

Diagenesis and reservoir properties of Campanian–Paleocene sandstones in the GANT#1 well, western Nuussuaq, central West Greenland

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As part of a study on reservoir characterisation of western Nuussuaq, central West Greenland (Sønderholm & Dam 1998) the diagenesis and reservoir properties of sandstone units in the GANT#1 well located in north-

western Nuussuaq have been investigated (Kierkegaard 1998). The GANT#1 well was drilled during the summer of 1995 by grøNArctic Energy Inc. (Calgary, Canada) as part of the company's hydrocarbon exploration activ-

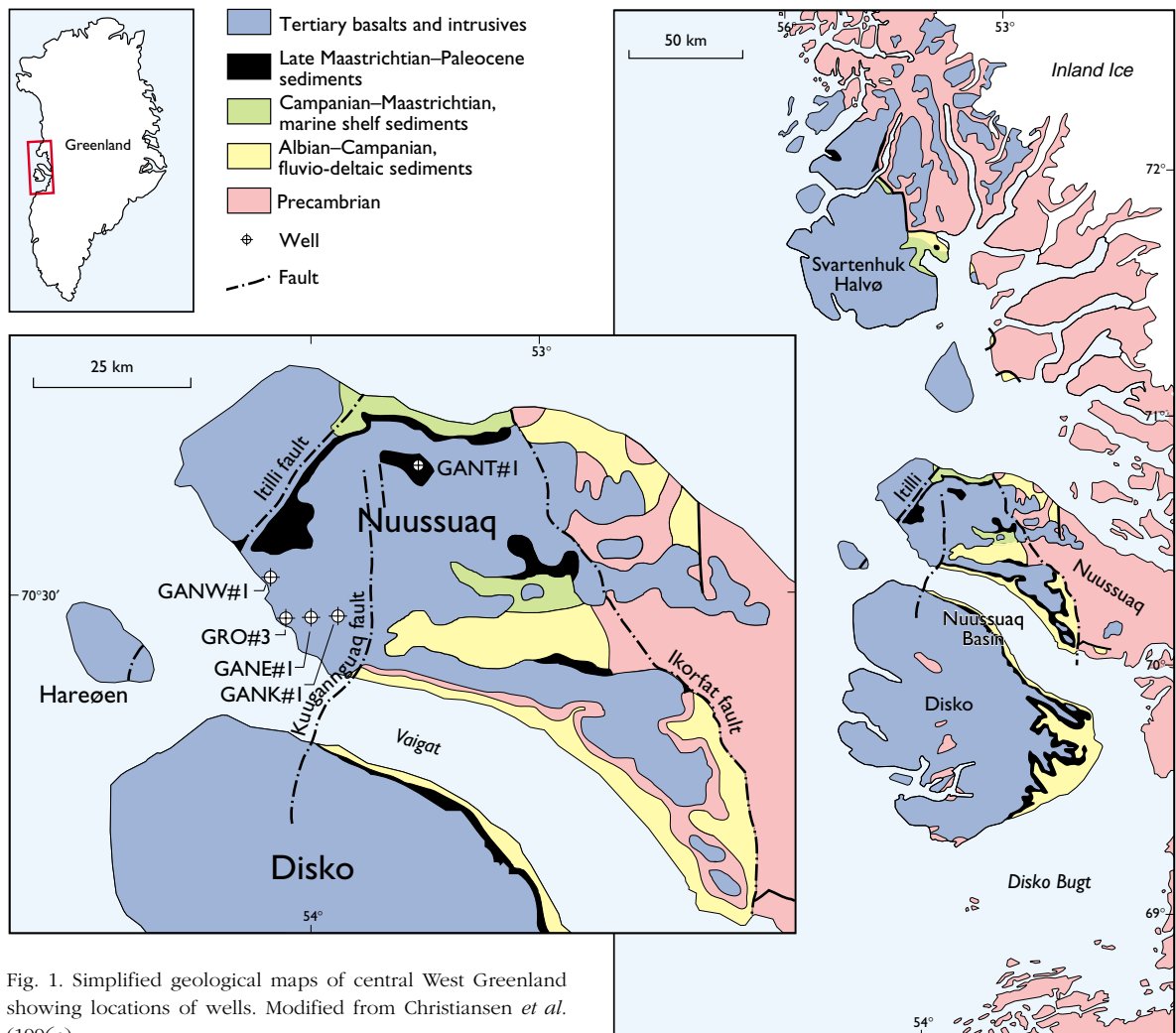


Fig. 1. Simplified geological maps of central West Greenland showing locations of wells. Modified from Christiansen *et al.* (1996a).

ities in the region. These also included the drilling of four other wells: GANW#1, GANE#1, GANK#1 and GRO#3 on the south-western coast of Nuussuaq (Fig. 1). The GANT#1 core was examined in order to elucidate the diagenetic and detritus factors that control the present porosity and permeability variations occurring in the Cretaceous – Lower Paleocene succession of western Nuussuaq. The examinations were carried out with standard petrographic methods, including X-ray diffractometry of mudstones and standard polarisation microscopy of thin sections from sandstones, supported by scanning electron microscopy (Kierkegaard 1998).

