Combined use of palynology and organic geochemistry in petroleum potential evaluation and paleoenvironmental interpretation of the Kazhdumi Formation (Aptian-Cenomanian) in the southwestern Zagros Basin, Iran

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Abstract

The Kazhdumi Formation of the Bangestan Group is a well-known and important source rock in most oil-fields in the Zagros Basin. In order to examine productivity of this formation in southwestern Iran, and to correlate petrographical and palynological data with geochemical properties, one of the best outcrops of this formation, located in Tange-Maghar 45 km northwest of Behbahan city, was sampled. Fifty-two rock samples were collected from the 270 m thick section which is made up of dark shales with intercalations of marl and limestones, and treated palynologically. Three palynofacies were differentiated based on statistical studies of palynological slides and the rock samples representing these palynofacies were geochemically analyzed. Palynofacies results were then correlated against the geochemical analysis. Palynofacies I (PF-1) with 90 to 100% Amorphous Organic Matter (AOM) presents high hydrogen index (HI) and total organic carbon (TOC) values. PF-1 contains kerogen type I/II and could potentially produce oil. The second palynofacies (PF-2) contains reduced amounts of AOM, HI and TOC and the kerogen is of type II/III, potentially producing oil and gas. Palynofacies III (PF-3) was recognized in a few samples and is characterized by low amounts of AOM, HI and TOC potentially producing meager amount of gas and oil. Plotting palynological data on Tyson ternary diagrams and Van Krevelen geochemical diagrams confirm that the kerogen is of type II/III, III and is originated mainly from algal organic matter. Potential for hydrocarbon generation is high for the samples falling in palynofacies I which contains high amount of kerogen type II while it is relatively good for samples representing palynofacies II with high amounts of kerogen type II, III. Tmax indicates that the samples are mainly mature or have entered the mature phase and are potentially able to produce oil and gas. The high amounts of clear AOM in most samples indicate dominance of redox environmental condition with low oxygen content. The HI/OI ratios curve indicates B and C restricts which confirms reducing environmental condition.

Key words: *Palynology, Organic geochemistry, Kazhdumi Formation, Cretaceous, Zagros Basin, Iran.*

Introduction

The Zagros Mountains which stretches hundreds of kilometers from northwest to southeastern Iran, is a system of large size whaleback asymmetric anticlines, formed as the result of a Late Miocene to Pliocene orogeny. It includes two uplifted areas; Lurestan to the North, where anticlines are deeply dissected and Fars to the South. In between a depressed area known as the Dezful Embayment corresponds to an impressive gathering of 45 oil fields (Motiei, 2003). The great majority of the oil production in Iran is concentrated in this small portion of the Zagros orogenic belt (Fig.1). Accumulation of the oil results from a Cretaceous/Tertiary petroleum system which includes six source rock units of unequal importance, i.e. the basal part of the Garau Formation (Neocomian), the Gadvan (Baremian), the Kazhdumi (Aptian-Cenomanian), the Ahmadi (Early Cenomanian), the Gurpi (Santonian-Danian) and the Pabdeh (Eocene) Formations (Motiei, 2003). In central and southern Dezful Embayment, source rocks of the Kazhdumi Formation are associated with excellent reservoirs.

Very large geological structures and the efficient seal provided by the Gachsaran Formation formed one of the most efficient petroleum systems, which would account for the accumulation of more than 95% of the onshore Iranian oil in place (Alsharhan & Nairn, 1997, Bordenave &Herge, 2005). The Kazhdumi Formation is a well known source rock for these oils though it has been shown that in some places in the Persian Gulf oil fields (e.g. South Pars Oil and Gas Field) it has not produced petroleum (Ghasemi-Nejad *et al.,* 2009).

This paper is aimed to evaluate the source rock qualities and application of Rock-Eval pyrolysis technique to characterization of organic matter and correlation of palynofacies and geochemical data for potential generation of hydrocarbon. The study is based on 52 rock samples collected from the Kazhdumi Formation in Tange-Maghar outcrop section, located in the ridge of Bangestan anticline, near the well number-1 Bangestan, Lat. N 31◦,01′,55″, Long. E 50º,07′,57″, (Fig.1). A palynomorph-based age is also determined and palynofacies analyses were used to deduce the palaeoenvironmental parameters and organic matter types.

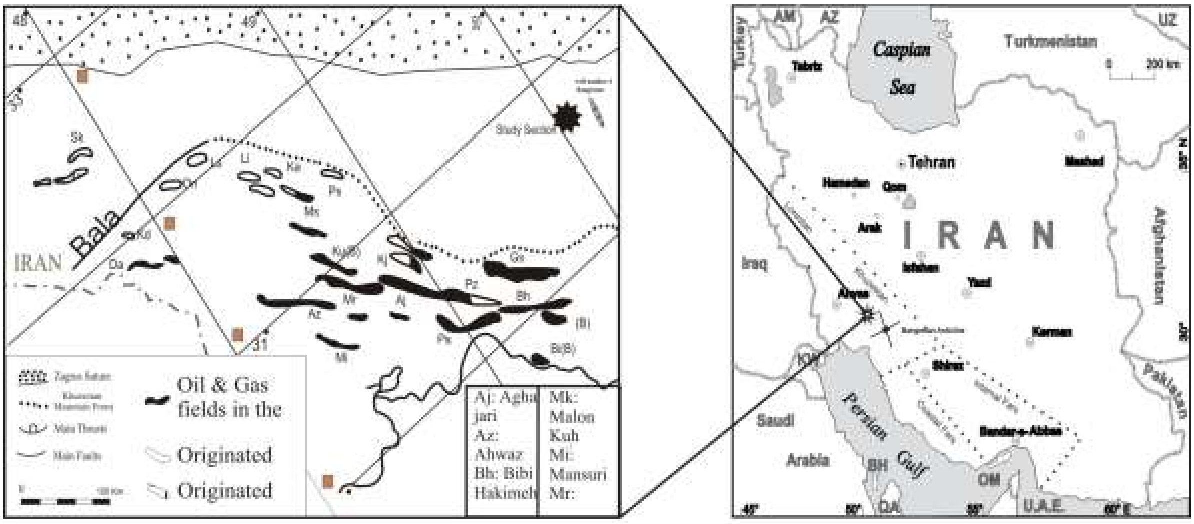

Figure 1: The oil accumulation in the Bangestan reservoir originated from the Kazhdumi Formation (after Bordenave & Burwood, 1995).

