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Paleocene-Oligocene dinoflagellate cysts from the Siah Anticline, Zagros Basin, Southwest Iran

Cistos de dinoflagelados do Paleoceno-Oligoceno do Anticlinal de Siah, Bacia de Zagros, sudoeste do Irã

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Abstract
A section of the Pabdeh Formation dating back to the Paleocene-Oligocene has been sampled in the Zagros Basin in Southwest Iran for palynological investigations and evaluation of thermal maturity and hydrocarbon generation potential. In total, 125 rock samples were collected and processed palynologically. The samples yielded rich assemblages of dinoflagellate cysts, and 65 cyst species were identified. Some index species allowed us age dating and establishment of seven dinoflagellate cyst zones in accordance with the existing European zonation. The dinoflagellate cyst zones allowed precise age assignment of the formation under study to late Paleocene to early Oligocene. For thermal maturity evaluation, spore and pollen grain color were correlated against the standard color chart prepared by the Shell Oil Company. The properties of the samples, according to palynomorph color changes, suggest that this formation is potentially oil prone and may have produced oil.

Keywords: Pabdeh Formation; Dinoflagellate cysts; Paleogene; Palynostratigraphy; Thermal maturity.

Resumo
Uma seção da Formação Pabdeh do Paleoceno-Oligoceno foi amostrada na Bacia Zagros, no sudoeste do Irã, para investigações palinológicas e avaliação de maturidade térmica e potencial de geração de hidrocarbonetos. Ao todo, 125 amostras de rochas foram coletadas e processadas palinologicamente. As amostras produziram assembleias ricas de cistos de dinoflagelados, nas quais foram identificadas 65 espécies de cistos. Algumas espécies-guia permitiram datação por meio do estabelecimento de sete biozonas de dinoflagelados de acordo com o arcabouço de biozoneamento europeu existente. As zonas de cistos de dinoflagelados permitiram atribuir a idade precisa da formação em estudo, a qual se estende do Neopaleoceno até o Eo-oligoceno. Para maturidade térmica, a coloração de esporos e grãos de pólen foi correlacionada com a escala padrão de cores da companhia de petróleo Shell. Propriedades das amostras, indicadas pela mudança de cor dos palinomorfos, sugerem que a formação é potencialmente geradora, podendo ter produzido petróleo.

Palavras-chave: Formação Pabdeh; Cistos de dinoflagelados; Paleógeno; Palinoestratigrafia; Maturidade térmica.

INTRODUCTION

The first studies on fossil dinoflagellates from Western Iran were made by Zahiri (1982). The main intent of these investigations was identifying dinoflagellate cysts. The stratigraphic application of dinoflagellate cysts in this area started only at the end of 1982, when a few boreholes were investigated and the first dinoflagellate cyst zones were erected (Zahiri, 1982). Later on, more studies conducted palynostratigraphy of some parts of the Zagros Basin (e.g., Ghasemi-Nejad et al., 2006; Rabbani et al., 2013). As the Pabdeh Formation, which is lithologically made up of shale, calcareous shale and limestone, is a relatively known source rock in the Zagros Basin, palynological studies on these strata could help establishing a stratigraphic framework and could be further investigated in terms of potential for petroleum generation.

MATERIALS AND METHODS

A total of 125 outcropping sediment samples from a Siah Anticline section were collected and processed using palynological techniques in several steps, according to palynological standard methods (Traverse, 1988, p.456-479). About 30 grams of rock samples were used for processing. The samples were first crushed and washed, then treated with 33% hydrochloric acid (HCl) and later with 40% hydrofluoric acid (HF). After these chemical steps, the residue was sieved through a 20 µm nylon mesh. The materials coarser than 20 µm were used for palynological studies. The thermal maturity discussed and used in this study is based on changes in spore or pollen color. Thermal maturity was used for oil exploration as it is capable of characterizing organic matter type based on which kerogen type could be identified in the source rocks. The yellow color usually indicates a degree of maturation for the rocks that have not yet attained a thermal maturation degree to generate petroleum. The brown range of color indicates an advanced maturation degree for oil generation.

PREVIOUS STUDIES

There are a few records of dinoflagellate cysts from the Pabdeh Formation of the Zagros Basin in the published literature (e.g., Rabbani et al., 2013). There are also a few records on foraminiferal biostratigraphy (e.g., Beiranvand et al., 2014), which yielded the Paleocene to Miocene age.

The Pabdeh Formation is a known source rock for the Asmari reservoir, one of the largest source rocks in the Middle East (Motiei, 2003). For this reason, it is important to study its palynology and palynostratigraphy, in order to establish a precise stratigraphic framework.

