Public-data File 89-4

# GENERAL STRATIGRAPHY OF THE KATAKTURUK DOLOMITE IN THE SADLEROCHIT AND SHUBLIK MOUNTAINS, ARCTIC NATIONAL WILDLIFE REFUGE, NORTHEASTERN ALASKA


By

James G. Clough

Alaska Division of
Geological and Geophysical Surveys


February 1989

THIS REPORT HAS NOT BEEN REVIEWED FOR TECHNICAL CONTENT (EXCEPT AS NOTED IN TEXT) OR FOR CONFORMITY TO THE EDITORIAL STANDARDS OF DGGS.


794 University Avenue, Suite 200
Fairbanks, Alaska 99709-3645

## ABSTRACT

The Katakturuk Dolomite is almost 2400 meters thick in the Sadlerochit Mountains and thins to about 1800 meters thick in the Shublik Mountains where the upper 500 meters has been removed beneath a pre-Nanook Limestone unconformity and approximately 100 meters of the lowermost member is missing. The Katakturuk Dolomite is now considered to be older than mid Upper Cambrian and probably is Proterozoic in age. It is a shallowing upward predominantly carbonate sequence with both low energy intertidal muddy and grainy sequences capped by supratidal deposits. Carbonate facies are laterally consistent along strike and can be correlated between the Sadlerochit and Shublik Mountains. The Proterozoic carbonate platform was situated with an east-west (present day) shelf margin trend and basin located to the south based on paleocurrent data and exposures of undifferentiated black dolomite and shale in the Third and Fourth Ranges situated to the south which may represent coeval basin margin and plain sedimentation. Regionally this infers a northward thickening carbonate wedge in the subsurface basement complex.

For geologic mapping purposes Robinson and others (1989) subdivided the Katakturuk Dolomite into sixteen informal units based on mappable characteristics. These mapping units are now presented as informal members of the Katakturuk Dolomite. Stratigraphically from bottom to top the sixteen Katakturuk Dolomite members are: Spire dolomite, Zebra dolomite, Variegated dolomite, Cobweb dolomite, Thin-laminated dolomite, Silicified Oolite, White marker, Brown marker, Lower gray craggy dolomite, Thin bedded algal dolomite, Upper gray craggy dolomite, Pink dolomite, Black laminated dolomite, Horsetooth dolomite, Dolomite breccia, and Upper siliceous dolomite.

# INTRODUCTION

The Katakturuk Dolomite is part of the Franklinian sequence (Lerand, 1973) of rocks exposed in the Sadlerochit and Shublik Mountains, Arctic National Wildlife Refuge, northeastern Alaska. Here, the Franklinian sequence includes the Neruokpuk Formation (Reiser and others, 1978), Mount Copleston volcanic rocks (informal) (Moore, 1987), Katakturuk Dolomite (Dutro, 1970) and Nanook Limestone (Dutro, 1970).

The Proterozoic Katakturuk Dolomite forms the anticlinal cores of the Sadlerochit and Shublik Mountains and is also exposed in the Old Man Creek-Hula Hula River region southeast of Kikiktat Mountain. The Katakturuk Dolomite uncomformably underlies rocks of the Lisburne Group, Endicott Group, and Nanook Limestone in the Sadlerochit and Shublik Mountains, and structurally overlies rocks of the Sadlerochit Group, Lisburne Group, and Neruokpuk Formation in the same ranges. The Katakturuk Dolomite is almost 2400 meters thick in the Sadlerochit Mountains and thins to about 1800 meters thick in the Shublik Mountains. Here the upper 500 meters has been removed beneath a pre-Nanook Limestone unconformity and the Katakturuk's lowest member is 100 meters thinner. A composite section from both mountain ranges (plate 1) yields a maximum aggregate thickness of over 2500 meters for the Katakturuk Dolomite. New age revisions of the Katakturuk Dolomite and the overlying Nanook Limestone (Blodgett and others, 1986) and detailed stratigraphic studies (Clough, 1986; Clough and others, 1987; 1988) suggest that the Katakturuk Dolomite is older than mid Upper Cambrian and probably is Proterozoic in age.