Geological setting

The Zagros orogenic belt of Iran is the result of opening and closure of the Neo-Tethys ocean and significantly influenced the generation, migration and entrapment of petroleum in this basin (Alavi, 1994, 2004). This influence was particularly important in the Dezful Embayment, which is one of the world's richest oil provinces, containing some 8% of the global oil reserves (Bordenave & Burwood, 1990; Bordenave, 2003; Bordenave & Herge, 2005). For large parts of the Phanerozoic, the Zagros Basin was covered by a wide, generally shallow intracratonic sea, the shoreline of which fluctuated widely according to sea level changes and low-amplitude subsidence variations. The Permian to Early Miocene succession is dominated by carbonates consisting generally of high-energy oxygenated limestones, with breaks in sedimentation on regional highs and low-energy argillaceous limestones and marls are present in depressions. Carbonate sedimentation was temporarily interrupted either by evaporitic episodes or by sudden influxes of siliciclastics (Alsharhan & Nairn, 1997). Thick evaporite sequences developed as a result of arid climatic conditions during the Triassic (Dashtak Formation), in the Late Jurassic (Gotnia and Hith formations), and toward the end of the Early Miocene (Gachsaran Formation). As a result of the erosion of the Arabian Shield during sea level lowstands and under humid climatic conditions, large quantities of siliciclastic sediments were transported into the shallow marine habitat during the Middle to Late Barremian (Zubair sandstones), Albian (Burgan sandstones), and Early Miocene (Ahwaz/Ghar sandstones).

The Zagros simple Fold Belt was the product of the Latest Alpine orogenic phase (Mio-Pliocene), followed by pronounced post-orogenic uplift still in progress. These movements caused the Cretaceous-Eocene release of hydrocarbons. Subsidence, though, gentle was hardly halted or reversed. The fracturing which resulted from Zagros Folding occurred in the Plio-Pleistocene and facilitated the expulsion of the hydrocarbons from the source rock and migration into the Bangestan and Asmari reservoirs (Alsharhan & Nairn, 1997).

Excellent source rocks were deposited during the Early Silurian, Middle Jurassic (Sargelu Formation), Neocomian (Lower part of the Garau Formation), Aptian-Cenomanian (Kazhdumi Formation), Early Cenomanian (Ahmadi Member) and Middle Eocene/Early Oligocene [(Pabdeh Formation) (Bordenave & Burwood, 1990, 1995; Bordenave & Huc, 1995; Bordenave & Herge, 2005)].

Kazhdumi Formation

The Bangestan Group in southwestern Iran is made up of the Kazhdumi, Sarvak, Surgah and Ilam formations and contains major oil and gas reserves. The Kazhdumi Formation is the major source for hydrocarbons of the Asmari and Sarvak reservoirs (Bordenave & Burwood, 1990, 1995). It is a distal equivalent of nearshore sandstones and shales of the Burgan Formation in Kuwait and the Nahr Umr Fm in both Iraq and Qatar (Alsharhan & Nairn, 1997; Ibrahim & Al-Hitmi, 2000; Alavi, 2004).

At the end of the Aptian, a major regression, which caused the shallow water Aptian carbonates to become emergent, was followed by a low amplitude transgression marked by a sudden influx of clastics. Most of Saudi Arabia, Kuwait and Iraq, West of the Euphrates river were covered by alluvial plain facies, while deltaic sediments rapidly prograded in the Safaniya-Burgan area. The more distal part of the basin was the locus for the deposition of the Kazhdumi Formation (Bordenave, 2002; Ghasemi-Nejad *et al.,* 2009). The depression was limited to the SE by the Fars Platform, where the deposition of the shallow water thin oxic marls was interrupted by temporary emergences. To the north, it was limited by the EW Bala-Rud carbonate shoal, which separated the Kazhdumi depression centered on the present-day Dezful Embayment from the Lurestan depression. To the East, the depression was bordered by a sill, on which anoxic and oxic facies fluctuated according to the sea level change, however little information is available on a possible eastern extension. In Dezful Embayment, the Kazhdumi Formation contains dark, organic rich ammonite bearing shale, argillaceous limestones and calcareous shale of open marine facies (Ghasemi-Nejad *et al.*, 2009). Crude oil generally is considered to be derived from marine organic matter, of algal origin (Bordenave & Burwood, 1995).

Method of study

Palynological preparation

The material used, includes 52 outcrop samples collected from shale and marl layers throughout the Kazhdumi Formation. Laboratory maceration procedures of Traverse (2007) were used to prepare the samples. These procedures include chemical treatment of 15-20 gr of each sample with HCL 20% to remove the calcareous fraction and with HF 50% to remove silicates, sieving with a 10 um nylon mesh and physical fraction by heavy liquid separation with $ZnCl_2$ and mounting on microscope slides using liquid Canada balsam for making 5 slides for each sample. Oxidizing agents were not used, because such treatments can affect the natural colours of palynomorphs and phytoclasts. Light photomicrographs were taken using a Zeiss axioscope microscope equipped with a Canon power shot A70 digital camera. Some of the index forms are presented here (Plate 1). At least three slides of each sample were examined thoroughly. All materials are filed in the collection of the laboratory of Palynology, Department of Geology of the University of Tehran.

Geochemical analysis

The Rock-Eval pyrolysis was carried out at the Research Institute of Petroleum Industry- National Iranian Oil Company (NIOC). Rock-Eval analysis is a standard screening technique used for evaluating the source rock potential of a sedimentary rock (Laforgue *et al.,* 1998) and consists a computer-controlled, temperature programmed pyrolysis oven and oxidation oven (Behar *et al.,* 2001). An approximately, 100 mgr sample of pulverized whole rock was placed in the pyrolysis oven (which has a nitrogen atmosphere). Three main factors are considered in determining the potential of a rock for generating oil and gas:

1) Quantity or generative potential based on TOC, S1 and S2,

2) Quality or type of hydrocarbon generated based on HI and S2/S3 ratio and 3) maturation or level of thermal alteration of the rock with respect to oil generation, based on Tmax and PI.

Guidelines published by Peters (1986), and Peters & Cassa (1994) were used for evaluating the source rock potential based on the Rock-Eval analysis.