GEOLOGICAL SETTING

The Pabdeh Formation crops out extensively in Kohgiluyehva Boyer-Ahmad, in the Zagros Basin, Southwest Iran (Figure 1). The lower contact with shale and limestones of the Gurpi Formation and the upper contact with limestone and marls of the Asmari Formation both display conformity.

BIOSTRATIGRAPHY

Stratigraphic distribution of dinoflagellate cysts recorded in this study is displayed in Figures 2 and 3. Based on the composition of the assemblages, seven zones are differentiated, ranging in age from late Paleocene to early Oligocene (Table 1). The most productive and rich associations have been revealed from the Maastrichtian, Danian and Ypresian intervals. The zones established here can be compared with those from different parts of Europe and the Urals (Table 1). The zonation established here is discussed ahead:

- Biozone1: *Areoligera gippingensis* Range zone
  This local biozone was introduced by Nøhr-Hansen (2002) from offshore sediments from West Greenland.
  Age: late Paleocene (Thanetian)
  Occurrence: from 79.36 m to 138.34 m
  Definition: this zone was defined as the range of *Areoligera gippingensis* and includes such forms as *Apectodinium homomorphus*, *Melitasphaeridium pseudorecurvatum* and *Areosphaeridium capricornum*.
  The index species, *Areoligera gippingensis*, has been recorded from Paleocene, Germany (Gocht, 1969); Maastrichtian– upper Paleocene, offshore South East Canada (Williams and Bujak, 1977); lower Eocene of England (Williams and Downie, 1966); upper Paleocene–basal upper Eocene of North West Germany (Köthe, 1990).
- Biozoe 2: *Deflandrea phosphoritica* Interval zone
  This has been introduced as a local biozone by Morgans et al. (2004) and it can be compared with *Deflandrea oebisfeldensis* Interval zone introduced by Nøhr-Hansen (2002).
  Age: early Eocene (Ypresian)
  Occurrence: from 138.34 m to 184.55 m
  Definition: this zone has been defined as the interval from the last appearance datum (LAD) of *Deflandrea phosphoritica* to the LAD of *Cleistosphaeridium placacanthum* and includes such taxa as *Chiropteridium galea*, *Cleistosphaeridium diversispinosum* and *Distatodinium tenerum*, *Impagidinium* sp.(Figures 4 and 5).
- Biozone 3: *Systematophora placacantha* Interval zone
  This local biozone was introduced by Vasilieva (1990) from Southern Ural region and by Bujak and Mudge (1994) and Mudge and Bujak (1996) from North Sea.
  Age: early Eocene (Lutetian)
  Occurrence: from 184.55 m to 229.93 m

Definition: this zone has been defined as the interval from the LAD of *Systematophora placacantha* to the LAD of *Enneadocysta pectiniformis* and includes *Distatodinium tenerum*, *Spiniferites mirabilis*, *Dapsilidinium pseudocoligerum*, *Lingulodinium machaerophorom* and *Enneadocysta pectiniformis*. It has been reported from middle-upper Eocene, England (Bujaket al., 1980); middle Eocene, offshore East Canada (Williams and Brideaux, 1975); and middle-upper Eocene, England (Eaton, 1971, 1976). *Systematophora placacantha* has stratigraphically been recorded from the Paleocene of West Tasmania (Cookson and Eisenack, 1967).

- Biozone 4: *Cordosphaeridium cantharellus* Interval zone
  This local biozone is being introduced here. The index species *Cordosphaeridium cantharellus* has been reported from the European region. *Cordosphaeridium cantharellus* has been reported from the upper Eocene of South England (Bujak et al., 1980); upper Eocene– lower Miocene, offshore East Canada (Williams and Bujak, 1977); upper-middle Eocene– basal Miocene, General (Drugg and Stover, 1975).
  Age: Eocene (Bartonian)
  Occurrence: from 229.93 m to 325.33 m
  Definition: this zone has been defined as the interval between the first appearance datum (FAD) of *Systematophora placacantha* and the LAD of *Cordosphaeridium cantharellus*, and includes *Cordosphaeridium gracile*, *Distatodinium* cf. *biffi*, *Glaphyrocysta* sp., and *Hystrichokolpoma eisenackii*. *Cordosphaeridium gracile* has been reported from lower-upper Eocene, South England (Bujak et al., 1980) and middle -upper Eocene, offshore North West Africa (Williams, 1978).
- Biozone 5: *Spiniferites pseudofurcatus* Interval zone
  This local biozone was introduced by Bujak and Mudge (1994) from offshore West Greenland.
  Age: late Eocene (Priabonian)
  Occurrence: from 325.33 m to 350 m
  Definition: this zone has been defined as the interval from the LAD of *Spiniferites pseudofurcatus* to the LAD of *Achomosphaera alcicornu* and includes *Impagidinium* sp., *Operculodinium* cf. O. *microtrainum* and *Spiniferites pseudofurcatus*, reported from lower-upper Eocene of South England (Bujak et al., 1980) and Middle Eocene of Mexico (Helenes, 1984).

