Title	Primary results of sedimetological research on the upper Jurassic to lower Cretaceous carbonate rocks in NW Zagros Mountains, Iran
Author(s)	KANO, Akihiro; TAKASHIMA, Chizuru; MATSUMOTO, Ryo; SHIGENO, Jun
Citation	Journal of science of the Hiroshima University. Series C, Earth and planetary sciences , 11 (2) : 119 - 131
Issue Date	2003-08-25
DOI	
Self DOI	10.15027/53165
URL	https://ir.lib.hiroshima-u.ac.jp/00053165
Right	
Relation	

Jour. Sci. Hiroshima Univ., Ser. C. Vol. 11, No. 2, 119-131 (2003)

Primary results of sedimetological research on the upper Jurassic to lower Cretaceous carbonate rocks in NW Zagros Mountains, Iran

By

Akihiro KANO, Chizuru TAKASHIMA, Ryo MATSUMOTO and Jun SHIGENO

with 7 figures

(Received on August 22, 2002)

Abstract: The upper Jurassic-lower Cretaceous carbonate extensively distributed in Zagros Mountains (southern Iran) is correlated to hydrocarbon reservoir rocks, however has not been studied with sedimentological aspects. The studied section of about 1000 m thick exposed in Kuh-d-Yaghma (Aligdaz Province) mainly consists of shallow marine facies exhibiting sedimentary structures, such as paleosols, paleokarsts, biostromes, and stromatolites. The section was subdivided into nine units based on the results of observation of outcrops and thin sections. Depositional ages were estimated by fossil occurrences and strontium stable isotope.

Units 1 and 2 represent subaerial-meteoric diagenetic structures (paleosols. paleokarsts, and banded cements) and dolomite of a mixed-water origin. Originally, the dolostone was highly-permeable coarse-grained sediment, in which dolomitization selectively subjected. These diagenetic processes may have been associated with global sea-level low or a regional tectonic event during Kimmeridgian, and formed lithified substrate, which is suitable for sedentary organisms. Unit 3 abundantly yields potential reef-building organisms, such as stromatoporoids, corals, and calcareous algae. However, the dominant constituents are broken uniserial branching stromatoporoids, their constructions should be regarded as biostromes and did not form reef framework. Fossil association and strontium isotopic ratio indicate that this unit was deposited in Tithonian. Units 4~7 are alternations of two deeper and two shallower facies. The deeper units (units 4 and 6) mainly consists of micritic limestone with biofacies characterized by ostracodes, bryozoans, and sponge spicules. The shallower units (units 5 and 7) represents stromatolites, oncoids, and ooids with rich assemblage of calcareous algae. Jurassic/Cretaceous boundary was placed in unit 5. First appearance of orbitolinid foraminifers at the base of unit 7 was interpreted to correspond to the base of Barremian. Units 8 and 9 consist of four upward-shallowing sequences. The base of each cycle consists of thinly bedded limestone containing brachiopod shell, and change into thickly bedded and massive limestone with shallow marine stromatolies and fauna, such as corals and rudists. Gradual decrease in thickness of the sequence indicates that the platform was in progradation due to accumulation of the carbonate deposits.

I. Introduction

The Mesozoic carbonate succession of Middle East is the one of the largest hydrocarbon reservoirs in the world. Especially, the Jurassic and Cretaceous in Persian Gulf combine several developmental conditions for a reservoir. The strata were deposited under oceanic anoxic events (OAE; Arthur and Schlanger, 1979), preserved significant primary and secondary porosity, and developed ideal cap rocks (e.g. the Tithonian Hith Anhydrite). Mainly petroleum geologists using various methods including boring and seismic profiling have carried out researches on the carbonate reservoir in Persian Gulf. Although stratigraphic framework of the Mesozoic was constructed by limited data of boring cores accompanied with field survey (e.g. Setudehna, 1978), problems were left in understanding details in depositional facies and age determination.

In Zagros Mountains area, located SW of Main Zagros Thrust bordering Iranian and Arabian Plates, outcrops

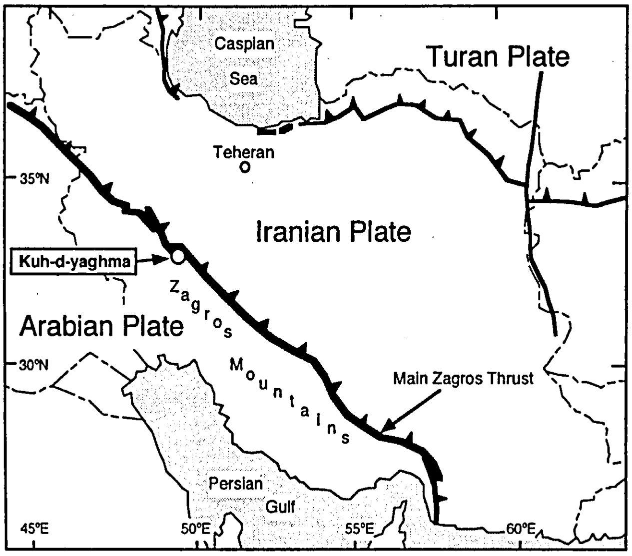

Fig. 1 : Location of the study area, Kuh-d-yaghma in northwestern Zagros Mountains, Iran.

extensively expose the Mesozoic carbonate succession, which is considered as an equivalent of the hydrocarbon reservoirs. However, no research has been published with a focus on depositional facies and paleontology of the Mesozoic succession in Zagros.

Japan National Oil Cooperation provided us an opportunity to study basic stratigraphy and geochemical properties of the Mesozoic in Zagros Mountains, in order to predict the reservoir potential of the equivalent strata in Persian Gulf. This paper represents the primary results on stratigraphy, sedimentary petrology, and paleontology.

II. Studied locality, methods and definitions

Three sections (K1~3) are all located at Kuh-d-yaghma (33°11'28"N, 49°29'47"E) near Aligdaz in northwestern Zagros Mountains (Fig. 1), and were investigated during expeditions in 2000~2001. The sections expose the upper Jurassic to lower Cretaceous carbonate rocks. In terms of their stratigraphic relation, the thickest (571 m) K1-section covers is lower, and without a significant gap, is succeeded by the upper K2-section (395 m). K3-section (136 m) covers the middle horizons of K1-section, which contain abundant reef-building organisms (Fig. 2). Number of collected specimens exceeds 300, from K1-section 100 specimens were collected in about 5m interval, 139 specimens were collected from K2-section in about 3m interval, and 65 specimens were collected from K3-section in about 2m interval. For observation of microfacies, one or two thin sections were made from each collected specimen. Thin sections were observed under optical microscope and cathodoluminescence method. It should be noted that numbering of the specimen is in the ascending order for K1-section (K-1 to K-100) and K3-section (K-301 to K-365), but in the descending order for K2-section (K-101 to K-239). Descriptive terms of limestone rock types and porosity types follow to Dunham (1962), Embrie and Klovan (1971) and Choquette and Prey (1970).

The investigated strata must be correlated to upper Jurassic Surmeh Formation and lower Cretaceous Fahliyan Formation (James and Wynd, 1965). However, it was difficult to place the boundary of the two formations, because we found difference in facies and thickness between the investigated strata and the type section. Another problem in stratigraphic correlation is that the studied sections lack anhydrite horizons, which occurs between the Surmeh and Fahliyan Formations in other areas. Therefore, we do not used names of defined stratigraphic units of previous studies.