Palynology and Palynostratigraphy

Palynological analysis of the samples led to recognition of a relatively rich assemblage of dinoflagellate cysts with many taxa such as:

Achomosphaera ramulifera, *A. neptuni*, *A. sagena*, *Alterbidinium acutulum*, *Cliestosphaeridium* sp., *Coronifera oceanica*, *Cribroperidinium orthoceras*, *C. globatum*, *C. edwardsi*, *Cyclonephelium distinctum*, *Dingodinium* sp., *Dinopterygium*

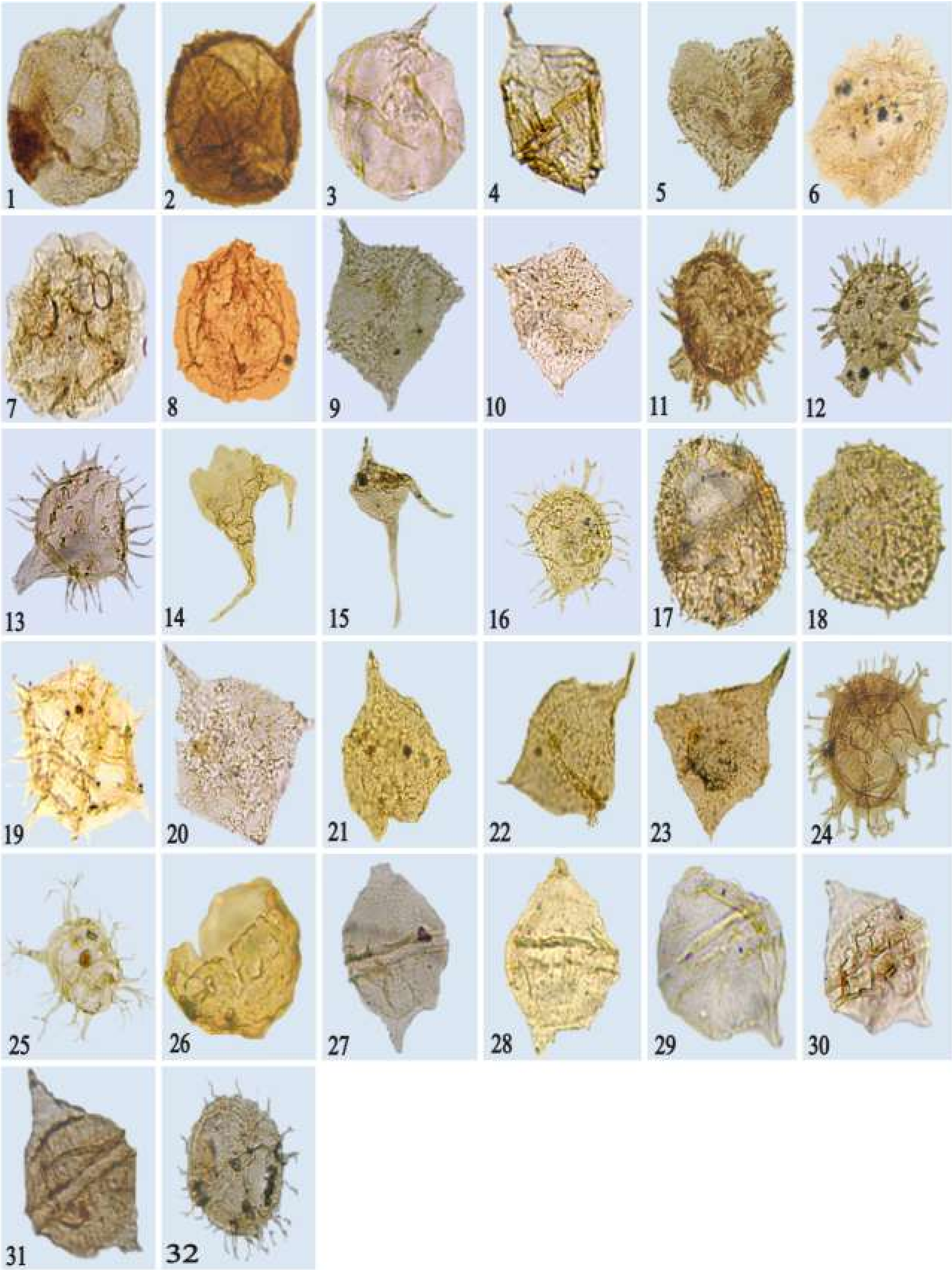

Plate1: For plate Captions see next page

cladoides, *D. tuberculatum*, *Diphyes* sp., *Ellipsodinium rugulosum*, *Endoceratium turneri*, *Epelidosphaeridia spinosa*, *Exochosphaeridium bifidum*, *Florentinia berran*, *F. mantellii*, *F. cooksonia*, *F. deanei*, *Gonyaulacysta helicoidea*, *Hystrichodinium pulchrum*, *Laciniadinium* sp., *Odontochitina operculata*, *Oligosphaeradinium complex*, *Palaeoperdinium spinosum*, *Pervosphaeridium cenomaniense*, *Prolixosphaeridium* sp., *Pseudoceratium polymorphum*, *P. retusum*, *Spiniferites ramosus*, *Subtilisphaera hyalina*, *S. perlucida*, *S. scabrata*, *Trichodinium castanea*, *Xiphophoridium alatum*.

The stratigraphically significant species are *Pseudoceratium polymorphum*; *P. retusum*; *Odontochitina operculata*; *Florentina cooksonia*; *Trichodinium castanea*; *Dinopterygium tuberculatum*; *D. cladoides*, *Xiphophoridium alatum*; and *Subtilisphaera hyalina*. The index species *P. polymorphum* and *P. retusum* recorded from the Upper Aptian in Australia (Oosting et al., 2006), Italy (Torricelli, 2000), Canada (Brideaux, 1977) and Western Europe (Powell, 1992). These taxa have been recorded in the lower part of the section studied. *Dinopterygium tuberculatum* and *D. cladoides* occur mostly in the Middle to Upper Albian as is documented from Egypt (Omran et al., 1990), Western Qatar (El Beialy, 1993; El Beialy & Al-Hitmi, 1994), and worldwide (Williams 1975; Williams et al., 1993, 1998) however, they may extend upward into the Cenomanian. These have also been recorded in the middle part of the section studied. *Trichodinium castanea* has sporadically been recorded from Albian of different places such as Libya (Uwins & Batten, 1988), USA (Hedlund & Norris, 1986), and Western Australia (Cookson & Eisenack, 1962). This species has been recorded in the lower and middle part of the section. *Xiphophoridium alatum* is reported from Albian to Early Cenomanian deposits in Libya (Uwins & Batten, 1988), Australia (Cookson & Eisenack, 1958, 1962; Helby *et al*, 1987), worldwide NML latitude (Brinkhuis *et al.,* 2006), North-east Europe (Fechner, 1985, 1989). This has also been recorded in uppermost part of the Kazhdumi Formation. Accordingly an age of late Aptian to early Cenomanian is inferred for the Kazhdumi Formation in this section.

