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INTRODUCTION

Shallow gas in marine sediments and sedimentary rocks is a widely occuring phenomenon, and has been reported from continental shelves throughout the world (Claypool & Kvenvolden 1983). "Shallow" is a somewhat vaguely defined term, but in this context it usually means within the upper 1000 m. Occurrences of shallow gas are important to locate for two reasons (Carlson et al. 1985): (1) Although shallow gas accumulations are usually not of economic interest, their presence may signal the existence of deeper, more extensive hydrocarbon accumulations, and, most important, (2) presence of shallow gas constitutes a hazard for drilling operations. High in-situ pore pressures may decrease the sediment's load-bearing capacity, and blow-outs may cause loss of buoyancy. Blow-out preventors are not placed before the well has reached a certain depth because of the high likelyhood of gas escape outside the casing in poorly consolidated material.

The gas, predominantly methane, may be biogenically formed in-situ by decomposition of organic matter in the sediments, or it may have a petrogenic origin, migrating from a deeper hydrocarbon source within the bedrock. The two types of gas may be distinguished from the ratio of light to heavy hydrocarbons and their ^{13}C values (Cline & Holmes 1977, Nelson et al. 1978, Nelson et al 1979, Faber & Stahl 1984). However, discussion of gas formation and chemistry is beyond the scope of this report.

Gas hydrates, where molecules of natural gas fit into structural voids in the lattice of the host water molecule, may form naturally in the Arctic offshore. Hydrates may become a source of recoverable gas, but today they mostly represent a hazard to drilling operations. Decomposition of hydrates around a borehole may result in loss of strength and discharge of large gas volumes. Reformation of hydrates after shut-in periods may furthermore induce high pressures on the casing.

Because gas has a large effect on the acoustic properties of sediments, shallow gas can be detected by means of high resolution seismic surveys. Gas contents of as little as 1 % are sufficient to significantly alter the character of seismic records (Fannin 1980). The most usual effects are gas blanking and amplitude anomalies (bright spots). Where gas migrates to the sea floor and escapes, small depressions, pockmarks, may form. Thus, the sea floor morphology can also indicate the presence of gas in the sediments.

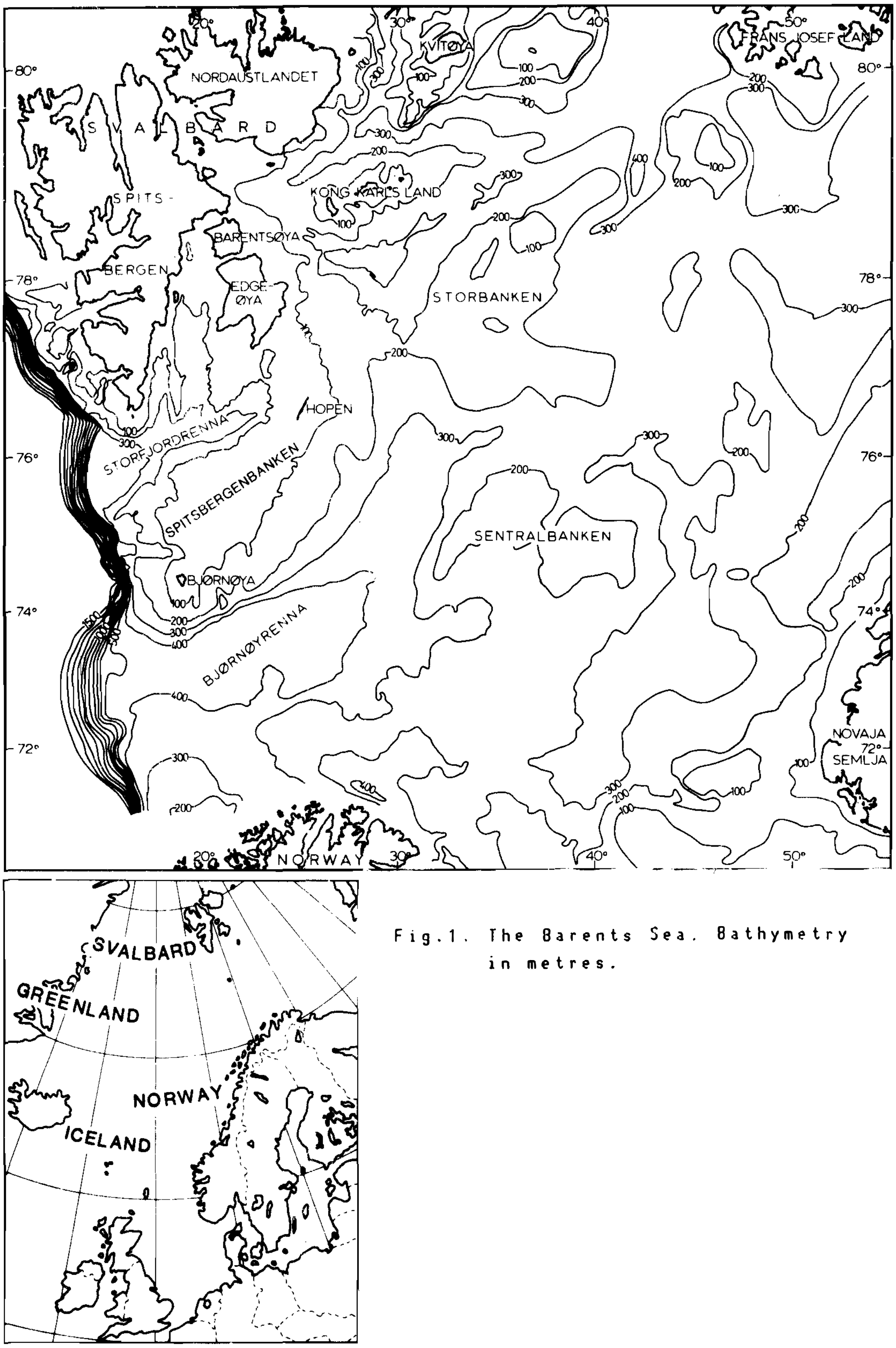


Fig.1. The Barents Sea. Bathymetry in metres.

Detection of shallow gas accumulations is an important objective of site surveys before drilling operations. Most work on shallow gas on the Norwegian continental shelf has been this type of local surveys. Of more regional work, Rokoengen and Tegdan (1983) used 4500 km of regional sparker lines to map shallow gas in the Norwegian North Sea between 60^0 N and 62^0 N. Pockmarks have been reported from the Norwegian North Sea by Hovland (1981, 1983).

The scope of this report is to present information on shallow gas indications based on the excisting shallow seismic data base for the northern Barents Sea (north of 74^0 N) (Fig. 1). The results are presented in an enclosed map and a table (Table 2), where also data quality and indication confidence are evaluated.

