Rapp. Grønlands geol. Unders. 69, 35–44 (1975)

SEDIMENTOLOGICAL NOTES ON SANDSTONES FROM NÛGSSUAQ, CENTRAL WEST GREENLAND

E. J. Schiener

During field work in 1972 samples from a large number of sandstone occurrences from most stratigraphic levels (Cretaceous – Lower Tertiary) on Nûgssuaq were taken. Both isolated sandstone units in shale-silt dominated sequences and thicker, arenite dominated sequences were sampled. Wherever possible, palaeocurrent directions were recorded predominantly from crossbedding; special attention was directed towards the cyclic sediments.

General statements on lithologies have been made by several authors (Gry, 1942; Koch, 1964; Birkelund, 1965; Rosenkrantz & Pulvertaft, 1969; Rosenkrantz, 1970); more detailed facies analysis based on the present investigations will be presented elsewhere. At present the results of microscopic inspection of some 60 thin sections will be combined with field observations into a tentative interpretation of the controlling factors for the sedimentation.

Sandstone petrography

Framework

The bulk of the samples are dominated by quartz and feldspar with overall quartz/feldspar ratios around 1; in a few cases the ratio can be as low as 0.3.

Muscovite together with carbonized plant debris can attain up to 15 per cent of the clastic components (the two components are considered together for reasons of their similar hydraulic behaviour).

Carbonate fragments (ferroan dolomite) were encountered in 9 samples from presumably similar stratigraphic levels. They are of organic origin, fibrous structures in radiating or anastomosing patterns with sizes not exceeding 5.0 mm. They occur both as *in situ* structures, engulfing small clastic grains (fig. 11) or as displaced fragments. The latter are recognizable by their mostly random orientation

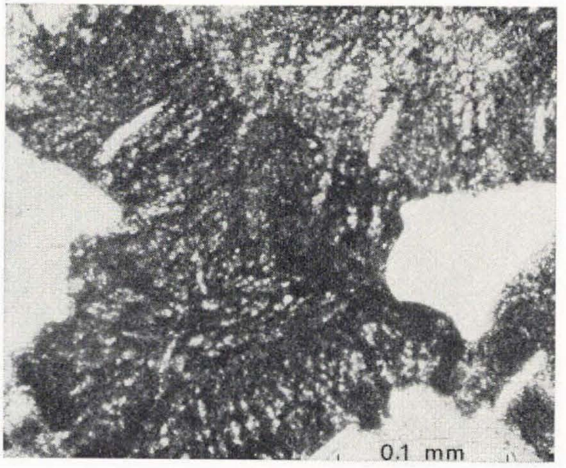

Fig. 11. Fibrous ferroan dolomite of probable algal origin. Parallel polarization.

in relation to the bedding. Structures with irregularly radiating filaments are generally recrystallized with maximum crystal sizes around 4 μ. The slightly coarser structured fibrous fragments are recrystallized to sparry carbonate with crystal sizes frequently comprising the whole of the fragment (several millimetres). Spheroidal or framboidal pyrite is commonly associated with the filamentous type. Organic compounds presumably cause a patchy darkening effect. These fragments are interpreted as partly reworked, partly *in situ* occurring blue algae of *Cayeuxia*-affinity (Elliott, 1956).

Chert fragments in various degrees of recrystallization, in places up to 10 mm across, are common in most sections.

Accessory minerals are encountered occasionally, including pink garnet, zircon, tourmaline and altered rutile. Notable is the absence of larger quantities of opaques, which is substantiated by the exceedingly poor crop of the heavy fraction gained by bromoform separation.

On average 55 per cent of the quartz components are single, only weakly strained crystal fragments; approximately 25 per cent are weakly strained quartz aggregates (this figure is somewhat uncertain especially in tightly packed samples); 12 per cent are grains with strongly undulatory extinction; 5 per cent (uncertain) consist of strained quartz aggregates and the remaining 3 per cent are made up of strongly recrystallized (gneissose) grains with relict grain boundaries extinguished.