Reliable and universally valid palynomorph zones are not formalized for this stratigraphic interval. However, the assemblage recorded is reminiscent of the two local palynozones, *Trichodinium castanea* and *Xiphophoridium alatum* zones erected by Al-Ameri and Batten (2001) for the neighboring Baghdad oil field. The *T. castanea* biozone has been defined by the total-range occurrence of *Luxadinium propatulum* and *Trichodinium castanea* in Nahr Umr Formation (Al-Ameri and Batten, 2001). In the section studied, *Luxadinium propatulum* has not been recorded but *T. castanea* occurs through 185 meters of the section between samples No. 5 (Three meters above the base of the section) to sample No. 36, (188 m above the base). The *X. alatum* zone has also been erected by the

Plate1. Light photomicrographs of dinoflagellate cycts recorded from the Kazhdumi Formation. Various magnifications. **1, 2:** *Cribroperidinium orthoceras* (Eisenack) Sarjeant, 1985, sample no. MM.07.17, slide no. 17b, ×725. **3:** *Cribroperidinium globatum (*Gitmez & Sarjeant 1972) Helens 1984 sample no. MM.07.21, slide no. 21b, ×781. **4:** *Cribroperidinium edwardsi* (Cookson & Eisenack, 1958) Davey 1969 sample no. MM.07.5, slide no. 5c, ×550. **5:** *Cyclonephelium distinctum, (*Deflandre & Cookson 1995*)* sample no. MM.07.5, slide no.5a, ×600. **6,7:** *Dinopterygium cladoides* Deflandre, 1935 sample no. MM.07.21, slide no.21a, ×625. **8:** *Dinopterygium tuberculatum (*Eisenack & Cookson) Stover & Evitt, 1978 sample no. MM.07.21, slide no. 21c, ×700. **9,10:** *Endoceratium turneri (*Cookson & Eisenack 1958*)* sample no. MM.07.12, slide no.12c,×600. **11:** *Florentinia cooksoni* Singh, 1971 sample no. MM.07.29, slide no. 29b, ×525. **12:** *Florentinia mantellii (*Davey & Williams 1966) sample no. MM.07.23, ×500. **13:** *Florentinia berran* Below, 1982 sample no. MM.07.19, slide no. 19c, ×550. **14, 15:** *Odontochitina operculata* (Wetzel 1933[a]) Deflandre & Cookson 1955 sample no. MM.07.22, slide no. 22a, ×500. **16:** *Coronifera oceanica* Cookson & Eisenack, *1958* sample no. MM.07.20, slide no.20b, ×313. **17,18:** *Trichodinium castanea (*Deflandre, 1935) Clarke & Verdier, 1967 sample no.MM.07.22, slide no.22a,×550. **19:** *Xiphophoridium alatum (*Cookson & Eisenack 1962b*)* sample no. MM.07.43, slide no. 43c,×500. **20,21:** *Pseudoceratium polymorphum* Eisenack, 1958a sample no. MM.07.5, slide no.5a, ×400. **22,23:** *Psudoceratium retusum* Brideaux, 1977 sample no. MM.07.7, slide no.7a, ×400**. 24:** *Spiniferites ramosus* (Ehrenberg) Loeblich & Tappan, 1966 sample no. MM.07.27, slide no.27b,×500.**25:** *Oligosphaeridium complex* (White 1842) Davey & Williams 1966 sample no. MM.07.18, slide no.18b,×313. **26:** *Canningia denticulate* Cookson & Eisenack, 1960b (Helby, 1987) sample no. MM.07.17, slide no.17a,×675. **27,28:** *Subtilisphaera scabrata* Jain & Millepied 1973 sample no. MM.07.26, slide no.26b,×750. **29:** *Subtilisphaera hyalina* Singh, 1983 sample no. MM.07.17, slide no.17a, ×725. **30,31:** *Subtilisphaera perlucida* (Alberti, 1961*)* sample no. MM.07.16, slide no.16c,×750. **32:** *Achmosphaera ramulifera* (Deflander, 1937b) Evitt 1967 sample no. MM.07.22, slide no.22a, ×600.

aforementioned authors based on the total range of the dinoflagellate cyst species *Dinopterygium tuberculatum* and *Xiphophoridium alatum* within the upper part of the Nahr Umr Formation and the lower part of the Mauddud Formation These species occur here from sample number 42 (228 m above the base of the section) to sample number 50 (270 m abone the base of the section) encompassing a thickness of 42 meters of the upper part of the section.

Palynofacies analysis

Palynofacies studies were undertaken to assess the paleoenvironmental conditions under which the Kazhdumi Formation was deposited and to evaluate whether the formation in this area is of oil or gas-prone. Three types of palynofacies were distinguished based on the relative abundances of the three main groups of palynological elements; marine palynomorphs, phytoclasts and amorphous organic matter (AOM). Marine palynomorphs recorded in the samples refer to dinoflagellate cysts and to a much lesser degree foraminiferal test linings. Phytoclasts consist of different parts of plants particles carried into the basin, while the term AOM refers to the particles with a lack of distinct shape, outline and structure (Batten, 1996). Different types of palynofacies classifications and AOM characterization and classification for palaeoenvironmental interpretation have been published (e.g. Van der Zwan, 1990; Whitaker *et al.,* 1992; Tyson, 1993, 1995; Batten, 1996; Batten & Stead, 2005). Three types of palynofacies identified herein were differentiated based on Tyson's (1993) classification.

Palynofacies Type I (PF-1); this facies is dominated by AOM (90-100%) with minor amount of marine palynomorphs (0-2%) and phytoclasts (2-10%). This facies is equivalent to palynofacies type IX of Tyson (1993) that indicates a distal suboxic-anoxic basin. Petrographical characteristics indicate dominance of Kerogen Type I and/or II (I ≥ II), (Fig. 2).

Palynofacies Type II (PF-2); this facies contains high percentages of AOM (45-65%) while marine palynomorphs varies from 2-8% and phytoclasts make up 15-30%. This facies is equivalent to palynofacies VIII of Tyson (1993) indicating a distal anoxic shelf with dominance of kerogen type II (II›I), (Fig. 3).

Palynofacies Type III (PF-3); in this facies AOM percentage is moderate to low (10-20%) and samples contain a relatively higher amount of marine palynomorphs (30-50%). Phytoclasts percentages range from 25 to 35%. This facies is comparable to that of type V of Tyson's (1993) and reflects an oxic shelf environment. Related kerogen is of type III,IV(III>IV), (Fig. 4).