The Katakturuk Dolomite was named by Dutro (1970) for its exposure in the Katakturuk River canyon in the Sadlerochit Mountains. Katakturuk is an English derivation of the Inupiaq word *Qattaqtuuraq* which means "a wide open place" (James Nageak, 1989, personal communication) and accurately describes the canyon through which the Katakturuk River flows north. Dutro (1970) subdivided the Katakturuk Dolomite into nine informal members based on his composite type section in the Shublik Mountains. Dutro's subdivision did not include two units immediately below his nine members and overlying the Mount Copleston mafic volcanic flows in the western Shublik Mountains. These units were considered to be an older highly silicified unnamed dolomite (Dutro, 1970). For the purpose of geologic mapping Robinson and others (1989) subdivided the Katakturuk Dolomite into sixteen informal units based upon observable mappable characteristics. These mapping units include the unnamed dolomite of Dutro (1970) and two units exposed only in the Sadlerochit Mountains which are stratigraphically above the uppermost Katakturuk in the Shublik Mountains where Dutro's (1970) type section is located. The unnamed dolomite was deposited as part of the Katakturuk Dolomite sequence of rocks and is considered herein to represent the lowermost members (informal) of the Katakturuk. Stratigraphically from bottom to top the sixteen informal Katakturuk Dolomite members are: (1) Spire dolomite (2) Zebra dolomite, (3) Variegated dolomite, (4) Cobweb dolomite, (5) Thin-laminated dolomite, (6) Silicified Oolite, (7) White marker, (8) Brown marker, (9) Lower gray craggy dolomite, (10) Thin bedded algal dolomite, (11) Upper gray craggy dolomite, (12) Pink dolomite, (13) Black laminated dolomite, (14) Horsetooth dolomite, (15) Dolomite breccia, and (16) Upper siliceous dolomite (plate 1).

The Katakturuk Dolomite can be characterized as a carbonate shallowing upward sequence with both low energy intertidal muddy and grainy sequences which culminate in supratidal sedimentation. An entire shallowing upward cycle from deep water basin plain and slope apron to supratidal environments is recorded in the lower part of the Katakturuk. Other cycles occurring are from restricted shelf to shoaling to intertidal and/or supratidal settings and reflect progradation of carbonate facies followed by minor sea level rises. The carbonate facies are laterally consistent along strike and can be correlated between the Sadlerochit and Shublik Mountains. The Proterozoic carbonate platform paleogeographically was situated with an east-west (present day) shelf margin trend and basin located to the south. Paleocurrent data strongly supports this interpretation (Clough 1986) and basinal to slope apron facies are thicker in the Shublik Mountains. Exposures of undifferentiated black dolomite and shale in the Third and Fourth Ranges situated to the south may represent coeval basin margin and plain sedimentation. Dolomite outcropping in the Hula Hula River-Old Man Creek region to the southeast, tentatively assigned to the Katakturuk Dolomite (Sable 1977), is representative of predominantly slope deposition. Regionally this infers a northward thickening carbonate wedge in the subsurface basement complex. The Katakturuk platform may have been contiguous with some of the Canadian arctic Proterozoic carbonate platforms however, the present level of understanding of Brooks Range and Canada Basin tectonics makes Precambrian palinspastic restorations difficult.

## STRATIGRAPHY AND DEPOSITIONAL SETTINGS

A composite general stratigraphic section of the Katakturuk Dolomite is shown in Plate 1. This stratigraphic column is derived from a composite of measured stratigraphic sections and represents the maximum thickness of exposed Katakturuk Dolomite. Informal member descriptions below include preliminary depositional settings and each unit's correlation to the earlier stratigraphic work by Dutro (1970). Interpretations of depositional settings are based on observations of sedimentary structures, rock fabrics and grain types during field studies and preliminary petrologic studies (thin section and hand specimen). The members are described in the order of their deposition and are assigned unit numbers 1 to 16 in parentheses, from base to top respectively. The informal member names used are the map units of Robinson and others (1989) for the 1:63,360 scale geologic map of the Sadlerochit and Shublik Mountains.

### (Unit 1) Spire dolomite member
*Supratidal setting*

The most complete package of Unit 1 of the Katakturuk Dolomite, the Spire dolomite, occurs in the central Sadlerochit Mountains where it forms steep outcrop and rubble-strewn noses on north facing ridges. Here this unit is about 500 meters thick where it is in thrust fault contact with the Lisburne Group limestone. In the western Shublik Mountains Unit 1 is much thinner where it overlies the Mount

Copleston volcanics and rubble cover precludes examination of the nature of the Spire dolomite/mafic contact.