Additionally, the report includes an extensive bibliography of shallow gas and related subjects.

SEISMIC DETECTION OF SHALLOW GAS.

Due to a significant reduction in acoustic impedance of gas charged sediments, shallow gas can be detected by high resolution seismic methods. Acoustic anomalies related to gasified sediments are:

1. <u>Gas blanking</u> (Fig.2a). No unified terminology exists, and this term is used differently by different authors. Other terms are also used to cover the phenomenon of masking or blanking of the acoustic records. Rokoengen and Tegdan (1983) describes dark and light blanking. The dark blanking represents areas where much energy is reflected in a disordered way, giving rise to a chaotic, dark record, whereas the energy is damped (absorbed) to give rise to the light blanking.

Mullins and Nagel (1983) use the term "seismic smear", introduced by Watkins and Worzel (1978), for the dark blanking, while they call the light blanking "seismic wipeouts". The smear is due to scattering of energy because of gas within interstitial water, while the wipeouts are caused by selective absorption of the higher seismic frequencies in the gas-saturated sediments. Thus, the wipeouts are most often seen on high frequency records.

2. <u>Amplitude anomalies (bright spots)</u> (Fig.2b,c). These result from the strong acoustic impedance contrast between the gas charged and water (or oil) saturated sediments. In addition to enhanced amplitudes, the passage into a medium with lower acoustic impedance (the gas charged sediment) gives rise to a <u>phase shift</u> of the seismic signal. The amplitude anomalies are frequently seen on single channel

data, but are usually most diagnostic on processed multi-channel records, where also amplitude-scaled plots can be made.

Variable gas content may also reduce the impedance contrast across a reflector without leading to a negative reflection coefficient. Thus gas may reduce amplitudes (Badley, 1985) and thereby cause wipeout of reflectors. However, such anomalies are more difficult to detect and are rarely reported in the literature.

3. Seismic pull-down (Fig.2a,c). The lower seismic velocity in the gas-layer may cause pull-down of reflectors underlying the gas charged sediments.

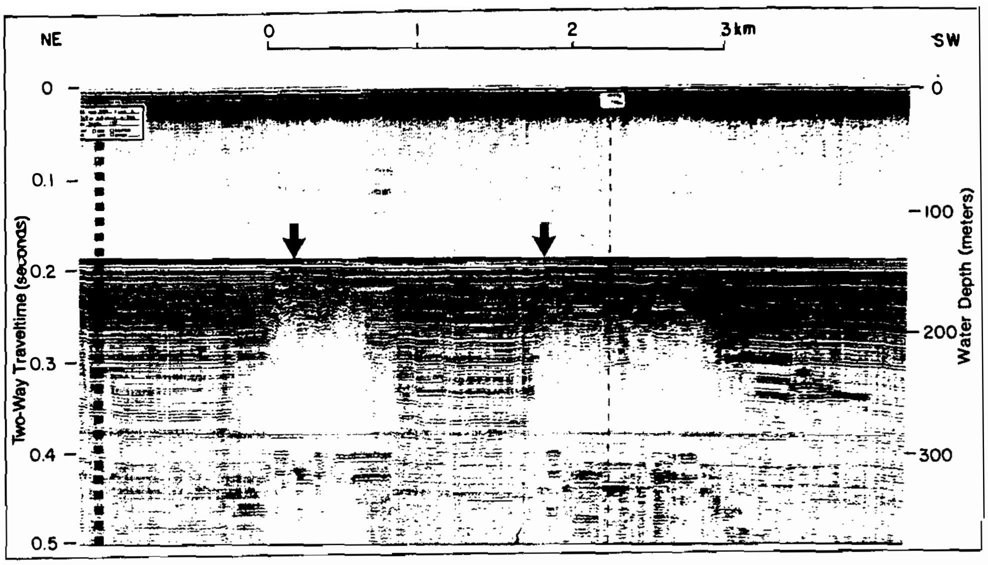
4. Diffraction. The termination of reflectors that are set up or enhanced by the gas, or reflectors that are terminated by gas blanking, may act as point reflectors and give rise to diffraction patterns at the boundaries of gas accumulations.

In addition to these four main criteria, gas leaks may be observed directly as water-column anomalies (Mullins and Nagel 1983). These are reflections from concentrations of gas bubbles rising through the water column and are often associated with subsurface anomalies like faults or diapirs. Gas leaking from the sea floor has been observed in several regions (McCartney & Bary 1965, Tinkle et al. 1973, Nelson et al. 1978).

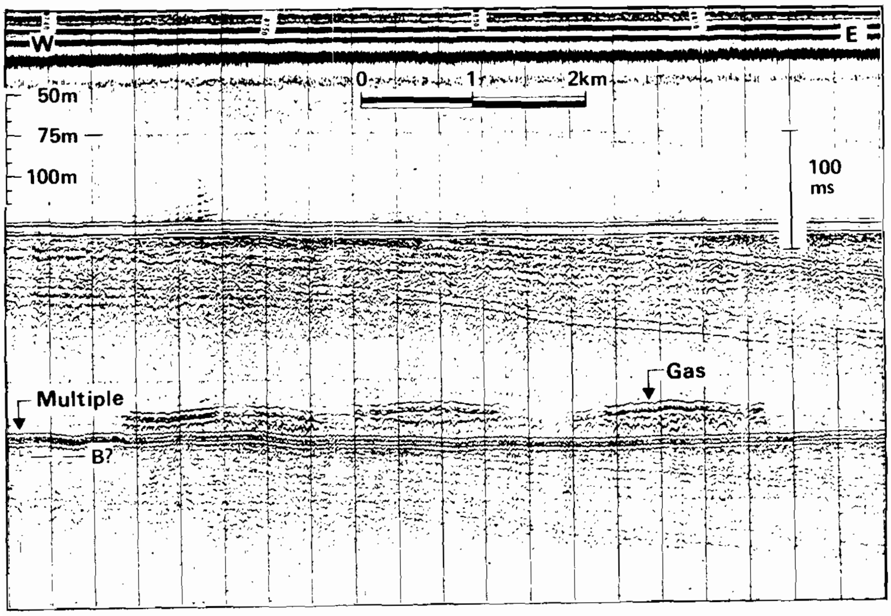
Where gas ascends through the sea floor, pockmarks may form. They are circular to oval depressions in the sea floor, with a diameter that may vary from 10 m to several hundred metres, averaging 50-90 m and depths ranging between less than a metre to 15 m, usually around 5 m. Although their formation has been widely debated, there is now a general agreement that ascending gas is the main mechanism. Pockmarks are common in fine grained sediments of many continental shelf areas (e.g. King & MacLean 1970, Hovland 1981, McQuillin et al. 1979, Josenhans et al. 1978, Nelson et al 1979). They are numerous in the North Sea, particularly in the deeper waters of the Norwegian Trench (McQuillin et al. 1979, Hovland 1981, Van Weering 1973), and are reported from the northern Barents Sea (Solheim & Elverhøi 1985).