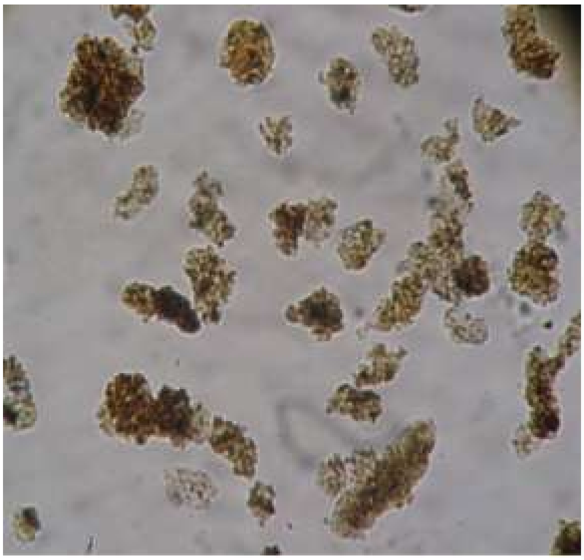

Figure 2: Palynofacies Type I (PF-1) showing dominance of AOM, sample no: MM.07.30, width of photomicrograph 480µm

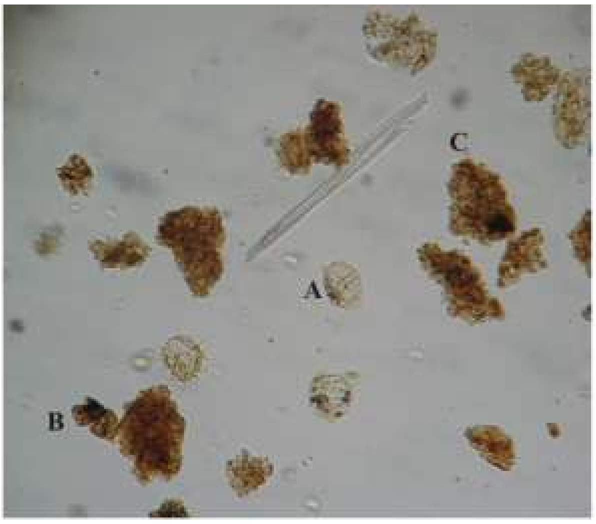

Figure 3: Palynofacies Type II (PF-2), A: dinoflagellate, B: terrestrial debris, c: AOM, sample no: MM.07.19, width of photomicrograph 600µm

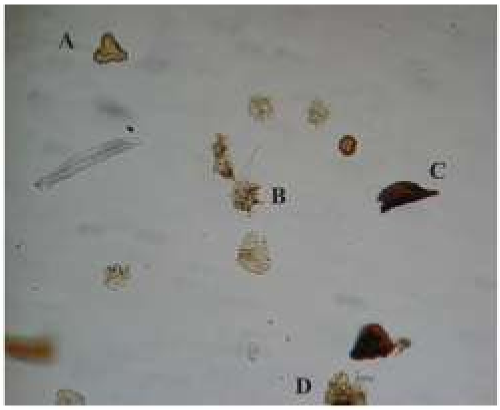

Figure 4: Palynofacies Type III (PF-3), A: spore, B: dinoflagellate, C: wood fragment, sample no: MM.07.21, width of photomicrograph 520µm

Palaeoenvironmental interpretation

Interplay between several factors affects the type of phytoclasts and palynomorphs recovered from modern and ancient sediments. Such factors include climate and vegetation in their natural environments, the mode and length of transportation into depositional basin, conditions in the depositional basin, burial rate, post burial changes and tectonics (Batten, 1996; Jaramillo & Oboh-Ikuenobe, 1999).

Terrestrial organic components consists woody material, spores and pollen grains and cuticles. Marine facies contains amorphous organic matter, dinoflagellates and occasional chitinous inner linings of foraminifera. Foraminiferal test linings are also useful environmental indicators, being common in marine coastal and shallow shelf environments (Lister & Batten, 1988; Tyson, 1993, 1995). The ternary diagram (Fig. 5) shows that the depositional environment of the Kazhdumi Formation was relatively suboxic-anoxic reflecting a restriction to open marine realm. AOM increases during transgression and early high stand (Li & Habib, 1996). Increase in AOM suggests dysoxic-anoxic environmental conditions or stratification of the water masses (Powell *et al.,* 1990, Tyson, 1995) and it is the dominant kerogen constituent in distal dysoxic to anoxic shelf environments (Tyson, 1995)

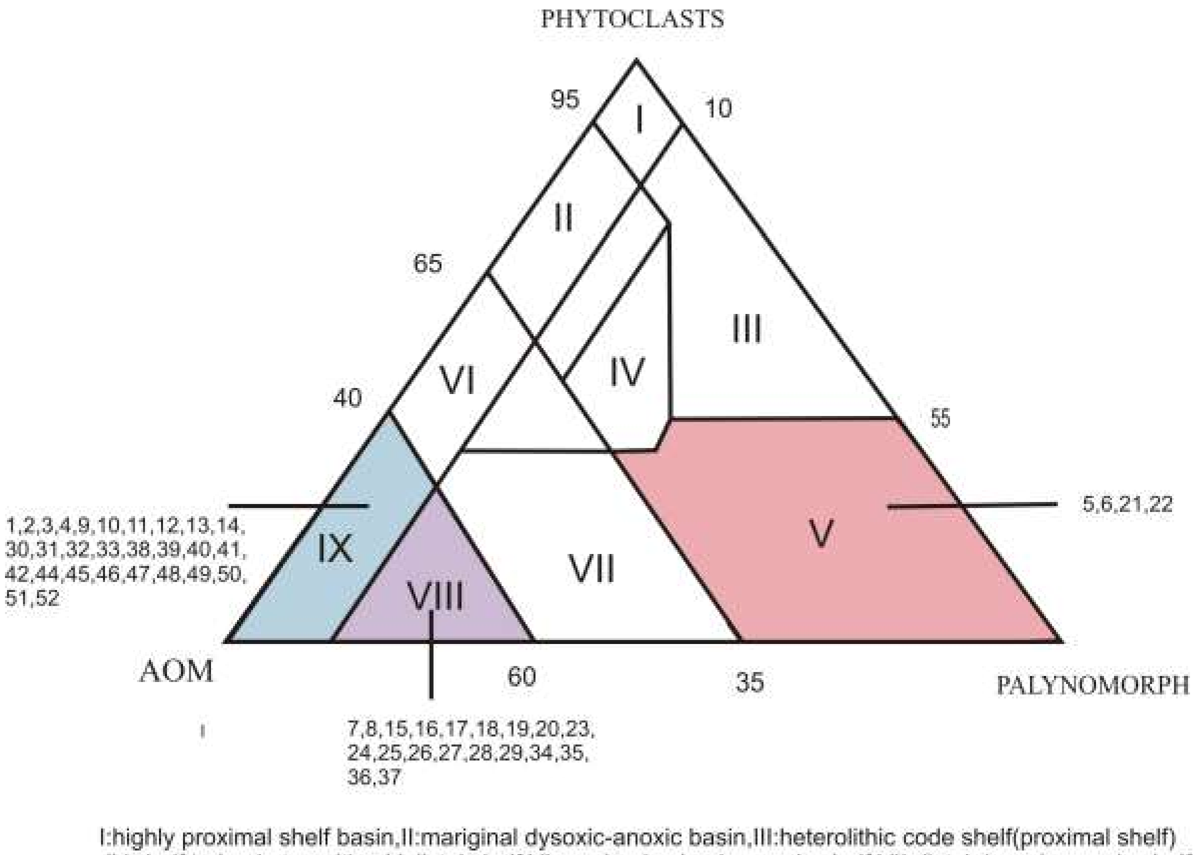

Figure 5: Schematic illustration of palynofacies and palynological groups used for paleoenvironmental interpretation

The high percentage of AOM in samples confirms that the Kazhdumi Formation has a good potential of being source rock in most parts of the section studied. These parts are affected by the changes in depositional environment probably as a result of sea-level changes that have influenced sedimentation in this region. The increase in percentage of AOM and marine palynomorphs indicate a transgression and/or a decrease in terrestrial influx in the area.