The Spire dolomite member is a light-gray to gray, thick-bedded to massive, oolitic but mostly pisolitic to faintly cryptalgal laminated dolomite that weathers into spires and tors on ridgelines. Silicification is common in Unit 1 consisting of interleaving veinlets, wholescale replacement and lining of irregular vugs. Pisoids are highly variable in size (up to 2cm in diameter) and shape and commonly are polygonally fitted with reverse grading (coarsening upward). The pisoids are most similar to those forming by hypersaline waters on Recent Persian Gulf supratidal flats exposed to storm and spring tides as reported by Shinn (1973). Alternatively they form by vadose diagenesis on subaerial exposure surfaces. This member corresponds to the lowermost of Dutro's (1970) unnamed dolomite.

### (Unit 2) Zebra dolomite member
*Supratidal setting*

Unit 2, the Zebra dolomite is a brown- to brownish-gray, fine-grained, thin- to medium-bedded dolomite containing abundant small to large (1 cm to 25 cm high) irregular white silicified vugs and chert bands. This member is brecciated locally and contains black chert clasts to 30 cm long. The vugs are stromatactoid-like and their origin has been attributed to evaporite solution features (Dutro, 1970) suggesting a supratidal depositional setting. Silicification may be due to subaerial and/or burial diagenetic overprinting. This member is 82 meters thick in the Sadlerochit Mountains and much thinner in the Shubliks where it consists mostly of rubble on ridge slopes. It corresponds to the upper part of Dutro's (1970) unnamed dolomite.

### (Unit 3) Variegated dolomite member
*Basin plain to slope apron setting*

The Variegated dolomite consists of interbedded light-gray, tan to orangish-tan weathering, fine- to medium-grained, silty dolomite, silty limestone, and brown and black, thin bedded, calcareous shale. The dolomite layers contain planer lamination and minor chert layers near the top of the unit. The variegated dolomite was deposited as carbonate periplatform ooze and hemipelagic shale in a deep water slope apron to basin plain setting. The member is over 80 meters thick where best exposed in the headwater canyon of Hue Creek in the Shublik Mountains. In the Sadlerochit Mountains exposures are mostly rubblecrop on ridgelines and the measured thickness is thinner. This member corresponds to Dutro (1970) unit 1.

**(Unit 4) Cobweb dolomite member**
*Slope apron setting*

The Cobweb dolomite is a 50 meter thick predominantly gray to brownish-gray dolomitic breccia with minor thin light gray and orange weathering planer laminated beds. Laminations are mm to cm scale, accompanied by thin black hummocky layers locally. The lower part of the unit contains minor thin chert layers. The dolomitic breccia was deposited as slope debris flows by multiple events with many clasts incorporated from Unit 3. The thin planer laminated and chert beds represent hemipelagic and periplatform ooze sedimentation. This member corresponds to Dutro (1970) unit 2 and is thin to nonexistent in the Sadlerochit Mountains.

**(Unit 5) Thin-laminated dolomite member**
*Slope apron setting*

The over 50 meter thick Thin-laminated dolomite member is a rhythmically interbedded orangish-tan-tan to red weathering dolomitic mudstone to very fine grainstone, and dark gray to black platy lime mudstone and calcareous shale, and minor black chert near the top. The dolomitic grainstone contains abundant imbricated rip up clasts derived locally, is occasionally graded, and has numerous channels which pinch out laterally. This member represents slope apron turbidite sedimentation and corresponds to Dutro (1970) unit 3.

**(Unit 6) Silicified Oolite member**
*Upper slope apron, shoaling, restricted shelf, and supratidal settings*

The Silicified Oolite member, Unit 6, characterizes a slope to shallow water shelf transition. This member is about 320 meters thick and its base is marked by a 22 meters thick, medium gray weathering to brownish-gray, dolomite containing black chert spheroids to 2 cm in diameter. These chert spheroids occur in small trough structures and also disseminated throughout bedding. Also occurring are similar scour troughs filled with silicified ooids deposited as downslope grain flows in an upper slope apron setting proximal to a shoaling shelf margin. Upsection from the grain flows are graded oolitic turbidites, approximately 20 meters thick, exhibiting thin Ta, Tb, and Tc beds.