III. Stratigraphy and facies of the sections

Nine units, numbered in the ascending order, were recognized (Fig. 2) due to the results of observation of outcrops and thin sections. Description of stratigraphy and facies (litho- and biofacies) will be started form stratigraphically lower section (K1-section), then K3-section, and finally the upper K2-section.

A. K1-section

This section is exposed in the middle flank of Kuh-d-Yaghma (Fig. 3a), 571m in the total thickness, and subdivided into five units.

1. Unit 1 (K-1~16)

Unit 1, 82m in thickness, mainly consists of thickly bedded or massive limestone of dark gray color. Paleosols (Fig. 3b) were recognized at least two horizons (K-6 and K-10) in the lower part, where the limestone is altered and exhibiting red color. The upper 30m is characterized by burrowed massive limestone intercalated with thin dolomitic layers.

Limestones of unit 1 are generally grain~packstone containing calcareous algae, corals, and brachiopods, but difference in dominant constituents is recognized between the lower and upper parts. Specimens lower than K-12 are peloidal and abundant in foraminifers, brachiopods, mollusks, and echinoderms. Ostracodes occur densely in K-1, K2, and K-4. In the horizons upper than K-13, foraminifers, brachiopods, and ostracodes became uncommon. The fossil constituents are less diverse and

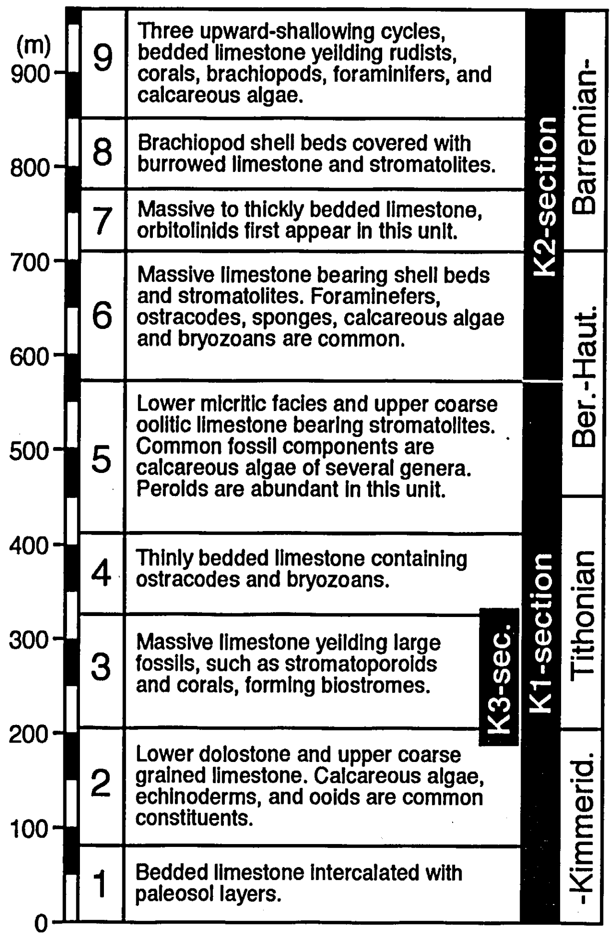

Fig. 2 : Stratigrahy and estimated ages of three sections (K1~3-sections) with brief description of lithology.

dominated by mollusks and echinoderms. Instead, corals are common in K-13 and K-16.

Ooids were recognized in K-15 and K-16, and intraclasts occur in K-8. Dolomite rhombs occur from K-5 and increase upwards. Organic matter is common, especially found in intercrystal porosity of dolostone and moldic porosity.

2. Unit 2 (K-17~32)

Unit 2, 123m in thickness, consists of the lower massive dolostone (about 60m; Fig. 3c) and the upper dark gray limestone (about 60m). The base of this unit is clearly marked by abrupt facies change from limestone to dolostone. The dolostone exhibits white to light gray in color, but partly black and contains much of organic matter. The upper limestone appears massive and partly coarse-grained. The top of the unit is accompanied with breccias and paleo-speleothems, which were originated from some subaerial exposed events.

Microscopic observation clearly reveals that the rocks of unit 2 were originally composed of coarse-grained carbonate. The dolostone, which occurs below K-20, consists of coarse-grained (about 1 mm in diameter) dolomite crystals (Fig. 3d). The rhombic crystals have brown-colored centers fringed by transparent margins. Original depositional fabrics were preserved rarely, but in black-colored part appears grainstone with coarse fractions of ooids, oncoids, mollusks, and calcareous algae. The dolostone develops intercrystal porosity but organic contents are insufficient except for black-colored ones.

The upper (above K-21) limestone appears grain~packstone facies and grainstone becomes dominant to the upward. Dolomite was only recognized from K-23. Common fossil constituents are calcareous algae, foraminifers, echinoderms, and mollusks. Some calcareous algae could be identified as *Kurnubia* sp. and *Salpingoporella* sp. Foraminifers are mostly smaller forms and *Protopeneropolis* sp. were found from K-27 and K-30. Brachiopods also became common from K-23. Stromatoporoids were found from K-25, and corals were in K-27 and K-28. Other than fossil components, ooids are prominent, and peloids occur in K-21, K-27, and K-28. Moldic porosity develops in K-26 and K-28.

3. Unit 3 (K-33~53)

Abundant large fossils characterize massive and thickly bedded limestone of this unit. The total thickness of the unit is 120m. Assemblage of the large fossils is dominated by stromatoporoids of uniserial branching forms (Fig. 3e). This potential reef-building fauna shows bufflestone or floatstone textures in laterally extended lentic bodies, rather than forms reef framework. Breccia of a possible paleo-karstic origin was found at the top of this unit.

The limestone fabric of this unit is mainly grainstone in the lower part, and changes packstone and wackestone in the upper part, due to decrease in local water energy. This unit is rich in large fossils. Stromatoporoids abundantly occur from K-42 to J-50, and corals (including a hydrozoa *Spongiomorpha)* are most common from K-49 to K-52. Several stromatoporoid taxa were recognized, and *Cladocoropsis* sp. (Fig. 3f) of uniserial branching forms is the most dominant genus. This genus is characteristic in terms of lack of distinct horizontal skeletal elements. *Parastromatopora* and *Milleporidium* (Fig. 3g) were also found. As other fossil components, calcareous algae, foraminifers, mollusks, and echinoderms are common. The following calcareous algae were identified, *Kurnubia* (K-38 and K-48), *Salpongoprella* (K-46 and K-47), and *Dasycla* (K-40 and K-42). Bryozoans are only common in the upper part, especially were densely found in K-48.

The lower unit 3 contains peloids, and the horizons above K-37 tend to contain ooids. Common porosity types of this unit are moldic and fracture porosities.

4. Unit 4 (K-54~69)

Unit 4, 75 m in thickness, easily weathered and thinly bedded limestone, which can be recognized from a distance due to light gray color.

The limestone exhibits wackestone to peloidal grainstone fabrics. To the upward, the grainstone tends to be dominant, and fossil components decrease in both terms of abundance and diversity. Bryozoans and ostracodes are characteristic in this unit. Bryozoans (Fig. 4a) are abundant in K-55 and K-56, and also found in the upper part of the unit. Ostracodes are abundant in the lower unit. Other common fossil components are foraminifers, mollusks, and echinoderms, however abundance of foraminifers is lower than units 2 and 3. Brachiopods increase in the upper horizons. Calcareous algae were found in K-55, K-56, and K-59, and some of the algae were identified as *Kurnubia* sp. Potential reef-builders are rare, but stromatoporoids were found in K-57 and K-62, and corals were in K-57, K-61, and K-70.