The feldspar fraction is dominated by 40 per cent single crystal orthoclase. The state of preservation varies from strongly carbonatized or sericitized to very fresh. All components can be encountered in a single section. As will be mentioned again below, it proved very difficult to even find the more strongly altered fragments in a more rounded state. 33 per cent consist of generally very fresh single crystal microcline; the remaining 25 per cent are one-component feldspar aggregates of

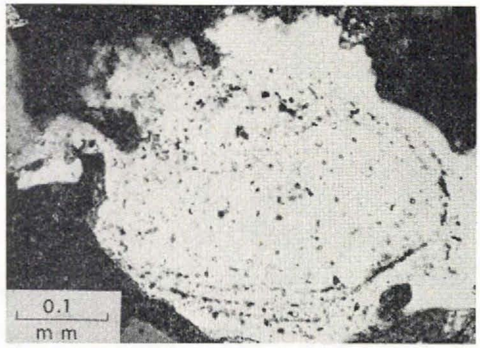

Fig. 12. Rounded quartz grain with secondary syntaxial overgrowth. X polarization.

either differently orientated crystals or aggregates composed of both feldspar types. Minor quantities of perthitic fragments were observer.

Quartz-feldspar aggregates occur frequently but are recognizable as such with certainty only in loosely packed samples. Recognition is in many instances assisted by the presence of multi-cycle quartz or feldspar (well rounded grains, frequently with syntaxial cementation overgrowths, fig. 12).

Cements

Composition, state of crystallization and sequence of introduction of cement into the clastic framework are highly important parameters for the understanding of depositional and diagenetic history of sediments, quite apart from the influence cement plays in rocks with special reference to mineralization potential.

The three main cement types are in decreasing order of importance: carbonates, silica, Fe-carbonates and Fe-oxide-hydrates. Their distribution is strongly dependent on the lithological relationship of the sampled sandstone to the surrounding rock

Fig. 13. Loosely packed framework with carbonate cement. Well rounded quartz and feldspar components indicated by arrows. X polarization.

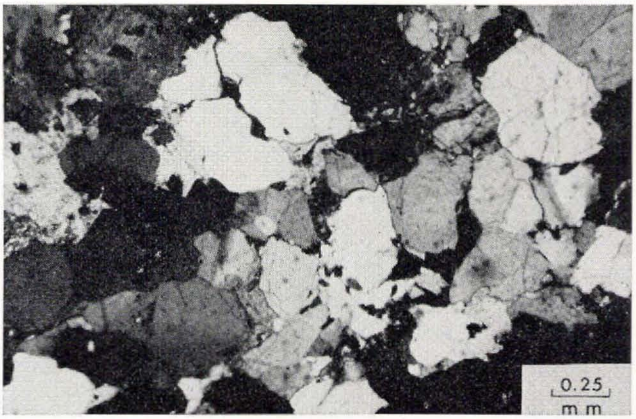

Fig. 14. Tightly packed framework with silica cement. X polarization.

types. Very generally it can be said that carbonate cement (ferroan dolomite and calcite) prevails in loosely packed sandstones characteristically from sandstone-dominated sequences (fig. 13). Here replacement of previous silica cement (opaline, chalcedonic, rarely crystallized quartz) is occasionally observable; framework particles are attacked and feldspars may be replaced to a very large extent.

Samples from sandstone units in silt or shale dominated sequences are primarily densely packed; they are largely silica cemented with very small amounts of replacing carbonate in patches (fig. 14).

The absence of carbonate cement indicates primarily rapid burial of the sands by silt and mud. Since the sandstones in the silt-shale sequences mostly are lensoid, they were probably sealed rather effectively from later pore water circulation. Waters derived from muddy and silty sediment, presumably owing to the higher concentration of Fe- and Al-colloids would allow diagenetic silicate precipitation in the sandstone (Bien *et al.,* 1958).

Ferruginous cements are uncommon for the bulk of the sampled rocks. They are found predominantly in the stratigraphically younger parts (Maastrichtian – Lower Danian), where they occur either as hardpans or as thin (1–5 cm thick) cementation crusts on top of individual sandstone beds, commonly associated with coal seamlets.

It should perhaps be emphasized here that only primary and secondary cementing agents are considered here. Later mobilization of carbonate and ferruginous compounds witnessed by macroscopic fracture fillings and microscopic veinlets are excluded.

As already indicated, the diagenetic history of some of the sandstones shows remains of silica cement included in the later carbonate cement. To complicate the story, the carbonates again underwent recognizable changes, the most obvious change here being a dedolomitization (Bausch, 1965). Both forms of microcrystalline and macrocrystalline dedolomitization have been observed. In the former single dolomite rhombohedra (0.1–0.2 mm) become replaced by microcrystalline calcite; in the latter partly irregular patches, but also euhedral dolomite are included in sparry calcite with maximum single crystals up to 0.5 mm across. Samples showing dedolomitization phenomena stem from western parts of the sedimentary area (north-east Disko). Exact stratigraphic position is uncertain, but uppermost Cretaceous can be reasonably assumed. The change from presumably marine transititional to apparently freshwater environment post-diagenetically (De Groot, 1967) is also demonstrated by the facies development on Nûgssuaq (Koch, 1964).