The upper 280 meters of the Silicified Oolite represents shallow water shelf deposition in platform subtidal to shoaling conditions. Lithologies range from coarsely cross bedded oolitic grainstone (shoaling environment) to stromatolitic mudstone to packstone (restricted shelf to intertidal environments) with hummocky, laterally-linked and discrete columnar stromatolite forms to pisolite (supratidal environment). The restricted shelf facies were deposited behind relict ooid shoals. The cross-bedded oolitic grainstone dominates the upper portion of Unit 6 and grain types include simple and compound ooids and algal mat debris. Algal mats are commonly silicified locally along with cross-bedded oolitic grainstone horizons which generally weather to a distinctive black.

The top of this member is marked by a very distinctive 11 meters thick pisolitic dolomite. Pisoids are locally up to 2 cm in diameter, reverse graded, polygonally-fitted, and show evidence of minor reworking. Thin layers of caliche-like crusts occur throughout the pisolite. The pisolite represents an brief episode of supratidal deposition similar to Unit 1. The beds bearing chert spheroids corresponds to Dutro's (1970) unit 4. The predominantly oolitic portion above the chert spheroid beds corresponds to Dutro (1970) unit 5.

**(Unit 7) White marker member**
*Low to high intertidal setting*

The White Marker member is a light gray dolomite weathering to yellowish-tan and very light gray. Its lithology is predominantly cryptalgal laminated mudstone and locally stromatolitic. Stromatolite morphologies follow a regular vertical succession from discrete columnar forms to hemispheroid forms to elongated forms representing intertidal shallowing. This unit averages 44 meters in measured thickness and corresponds to Dutro (1970) unit 6 with the exception of Dutro's pisolite zone which is depositionally part of and placed in the underlying Silicified Oolite member.

**(Unit 8) Brown marker member**
*Supratidal setting*

The Brown Marker member consists of interbedded, brown to light-brown, fine- to medium-grained, thin- to medium-bedded, dolomitic mudstone; and dark-gray to black, thin-laminated, recessive weathering, dolomite. It contains polygonal mudcracks, rip-up clasts, tepees, small solution collapse breccias, pisoids, and microspeleothem infillings representative of supratidal deposition. The microspeleothems consist of laminar flowstone precipitated in internal cavities and are remarkably similar to those forming in Recent supratidal sediments of Fisherman Bay, South Australia described by Ferguson and others (1982). Thin beds of laminated black dolomite occurring locally in Unit 8 apparently formed in supratidal pond settings. The member averages 35 meters in measured thickness and corresponds to the lower 50 feet of Dutro's (1970) unit 7.

**(Unit 9) Lower gray craggy dolomite member**
*Restricted shelf to intertidal settings*

The Lower gray craggy dolomite was deposited in a restricted shelf (predominant) and intertidal to locally shoaling (minor) setting probably in a broad current-swept lagoon behind shelf margin ooid shoals. Deposition of Unit 9 was initiated during a minor marine transgression occurring at the end of Brown Marker deposition. The member is a medium- to dark-gray, fine- to medium-grained, thick- and massive-bedded, dark-gray to black weathering cross-bedded and stromatolitic dolomite. It is characterized by coarse cross- and parallel-bedded rip up clasts of algal mat debris and ooids; and laterally linked to discrete columnar and digitate stromatolites. Cross-bedding and scour channels suggest storm surge and relaxation flow, locally in the upper flow regime; and bimodal cross beds (herringbone) indicate tidal current flow conditions. Stromatolites occur throughout this member and grew in the subtidal and intertidal restricted shelf setting during periods of quiescence with algal growth terminated by storm events. The Lower gray craggy dolomite averages 150 meters in measured thickness and corresponds to the middle part of Dutro (1970) unit 7.

**(Unit 10) Thin bedded algal dolomite member**
*Intertidal setting*

The Thin bedded algal dolomite is characterized by algal laminated dolomitic mudstone and was deposited in an intertidal setting shoreward of a restricted shelf environment. The thickness of this member is variable ranging from about 50 to 100 meters and it corresponds to the upper part of Dutro (1970) unit 7. The member is a dark-gray to gray, thin bedded to thin-laminated, locally recessive weathering, dolomite. The thin-laminated horizons contain various planer to irregular algal mat types and some laterally-linked to discrete columnar and digitate stromatolites are present in the lower part of the member. Locally facies are high intertidal displaying well developed fenestrae and minor desiccation cracks disrupting algal laminae. Thinly bedded layers are often grainstone composed of broken and rounded algal mat debris as grains. This member represents the culmination of a minor shallowing upward cycle as it prograded over the underlying, mostly subtidal, Lower gray craggy dolomite.