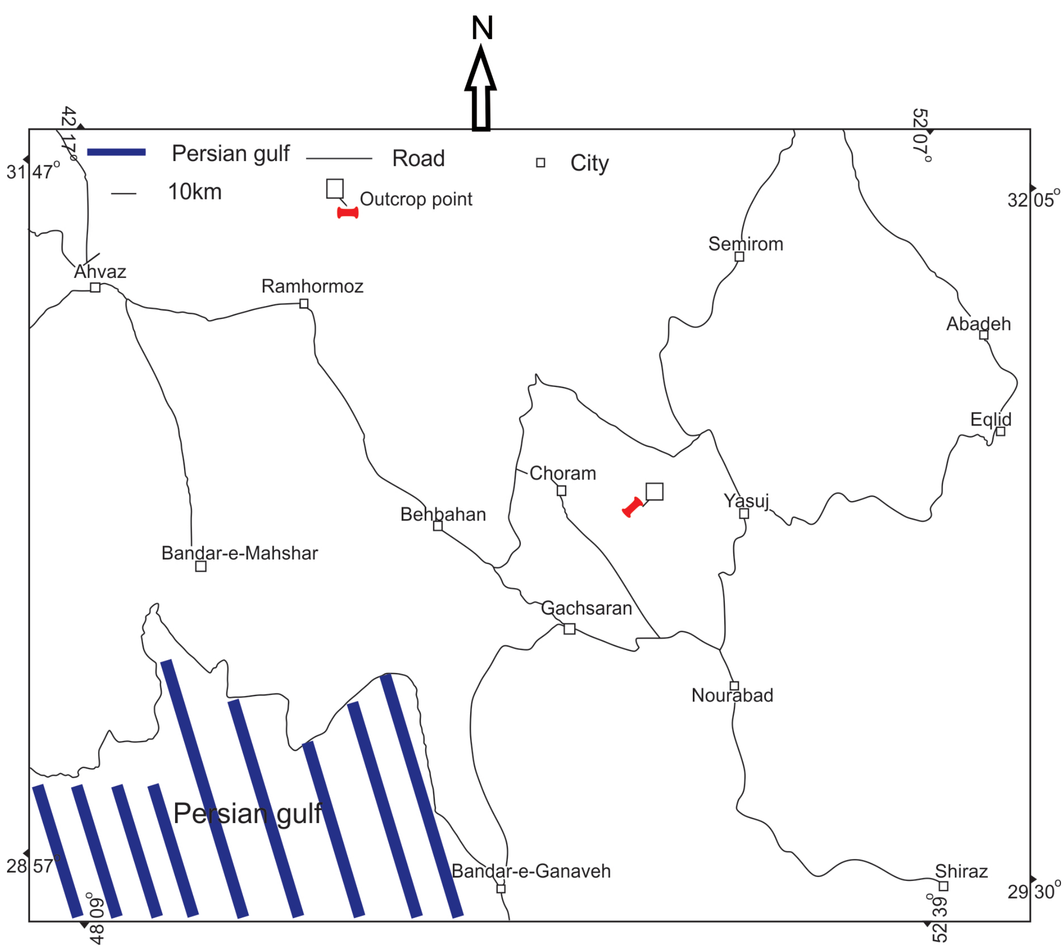


Figure 1. Location map of the studied section.