Texture

Textural parameters like packing, sorting, and maturity are largely dependent on grain-size analyses. The most convenient method for not too strongly cemented materials is sieving after mechanical and/or chemical disaggregation of samples. Only for a limited number of specimens did this procedure prove successful. In most cases, it was impossible to segregate the rock into single particles by acid treatment, presumably owing to the still quite thorough silica cementation. As a second factor impeding usability of sieving results, the large proportion of fragments of sedimentary rock (aggregates) occurring as framework particles has to be mentioned. It is impossible to separate them from insufficiently crushed rock material, especially in the size range from 1–4 mm. Systematic microscopic size analyses have not been carried out yet; only estimated size averages and maxima can be given here.

At first glance the majority of the sandstones appear surprisingly ill sorted, but without any matrix developed. However, already when estimating the average ranges of the predominant size classes it becomes apparent that in most cases a bimodal size distribution can be expected. The smaller fraction lies in the range 0.15–0.4 mm with a characteristic subfraction around 0.1–0.15 mm. Components of the subfraction are very well rounded single quartz grains or cherts, which stand out clearly against the majority of angular to subangular components (fig. 13). The remaining bulk of the small fraction is dominated by a quartz-feldspar mixture in ratios as given earlier in the text.

Generally there is a greater tendency towards quartz grains being better rounded than feldspar grains (owing to control by cleavage planes in the latter), but frequently well rounded microcline grains are encountered in the fine (0.15–0.4 mm) fraction.

The coarser fraction lies commonly between 0.8–1.5 mm with maxima exceeding 15 mm. Composite grains and large feldspar grains outnumber quartz components frequently, and rounding is understandably better developed in this size fraction.

Grain-grain relationships are in many instances also of more than general interest. As far as the position of the plane of section permitted the use of the observations (either parallel or normal to *SS)*, an open framework of coarse components could be recognized, which rather loosely became filled in by the small fraction. In thin sections most grains are floating in the cement, with point contacts developed only occasionally especially for the fine fraction.

Approximately 30 per cent of the studied samples show reasonable to good sorting; their size range is very similar to the small fraction as mentioned above with maxima around 1.0 mm. Shapes vary from very angular to very well rounded, the former constituting the majority.

Although unambiguous textural evidence from most ancient sediments for a specific depositional environment depends on careful analysis of a large number of samples, some ideas were developed on the depositional processes involved in the formation of the sandstones.

The strongly arkosic character of the sandstones leads to the immediate assumption that the basement gneisses outcropping to the east and south of the sedimentary area represented the parent material. This must certainly be true for a large part of the fresh, unworn feldpar fraction, which under postulated climatic conditions (Heer, 1883) would not have survived extended exposure and transport. There is, however, a significant abundance of obviously multi-cycle single quartz grains in a limited size range (0.15 mm). Well worn larger rock fragments (0.5–1.5 mm) containing multi-cycle quartz, chert and feldspar provide evidence for the existence of a second source in non-tectonized sedimentary rocks.

The two fractions of different provenance are so thoroughly mixed that this initial survey could not demonstrate regional or stratigraphically controlled trends. It is expected though, that further, more detailed sampling will provide more definite answers, especially if the present assumption of a southerly derivation for components of sedimentary origin finds a stronger footing. Gry (1942) has come to similar conclusions by studying basal sediments from Itsako, where he found sedimentary fragments as components.

Some minor textural characteristics observed in some sandstones may be of importance for environmental interpretation. In sandstones with bimodal size distribution the coarse fraction forms a grain supported framework with the fine fraction loosely filling in the spaces in between. In samples containing algal carbonate as framework components it is frequently observable that minute vertical cracks in the delicate, bedding-parallel crusts are filled from above by small (on average 0.08–0.1 mm) clastic fragments. Strongly frosted quartz grains were observed in disaggregated samples; together with the conspicuous lack or absence of mica, this would substantiate at least temporary wind transport as being involved in the deposition of the fine fraction.