**(Unit 11) Upper gray craggy dolomite member**
*Restricted shelf to platform ooid shoal settings*

Following deposition of Unit 10 a minor sea level rise returned sedimentation to subtidal shoaling conditions. The Upper gray craggy dolomite represents mobile ooid shoals and relict sand sheets. The member is about 250 meters of dark-gray to gray, fine- to coarse-grained, thick-bedded, coarsely crossbedded dolomite. It contains abundant ooids and algal mat rip up debris including tabular clasts oriented parallel to bedding. Sedimentary structures include tabular and trough cross bedding with numerous reactivation surfaces. Laterally-linked to discrete columnar stromatolites occur locally in the middle to lower part of the member. This member corresponds to Dutro (1970) unit 8.

**(Unit 12) Pink dolomite member**
*Restricted shelf to ooid shoal settings*

The Pink Dolomite member is a medium-gray, brown, pink and buff, medium- to coarse-grained, dolomite which weathers to a distinctive pinkish gray alternating with gray in beds averaging 5 meters thick. It is generally a cross bedded to massive dolomitic grainstone containing ooids and algal mat debris deposited in restricted shelf and shoaling conditions. Locally, thinly laminated dolomite horizons occur near the top of the unit representing low intertidal sedimentation events. Minor tectonic breccia and secondary quartz veining and vugs are present throughout. The Pink Dolomite member is about 200 meters thick and corresponds to the lower part of Dutro (1970) unit 8.

**(Unit 13) Black laminated dolomite member**
*Platform ooid shoal setting*

The Black laminated dolomite represents persisting shoaling conditions initiated in Unit 11. Lithologies are dark-gray to brown, fine- to medium-grained, thin-laminated to thick-bedded, dolomitic grainstone, interbedded with fine-grained, brown dolomitic grainstone to mudstone and dolomitic breccia. The member contains abundant, large-scale trough cross-bedding composed of ooids. Where oolitic beds are silicified they weather a distinctive black, similar to the Silicified Oolite member. The Black laminated dolomite is about 75 to 100 meters thick corresponding to the upper part of Dutro (1970) unit 9.

**(Unit 14) Horsetooth dolomite member**
*Platform shoaling to intertidal (?) settings*

The Horsetooth dolomite is a black-weathering, thin laminated and cross-bedded, fine-to very coarse-grained, dolomitic grainstone. However, most of this original texture has been obscured within the member by tectonic overprinting which has produced abundant webwork quartz veining and coarse-grained secondary quartz flooding that results in a texture resembling horseteeth and vugs filled with quartz crystals. The occurrence of this secondary tectonically-induced texture may be lithologically controlled. It is about 75 to 100 meters thick and corresponds to the upper part of Dutro (1970) unit 9.

**(Unit 15) Dolomite breccia member**
*Subaerial exposure setting*

Unit 15 is a brown, buff and light-gray, thin- to massive bedded, siliceous dolomitic breccia. The unit weathers to mottled gray and creamy orange on scree slopes. Brown chert beds to 1 meter thick occur in the upper part of the unit. The breccias often have light colored, rounded to angular dolomite clasts to 4cm in diameter in a darker dolomite matrix and represents solution collapse of subaerially exposed early-cemented carbonates. Most of the original sedimentary textures in this unit have been destroyed by diagenesis. The brecciated beds are locally laced with siliceous webs, and form resistant ledges. This member is about 300 meters thick in the Sadlerochit Mountains and is absent in the Shublik Mountains.

**(Unit 16) Upper siliceous dolomite member**
*Restricted shelf to intertidal and shoaling settings*

This member is a medium-gray to dark-gray and brown, very fine- to medium-grained, brown, gray or orange weathering, siliceous dolomite. It consists of numerous, thick beds of very siliceous dolomite, separated by recessive weathering, thin bedded dolomite. Sedimentary structures include algal laminae, cross laminations and cross bedding indicative of intertidal and shallow subtidal to shoal deposition. This is the uppermost unit of the Katakturuk Dolomite in the central and western Sadlerochit Mountains and is absent in the Shublik Mountains. About 150 meters of Unit 16 is exposed in the central Sadlerochit Mountains.