Common non-skeletal grains are only peloids, which are abundant in the upper unit. Grains indicating high-energy environments, such as oncoids, ooids, and intraclasts, were not found. Common porosities are fracture and moldic types, in which organic matter is preserved.

5. Unit 5 (K-70-100)

The uppermost 160 m of K1-section belongs to unit 5. It consists of lower massive and thickly bedded micritic limestone and the upper massive coarser-grained limestone. The unit exhibits sedimentary structures indicating shallow marine environments, such as paleo-karst and possible birds-eye. However, the most characteristic structures are stromatolites (Fig. 4b), which were recognized at least in three different horizons.

This unit is throughout characterized by abundance of peloids. However due to the dominant microfacies, it can be divided into the lower wackestone (K-70~83), and the upper grainstone (K-84~100) containing oncoids and ooids. The biofacies of this unit is low in diversity, and mollusks are the only constituents occurring continuously. The poor biofacies is distinctly seen in peloidal limestones from K-85 to K-89 in which occurrences of foraminifers and calcareous algae are unusually rare. In other horizons, calcareous algae are common and *Dasycla, Salpingoporella, Thaumatoporella,* and *Clypeinea* were identified. Bryozoans and ostracodes are less abundant than unit 4, and found in several horizons of the lower part and K-100. Brachiopods also occur in some horizons, but their contribution is small. The stromatolites exhibit mm-order repetition of dark and light-colored laminae, poorly containing clastic grains (Fig. 4d). It largely differs from the texture of the recent stromatolites formed in tidal flat environments.

As non-skeletal components other than peloids, ooids (K-76, K-94, and K-99) and oncoids (K-82, K-88, K-93, K-96, K-97, and K-99) are prominent. Limestones of K-76 and K-94 include intraclasts. The most common porosity type is moldic. Fracture, intraparticle, and intercrystal porosities were also found. Organic matter was commonly preserved in porosities developed among dolomite crystals and in primary pores of foraminifer and bryozoan skeletons.

B. K3-section

This section is 136 m in total thickness and was studied to investigate the lateral facies change of unit 3 yielding potential reef-building organisms. The lowermost 18 m of this section (K-301~308) consists of thickly-bedded and coarse-grained limestone containing bivalves and calcareous algae, and underlies massive limestone which sparsely yields corals and stromatoporoids. The top of this thickly-bedded limestone probably corresponds to the boundary between units 2 and 3. The massive limestones, developed from K-308 to K-361, are intercalated with bedded limestone at three horizons. The massive limestones are generally rich in large fossils, and especially from K-333 to K341 uniserial branching stromatoporoids densely occur. The branches of stromatoporoids *(Cladocoropsis)* are normally oriented parallel to bedding planes. The section rarely yields stromatoporoids of massive and domical forms, which are common in K1-section. From K-362, the limestone becomes micritic, bedded and less abundant in large fossils. This horizon can be the boundary between units 3 and 4.

Limestones of K3-section generally show wackestone-packstone fabric. Abundance in large fossils is recognized also in thin sections. Stromatoporoids are the most dominant group, but their assemblage is poorly diverse and dominated a single genus *Cladocoropsis.* In microscopic investigation, corals were recognized in K-314, K-315, K-320, K-321, K-322, K-345, and K-350. Hydrozoan genera *Spongiomorpha* was in K-310 and K-350.

The limestone also includes other fossil groups, such as calcareous algae, brachiopods, mollusks, ostracodes and echinoderms. The identified calcareous algae was *Kurnubia* sp. Occurrence of bryozoans is noteworthy and limited in both lower (K-302~308) and upper (K-351~363) horizons of K3-section. Sponge spicules were found in K-331 and K-349. This fossil association is generally similar, but is different from that of unit 3 of K1-section, in terms of occurrence of ostracodes and sponge spicules. This may result from environmental gradient between K1-section

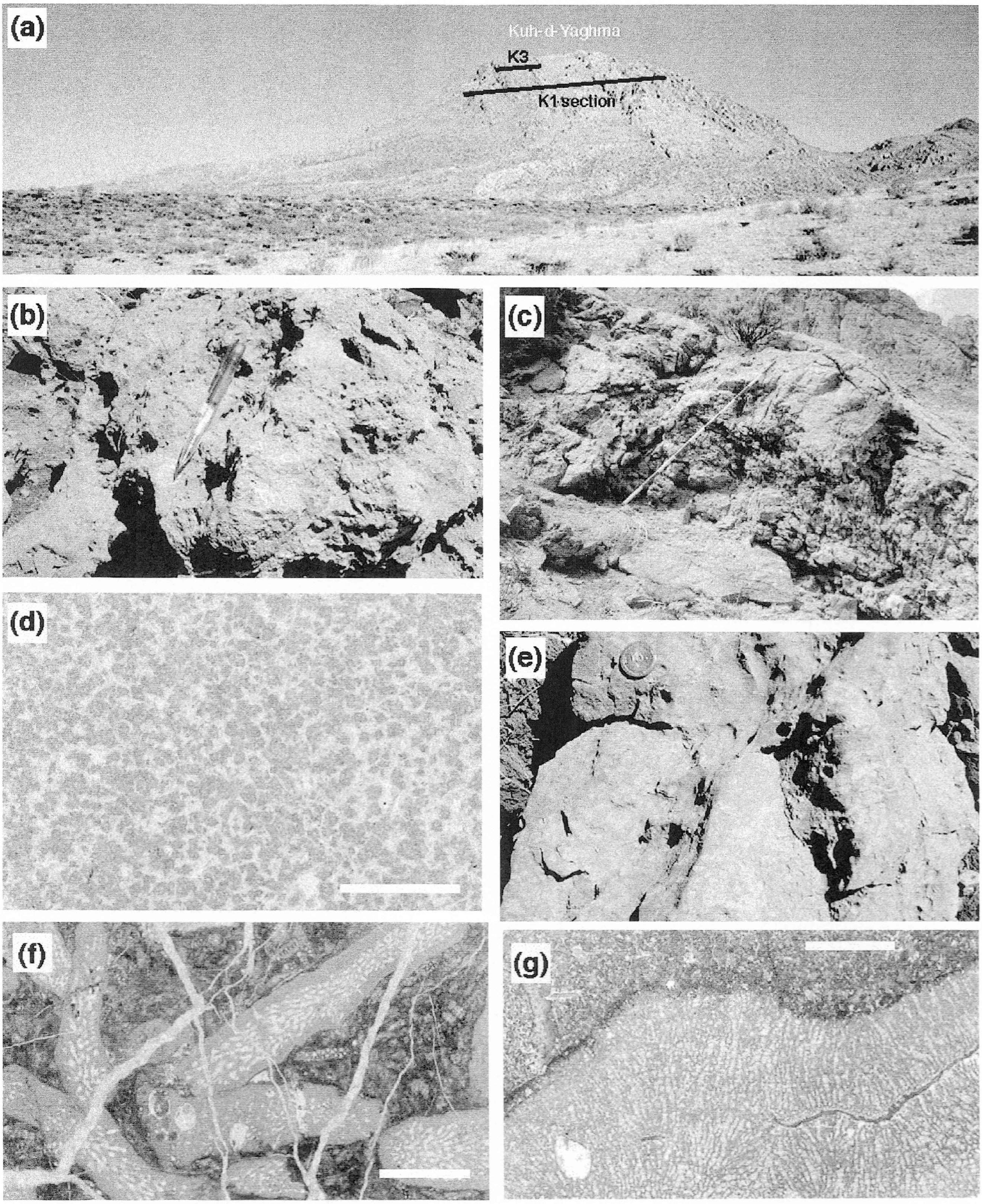

Fig. 3 : Outcrops and microfacies of the lower K1-section. (a) View of Kuh-d-yaghma showing locations of K1- and K3-sections. (b) Paleosol of unit 1 (K-6). (c) Massive dolostone of the lower unit 2. (d) Coarse-grained dolostone (K-17). Scale bar is 5 mm. (e) Stromatoporoid biostrome consisting of uniserial branching forms (Unit 3). Scale bar is 5 mm. (f) Branches of *Cladocoropsis* sp. from K-54. (g) *Milleporidium* sp. from K-47. Scale bar is 5 mm.