In polar and subpolar regions, pockmarks can only be detected with certainty with side scan sonar techniques. Depressions seen in a vertical section on echograms or seismic lines may represent cross sections of iceberg plough marks.

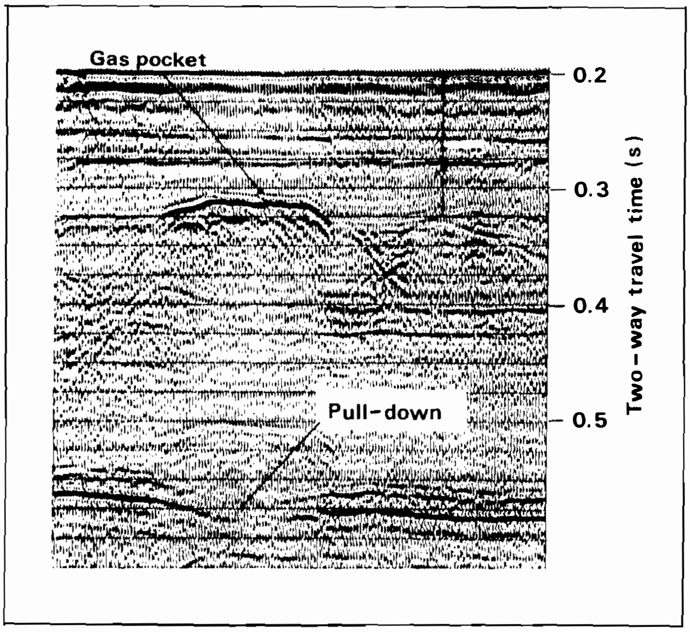
Fig.2a)


NE
0
1
2
3km
SW
0
0.1
0.2
0.3
0.4
0.5
Two-Way Traveltime (seconds)
0
100
200
300
Water Depth (meters)

b)


W
E
0
1
2km
50m
75m
100m
100
ms
Gas
Multiple
B?

c)


Gas pocket
Pull-down
0.2
0.3
0.4
0.5
Two-way travel time (s)

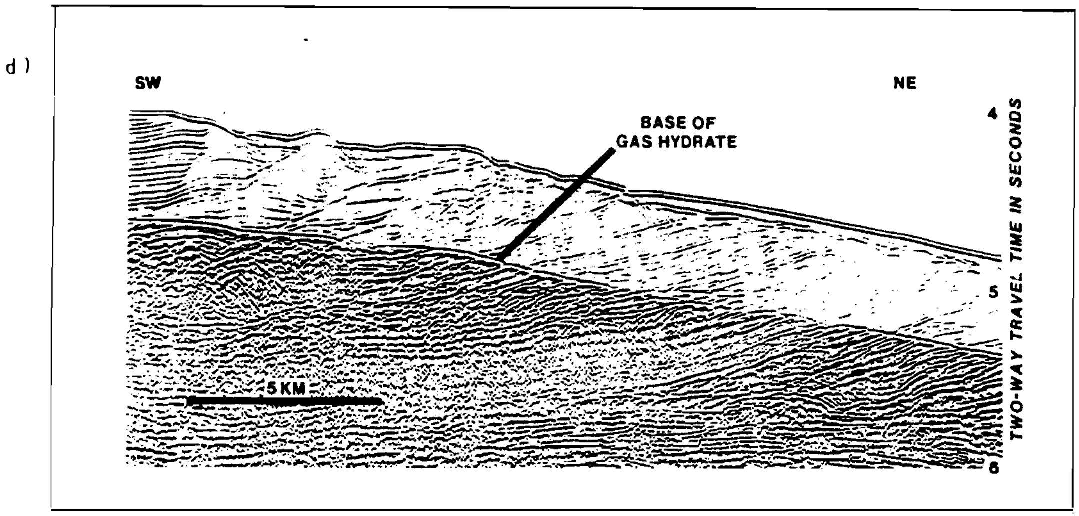


Fig.2. Data examples from other areas. a) Sparker profile from the Bering Sea showing gas blanking and reflector pull-down (arrows). This is an example of light blanking. From Carlson et al. (1985). b) Sparker profile from the North Sea showing enhanced amplitudes due to gas charged sediments. From Rokoengen and Tegdan (1983). c) Multichannel seismic record from the North Sea showing enhanced amplitudes and reflector pull-down. From Rokoengen and Tegdan (1983). d) Multichannel seismic record from offshore southeastern United States showing bottom simulating reflector (BSR) caused by gas hydrates. From Shipley et al. (1979).

Under low temperatures and high pressure, gas may also exist as hydrates in the sediments. In oceanic sediments, gas hydrates can form at waterdepths greater than about 500 metres when bottom water temperatures approach 0 ^{0}C (Kvenvolden 1982). In polar regions, with subzero water temperatures, hydrates may form in shallower water, and are reported to exist at water depths greater than 2-300 m off Alaska and Canada (Weaver & Stewart 1982, Judge 1982). The seismic feature diagnostic for gas hydrates is a bottom simulating reflector (BSR) at some depth below the sea floor (Fig.2d). The BSR marks the base of the gas hydrate zone (Kvenvolden 1982, Carlson et al. 1985). It subparallels the sea floor at some depth, but cuts across other reflectors.

Under suitable conditions permafrost may exist offshore. Acoustic anomalies related to submarine permafrost may appear as amplitude anomalies similar to gas-related bright spots (O'Connor & King 1982) and thus be mistaken for shallow gas indications. However, phase shift of the seismic signal should not occur in the case of permafrost, which would have a higher velocity than the unfrozen material. Offshore permafrost usually results from one of three different modes of formation: 1) relict permafrost in a previously emerged region, 2) passage of mobile barrier islands and 3) freezing from land into near-coastal waters (Neave & Sellman 1984). As none of these mechanisms are likely to have occurred in the study area (Elverhøi & Solheim in press), we exclude the possibility of any of the anomalies seen being caused by permafrost.

PHYSIOGRAPHY AND SHALLOW GEOLOGY

The epicontinental Barents Sea (1.3 mill. km^2) is bounded by the Arctic ocean to the north, the Svalbard archipelago and the Norwegian-Greenland Seas to the west, the Fennoscandian shield in the south and Franz Josef Land and Novaya Zemlja to the east (Fig. 1). It is characterized by northeast-southwest trending basins (300 - 500 m waterdepth) and shallow banks (30-150 m water depth), and has an average water depth of 230 m, significantly deeper than most other present-day high Arctic continental shelves (10 - 60 m). The shelf depth is most likely a response to repeated glaciations in the Late Cenozoic (Elverhøi & Solheim 1983, Solheim & Kristoffersen 1984), leaving only a thin (less than 15 m in average) sediment cover above the Mesozoic and Paleozoic bedrock.