## REFERENCES CITED


Blodgett, R.B., Clough, J.G., Dutro, J.T., Jr., Ormiston, A.R., Palmer, A.R., and Taylor, M.E., 1986, Age revisions of the Nanook Limestone and Katakturuk Dolomite, northeastern Brooks Range, Alaska; in Bartsch-Winkler, S., and Reed, K.M., eds., Geologic studies in Alaska by the U.S. Geological Survey during 1985: U.S. Geological Survey Circular 978, p. 5-10.

Clough, J.G., 1986, Peritidal sedimentary facies and stromatolites of the Katakturuk Dolomite (Proterozoic), northeastern Alaska [abs]: 12th International Sedimentological Congress, Abstracts, Canberra, Australia, p. 64.

Clough, J.G., 1989, Stratigraphy of the Katakturuk Dolomite in the Sadlerochit and Shublik Mountains, Arctic National Wildlife Refuge, Alaska: Alaska Division of Geological and Geophysical Surveys Public Data File 89-4a.

Clough, J.G., Blodgett, R.B., Imm, T.A., and Pavia, E.A., 1988, Depositional environments of Katakturuk Dolomite and Nanook Limestone, Arctic National Wildlife Refuge, Alaska [abs]: American Association of Petroleum Geologists Bulletin, v. 72, no. 2, p. 172.

Clough, J.G., Reifenstuhl, R.R., Smith, T.E., Pessel, G.H., Watts, K.F., Rhyherd, T.J., and Bakke, Arne, 1987, Precambrian carbonate platform sedimentation of the Katakturuk Dolomite (Proterozoic), Sadlerochit Mountains, northeastern Brooks Range, Alaska [abs]: Geological Society of America, Cordilleran Section, Abstracts with Programs, p. 367.

Dutro, J.T., Jr., 1970, Pre-Carboniferous carbonate rocks, northeastern Alaska, in Adkinson, W.L., and Brosge, W.P., eds., Proceedings of the geological seminar on the North Slope of Alaska: Los Angeles, California, American Association of Petroleum Geologists, Pacific Section, p. M1-M8.

Ferguson, James, Burne, R.V., and Chambers, L.A., 1982, Lithification of peritidal carbonates at Fisherman Bay, South Australia, to form a megapolygon/spelean limestone association: Journal of Sedimentary Petrology, v. 53, p. 1127-1147.

Lerand, Monti, 1973, Beaufort Sea, in McCrossan, R.G., ed., The future petroleum provinces of Canada- their geology and potential: Canadian Society of Petroleum Geologists Memoir 1, p. 315-386.

Moore, T.E., 1987, Geochemistry and tectonic setting of some rocks of the Franklinian assemblage, central and eastern Brooks Range; in Tailleur, I.L. and Weimer, Paul, eds., Alaska North Slope Geology: Society of Economic Paleontologists and Mineralogists and the Alaska Geological Society, p. 691-710.

Reiser, H.N., Norris, D.K., Dutro, J.T., Jr., and Brosge, W.P., 1978, Restriction and renaming of the Neruokpuk Formation, northeastern Alaska, in Sohl, N.F., and Wright, W.B., 1977, Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1977: U.S.Geological Survey Bulletin 1457-A, p. A106-A107.

Robinson, M.S., Decker, John, Clough, J.G., Bakke, Arne, Reifenstuhl, R.R., Dillon, J.T., Combellick, R.A., and Rawlinson, S.E., 1989, Geology of the Sadlerochit and Shublik Mountains, Arctic National Wildlife Refuge (ANWR), northeastern Alaska: Alaska Division of Geological and Geophysical Surveys Professional Report 100, 1 sheet, scale 1:63,360.

Sable, E.G., 1977, Geology of the western Romanzof Mountains, Brooks Range, Alaska: U.S. Geological Survey Professional Paper 897, 84 p.

Shinn, E.A., 1973, Sedimentary accretion along the leeward, SE coast of Qatar Peninsula, Persian Gulf, in Purser, B.H., ed., The Persian Gulf-Holocene carbonate sedimentation and diagenesis in a shallow epicontinental sea: Springer-Verlag, Heidelberg, Berlin, p. 199-209.