et al.,* 2001) and globally (Snedden & Liu, 1987). This surface is located at the base of a condensed section. In this case, the condensed section is actually a part of the HST. This is a boundary characterized by an abrupt increase of PMI value. The highstand systems tract of the sequence is also marked by a decreasing trend of PMI and AOM values and an abrupt increase of phytoclasts.

The depositional sequence of Gu6 was identified in the uppermost part of the Cretaceous sediments. It shows a dramatic increase in dinoflagellate species diversity and PMI and AOM values during the pulse of sea level rise and marine transgression stage (Fig. 3). The number of species increases gradually during the early stage of the transgressive interval. Then, after a small decrease, species diversity increases again at the beginning of the upper part of transgressive stage. The pulses of steady state and sea level fall can be supported by decreasing of species diversity and increasing of phytoclast particles which are showing a regression trend in the sequence. A rich amorphous debris matrix suggests a more stable offshore environment during the cycle of transgression and regression. The upper boundary of the sequence is marked by K/Pg boundary. Finally, the last three sedimentary cycles (Gu7-9) of the formation coincide to the upper third-order cycle level of the Supercycle TA-1 (Haq *et al.,* 1988) and the last cycle of the AP9 and basal AP10 tectonostratigraphic megasequences (Sharland *et al.,* 2001; Haq and Al-Qahtani, 2005) in the northeast margin of the Arabian Plate. The first sea level cycle of the Paleogene (Gu7) correspond to the Da1, Da2, and Da3 cycles of Snedden and Liu (2010) with time duration of 65.1-62.1Ma. All these sequences are characterized by high abundance and species diversity, PMI and AOM values. The species richness increases dramatically at the beginning of the transgressive phase of the sequences, then decreases systematically into the highstand interval (Fig. 3).

Conclusions

Analysis of the late Campanian to Paleocene strata in the section studied in southwest of Iran revealed rich and well-preserved dinoflagellate cyst assemblages. Based on statistical studies on these assemblages many conclusions have been drawn. Dinoflagellate cysts species diversity, AOM, PMI, S/C, and TOC values along with distribution of other organic matter and natural gamma ray response, is closely related to marine transgression and regression resulting from changes in relative sea level. Palynologic cycles developed during the early transgressive interval, represented by a significant species diversity associated with abundant amorphous debris, dramatic increase in PMI values and S/C ratio, and is followed by a marked drop in species diversity associated with an increase in TOC, phytoclast and sporomorph content, which represents a regressive interval resulted from a still-stand or possible drop in sea level. This kind of cyclic change in species diversity, PMI, S/C, and TOC values in response to marine transgression and regression was recorded in all sequences differentiated. The clearest cyclicity of species richness, PMI value and S/C ratio is recorded in the two last sequences in the upper most part of the formation. The boundary between two cycles is indicated by a significant drop in species diversity and lower S/C ratios.

Combination of the lithofacies, palynofacies, and gamma-ray log data indicates that the Gurpi Formation consists of depositional sequences correlatable with regional integrated sea level fluctuations in northeast of the Arabian Plate. These integrated data helped us to recognize the systems tracts and key horizons such as flooding surfaces and sequence boundaries. In addition, the 'AAP' ternary diagram integrated with sedimentary facies can confirm deep basin and stratified shelf sea depositional environment for the Gurpi Formation.

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