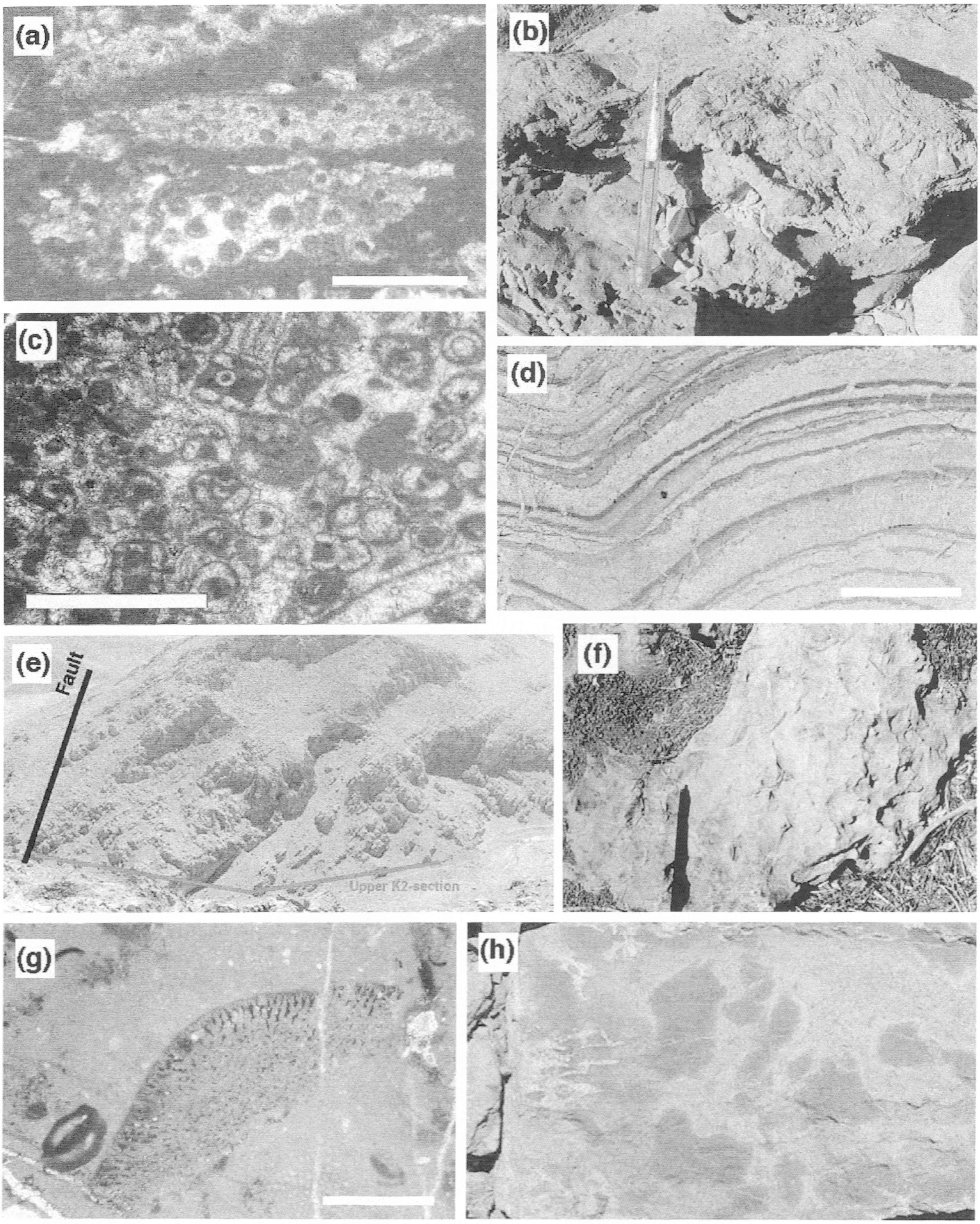

Fig. 4 : Outcrops and microfacies of the upper K1-section and K2-section. (a) Bryozoans of unit 4. Scale bar is 1 mm. (b) Stromatolite of K-80 (unit 5). (c) *Dasyclad* sp., common calcareous algae of unit 5. (d) Laminae of stromatolite (K-80). Scale bar is 5 mm. (e) View of the upper part of K2-section. (f) Shell bed in unit 6. (g) Orbitolinid foraminifer containing organic matter in chambers (K-185). Scale bar is 1 mm. (h) Oncoidal limestone (K-189).

and K3-section. A possible reconstruction is that K3-section was deposited somewhat deeper environments. This is supported by strong domination by uniserial branching *Cladoclopsis* sp., which may have adapted to low-energy environments.

Peloids are common non-skeletal constituents. The limestones in some horizons contain intraclasts (K-309, K-314, K-325, and K-333), oncoids (K-308 and K-309), and ooids (K-309 and K-359). Dolomite was recognized in K-302 and K-360. The upper part of the section was styrolized. The common porosity types are fracture and moldic. Organic matter occurs in both of lowermost and uppermost horizons in association with porosities and dolomites.

C. K2-section

The total thickness of K2-section is 395 m. The section was measured a hill slope next to Kuh-d-Yama (lower) and along the valley down from this hill (upper; Fig. 4e). There is no significant stratigraphic gap or overlap with K1-section.

1. Unit 6 (K-239~191)

The lowermost 140 m of K3-section was defined as unit 6, although this part shows lithological similarities with unit 5. This unit consists of massive limestone of light dray-gray colors, and yields bivalve-gastropod shell beds. Stromatolites occur at K-194. The limestone was partly dolomitized and is easily weathered due to development tiny fractures.

The limestone is normally micritic and exhibits wackestone to lime-mudstone fabrics. Common fossil constituents are foraminifers, ostracodes, sponge spicules, calcareous algae, and bryozoans. The dominant calcareous algae are identified as *Dacycla* sp., which especially shows dense occurrence in K-222, K-223m K-228, K-234, and K-239. Specimen of K-205 yields *Bacinella* sp. (a calcified microbe).

The peloids are only common non-skeletal constituents. Fracture, intercrystal, and moldic porosities were recognized.

2. Unit 7 (K-190-168)

Unit 7 is massive to thickly-bedded limestone of 65 m thick and dark gray to light gray colors. The base of unit was defined by the first appearance of orbitolinid foraminifers (Fig. 4g). Oncoid-foraminifer association forms characteristic coarse-grained layers (Fig. 4h) in some horizons of this unit.