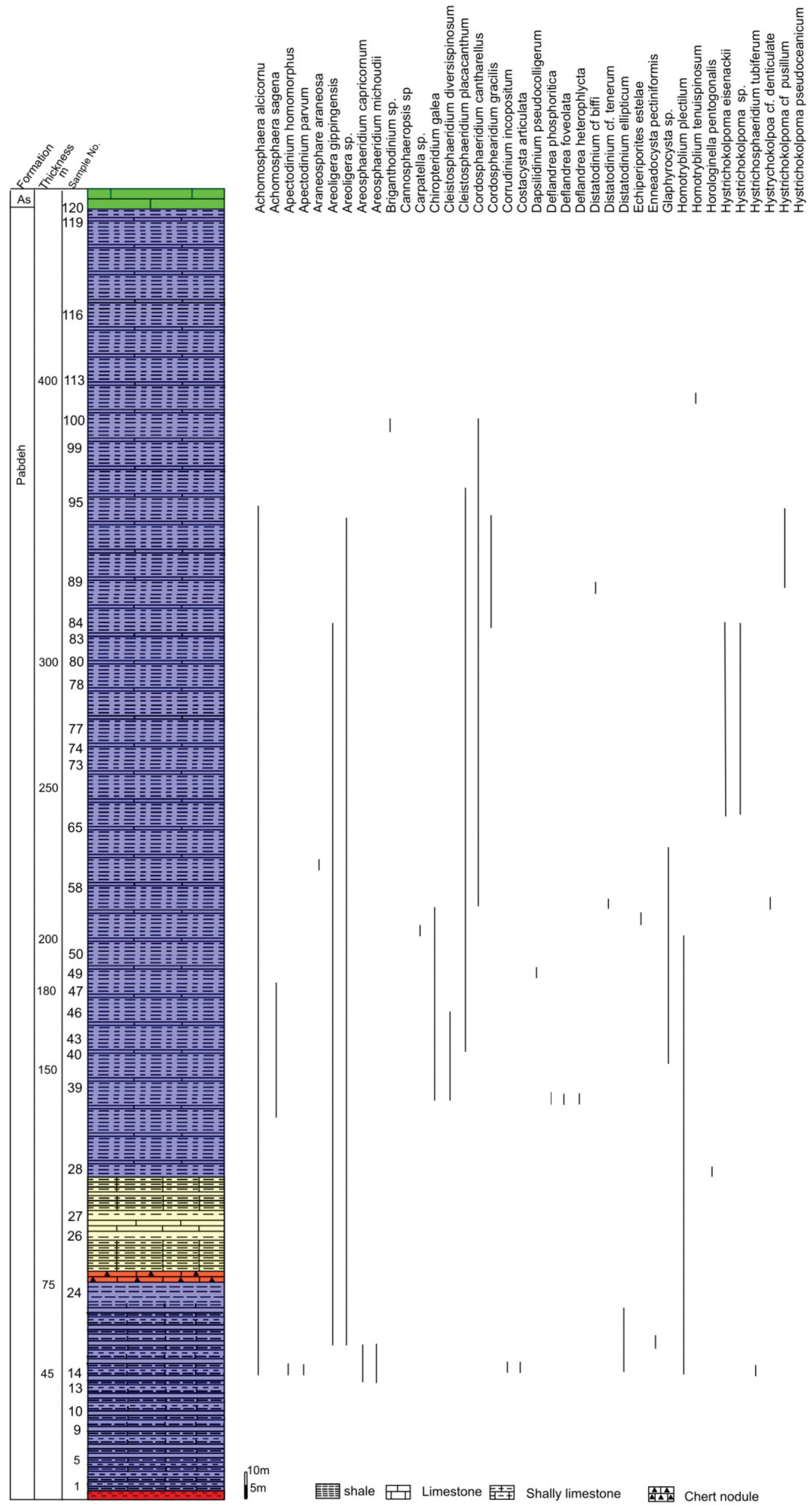


Figure 2. Stratigraphical distribution of dinoflagellate cysts: A to H.