The difference in packing between carbonate cemented and silica cemented sandstones has been mentioned earlier in this text. In cases where no silica cement is seen to have been replaced by carbonate, and where ferroan dolomite constitutes the bulk of the cement, it is assumed that early and rapid cementation of loosely packed sand has taken place. The presence of dolomite, unless it is a much later introduction into the environment, would indicate strong alkalinity. This, seen in connection with temporary evaporation, points to a marginal environment with fluctuating marine influence.

Interpretation

The sedimentological reconnaissance work in the onshore parts of the West Greenland basin, together with the existing literature (reviewed in Henderson, 1969) assisted in the broader conception of the regional palaeogeographic framework. The petrographic analysis of sandstones and of the silt-sand fraction in some shales provide support for some of the ideas conceived. The real importance, however, is seen in the extent these preliminary studies will influence further investigations, and in the implications of the results on the offshore prospects for oil and gas.

(1) The Cretaceous-Tertiary sediments are seen to overlie Precambrian basement rocks in their eastern termination in the double fault system of the Ikorfat and Kûk faults. The movements on these faults persisted into post-basalt times and there is very little evidence for a depositional pinch-out along these tectonic lines (Rosenkrantz & Pulvertaft, 1969). There is however ample evidence in the sediments for repeated movements during sedimentation: sandstone horizons show signs of slumping; reworked concretionary sandstones form conglomerates in shale predominated lithologies.

The western termination on southern Disko, much less well exposed and therefore less well studied, can be taken at the ridge of Precambrian gneisses extending northward from Godhavn to Disko. The base of the succession is concealed to a large extent but facies would indicate proximity of a source. There are no indications of large scale faulting.

The western limit of the onshore sediments is thus probably defined by a pinch-out towards the Disko gneiss ridge, whereas the eastern boundary consists of a fault system. It seems therefore appropriate to define the onshore parts of the sediments in the Disko–Nûgssuaq area as the Nûgssuaq embayment, since with some certainty they constitute a separate part of the West Greenland basin.

(2) The occurrence of recycled, presumably pre-Cretaceous non-metamorphosed clastic sediments in the embayment, seen in conjunction with prevailing transport directions already in the Lower Cretaceous from the south-west and south (fig. 15) would point to some control of sedimentation by the Disko gneiss ridge. A continuous lifting tendency could well have led to a progressive stripping of older sediments.