The limestone mainly appears wackestone although less commonly lime-mudstone and packstone occur. Two types of fossil association were recognized, one mainly consisting of foraminifers, ostracodes, and calcareous algae, and the other rich in brachiopods and sponge spicules. The former association was typically seen in unit 6, and the latter is similar to the association of unit 8. Foraminifers are highly various in their morphology, from small forms having only a few chambers, to large forms such as orbitolinids. Orbitolinids are especially abundant in K-172~170.

Non-skeletal grains, such as oncoids and peloids, are common in this unit. Dolomite was also recognized in some thin sections. Common porosity types are moldic and intercrystal. Moldic porosities was developed by dissolution of mollusks and foraminifers within micritic matrix. Intercrystal porosities, associated with dolomitization, is prominent in K-177~171. Large foraminifers often preserve organic matter in their chambers (Fig. 4g), and shows pigmented skeletons.

3. Unit 8 (K-167~144)

Unit 8, 75 m in thickness, forms an upward-thickening sequence, in which the lower thinly bedded limestone (Fig. 5a) changes into the upper thickly bedded layers exhibiting stromatolites. Flat pebbles occurs in K-161.

This unit mainly consists of packstone and wackestone, and is coarser grained than other units of K2-section. The most characteristic fossil components are large brachiopod shells (Fig. 5b), which are associated with sponge spicules in micritic matrix. This association is common in the lower thin-bedded limestone, and may indicate deeper environments. Contrary, above K-149, proportion of foraminifers and calcareous algae increased. Orbitolinids were commonly recognized.

Unit 8 lacks oncoids, which abundantly occur in unit 7. The lower of unit 8 is poor in porosity and altered textures. Whereas, the upper part commonly show porosity and dolomitized textures (Fig. 5c).

4. Unit 9 (K-143~101)

This uppermost unit of K2-section is about 115 m in thickness, and the top of the unit is truncated by a fault. The unit consists of three upward-thickening sequences, ranging their thickness from 60 m to 20 m. We define the three sequence as cycles 1 to 3, in the ascending order. The lower part of each cycle is thinly-bedded pale-green limestone contains brachiopod shell and terrigenous components. The limestone becomes massive and rich in burrows to the upward. The outcrops shows some strike-slip faults, and along the one near K-140 a cave is developed. Oil is percolated out on this fault plane (Fig. 5d) and from the cave (Fig. 5e).

Limestone is mainly wackestone. Fossil composition varies due to the cycles. Cycle 1 is dominated by foraminifers (including orbitolinids; Fig. 5f) and calcareous algae. Cycle 2 is rich in brachiopods and mollusks, but poor in orbitolinids. Cycle 3 exhibits diverse fossil association including corals (Fig. 5g) and rudists (Fig. 5h). In this cycle, ostracodes and small foraminifers are abundant, but calcareous algae is poor.

As non-skeletal grains, peloids are common especially in cycle 2. Occurrence of dolomite is restricted in cycle 1. Porosity is also well developed in cycle 1, and moldic porosity is the most common type. Foraminifers preserve intraparticle porosity, in which organic matter normally occurs.

IV. Diagenetic textures in cathodoluminescence

Cathodoluminescence method was applied to investigate cementation and dolomitization stages of specimens collected from K1-section, which are supposed to be subjected under various diagenetic processes. In this chapter, we show cathodoluminescence (CL) views of thin sections (Fig. 6) and interpret the textures.

A. CL textures

A partly-dolomitized grainstone of K-10 consists of sedimentary particles (dull CL) fringed by calcite cement exhibiting bright CL (Fig. 6b). Sparitic crystals of non-luminescent CL truncate these CL textures, which may be dolomite. The dolomite crystals of non-luminescent to dull CL were recognized in K-6.

Coarse grained dolostone of K-17 show any distinct CL texture, and consist of crystals having dull centers and non-luminescent fringes (Fig. 6d). The dolostones of other horizons of the lower unit 2 show similar CL textures.

Limestones of the upper unit 2 and the lowermost unit 3 (K-21~34) often exhibit banded cement consisting of growth stages of different CL intensity (Figs. 6f, h). The banded cement is normally developed as syntaxial overgrowth on echinoderm grains (Fig. 6h).

The banded cement was not recognized in horizons above K-35. The limestones exhibit only weak CL intensity, although limestones of unit 4 as a whole increase CL intensity.

B. Interpretation

Cathodoluminescence of carbonate minerals is primary controlled by the contents of Mn^{2+} (Frank et al., 1982). Due to increase of Mn^{2+} content, the CL changes from non-luminescence, through dull, to bright. Mn^{2+} content of carbonate minerals is related to Mn^{2+}/Ca^{2+} ratio of the diagenetic fluid, which is the function of redox conditions. Since an oxidizing (high Eh) condition causes formation of manganese hydroxide, content of free Mn^{2+} is largely reduced and the resultant CL is normally non-luminescence. Contrary, a reduced (low Eh) condition increased Mn^{2+} content of the fluid and CL intensity of the precipitated carbonate minerals. These relation work in many diagenetic processes. Therefore, a banded cement showing repetition of different CL intensity has been thought to indicate fluctuation of redox conditions during diagenesis.

This circumstance normally occurs in meteoric diagenetic environments (Meyers, 1974). Because seawater is stable in chemical characteristics due to a large moderating effect of water mass, the fluctuation of redox condition is hardly expected. Fluid of sediment/seawater interface generally keeps oxidizing conditions or is gradually reduced due to accumulation of sediment and decomposition of organic matter.

If the banded cements of K-21~34 (Figs. 6f, h) was formed under meteoric diagenesis, the dolomite of the lower unit 2 was most reasonably formed in mixed water (meteoric water and seawater) diagenesis. This interpretation supported by paleo-karst structure at the top of unit 2 and stable isotopic values ($\delta^{13}C = +1.0‰$, $\delta^{18}O = -3.5 \sim -3.2‰$) of the dolostone. A possible paleo-karst structure was also found in the upper unit 5, however results of CL investigation presented no indication of meteoric diagenesis.

V. Age determination

Precise biostratigraphy can not be applied to the investigated limestone sections, because the limestones are shallow marine lithified ones and do not yield fossils used for global correlation, such as ammonites and nanofossils. Age estimation of this study, is therefore somewhat rough, and should be based on other fossils. Strontium stable isotope was measured at two horizons, and the values provided useful reference to estimate ages.