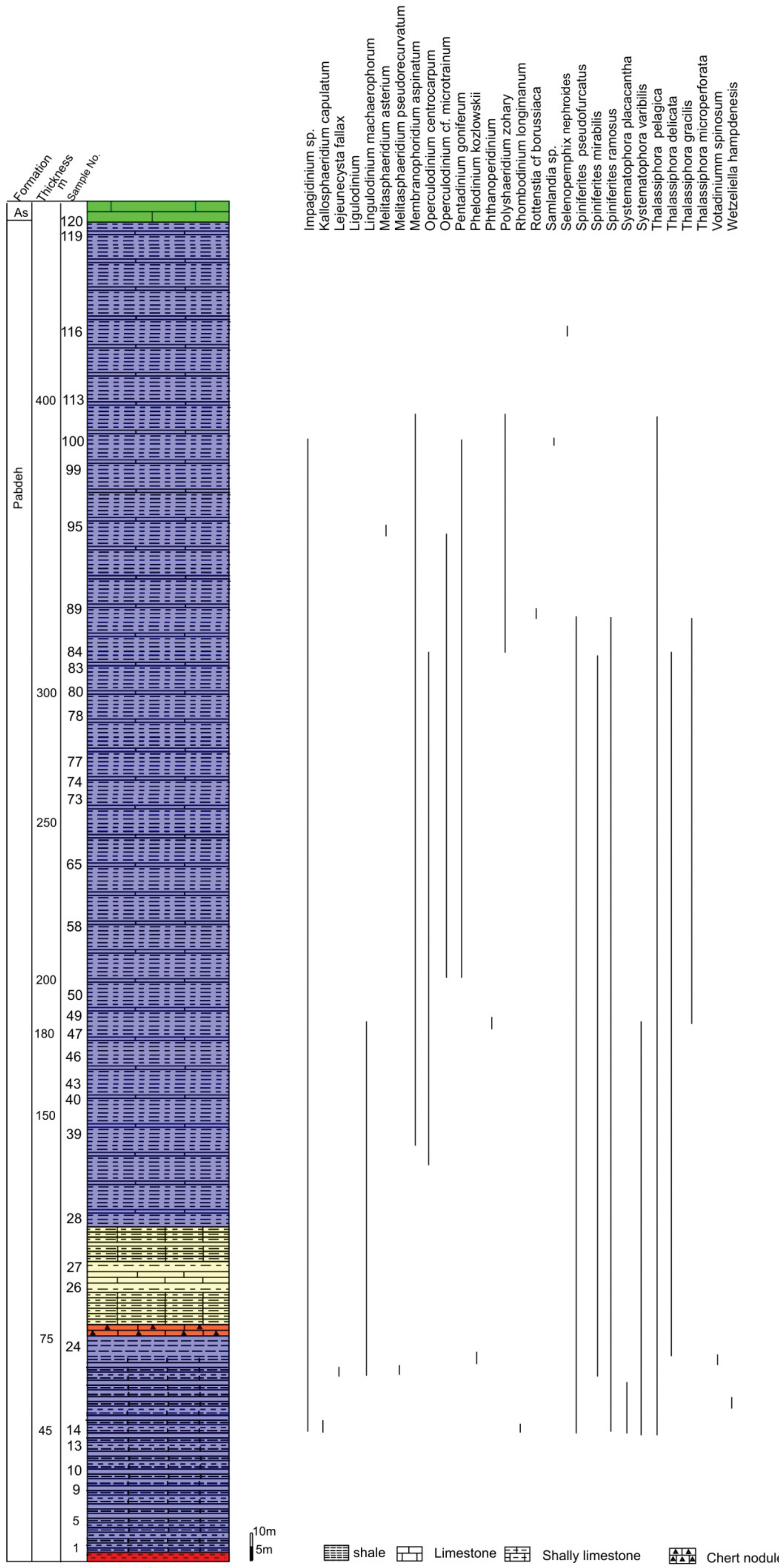