The modern Barents Sea spans a range of environments. In the north, sediments are delivered directly from calving glaciers into an ice-proximal glaciomarine regime, dominated by cold, polar water masses, while year-round ice free conditions caused by warm Atlantic water, prevail in the south (Elverhøi 1984, Pfirman 1985).

Bedrock.

Knowledge on the bedrock of the northern Barents Sea is limited and suffers from the lack of "ground truth". Existing information is based on geophysical investigations, surface sediment samples, and correlations with the geology of the surrounding onshore areas (Eldholm & Talwani 1977, Dibner 1978, Rønnevik et al. 1982, Faleide et al. 1984, Eldholm et al. 1984, Kristoffersen et al. 1984, Elverhøi & Lauritzen 1984, Elverhøi et al in prep.) and lead to the following broad outline:

- In the northernmost parts of the Barents Sea between Kvitøya and Nordaustlandet, metamorphic rocks of Precambrian and Lower Paleozoic age (Hecla Hoek complex) extend from the islands out into the offshore areas.
- Permo-Carboniferous rocks underlying the southern part of Nordaustlandet extend to the east. This is confirmed by shallow rock core drilling on the southern tip of the Kvitøya Plateau (Elverhøi & Solheim 1983b).
- A transition into the Mesozoic rocks that cover most of the Barents Sea (Dibner 1978, Rønnevik et al. 1982) occurs north and northwest of Kong Karls Land. From clast analyses of dredged surface samples (Elverhøi & Lauritzen 1984) the northern part of this area seems to

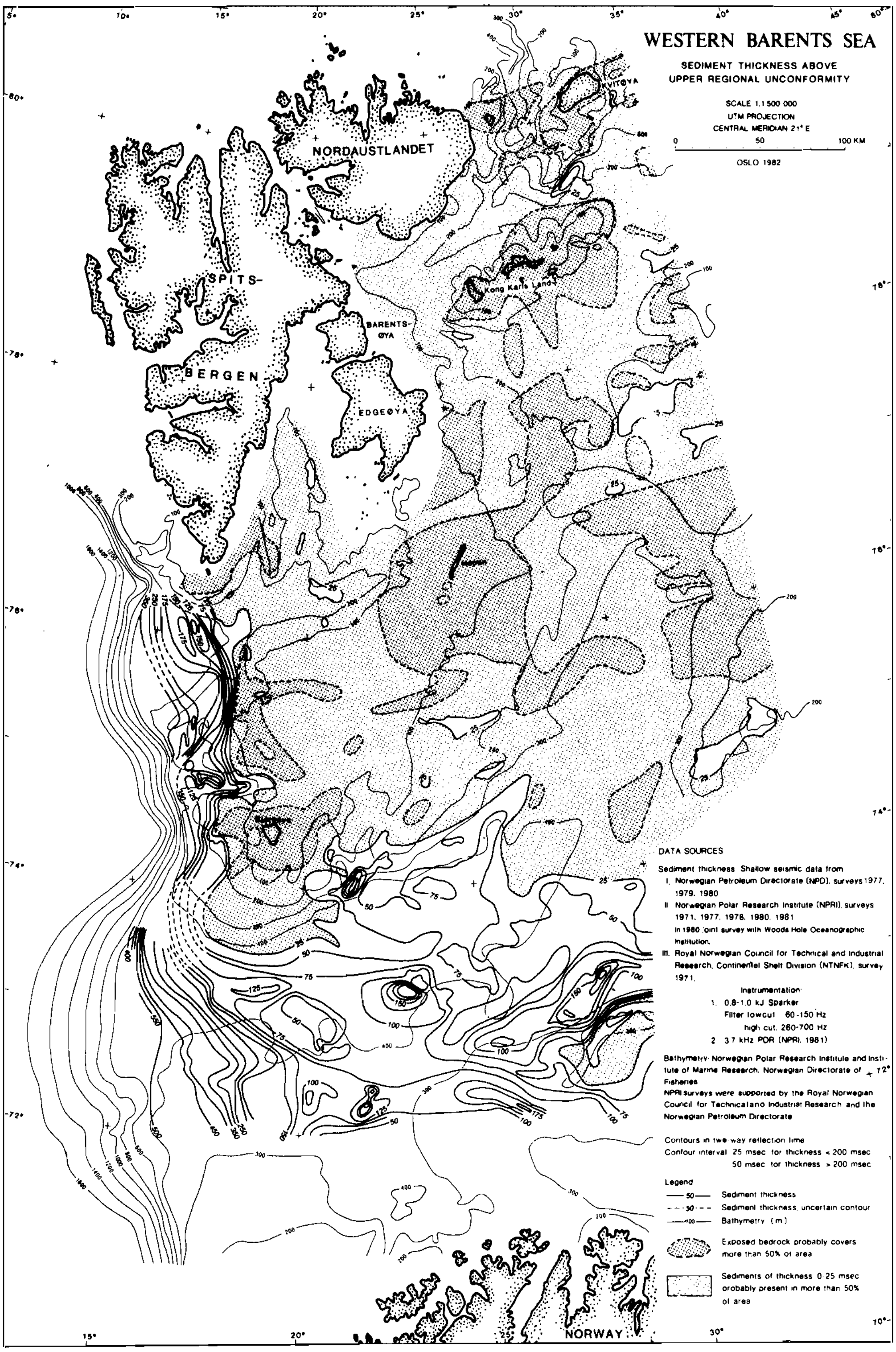
have a Triassic/Lower Jurassic age, younging southeastwards to Jurassic/Lower Cretaceous in the Storbanken/Sentralbanken region. Sandstones dominate the lithology of the surface samples. Deep seismic surveys (Rønnevik et al. 1982, Faleide et al. 1984) also indicate extensive Triassic subcrop in the northern Barents Sea, while Jurassic/Lower Cretaceous rocks are confined to the southern parts of Storbanken and Sentralbanken. However, new data seem to indicate that local, thin subcropping basins of Jurassic/Lower Cretaceous rocks may also exist in the northern Barents Sea (Elverhøi et al. in prep.). North of Kong Karls Land the strata tend to dip southeastwards with slopes of $1-3^{0}$. Further south the bedrock is structurally more disturbed, with dips of up to 7^{0}. In spite of the complexity of the area, there seems to be a regional southward dip of the strata (Kristoffersen et al. 1984).