Potential reef-building community mainly consisting of stromatoporoids should be developed in a period from early Kimmeridgian to late Valanginian. According to Scott (1988), corals dominated reef communities of older Jurassic, and rudists started to join and dominate the communities after Hauterivian. This range of inferred age is more specified by identified genera. The most common genus, *Cladocoropsis*, has been reported from Jurassic in Saudi Arabia (Hudson, 1954) and Oxfordian-Kimmeridgian of Slovenia and Croatia (Trunsek, 1966, 1968). Less abundant genera, *Milleporidium*, *Parastromatoporam*, and *Spongiomorpha*, were common constituent of limestone of the Torinosu Group (SW Japan;

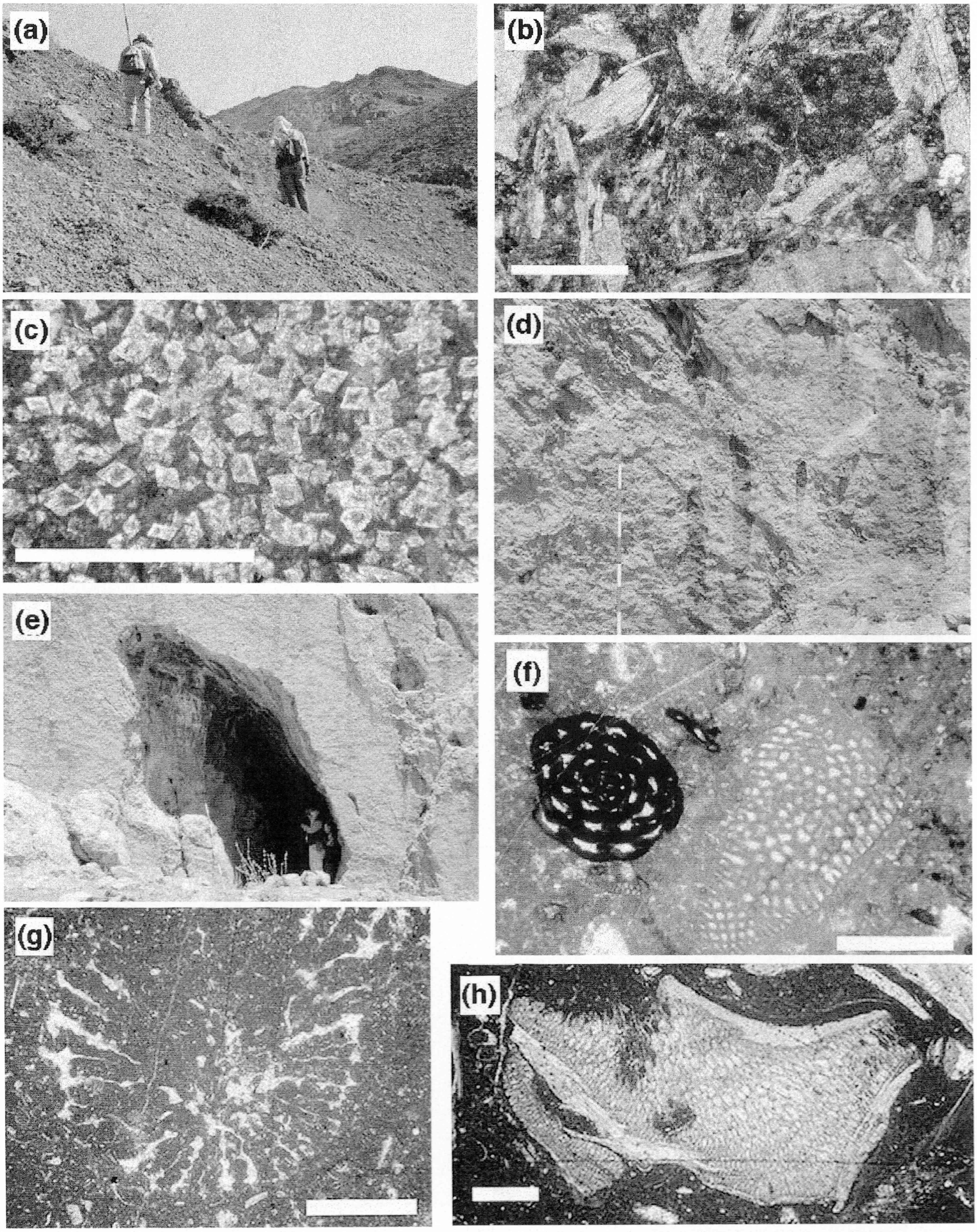

Fig. 5 : Outcrops and microfacies of the upper K2-section. All scale bars are 1 mm. (a) Thinly bedded limestone of the lower unit 8. (b) Packstone consisting of coarse brachiopod fragments. (c) Rhombic dolomite crystals occurring micritic matrix (K-154). (d) Oil percolation seen on a strike-slip fault plane. (e) A cave developed on a fault plane. (f) Foraminifers; one on the left shows a test pigmented by organic mater (K-133). (g) A coral (K-106). (h) A rudist (K-104).

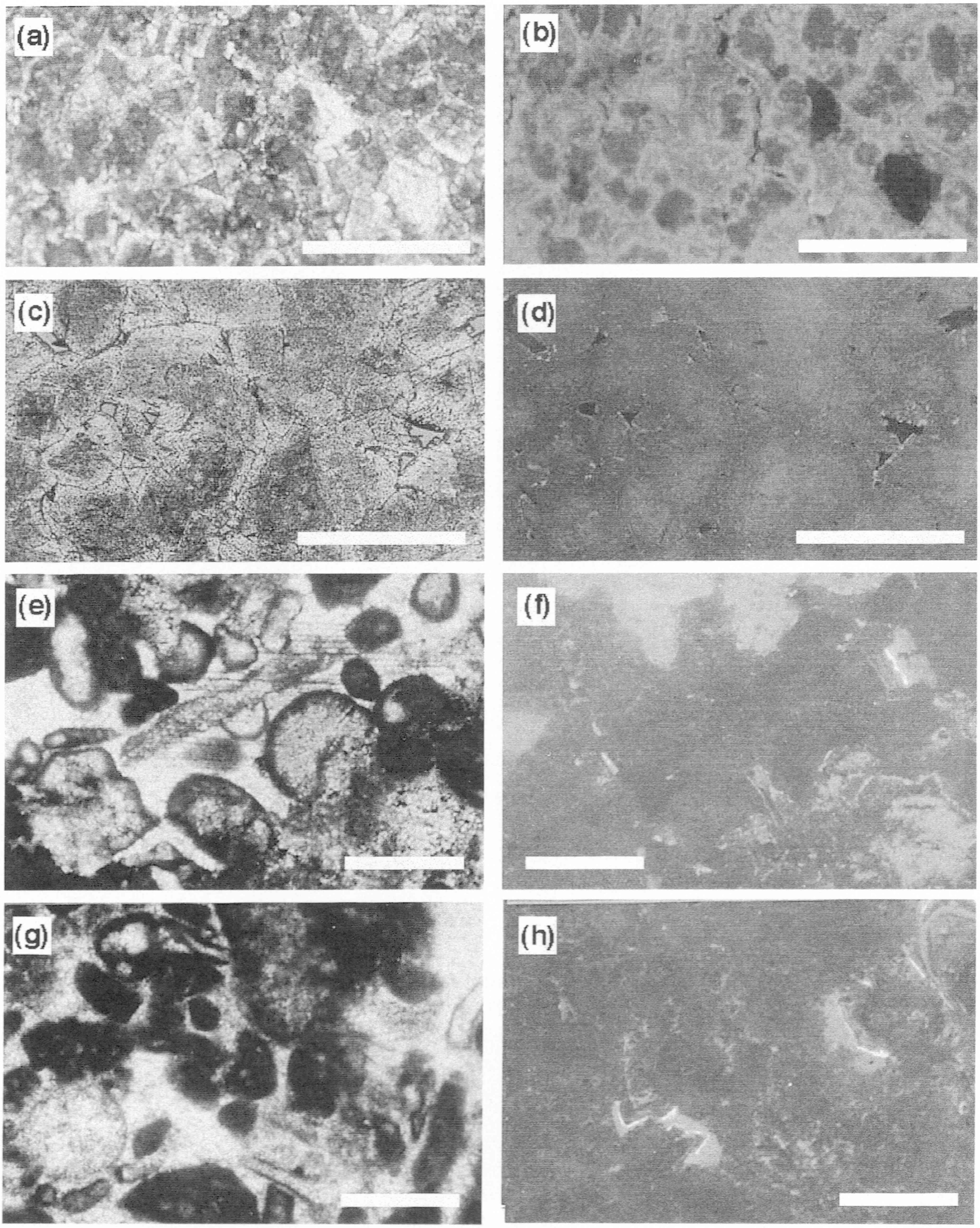

Fig. 6. Textures of optical microscopic (on the left hand) and cathodoluminescence (CL) views (on the right hand) of limestone and dolostone of units 1 and 2. All scale bars are 1 mm. (a, b) Partly dolomitized grainstone (K-10; unit 1). (c, d) Coarse dolostone (K-17; unit 2). (e, f) Peloidal grainstone (K-21; unit 2) showing banded cements. (g, h) Peloidal grainstone (K-25; unit 2) with cements showing clear zonation of CL intensity.