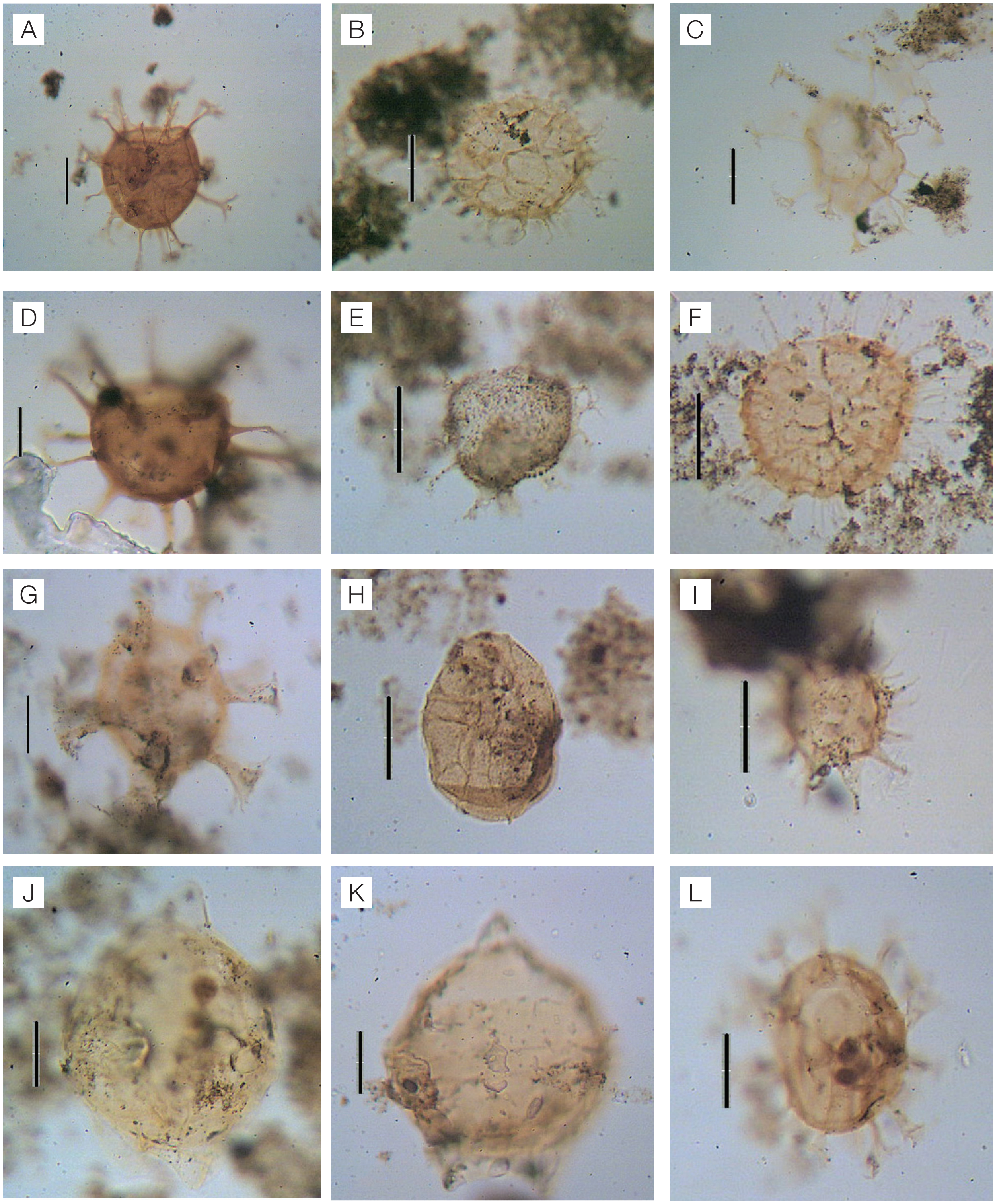