The information from Spitsbergenbanken is limited. High velocity rocks (3.8-4.4 km/s) (Eldholm and Talwani 1977) at the sea floor, cause poor seismic penetration. Studies of dredged clasts, supposed to be of relatively local origin, indicate Triassic sediments towards Hopen and Bjørnøya, while Jurassic rocks may be present in the central part of the Spitsbergenbanken topographic plateau (Edwards 1975, Bjørlykke et al. 1978). Southeast of Bjørnøya, the Permian succession found on land seems to continue offshore down to water depths of approximately 300 m (Grønlie et al. 1980).

Sediments above bedrock.

The boundary between bedrock and unlithified sediments is usually seen as a well defined angular unconformity, but may be difficult to detect in areas where bedrock layers are subconformable with the sea floor.

The general, broad scale sediment distribution in the Barents Sea (Solheim & Kristoffersen 1984) is that the northern part has less than 25 msec (two-way reflection time) sediment thickness above bedrock, increasing to more than 50 msec south of approximately 74^{0} N, and with a considerably thicker cover along the western shelf edge. More than 500 msec of sediments are recorded in the outer parts of Bjørnøyrenna (Fig.3). Large areas of the northern part have thicknesses less than the resolution of the sparker systems used (commonly 10-15 msec). Recent investigations with 3.5 kHz echo sounding has, however proved that most areas do have a sediment cover and that actual outcrop rarely occurs.



DATA SOURCES

Sediment thickness. Shallow seismic data from

I. Norwegian Petroleum Directorate (NPD), surveys 1977, 1979, 1980

II. Norwegian Polar Research Institute (NPRI), surveys 1971, 1977, 1978, 1980, 1981
In 1980 joint survey with Woods Hole Oceanographic Institution.

III. Royal Norwegian Council for Technical and Industrial Research, Continental Shelf Division (NTNFK), survey 1971.

Instrumentation:
1. 0.8-1.0 kJ Sparker
Filter lowcut 60-150 Hz
high cut. 260-700 Hz
2. 3.7 kHz PDR (NPRI, 1981)

Bathymetry: Norwegian Polar Research Institute and Institute of Marine Research, Norwegian Directorate of Fisheries

NPRI surveys were supported by the Royal Norwegian Council for Technical and Industrial Research and the Norwegian Petroleum Directorate

Contours in two-way reflection time
Contour interval 25 msec for thickness < 200 msec
50 msec for thickness > 200 msec

Fig.3. Distribution of sediments above bedrock in the western Barents Sea. From Elverhøi and Solheim (1983a).

The various sediment types and their distribution and composition can be summarized as follows (Bjørlykke et al. 1978, Elverhøi & Solheim 1983a,b,c, Elverhøi 1984, Solheim & Kristoffersen 1984, Kristoffersen et al. 1984, Solheim & Pfirman 1985, Solheim et al. in prep.):

- Stiff, pebbly mud (till and/or overcompacted glaciomarine sediments, Su > 30 kPa) covered by soft mud with pebbles (glaciomarine deposits, Su < 10 kPa) is found over most of the region. In areas of less than 300 m water depth the thickness of the two units is in general less than 15 m and less than 5 m, respectively.
- In areas with water depth less than 300 m, sediment accumulations occur locally as: (1) transverse moraine ridges around the shallow banks and (2) acoustically transparent, probably glaciomarine deposits in troughs and also as ice proximal accumulations on the banks.
- In regions of water depth greater than 300 m, the glaciomarine sediments increase in thickness to 15-20 m and are covered by a thin (usually less than 1.5 m) layer of fine grained Holocene mud. The Holocene mud is also present in shallower areas, in particular in depressions and as infill in iceberg plough marks. A large part of the Holocene mud is formed by erosion and redeposition of fines from the glacigenic sediments in the bank areas.
- Large sediment accumulations are present in water depths exceeding 300 m in the western parts of the two major troughs Bjørnøyrenna and Storfjordrenna. These sediments are most likely stiff, pebbly mud, i.e. till or glaciomarine material, reworked, and overcompacted by a glacier.
- On Spitsbergenbanken the glacial sediments are reworked by currents and mixed with Holocene bioclasts. Due to strong currents, erosion/non-deposition conditions prevail on the southern flank of Spitsbergenbanken, down to 300-400 m water depth.
- Adjacent to calving ice fronts along the coast, surge deposits may exist as sediment ridges of varying width and relief.

The major part of the sediments found are of glacigenic origin and have organic carbon content rarely exceeding 1-2 %, most of which are reworked coal fragments (Forsberg 1983). Thus the likelihood of biogenic gas formation in the unlithified sediments is small. Furthermore, it is probably only the stiff, pebbly mud that has high enough strength to allow pore pressures to build up in the sediment.

DATA BASE

Shallow seismic data from various sources form the data background for this study (Table 1, Fig.4). All data are single channel, analogue sparker records, totalling 32,000 km. Energy level has ranged between 0.5 and 3.5 kJ, and filter settings between 50 Hz and 3 kHz. Most commonly a pass band of approximately 100-500 Hz has been used.

None of the surveys were particularly designed for shallow gas detection. The NP surveys were regional studies of sediment distribution and glacial history, and the IKU surveys were run to detect sites for shallow bedrock drilling. While these surveys were run with shallow seismic investigations as the main program, the NPD data were recorded during regional and semi-regional deep seismic exploration surveys. This may be the reason why these data have particularly bad noise problems.

Different navigation systems have been used. Most common is satellite navigation, using the Transit system, often combined with Loran C or Decca main chain. Some of the NP surveys used a Decca Sea Fix system, which has an accuracy of approximately 10 m. In the last few years, new navigation systems have become operative in the southern Barents Sea, and the IKU surveys in 1984 and 1985 and the NPD 1984 survey utilize the Hyperfix system, which is accurate within less than 10 m.

The data coverage is uneven, and must in general be considered as sparse. In particular is the line spacing large in the northern and easternmost regions (Fig.4). With some exceptions, the mapped gas indications are only recorded by single seismic lines, and we have little control of the areal extent of the potential gas zones. The quantitative distribution of gas indications must also be seen in relation to the uneven data coverage.

The data quality shows large variations, and in particular NPD77, NPD79 and NPD84 are poor. Due to large noise problems, gas indications from these records are most often uncertain (Fig.10). The data quality has been given a three-step scale; poor, intermediate and good. Among the better ones are NP78 and partly NP83 and IKU85. It should be noted however, that the poor data sets occasionally also have given strong indications of shallow gas (e.g. NPD80, line 3400-80) (Fig.5).