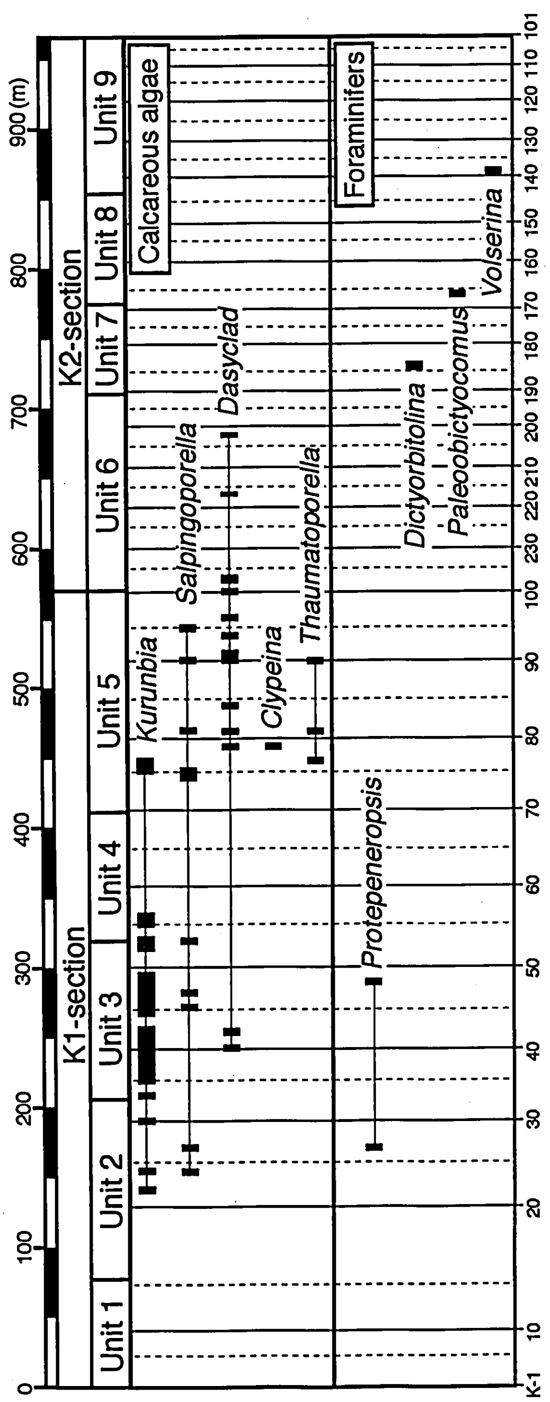

Fig. 7. Stratigraphic ranges of identified genera of calcareous algae and foraminifer.

Yabe and Sugiyama, 1935; Kano, 1988), which was mainly deposited from Tithonian to Berriasian. The reef community of NE Zagros indicates late Jurassic elements rather than early Cretaceous.

Several identified calcareous algae (Fig. 7) can be also used for age estimation. *Kurnubia* sp. abundantly occurring K-30~57, is most common in shelf-lagoon facies of late Callovian-early Kimmeridgian, according to study in north Italy (Jaffrezo, 1980). *Salpingoporella* sp. found in K-24~95 is abundant in shelf-lagoon facies of the latest Jurassic (Crescenti, 1971). *Thaumatoporella* sp. in unit 5 has a wide range from Triassic to late Cretaceous, but is most common in late Jurassic shallow marine environments (Crescenti, 1971). *Clypeina* sp. identified at K-78 is shallow marine genus of early Kimmeridgian-Berriasian (Jaffrezo, 1980). *Dasyclad* sp., which has been thought to be common in Berriasian, abundantly occur from K-78 to K-236 and ranges up to K-202 (Fig. 7).

Foraminifers provide some age-controls. *Protepeneropsis* sp. found from K-27 and K-48 (Fig. 7) is the late Jurassic genera. Orbitolinids, which were frequently found from K2-section (unit 7~9), are important to determine ages of carbonate rocks. Orbitolinids indicate a wide range of geological age due to genus and species, however three identified orbitolinid genera in this study, *Dictyorbitolina, Paleobictyocomus,* and *Volserina,* are all younger than Barremian (Loelich and Tappan, 1988).

Next, we consider Sr isotopic ratio measured at K-41 and K-98, which are 0.707053 and 0.707202, respectively. If these values inherited the seawater values of depositional ages, K-41 was early Tithonian and K-98 was from late Tithonian to Berriasian (Jones et al., 1994).

Taking all of the above-mentioned data into account, the followings are concluded. The stromatoporoid-bearing unit 3 is probably Tithonian, however this unit contains also older element such as abundance of *Kurnubia* sp. Because there is an inferred stratigraphic gap between units 2 and 3, the underlying unit 2 should be older, and most reasonably Kimmeridgian. The Jurassic/Cretaceous boundary was placed around K-78 by referring occurrence of *Dasyclad* sp., which is a typical genus of Berriacian. These age estimations are consistent with the values of Sr isotopic ratio. Finally, since we consider that the first appearance of orbitolinids correspond to the beginning of Barremian, the Hauterivian/Barremian boundary was set at K-190 (Fig. 2).

VI. Depositional history

Based on the description and discussion, depositional history of the upper Jurassic and lower Cretaceous of the studied sections is summarized as followings.

The lower part of unit 1 was deposited in subtidal platform, which was probably deep and habits of ostracod-bryozoan association. However, the platform was exposed at least twice and developed paleosol horizons. The platform became shallower subtidal or tidal flat environments in the upper part, and corals increased instead of decreased ostracodes. Sea bottom was strongly burrowed.

Sediments of unit 2 were originally coarse-grained. They consisted of ooids, oncoids and coarse skeletal particles deposited in high-energy and shallow water, such as shoal. To the upper part, water energy decreased, and calcareous algae including *Kurnubia* sp. started inhabiting on the platform. In the uppermost part exhibiting grainstone fabrics, water energy again increased.

Platform was subaerially exposed after the deposition of unit 2 (and/or after the lowermost unit 3). It may have correspond to the Kimmeridgian sea-level low (Vail et. al., 1984) or the early Kimmeridgian uplift event related to the final collision of the Iranian and Turan Plates (Davouzadeh and Schmidt, 1984). The subaerial exposure developed meteoric and mixed water diagenetic environments, and resulted in banded cements (Figs. 6f, h) in the upper unit 2 and dolomitization of the lower unit 2. Probably, this dolomitization was selectively worked to initially porous and permeable sediments.