Figure 3. Stratigraphical distribution of dinoflagellate cysts: I to W.

Table 1. Correlation of Paleogene dinoflagellate cyst biozones established for Zagros Basin with those from Europe and Ural.

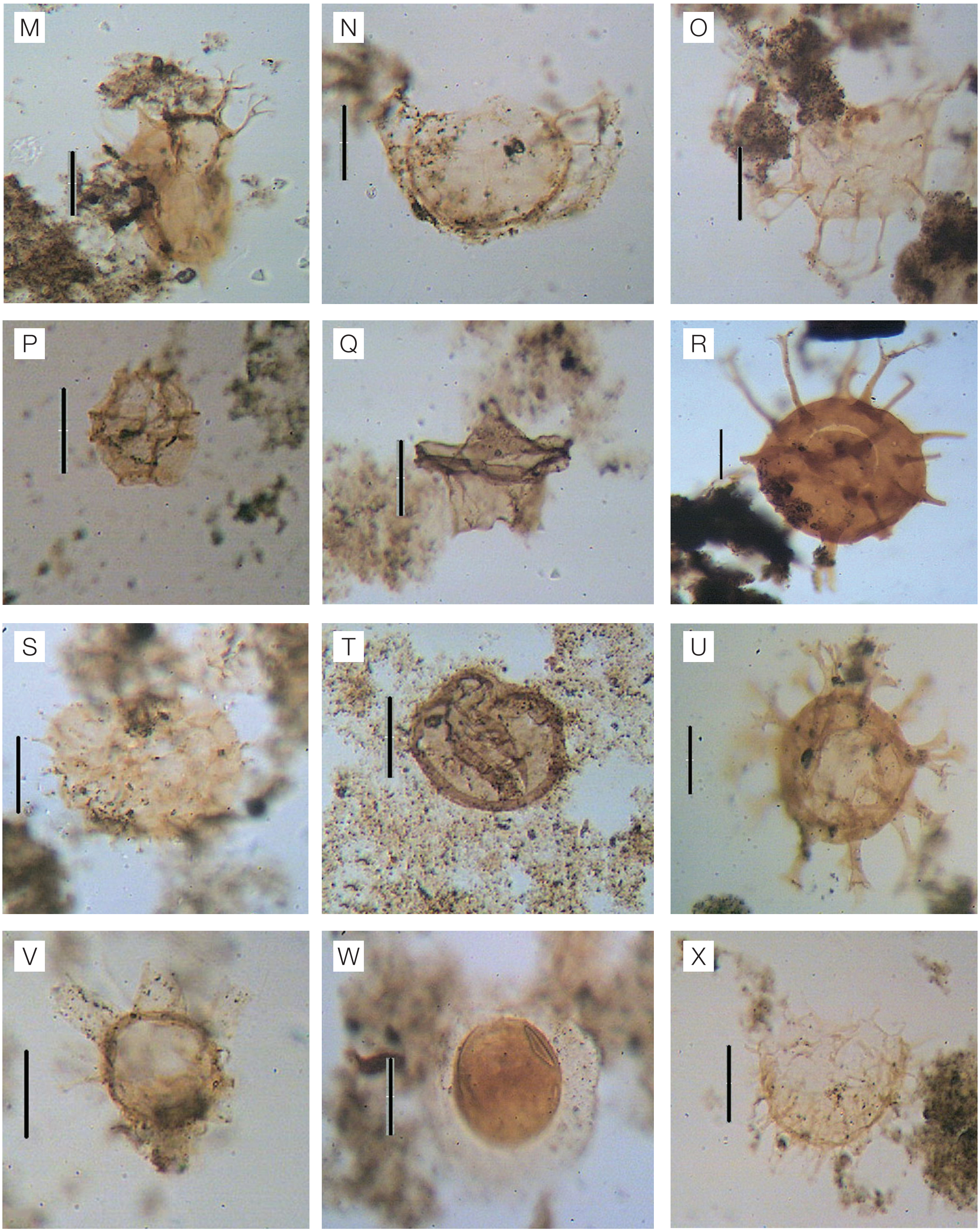
System/ Period	Series/Epochs		Stage/ Age	Planc. form. biozones (Berggren et al., 1995)	Calc. nanno biozones (Martini, 1971)	Dinoflagellate zones (Heilmann-Clausen, 1988)	Bujak (1984)	Dinoflagellate zones of Southern Ural region (Vasilieva, 1990)	Nøhr-Hansen (2002) Ikermiut-1, West Greenland offshore	North Sea dino. cyst (Bujak and Mudge, 1994; Mudge and Bujak, 1996)	This study
Paleogene	Oligocene	up.	Chat.			Thalassiphora reticulata Zone	*Gelatia inflata*	*Ch. clathrata angulosa*			
		Low	Rupelian				*Spiniferites sp.* cf. *S. membranaceus*				Selenopemphix nephroides
	Eocene	Late	Priabotian	P17	Np20		*Trinovantedinium boreale*			A. diktyoplokus	Thalassiphora delicate
				P16	Np19						
				P15	Np18	Enneadocysta arcuata Zone					Spiniferites pseudofurcatus
		Middle	Bartonian	P14	Np17			*Kisselevia ornata*	*G. semitecta*	H. porosa	Cordosphaeridium cantharellus
				P13	Np16			*Systematophora placacantha*			
			Lutetian	P12						D. colligerum	Systematophora placacantha
				P11	Np15	Phthanoperidinium regalis Zone	*Kallosphaeridium boreal*			S. placacantha	
				P10						D. ficusoides	
					Np14						
		Early	Ypresian	P9	Np13			*Ch. coleotrhypta plexus Dr. politum*		E. ursulae	Deflandrea phosphoritica
				P8					*A. medusettiformis*		
				P7	Np12			*D. varielongitudum/ D. simile/W. meckelf*	*F. bipolaris*	A. medusettiformis	
				P6b	Np11				*D. oebisfeldensis*	H. tubiferum	
				P6a	Np10			*Apectodinium homomorphum*			
	Paleocene	Late	Thanetian	P5	Np9				*Apectodinium acme*	A. augustum	Areoligera gippingensis
				P4	Np8			*Cerodinium speciosum*	*A. gippingensis*	A. margarita	
					Np7						
					Np6				*P. pyrophorum*		
				P3	Np3					P. pyrophorum	