INSTITUTION-YEAR	SURVEY AREA	SOUND-SOURCE	ENERGY (kJ)	FILTER (Hz)		NAVIGATION SYSTEM
				LOW	HIGH	
NP/NTNFK-1971	Spitsbergen-banken	Sparker	0.5-8.0	150	600	Decca Hi-fix
NP-1977	NW & SE of Bjørnøya	"	1.0	50	200-500	Decca Hi-fix
NPD-1977	Central Barents Sea	"	0.8	150	700	Satellite/Decca
NP-1978	Western Margin and Bjørnøyrenna	"	1.0	75-100	200-400	Loran C
NPD-1979	S of 76°30'	"	1.0	60-100	260-400	Satellite
NP/WHOI-1980	Hopen-Kvitøya area	"	1.0	60-80	300-3000	Satellite
NPD-1980	All western Barents Sea	"	1.0	80	300	Satellite
NPD-1981	All western Barents Sea	"	1.0	70	100	Satellite/Loran C
NPD-1982	Central and northern Barents Sea	"	1.0	80	300	Satellite
NP-1983	All western Barents Sea	"	1.0-3.0	100	600	Satellite
NDP-1984	S & SE of Bjørnøya	"	1.0	80	300	Hyperfix
IKU-1984	S & SE of Bjørnøya	"	2.8	100	500	Hyperfix
IKU-1985	S & E of Bjørnøya	"	3.5	100	500	Hyperfix

NTNFK = Continental Shelf Division of the Royal Norwegian Council for Scientifical and Industrial Research (now IKU).

NP = Norwegian Polar Research Institute.

NPD = Norwegian Petroleum Directorate.

WHOI = Woods Hole Oceanographic Institution.

IKU = Continental Shelf and Petroleum Technology Research Institute Ltd.

Table 1. Seismic data base for this study

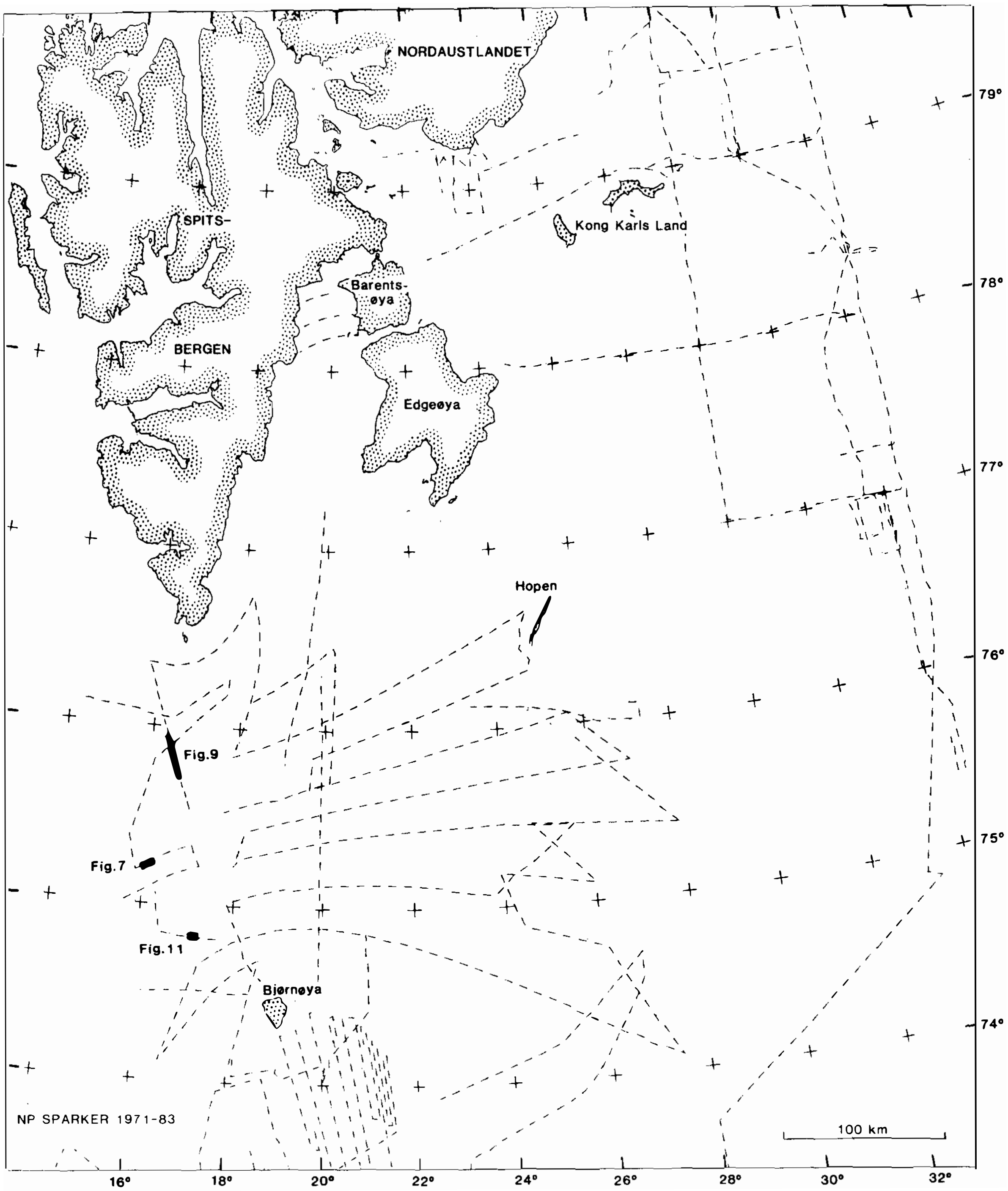


Fig.4a. Seismic lines from the Norwegian Polar Research Institute (NP)