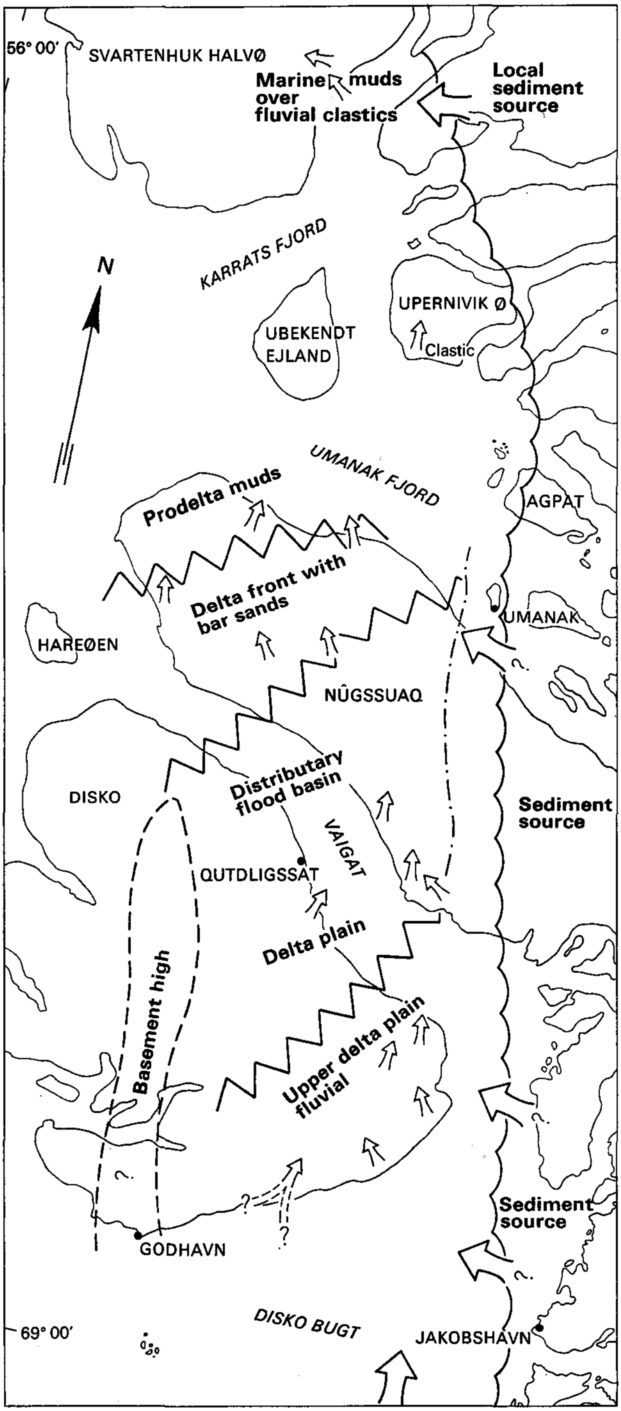

Fig. 15. Sketch map of the Nûgssuaq embayment, showing approximate limit between marine and deltaic facies in the Cretaceous.

West of the ridge step faulting is strongly developed in the Tertiary basalts (Pedersen, personal communication). If this pattern is in any way inherited, it is only reasonable to assume that larger quantities of these older sediments found their way also into the offshore parts of the basin. Through probably prolonged marine reworking they would provide texturally well suited reservoir rocks for migrated hydrocarbons.

(3) Marine influence during the Cretaceous in rocks of the Nûgssuaq embayment is, apart from the area shown in fig. 15, rather sporadic and poorly documented by occasional and widely separated horizons with marine fauna. Environmental interpretation of the 'non-marine' part by earlier workers ranges from limnic-fluviatile to very generally deltaic. Macroscopic lithological considerations presumably provided the basis for interpretation.

The horizontally and vertically widespread occurrence of abundant carbonate cement, including dolomite in the 'non-marine' facies, requires at least migration of saturated pore water during compaction (Garrison *et al.*, 1969). However, with reasonable macroscopic (concretion formation) and petrographic evidence for rapid cementation prior to compaction of the sands, a more continuous marine influence might be postulated. Offshore parts of the West Greenland basin were affected by presumably more continuous sinking tendency, which could have led to actual carbonate deposition. The chances for the existence of possible oil source rocks would thus be greatly enhanced.

References

Bausch, W. M. 1965: Dedolomitiserung und Recalcitisierung in fränkischen Malmkalken. *Neues Jb. Miner. Mh.* **3,** 75–82.

Bien, G. S., Canbois, D. E. & Thomas, W. H. 1958: Removal of soluble silica from fresh water entering the sea. *Geochim. cosmochim. Acta* **14,** 35–54.

Birkelund, T. 1965: Ammonites from the Upper Cretaceous of West Greenland. *Bull. Grønlands geol. Unders.* **56** (also *Meddr Grønland* **179,** 7) 192 pp.

De Groot, K. 1967: Experimental dedolomitization. *J. sedim. Petrol.* **37,** 1216–1220.

Elliott, G. F. 1956: Algues calcaires Codiacées fossiles d'Iraq, nouvelles ou peu connues. *Bull. Soc. géol. Fr.* **6,** 789–796.

Garrison, R. E., Luternauer, J. L., Grill, E. V., MacDonald, R. D. and Murray, J. W. 1969: Early diagenetic cementation of Recent sands, Fraser River delta, British Columbia. *Sedimentology* **12,** 27–46.

Gry, H. 1942: The Cretaceous and Tertiary sediments on Itsako. *In* Rosenkrantz, A. *et al.* A geological reconnaissance of the southern part of the Svartenhuk Peninsula West Greenland. *Meddr Grønland* **135, 3,** 27–35.

Heer, O. 1883: Oversigt over Grønlands fossile flora. *Meddr Grønland* **5,** 82–202.

Henderson, G. 1969: Oil and gas prospects in the Cretaceous-Tertiary basin of West Greenland. *Rapp. Grønlands geol. Unders.* **22,** 63 pp.

Koch, B. E. 1964: Review of fossil floras and nonmarine deposits of West Greenland. *Bull. geol. Soc. Am.* **75,** 535–548.

Rosenkrantz, A. 1970: Marine Upper Cretaceous and lowermost Tertiary deposits in West Greenland. *Meddr dansk geol. Foren.* **19,** 406–453.

Rosenkrantz, A. & Pulvertaft, T. C. R. 1969: Cretaceous-Tertiary stratigraphy and tectonics in northern West Greenland. *Mem. Am. Ass. Petrol.* **12,** 883–898.