the gamma ray, changing very abruptly from low values in the sand uppermost in the CEN-5 Unit, to high values in the basal clay bed of the CEN-6 Unit. The upper boundary is represented by the sea floor.

Distribution: The Unit is widely distributed within the Danish North Sea region and is found in all Danish Central Graben wells (fig. 35).

Geological age: Foraminifera occur abundantly in the lower part of the Unit, while they are rare or absent above. The restricted number of foraminiferal species recorded points unambiguously to a Pleistocene to recent age. The lower bed with abundant foraminifera is referred to the Early Pleistocene (Icenian).

Depositional environment: The alternating sand and silty clay layers, the frequency of lignite and megaspores, and the common accumulations of shells point to marine, littoral to inner sublittoral environments related to a delta front in the subsiding North Sea Basin.

Source rock potential: Poor. Studies in a few well sections indicate an immature stage for oil generation.

Reservoir potential: Good in unconsolidated porous sand layers.

Sealing potential: Poor in the intraformational parts. The lower clay layer may probably act as a seal for hydrocarbon accumulations in the unit below.

4.0 Formation temperatures

By Peter Klint Jensen

Borehole temperatures have been studied to evaluate the natural temperature field of the geological formations (fig. 37). Formation temperature and time are main factors affecting maturation of source rocks and should, therefore, be compared with maturation measurements. Furthermore, temperature gradients through sedimentary sequences provide information about relationships between their heat conductivities, and this can be used to extrapolate temperatures measured in wells to the surrounding rock masses.

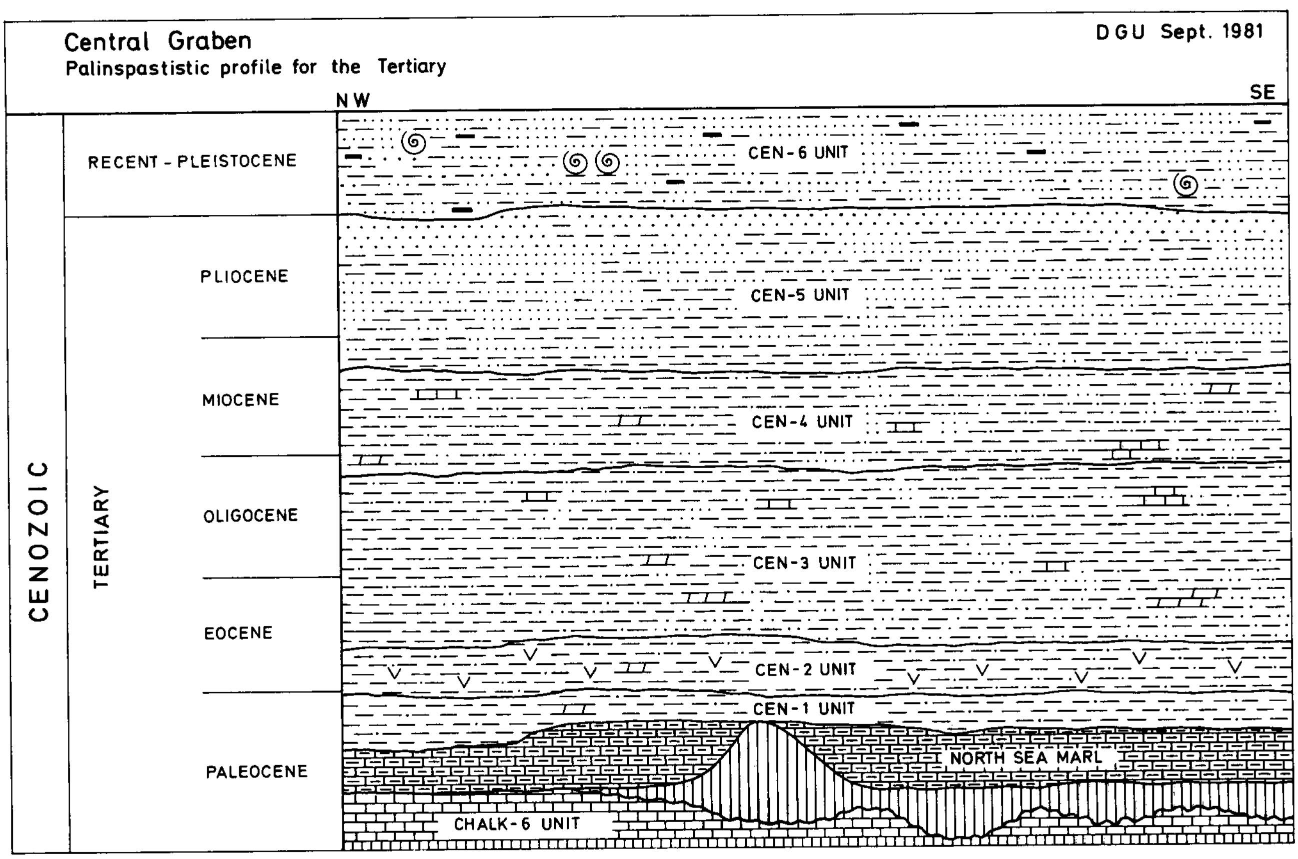

Fig. 36: Palinspastic profile of the Cenozoic deposits. For legend, see fig. 3.