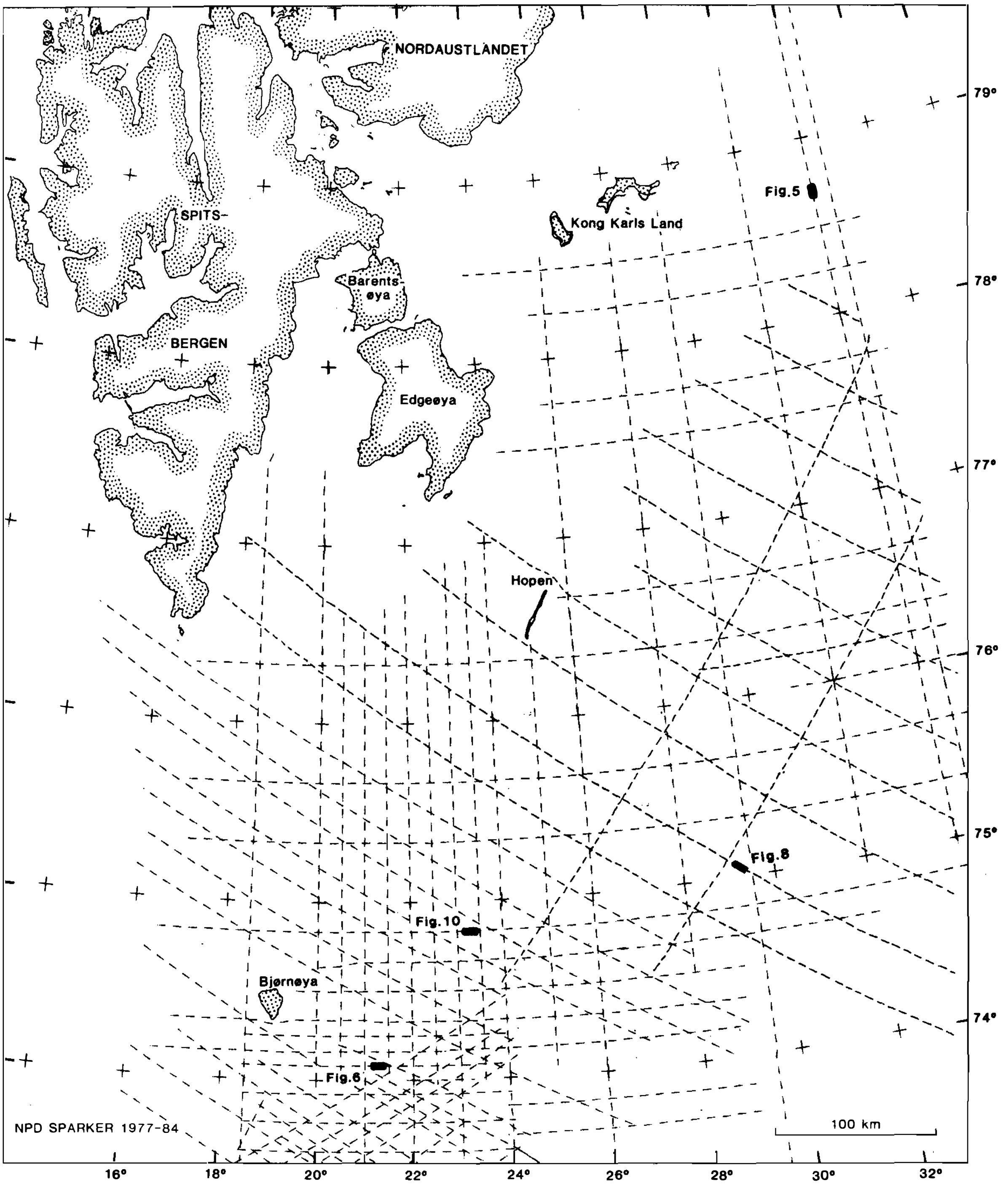


Fig.4b. Seismic lines from the Norwegian Petroleum Directorate (NPD).

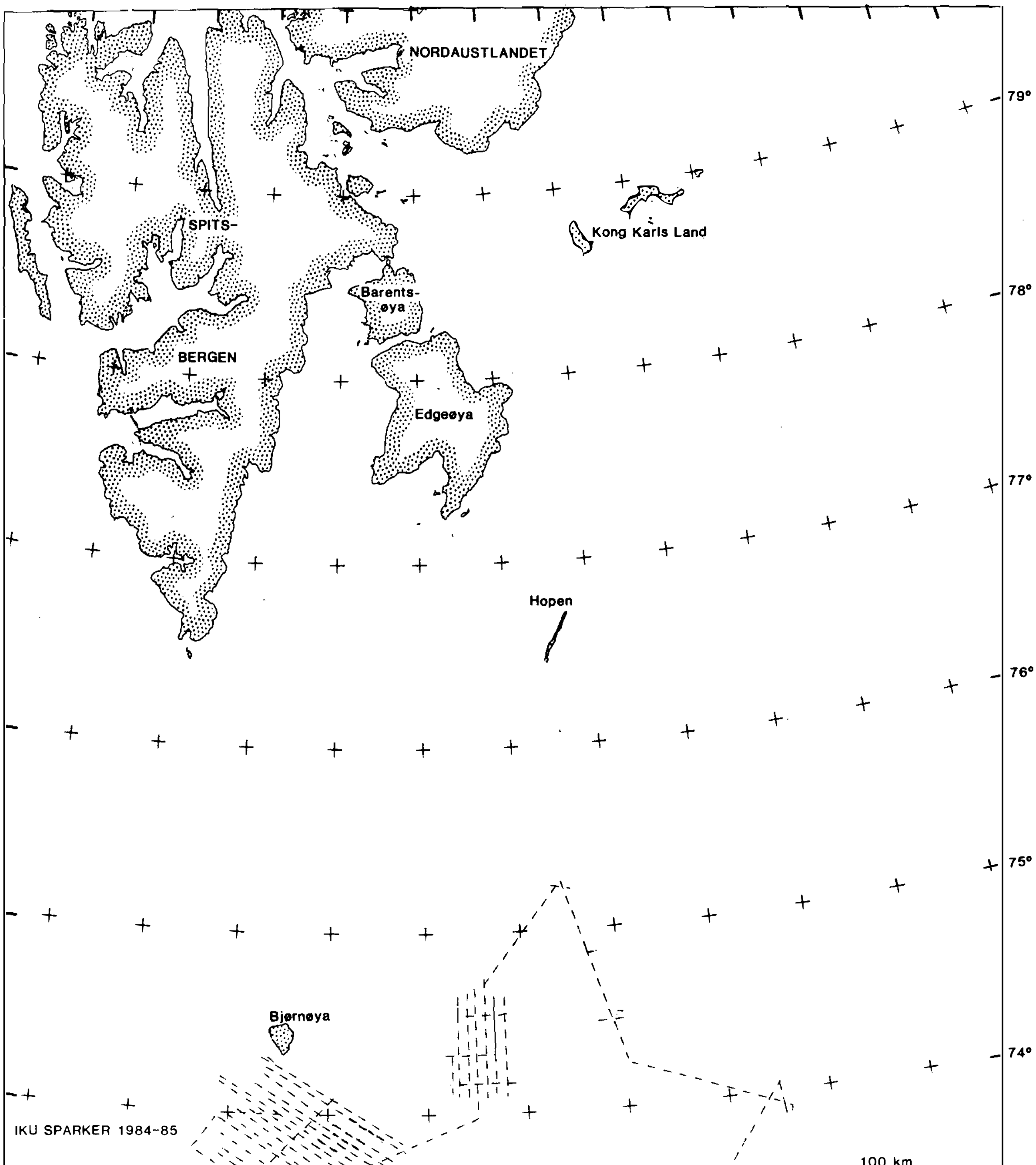


Fig.4c. Seismic lines from the Continental Shelf and Petroleum Technology Research Institute Ltd. (IKU).