The subaerial exposure event consolidated the carbonate sediments, which in turn provided stable sea bottom for sedentary organisms. Stromatoporoids, corals, and calcareous algae formed bioherms on the stable substrate. Since delicate branching forms, *Cladocaropsis* sp. dominated the community, environments of the platform were subtidal and relatively low-energy. Most of branches of *Cladocaropsis* sp. were destroyed and transported together with *Kurnubia* sp. It was not a real reef, but was rather called as a biostrome. Considering facies and fossil associations, K3-section was located in deeper than K1-section.

Abundance of ostracodes and bryozoans in the lower unit 4, the environments became deeper. However, gradual decline of these fossil groups indicates upward-shallowing tendency. The sea bottom became peloidal and inhabited by less diverse fauna and flora.

Development of stromatolites and oncoids in unit 5 reminds shallow marine environments, such as tidal flat. Occurrences of ooids indicates periodical increase of water energy. Biofacies of this unit was characterized by various calcareous algae, *Kurnubia, Clypenia, Salpingoporella,* and *Thaumatoporella* (Fig. 7), which lived in lagoon and shelf environments.

Unit 6 differs from unit 5, in terms of micritic lithofacies and deeper water fossil association consisting of sponge spicules, bryozoans, and ostracodes. The environments should be deeper subtidal.

Unit 7 characterized by oncoids and orbitolinids (Figs. 4g, h) was probably deposited in somewhat restricted and low-energy intertidal-subtidal environments.

Unit 8 shows gradual increase of thickness of limestone beds. The biofacies also gradually changed from brachiopod-sponge spicule association to calcareous algae-orbitolinid association. These trends indicate the upward shallowing probably due to progradation. The shallowing tendency is supported by occurrence of stromatolites in the upper part.

Unit 9 is interpreted as three upward-shallowing cycles with the characteristics sheared with unit 8. Each cycle started from biofacies dominated by brachiopod shell and ended with facies exhibiting stromatolites and burrows. However, difference in biofacies was recognized among three cycles. The lowermost one abundantly contains bryozoans and orbitolinids, whereas the uppermost one yields shallow-marine constituents, such as corals and rudists. This difference can be attributed to difference in age, but more probably to progressive shallowing. If the cycles were controlled by the orbital forcing, thickness of the cycle decreased upwards due to sediment accumulation of platform. This can be the case of the four cycles (including one seen in unit 8). It is noteworthy, at the end of this paper, to describe that such orbitally controlled cycles became common from Albian (De Bore, 1982; Herbert and Fischer, 1986).

Acknowledgements

This project has been conducted under the Agreement of Academic Exchange between the University of Tokyo and Geological Survey of Iran. It was financially supported by Japan National Oil Cooperation and a grant from Japanese Ministry of Education and Science. We were helped in field by Dr. B. Hamdi, Dr. R. Rafmaty (Iranian Geological Survey), Dr. K. Niikawa (Niigata University), Dr. Wang Wei (Nanjin Institute of Geology and Paleontology), Dr. N. Matsuda (Tokyo University) and Mr. T. Ihara (Oyo Cooperation). We thank Mr. S. Kobayashi (Hiroshima University) who made number of thin sections and observed foraminifers carefully.

References

Arthur, M.A. and Schlanger, S.O., 1979, Cretaceous "Oceanic Anoxic Events" as causal factors in development of reef-reservoired giant oil fields. AAPG Bull., **61**, 1069-1082.

Choquette, P.W. and Pray, L.C., 1970, Geologic nomenclature and classification of porosity in sedimentary corbonates. AAPG Bull., **54**, 207-250.

Crescent, U., 1971, Biostratigaphic correlations in the Jurassic facies of central Italy by means of the microfossils. Ann. Inst. Geol. Publ. Hungarici, **54**, 209-213.

Davoudzadeh, M. and Schmidt, K., 1984, A review of the Mesozoic paleogeography and paleotectonic evolution of Iran. N. Jb. Geol. Paläont. Abh., **168**, 182-207.

De Boer , P.L., 1982, Cyclicity and the storage of organic matter in Middle Cretaceous pelagic sediments. *In*: Einsele, G. and Seilacher, A. (eds.) Cyclic and Event Stratification, 456-475, Springer-Verlag, Berlin.

Dunham, R.J., 1962, Classification of carbonate rocks according to depositional texture. AAPG Mem., **1**, 108-121.

Embry, A.F., III and Klovan, J.E., 1971, A Late Devonian reef tract on northeastern Banks Island, N.W.T. Bull., Canadian Petroleum Geology, **19**, 730-781

Frank, J.R., Carpeter, A.B., and Oglesby, T.W., 1982, Cathodoluminescence and composition of calcite in Taum Sauk Limestone (Upper Cambrian), Southeast Missouri. Journal of Sedimentary Petrology, **52**, 631-638

Herbert, T.D. and Fischer, A.G., 1986, Milankovitch climatic origin of mid-Cretaceous black shale rhythms in central Italy. Nature, **321**, 739-743

Hudson, R.G.S., 1954, Jurassic stromatoporoids from Southern Arabia. Notes Mem, Moyen-Orient, **5**, 207-221

Jaffrezo, M., 1980, Les formations corbonatées des Corbières (France) du Dogger-Aptien, Micropaléontologic Stratigrapohique, biozonation paléoecologic. Extension des resultants ala Mésogée, Thèse Doctorat, Etat, Univ, Pierre et Marie Carie, Paris Ⅵ, 613p.

James, G.A. and Wynd, J.G., 1965, Stratigraphic nomenclature of Iranian oil consortium agreement area. AAPG Bull., **49**, 2185-2245.

Jones, C.E., Jenkyns, H.C., Coe, A.L., and Hesselbo, S.P., 1994, Strontium isotopic variations in Jurassic and Cretaceous seawater. Geochim Cosmochim Acta, **58**, 3061-3074

Kano, A., 1988, Facies and depositional conditions of a carbonate mound (Tithonian-Berriasian, SW-Japan). Facies, **18**, 27-48

Loeblich, A.R.Jr. and Tappan, H., 1988, Foraminiferal Genera and Their Classification. 650p. Van Nostrad Reinhold Co.

Meyers, W.J., 1974, Carbonate cement stratigraphy of the Lake Valley Formation (Mississippian) Sacramento Mountains, New Mexico. Jour. Sediment. Petrol., **44**, 837-861

Scott, R.W., 1988, Evolutionary of Late Jurassic and Early Cretaceous reef biotas. Palaios, **3**, 184-193

Setudehnia, A., 1978, The Mesozoic sequence in south-west Iran and adjacent areas. Jour. Petrol. Geol., **1**, 3-42.

Turnsek, D., 1966, Upper Jurassic hydrozoan fauna from southern Slovenia. Razprave IX Razr SAZU, **9**, 337-428.

Turnsek, D., 1968, Some hydrozoans and corals from Jurassic and Cretaceous strata of southwestern Jugoslavia. Razprave IX Razr SAZU, **11**, 353-376.

Vail, P.R., Hardenbol, J. and Todd, J.M., 1984, Jurassic unconformities, chronostratigraphy, and sea-level changes from seismic stratigraphy and biostratigraphy. AAPG Mem., **36**, 129-144.

Akihiro Kano, Chizuru Takashima and Jun Shigeno:
Department of Earth and Planetary Systems Science, Graduate School of Science, Hiroshima University, Higashi-Hiroshima 749-8526, Japan

Ryo Matsumoto:
Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo, Tokyo 113-0033, Japan