Porosity and permeability measurements from the GANT#1 core generally reveal poor reservoir quality with a range in porosity from 4.92 to 18.79% and in permeability from 0.106 to 90.7 mD, but both porosity and permeability are greater in post-Campanian sandstones compared to Campanian sandstones (Kierkegaard 1998). The GANE#1 well provides a section through Upper

Paleocene turbiditic sandstone units alternating with mudstone units which thus furnishes a complementary and stratigraphically higher section to that found in GANT#1. However, porosity and permeability measurements from the GANE#1 well show low arithmetic average values of 6.4% and 1.46 mD, respectively (Andersen 1996).

Sedimentary environment

The West Greenland margin is a continental margin subdivided into linked basins where Cretaceous to Lower Tertiary, and probably older, sediments have been deposited (cf. Chalmers & Pulvertaft 1993; Dam & Sønderholm 1994). In the Nuussuaq area these sediments are overlain by an up to 2.5 km thick volcanic succession of Early Tertiary age (cf. Pedersen *et al.* 1993).

The GANT#1 well drilled through a 901 m succession of sediments which are penetrated by 15 small intrusions. A major, regional unconformity separates the upper 256 m, which include mudstones, coarse-grained sandstones and conglomerates of post-Campanian age, from a lower 646 m thick succession comprising mudstones and medium- to coarse-grained sandstones of Early to Late Campanian age (Fig. 2; Dam 1996; Nøhr-Hansen 1997).

The vertical facies development suggests that deposition took place on a fault-controlled slope in canyons, major and minor distributary feeder channels, small turbidite lobes and interdistributary channel areas (Dam & Sønderholm 1994; Dam 1996).

Detrital composition of sandstones

The sandstones are classified as subarkoses and are generally poorly sorted; however, the post-Campanian sandstones above the unconformity seem to be better sorted and contain only little, if any, detrital clay. Feldspars are found both as unaltered and strongly sericitised grains and include both K-feldspar (mostly as microcline) and plagioclase generally in equal amounts. Lithic fragments are dominated by mudstone clasts. Compaction deformation, especially of the mudstone clasts, is the most significant alteration of the lithic fragments.

A slight difference in detrital composition between the Campanian and the Maastrichtian–Paleocene successions may represent a shift in provenance (Kierkegaard 1998).

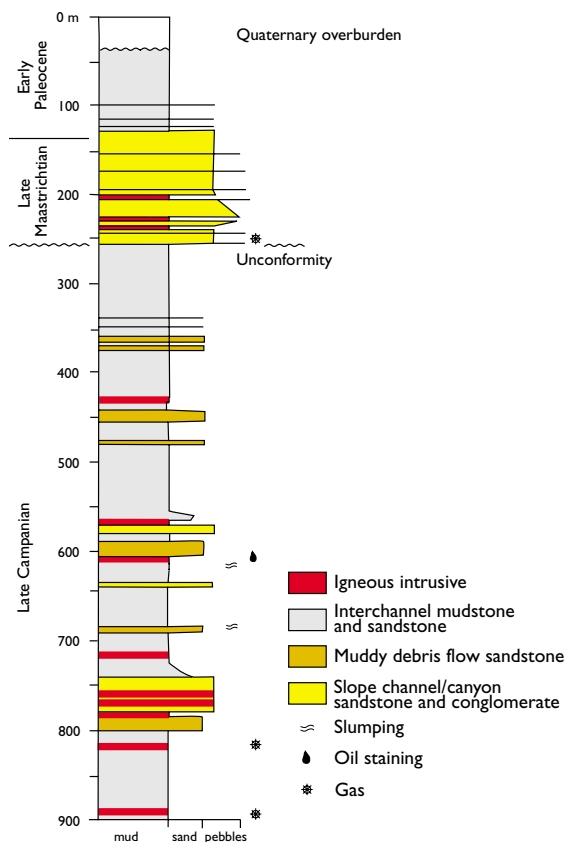



Fig. 2. Generalised sedimentological log from the GANT#1 core. Modified from Dam (1996).

Fig. 3. Paragenetic sequence of diagenetic events during the Campanian and Early Paleocene as observed in the GANT#1 well. Modified from Kierkegaard (1998).