Geochemistry

Eight samples representative of the three palynofacies differentiated were selected and pyrolysed in the Research Institute of Petroleum Industry, National Iranian Oil Company (NIOC). The pyrolysis values collected on the computer include: Tmax, S1, S2, S3, TOC, HI, OI and PI (Table 1).

Table 1: Rock-Eval results for the samples analyzed

SAMPLE	**SI**	**S2**	**S3**	**TMAX**	**HI**	**OI CO2**	**TPI**	**TOC**
K 04	1.3	39.65	1.2	427	574	17	0.03	6.91
K 05	0.13	1.86	1	426	179	96	0.07	1.04
K 07	0.16	3.06	1.03	435	234	79	0.05	1.31
K 20	0.13	4.12	1.45	435	228	80	0.03	1.81
K 21	0.08	1.5	1.24	441	152	125	0.05	0.99
K 31	0.94	29.73	1.2	426	542	22	0.03	5.49
K 36	0.08	7.35	1.93	431	249	65	0.01	2.95
K 47	0.45	22.65	0.78	424	546	19	0.02	4.15

The Rock-Eval pyrolysis technique followed in this study is based on the methodology described by Espitalie *et al.,* (1977, 1985), Espitalie (1986), Peters (1986), Peters & Cassa (1994).

Tmax: represents the temperature at which the maximum amount of hydrocarbons degraded from kerogen (S2 peak) are generated. S1: represents milligram of hydrocarbons which are thermally distilled from one gram of rock. The S1 peak is measured during the first stage of pyrolysis at the fixed temperature of 300ºC. S2: indicates milligrams of hydrocarbons generated from degradation of the kerogen in one gram of rock during the second stage of pyrolysis. The S1/S2 ratio and Tmax indicate the level of maturity of the organic matter. The fourth value S3, expresses the milligram of carbon dioxide generated from a gram of rock during temperature programming. Two other obtained values are the Hydrogen Index (HI) and Oxygen Index (OI). HI is defined as the ratio of S2/TOC, and represents the quantity of pyrolysable organic compounds from S2 relative to TOC in the samples. OI is defined as S3/TOC and corresponds to the quantity of carbon dioxide from S3 relative to TOC. The production index (PI) is defined as the ratio S1/(S1+S2). PI is an indicative of the amount of hydrocarbon which has been produced geologically relative to the total amount of hydrocarbon which the sample can produce.

Source rock evaluation

Organic matter (kerogen) type:

Organic matter type is an important factor in evaluating source rock potential and has important influence on the nature of the hydrocarbon produced (Tissot & Welte, 1984; Barker, 1979). Hydrocarbons are generated from sediments containing sufficient organic matter which undergone thermal maturation through catagenesis. Acquiring this information is important for understanding the relationship between depositional environment and hydrocarbon generation. This simply follows the fact that environments are characterized by definite maceral assemblages, implying a link between environment and source rock geochemistry. The general rule is that macerals rich in lipids will form a potential source rock capable of producing abundant liquid and gaseous hydrocarbons, whereas lignin-rich maceral will produce only a moderate amount of gaseous hydrocarbons and little if any liquid hydrocarbons. Phytoclasts are generally rich in lignin and cellulose. However certain parts may show an abundance of lipids and proteins. For example leaves are enriched in lipids and related chemicals and miospores are rich in sporopollenin (Hunt; 1979, 1996). Palynomorphs are generally richer in lipids than phytoclasts. They do not contain lignin and there is usually a higher protein content than in phytoclasts. The amount and type of hydrocarbons formed from a source rock is particularly dependent upon the kind and abundance of maceral.

Kerogen type I is characterized by high values of HI (>600) and represents organic matter produced by algae or cyanobacteria, accumulated mainly in anoxic lacustrine and marine depositional environments (Peters, 1986; Hunt, 1996). Kerogen type II shows medium values of HI (300-600). It is composed of mixtures of phytoplankton, zooplankton and microorganisms preserved in a reduction environment. Kerogen type III presents relatively low value of HI (50-200) and essentially derived from land plants. Generally kerogens with HI less than 50 are inert so a reasonably robust relationship exist between increasing percent of terrestrial organic macerals and decreasing HI values,[Peters & Cassa, 1994; Tyson, 1995, Table 2].

Kerogen Type I/II are usually associated with laminated intervals deposited on a periodically dysoxic to anoxic sea floor while Type III terrestrial organic matter preserved in bioturbated sediments deposited under predominantly dysoxic to oxic conditions, in limited horizons (Barker, 1974).

It is suggested that gas-prone organic matter bears hydrogen index (HI) of less than 200 mgHC/gTOC, mixed oil and gas-prone facies between 200 and 350 while oil-prone facies has values of 350 to more than 1000 (Jones,1987). Peters (1986) proposed HI of less than 150 for mature gas-prone organic matter, a range of 150-300 for gas oil-prone organic matter and an HI of more than 300 for oil-prone organic matter. Plotting hydrogen versus oxygen indices on a modified Van-Krevelen diagram (Fig. 6) for the studied samples shows that the Kazhdumi Formation is dominated with Kerogen type II. Values of HI range from 152 to 574mgHC/gTOC reflecting oil producing nature of the organic matter for the majority of the samples.

Relationship between HI and Tmax is used to determine the percentage of kerogen Type II in the mixed organic matter (Fig. 7). It is clear that most of samples from palynofacies type I have a higher percentage of kerogen Type II that indicates their capability to produce oil associated with gas producing kerogen Type III.