Experience shows that mean gradients calculated from well measurements are related to the structural style of the area.

The temperature field in a sedimentary basin is controlled by the following factors:
1) Heat flow beneath the basin floor partly caused by radioactive elements in the crust.
2) Distribution of heat conductivities of the formations. This also implies focusing and de-focusing effects caused by the geometry of the formations.
3) Faulting or folding of rock masses contemporaneous with erosion and sedimentation, and other movements, e.g. those caused by halokinesis.
4) Circulation of formation water in thick porous and permeable sedimentary sequences, or in fracture systems penetrating deeply into the crust.
5) Intrusion of igneous rocks during tectonically active periods.
6) Change of surface temperature through time.

Geothermal gradients in North Sea wells have been computed by Evans & Coleman (1974) showing mean values from 18°C/km to 40°C/km, with high values found in the northern Central Graben. Mean values for the gradients between surface and bottom of wells in the Danish area have been mapped by Madsen (1975). The trend shows high gradients, about 32°C/km for the Central Graben, and low gradients, about 22-29°C/km for the Ringkøbing-Fyn High. Anomalous high gradients are to be expected above salt structures.

The area which has been re-investigated here is the deepest part of the Danish Central Graben around the Tyra field, and parts of the Tail End Graben. The wells selected are presumably uninfluenced by refraction of heat flow caused by salt structures. An exception could be the I-1 well.

The temperature calculations are based on down-hole temperatures measured during tests with production of fluid, and measurements of bottom hole temperatures during wire line logging. The flow conditions during a test period seem to disturb the temperature, especially when producing gas. Therefore, measurements from gas-producing periods of the test are omitted. The temperature level is furthermore influenced by the drilling operation itself, including the circulation of the drilling fluid. The total effect is a cooling of the formation around the bottom of the borehole. If at least two measurements are obtained after cessation of the mud circulation, a correction formula can be used to find a true formation temperature. The following parameters must be known:
a) Bottom hole temperature.
b) Time of the measurements since cessation of circulation.
c) Time of cooling at the depth of measurement, which is assumed to be 30' above maximum depth. This means, that the drilling rate and the time of mud circulation after cessation of drilling must be known. The last parameter is taken to be from a half to one hour.

Changes in surface temperature during the past is reflected in the temperature profile of the subsurface formations. Heating after the end of the last glaciation is especially important. During the Quaternary glaciations, a mean surface temperature of approximately 0°C is normally accepted. During the last 10,000 years the mean surface temperature has increased to approximately 8°C. At a depth of 1 km, the temperature has increased to about 10% of the original surface formation temperature. Heating can be disregarded at depths greater than 1.5 km.

The results of temperature investigations in six wells are summarised in the table below. The final tempera-

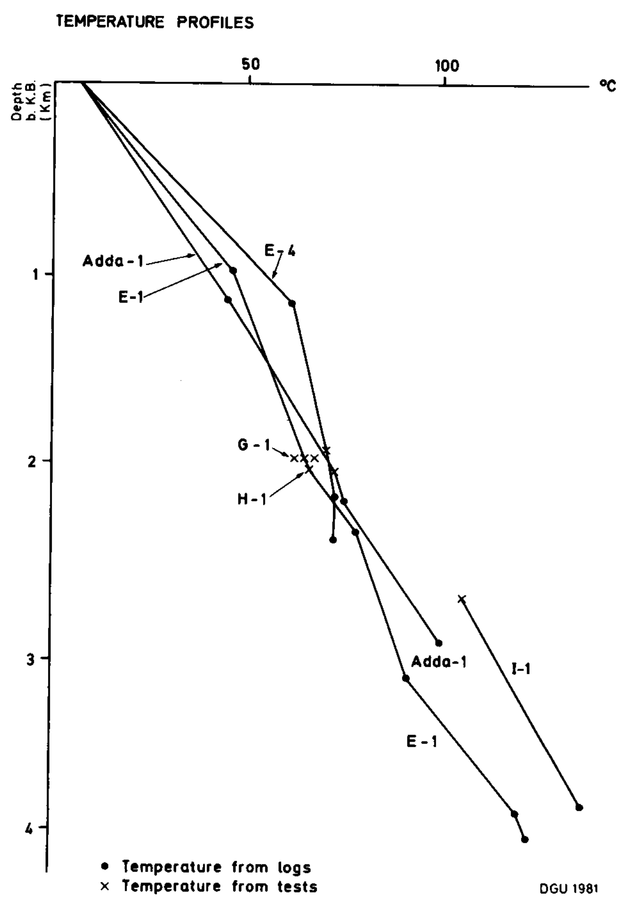

Fig. 37: Temperature profiles calculated from borehole measurements of the Adda-1, E-1, E-4, G-1, H-1, and I-1 wells.