		Campanian burial	Post-Campanian burial
Shallow burial	Apatite	-	-
	Pyrite framboids	-	-
	Early siderite	-	-
	Early quartz	-	-
	Mixed-layer clay	-	- - ? -
	Ferroan carbonate	-	-
Deep burial	Calcite		-
	Feldspar dissolution		-
	Kaolinite		-
	Albite		-
	Third generation quartz		-
	Late siderite		?
	Ankerite		-
	Pyrite concretions		-
Compaction			

Diagenetic alteration

The unconformity at a depth of 256 m in the GANT#1 well can be traced throughout the Nuussuaq Basin (Dam & Sønderholm 1998), and is interpreted as separating two distinct diagenetic stages of which the first only affects the Campanian deposits and the second the combined Campanian–Paleocene succession (Fig. 3; Kierkegaard 1998).

Organic maturity data indicate a shift from thermally immature to mature at around 350 m (Christiansen *et al.* 1996b) which parallels a change in mudstone composition from a succession dominated by smectitic illite/smectite to illite/vermiculite occurring between 270 and 400 m (e.g. Boles & Franks 1979; Burley *et al.* 1985). This suggests that the change in mudstone composition is probably related to burial diagenesis, a conclusion which is in agreement with most of the diagenetic alteration observed in the sandstones.

The Campanian diagenetic stage is characterised by growth of apatite, pyrite, siderite, quartz and mixed-layer clay, which all formed during shallow burial in a marine, eogenetic environment (Fig. 3; Kierkegaard 1998).

The shallow burial diagenetic changes were followed by cementation of the sandstone beds with ferroan carbonate forming conspicuous concretionary zones. These zones are only found in the Campanian sedimentary succession and are characteristically absent in the section overlying the unconformity. The amount of ferroan carbonate in the carbonate-cemented beds represents pre-cement porosity and varies from 26 to 40%.

The development of the concretionary zones is probably related to the formation of the major erosional unconformity recognised at a depth of 256 m in the well (Fig. 2). This conclusion is supported by the fact that the zones only occur in the Campanian sandstone beds, and that oxygen and carbon stable isotopes suggest

that they formed under the influence of meteoric water (Kierkegaard 1998).

Shallow Maastrichtian–Paleocene burial diagenesis is characterised by the development of pyrite, siderite, second generation quartz overgrowths, mixed-layer clay and calcite, which are all considered as phases developed in sediments influenced by evolved marine pore waters (Fig. 3).

Deeper burial diagenetic changes include feldspar dissolution and formation of secondary porosity followed by growth of kaolinite, albite, chlorite, third generation quartz, siderite, ankerite and concretionary pyrite. The changes affect both the post-Campanian sandstones and the Campanian sandstones which are not cemented by ferroan carbonate, and they mainly took place in detrital intragrain positions since most primary porosity was obliterated by compaction and the earlier diagenetic alterations (Kierkegaard 1998).

Reservoir conditions

Most of the present porosity in GANT#1 is secondary, originating from dissolution of detrital feldspar grains. However, growth of kaolinite, albite, quartz, siderite and ankerite all reduce this porosity. Formation of secondary porosity may not significantly have raised permeability, since most feldspar dissolution porosity in GANT#1 seems to be intragranular (cf. Ehrenberg 1990). There is, however, a marked difference in the degree of cementation between the Campanian and post-Campanian sandstones, as the Campanian contain relatively high amounts of authigenic mixed-layer clay and quartz (Kierkegaard 1998).

It is notable that although the post-Campanian sandstones contain only minor amounts of cement, permeabilities do not exceed 100 mD, implying that detritus

is a major control on reservoir quality. This is supported by the poor sorting of the sediment, which reduces both porosity and permeability, and the high content of ductile mudstone clasts and siderite aggregates, which increase the degree of mechanical compaction (cf. Beard & Weyl 1973; Pittman & Larese 1991).

It is thus concluded that the rather poor reservoir quality generally characterising the sandstones of the GANT#1 core mainly results from compaction of a poorly sorted sediment containing ductile clasts, combined with precipitation of minor amounts of diagenetic minerals during shallow burial reducing primary porosity.

Although the reservoir properties of the sandstone intervals in the GANT#1 and GANE#1 wells are generally relatively poor, it is suggested that moderate to good properties may be found in certain intervals within the Maastrichtian–Paleocene succession. This conclusion is supported by petrophysical log evaluation of the GRO#3 well where the Paleocene sandstones show porosities between 10 and 15% and hydrocarbon saturations up to 50% (Kristensen & Dam 1997). However, the reason for the locally enhanced reservoir properties in GANT#1 was not clarified by this study, partly due to the lack of regional petrographic data.

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