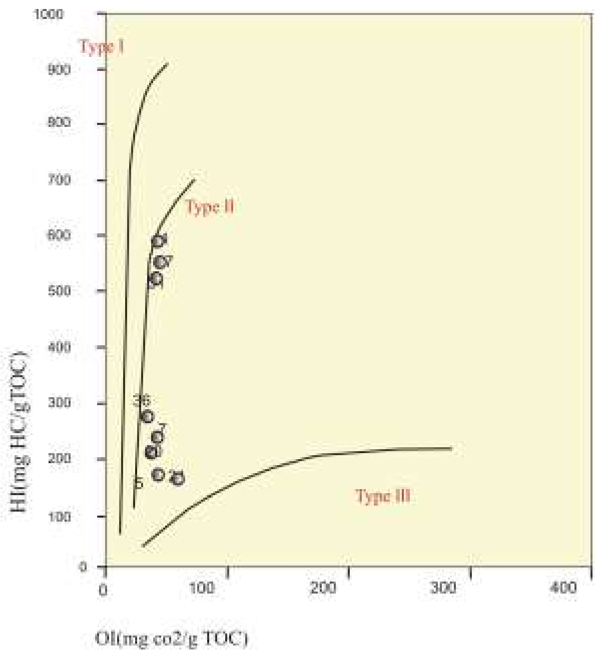

Figure 6: Modified Van Kervelen diagram of the Kazhdumi Formation for the samples studied.

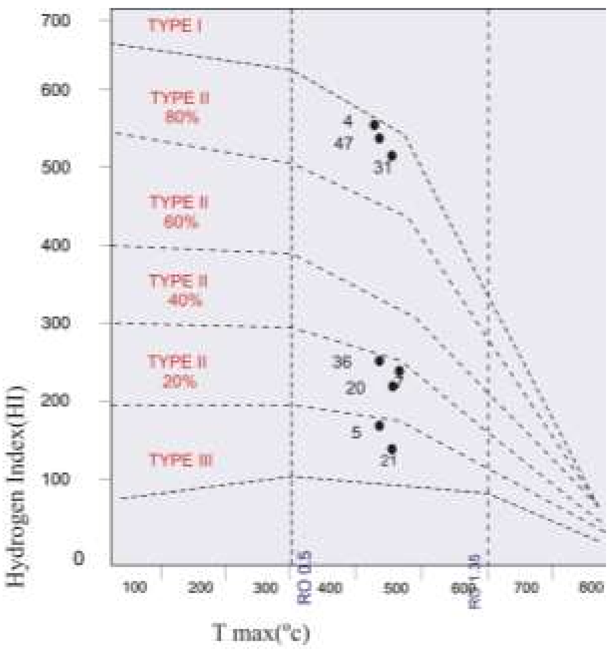

Figure 7: Plotting HI versus Tmax for the Kazhdumi Formation to show the percentage of the kerogen type II.

Source rock quantity

The organic matter richness of the source rocks is usually estimated by using the total organic carbon content (TOC). In marine facies, low (<1%) TOC values often characterize intervals containing primarily terrestrial organic matter, whereas higher TOC content are most often attributed to marine forms of organic matter (Peters, 1986). The type of organic matter and host sediment provenance can be used to unravel stratigraphic stacking patterns and to understand the development of accommodation space in a basin (White, 1999). Barker (1996) considered a TOC value of 1.0% as the lower limit for an effective source rock and believes a source rock with less than 1.0% TOC could never generate enough oil to initiate primary migration. Peters & Cassa (1994) however, believe that the TOC values between 0.5 and 1.0% indicate a fair source rock generative potential, from 1.0 to 2.0% reflect a good generative potential and TOC value greater than 2.0% refer to a very good generative potential (Table 2).

Table 2. Guideline for pyrolysis parameters of quality, quantity and thermal maturity (From Peters & Cassa, 1999)

Quantity	TOC(wt%)	S1(mg HC/ g rock)	S1(mg HC/ g rock)
Poor	0 - 0.5	0 – 0.5	0 – 2.5
Fair	0.5 - 1	0.5 – 1	2.5 - 5
Good	1 – 2	1 - 2	5 - 10
Very good	2 – 4	2 – 4	10 - 20
Excellent	>4	>4	>20
Quality Kerogen type	HI(mg HC/ g TOC)		S2/S3
None	<50	<1	IV
Gas	50 – 200	1 – 5	III
Gas & Oil	200 – 300	5 – 10	II/III
Oil	300 – 600	10 – 15	II
Oil	>600	>15	I
Maturation TAI		R0 (%)	Tmax(^{0}C)

The pyrolysis results gained from the samples studied are shown in Table 2. The highest TOC value is measured 6.91% and the lowest 0.99%. Most of the samples reveal a good source potential. Samples numbered 4, 31 and 47 representatives of palynofacies Type I dominated with AOM and correspond with type IV of Tyson (1993) show high values of TOC 6.91, 5.49, 4.15 and kerogen type II as revealed in palynofacies studies. Samples numbered 7, 20 and 36 representative of palynofacies Type II dominated with AOM and to a lesser degree phytoclasts with orderly TOC values of 1.31%, 1.81% and 2.95% reveal relatively good source richness. These values are in accord with Kerogen Type II and II/III. Sample numbered 5 and 21 from palynofacies Type III have the lowest TOC values of 1.04% and 0.99%. These are in accord with high content of Phytoclasts and Kerogen Type III as shown by Palynofacies studies.

Source rock maturity

The Tmax is the temperature at which the S2 (mg HC/ gr rock) reaches its maximum amount during Rock-Eval pyrolysis. Peters (1986) proposed that many maturity parameters especially Tmax depend on the type of organic matter, from which they derived. Rocks with HI value above 300 mgHC/g TOC will produce oil, those with HI values between 300 and 150 mgHC/gTOC will produce oil and gas while, those with HI values between 150 and 50 mgHC/gTOC will produce gas. Tmax values lower than 435◦ C indicate immature organic matter. Tmax values between 435◦ C and 455◦ C indicate oil window conditions (mature organic matter). Values between 455◦ and 470◦ C represent the wet-gas zone and over mature organic matter (Peters, 1986). The thermal maturation level for oil-prone type I kerogens is often higher than for the other types of kerogen (Tissot *et al.,* 1987).

Plotting values of HI versus Tmax indicate the type of organic matter and maturity level for the analyzed samples (Fig. 8). Thermal maturity of the samples is estimated in mature stage.

Generation potential

The generation potential is usually expressed by the TOC/(S1+S2) ratio (Fig. 9). Very good and good generation potential is confirmed by dominance of kerogens Type I & II (Peters, 1986). Fair generation potential is supported by presence of kerogen Type III, which is mainly gas prone. Values of the total generic potential (S1+S2) range from 1.99 to 40.95 mg/gHC. The (S1+S2) versus TOC shows that samples from palynofacies Type I have a very good source potential.

All of the samples from palynofacies II (samples 7, 20 and 36) show a good to fair source potential with moderate content of kerogen Type II as compared with palynofacies I. Samples 5 and 2 from palynofacies III recorded a poor source potential probably due to the increased amount of kerogen Type III.

Organic facies

Jones (1987) specified organic facies by plotting HI versus OI values based on which classified environmental condition from thoroughly anoxic (high HI, low OI) to completely oxic environments (HI lower than 100 mgHC/gTOC).