ture measurement for a given depth (last °C) and the time since cessation of circulation are noted. If at least two measurements have been carried out after cessation of mud circulation, the true formation temperature is estimated by the above mentioned correction formula (corr. °C). The maximum correction factor was 10°C. The mean gradient between the surface and a given depth is computed (grad. °C/km). Mean values for sea floor temperatures as a function of depth can be found in Evans & Coleman (1974). To avoid the influence of local heating of the upper 1.5 km since the last glaciation, the true formation temperature has been corrected (ice corr. °C), accepting a value of 0°C as the mean surface value during the Quaternary. The corresponding mean gradients are listed (corr. grad. °C/km).

Table on temperatures and mean gradients

Well	Feet b.KB	Metres b.GL	Time since circ. hrs.	Last °C	Corr. °C	Ice corr. °C	Grad. °C/km	Corr. grad. °C/km	Type
Adda-1	3973	1139	4	40	45	41	34	36	logs
	7042	2074	-	74	-	74	32	36	tests
	7474	2206	18	72	76	76	31	34	logs
	10000	2976	18	94	101	101	31	34	logs
E-1	3526	1000	5.5	46	47	42	40	42	logs
	6798	1997	-	66	-	66	29	33	tests
	6900	2028	-	67	-	67	30	33	tests
	8088	2391	26	80	80	80	31	34	logs
	10650	3171	5.5	94	-	94	27	30	logs
	12926	3865	-	122	-	122	30	32	tests
	13406	4012	12.5	126	-	126	30	31	logs
E-4	4038	1162	4.5	62	67	60	51	52	logs
	6599	1942	-	71	-	71	33	37	tests
	7425	2195	7	73	-	73	30	33	logs
	7520	2233	27	72	73	73	30	33	logs
G-1	6822	1993	5.5	63	-	63	28	32	tests
H-1	6789	1986	-	67	-	67	30	34	tests
I-1	9195	2708	-	107	-	107	37	40	tests
	12848	3822	10	129	139	139	35	36	logs

The corrected formation temperatures (corr. °C) listed in the table are plotted on fig. 37 as a function of depth. The temperature around the Tyra field at 1 km depth is between 40 and 55 °C. The mean gradients to this depth (33-48 °C/km) indicate a surface layer of relatively low heat conductivity which corresponds approximately to the uncompacted Quaternary and Upper Tertiary sandy/silty formations. At a depth of 2 km, the temperature ranges from 63 to 72°C. The mean gradient through the consolidated Lower Tertiary and Upper Cretaceous formations is about 20°C/km. Computation of the temperature and the gradient in the Upper Jurassic formations is of interest since these are considered to be possible source rocks. The temperature for the Upper Jurassic varies from 82 to 88°C. The E-1 well indicates a gradient of 40°C/km in Jurassic shales. A temperature estimate of the Upper Jurassic boundary at I-1 yields 123°C and a gradient for the Lower Cretaceous and Jurassic formations of 30°C/km. The relatively high temperature is caused by greater depth of burial and a high mean gradient for the I-1 well.

The few examined temperature measurements indicate that the present temperature field can be explained by a purely conductive model. During previous geological periods, the higher tectonic activities might have contributed to a higher regional heat flow as well as local heating by intrusions or convective systems.

Presently, additional wells in the Central Graben are being investigated to discover the regional trend and to determine relative heat conductivity contrasts for all lithostratigraphical units.

5.0 Source rocks

By Holger Lindgreen, Erik Thomsen & Per Wrang

Little has been published on source rocks of Paleozoic and Mesozoic ages in the North Sea. Gas in many fields of the southern North Sea is known to originate from Late Carboniferous Coal Measures, (Eames 1975). In the East Midlands area of England, the oil in Carboniferous reservoirs is believed to originate from Carboniferous rocks (Bernard & Cooper 1981). Several papers published on the oil fields in the southern and northern North Sea suggest a Late Jurassic source rock (see review by Weismann 1979 and Bernard & Cooper 1981). Also Early and Middle Jurassic shales are suggested as possible source rocks in parts of the North Sea (Fuller 1975, Oudin 1976). Published data on source rock conditions in the Danish sector is limited to Weismann (1979).

5.1 Source rock definition

The term source rock is often used in an ambiguous way.

In the present report a source rock is defined as a rock containing a sufficient amount of organic matter of a proper type, and of sufficient maturity. A potential source rock is an immature source rock. The source rock parameters applied herein are 1) amount