up.: Upper, Chat.: Chattian.



Scale bar: 30 μm.

Figure 4. (A) *Achomosphaera alcicornu* (Eisenack) Davey and Williams, 1966; (B) *Areoligera gippingensis* Jolley, 1992; (C) *Areosphaeridium capricornum* (Cookson and Eisenack, 1965) Stover and Evitt, 1978; (D) *Areosphaeridium michoudii* Bujak, 1994; (E) *Chiropteridium galea* (Maier, 1959) Sarjeant, 1983; (F) *Cleistosphaeridium placacanthum* (Deflandre and Cookson) Eaton et al., 2001; (G) *Cordosphaeridium cantharellus* (Brosius, 1963) Gocht, 1969; (H) *Corrudinium incopositum* (Drugg, 1970) Stover and Evitt, 1978; (I) *Dapsilidinium simplex* (White, 1842) Bujak et al., 1980; (J) *Deflandrea phosphoritica* Eisenack, 1938; (K) *Deflandrea foveolata* Wilson, 1984; (L) *Distatodinium* cf. D. tenerum (Benedek, 1972) Eaton, 1976.



Scale bar = 30 µm.

Figure 5. (M) *Distatodinium* cf. D. biffi Brinkhuis et al., 1992; (N) *Membranophoridium aspinatum* Gerlach, 1961; (O) *Enneadocysta pectiniformis* (Gerlach, 1961) Stover and Williams, 1995; (P) *Impagidinium* sp.; (Q) *Lejeunecysta fallax* (Morgenroth, 1966) Artzner and Dörhöfer, 1978; (R) *Melitasphearidium pseudorecurvatum* (Morgenroth, 1966) Bujak et al., 1980; (S) *Polysphaeridium zoharyi* (Rossignol, 1962) Bujak et al., 1980; (T) *Selenopemphix nephroides* Benedek, 1972; (U) *Spiniferites pseudofurcatus* (Klumpp, 1953) Sarjeant, 1970; (V) *Hystrichokolpoma cinctum* Klumpp, 1953; (W) *Thalassiphora pelagica* (Eisenack, 1954) Eisenack and Gocht, 1960; (X) *Systematophora placacantha* (Deflandre and Cookson, 1955) Davey et al., 1969.

Table 2. Spore and pollen color changes used for thermal maturity evaluation.

Sample No.	Color of spore and pollen grains	TAI	Maturity	Hydrocarbon
38	*Brown*	3+	*Mature*	*Liquid petroleum*
46	*Brown*	3+	*Mature*	*Liquid petroleum*
48	*Very dark brown*	4-	*Overmature*	*Dry gas or barren*
54	*Light brown*	3-	*Mature*	*Liquid petroleum*
74	*Very dark brow*	4-	*Overmature*	*Liquid petroleum*
84	*Brown*	3+	*Mature*	*Liquid petroleum*
116	*Light brown*	3-	*Mature*	*Liquid petroleum*

TAI: Theraml alteration index.

- Biozone 6: *Thalassiphora delicata* Interval zone
  This local biozone was introduced by Heilmann-Clausen (1988) from Central Danish basin.
  Age: early Oligocene (Rupelian)
  Occurrence: from 350.46 m to 421.33 m
  Definition: this zone has been defined as the interval from the LAD of *Thalassiphora delicate* to the LAD of *Homotryblium tenuispinosum* and includes *Operculodinium* cf. *O. microtrainum*, *Melitasphaeridium asterium*, *Impagidinium* sp. (Figure 5) and *Thalassiphora delicata*, reported from late Eocene of West Greenland offshore (Nøhr-Hansen, 2002). *Homotriblium tenuispinosum* has also been reported from lower Oligocene of Central Italy (Biffi and Manum, 1988); upper Eocene, Egypt (El-Beialy, 1987); lower-upper Eocene of England (Eaton, 1976); and lower-upper Eocene of East Canada offshore (Williams and Bujak, 1977).
- Biozone 7: *Selenopemphix nephroides* Interval zone
  This local biozone is being introduced here. The index species *Selenopemphix nephroides* has been reported from European region. *Selenopemphix nephroides* has been reported from lower Oligocene of Egypt (El-Bassiouni et al., 1988); upper Eocene – lower Oligocene of Netherlands (De Coninck, 1986); and Oligocene of Nigeria (Biffi and Grignani, 1983).
  Age: early Oligocene (Rupelian)
  Occurrence: from 421.33 m to 457 m
  Definition: this zone has been defined as the interval from the LAD of *Polysphaeridium zohary* to the LAD of *Selenopemphix nephroides* and includes *Memranophoridium aspinatum* (Figure 5). *Polysphaeridium zohary* has been reported from lower Eocene-Oligocene of East Canada offshore (Williams and Brideaux, 1975) and middle Eocene of Pakistan (Köthe et al., 1988).

THERMAL MATURITY

The thermal maturity discussed and used in this study is based on changes in spore or pollen color. Thermal maturity was used for oil exploration, as it is capable of characterizing organic matter type based on which kerogen type could be identified in the source rocks. The yellow color usually indicates that the rocks had not yet attained a thermal maturation degree to generate petroleum. The brown range of color indicates a good maturation degree for oil generation. Seven samples that contain diverse assemblages of spore and pollen are selected for studying the color change of their spore and pollen contents. Of these, five samples are located within the oil prone sector and two samples indicated an overmature condition (Table 2). In general, these indicate that the Pabdeh Formation is a good source rock for the big reservoir rock unit, the Asmari Formation.

CONCLUSIONS

The Siah Anticline, located in Southwest Iran, contains a rich Paleocene-Oligocene record of dinoflagellate cysts. These palynomorphs are abundant in the lower and upper parts of the section, but their abundance decreases in some parts of the section because of the limestone lithology of the layers. Seven biozones are established based on the presence of *Areoligera gippingensis*, *Deflandrea phosphoritica*, *Systematophora placacantha*, *Cordosphaeridium cantharellus*, *Spiniferites pseudofurcatus*, *Thalassiphora delicata* and *Selenopemphix nephroides*. The zones in general confirm the late Paleocene to early Oligocene age for the Pabdeh Formation at this section, which has also been gained from studies on foraminifera and nannofossils (Aghanabati, 2004). Dinoflagellate cyst zones erected here are compatible with those from European countries.

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