Figure 10 shows this diagram for the samples studied. The samples are all located in restricts B and C indicating relatively anoxic marine environment with moderate rate of sedimentation. These environmental conditions confirm the results gained from palynological studies.

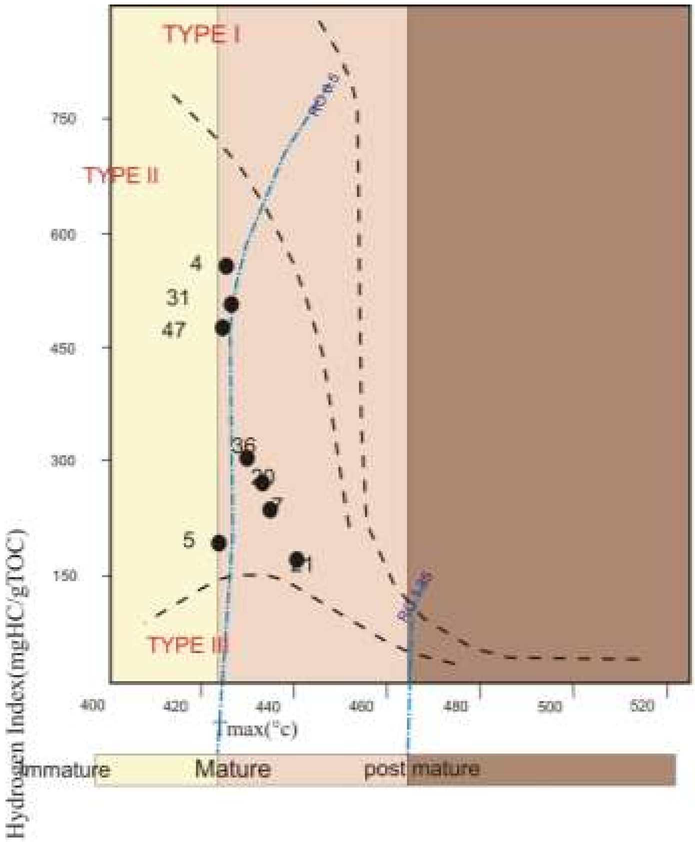

Figure 8: A plot of HI versus Tmax indicating type of organic matter and maturity level for the analyzed samples.

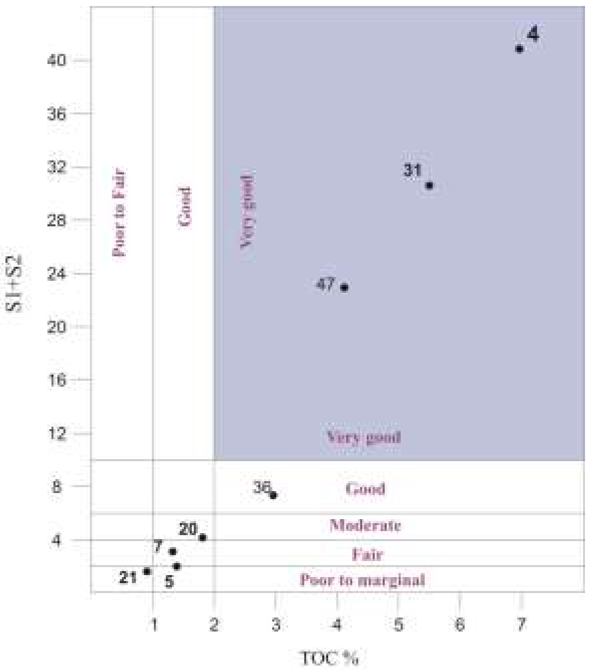

Figure 9: Plotting TOC versus S1+S2 to indicate generation potential of the samples studied.

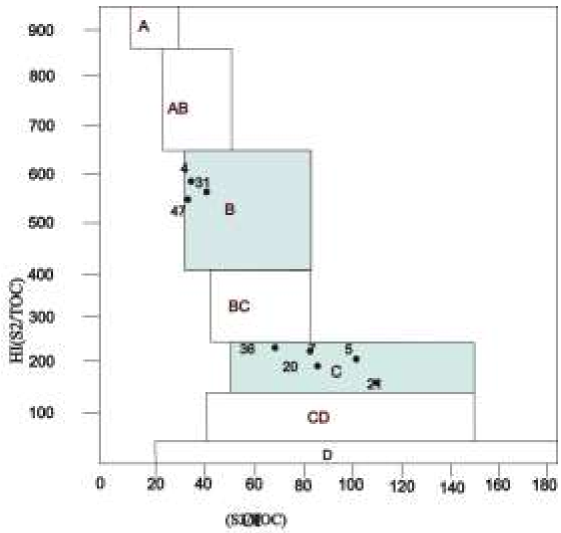

Figure 10: A plot of HI versus OI to indicate the organic facies.

Conclusions

The Kazhdumi Formation, a well-known source rock for petroleum in many part of the Zagros basin, was studied palynologically and geochemically in a section in southwestern Iran. Based on the presence of index species of dinoflagellate cysts an age of Late Aptian to Early Cenomanian was determined to the formation. The two index dinoflagellate cysts *Trichodinium castanea* and *Xiphophoridium alatum* based on which a local biozonation has been erected for the neighbouring Baghdad were also recorded. Regionally this section is the deeper eastward extension of the basin which deposited the Kazhdumi Formation during Aptian-Cenomanian over hundreds of kilometers in Iraq, Iran and Southern Persian Gulf countries. Towards South, in northern Persian Gulf great gas Field in Iraq and the neighboring countries the Kazhdumi Formation does not produce oil or gas but in Parts bears characteristics of reservoir for petroleum (Burgan Member).

The samples examined show that the formation is rich in marine organic matter associated with laminated intervals deposited under dysoxic to anoxic conditions. Deposition evidently occurred in offshore and open marine conditions under slight influence of fluvio-deltaic conditions. This is supported by palynological evidences such as moderate species diversity in dinoflagellates, abundance of chorate forms, relative ratio of gonyaulacean over peridiniacean groups, and abundance of Oligosphaeridium species. Palynofacies analyses were supported by geochemichal evidences indicating that the primary source of organic matter in the Kazhdumi Formation at the studied section is of marine origin. Rock-Eval analysis shows the predominance of kerogens Type I/II with marine element source and shows that the deposits have high organic content and are thermally mature. HI and OI values also indicate mostly marine organic matter with less preservation of terrestrial organic matter, a continuation of organic matter sedimentation/preservation style in the Kazhdumi Formation. The higher average value of TOC shows a direct relationship to the units characterized by a high percentage of AOM. Where the highest amount of TOC is observed, AOM surpasses 80% of the total kerogen.

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