Limited and partly poor penetration of the sparker data is another serious problem. Only rarely does the penetration exceed 300 msec, which is far too little considering the depth interval where shallow gas may occur. Due to the limited cover of unlithified sediments, high seismic velocities (up to 4.5 km/s) at or close to the sea floor give rise to multiple problems that are particularly bad on the shallow banks. On Spitsbergenbanken, which has water depths from 100 to less than 50 m, little can be seen below the first water bottom multiple.

Due to the varying data quality and coverage, there has to be a certain degree of subjectivity as to whether a seismic anomaly is real or caused by noise. However, where two lines cross or overlap, gas indications on both lines are required unless one of the lines is of particularly poor quality.

SHALLOW GAS INDICATIONS

Results of this study are mainly presented in Table 2 and the enclosed map. Due to largely insufficient data quality and lack of other subsurface information, it is essential to notice that the map and table show areas of acoustic anomalies that may result from shallow gas. However, other explanations, like lithologic changes, reflector interference or just noise, can not be ruled out. Most of the mapped gas indications appear as relatively small, isolated patches. Where densely spaced, apparently isolated anomalies are marked as one continuous zone, both on the map and in Table 2. In the following, only the general aspects and a few of the different areas are discussed. Concerning the majority of the small anomalous areas, the necessary information can be read from Table 2.

The shallow gas indications mapped in the northern Barents Sea are mainly of two types, (1) amplitude anomalies (bright spots) (Figs.5,6, 7,8,9,11) and (2) gas blanking (Figs.9,10,11). The majority of the indications, are bright spots. Phase shifts are clearly seen in some of them (Figs.6&8), but quite often the data quality makes this difficult to identify. The penetration and data quality makes it highly speculative to infer anything about the vertical extension of the anomalous zone.

The majority of the gas zones are mapped in the southwestern areas, where the data coverage also is densest. The most prominent gas indication in the eastern regions is found east of Kong Karls Land (enclosed map). This bright spot (Fig.5), with associated diffraction patterns, is recorded on two parallel lines, and although they are 15 km apart, the similarities in size, depth and character of the anomalies justify the correlation between the lines. The bedrock subcropping in this area is most likely of Triassic/Lower Jurassic age, and the dominating lithology in the surface samples is sandstone (Elverhøi et al. in prep.). The region along the western shelf edge has several rather significant gas indications. This region is the most important area in the northern Barents Sea for possible gas in the unlithified sediments, due to its greater sediment thickness. The dominant zone in the southwestern part of Storfjordrenna is covered by lines both from NP and NPD. Intensity of individual reflectors varies, and it may be difficult to pick single, isolated indications within this zone. The shallow gas indications are found both in the bedrock and in the unlithified sediments (Fig.9). There are both amplitude anomalies and gas blanking, but the general impression is that of blanking (Fig. 9), and the zone is thus mapped as such. Varying intensity of the lower reflector, which is the base of the unlithified sediments, is interpreted to result from reduced impedance contrast between the overcompacted unlithified sediments and the upper bedrock, caused by gas in the latter. As for the rest of the western margin, the majority of the unlithified sediments are of glacigenic origin, resulting from several oscillations of grounded ice sheets during the late Cenozoic (Solheim & Kristoffersen 1984). The underlying bedrock is largely unknown in this area and the sediment thickness is too large to use surface samples for bedrock information.

An example of gas blanking within the bedrock is found ENE of Bjørnøya (at $23^0 12'$ E, $74^0 50'$ N) (Fig.10). All zones of gas blanking are quite restricted in areal extent, with the exception of the zone described from outer Storfjorden (enclosed map) which extends approximately 50 km in the north-south direction.

Depths below sea floor to the top of the gas zones are indicated in the enclosed map. The deepest zone recorded is 0.23 s (two-way reflection time) below sea floor. This, however, is clearly a function of the penetration achieved by the sparker systems used. As the cover of unlithified sediments is generally thin, the majority of the shallow gas indications are recorded in the sedimentary bedrock. With only a few exceptions, gas indications in the unlithified sediment cover are mainly found along the western margin, where the sediments reach considerable thickness.

Gas hydrates, identified by bottom simulating reflectors (BSR) have not been recorded from the existing data base.

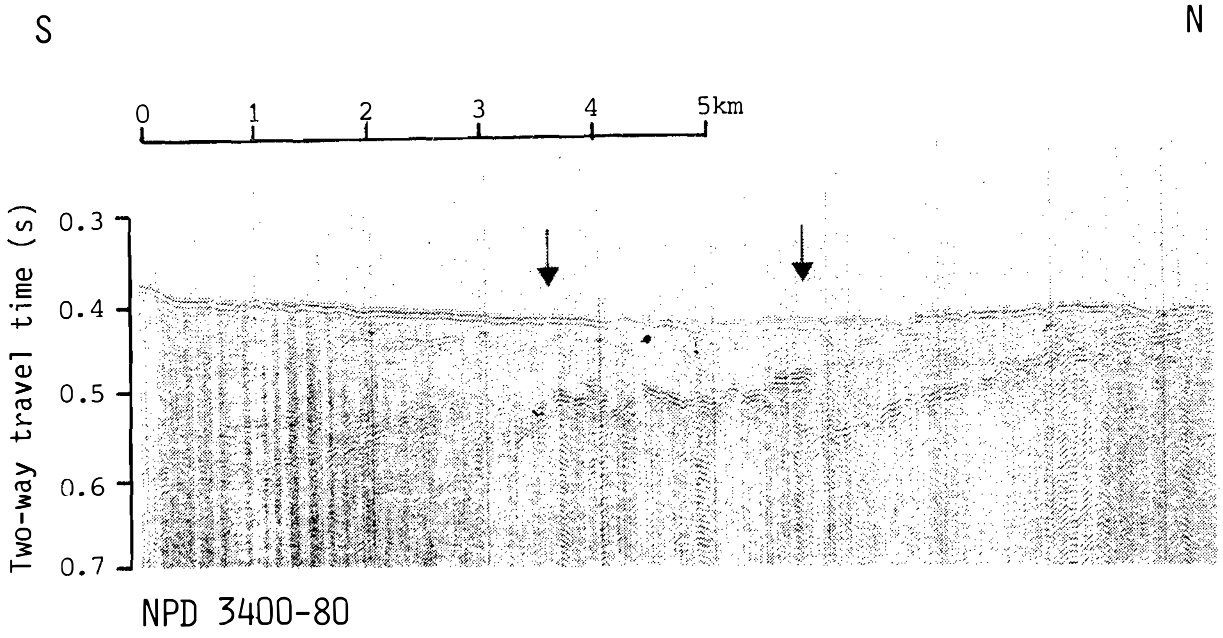


Fig.5. Low to intermediate quality data from east of Kong Karls Land showing amplitude enhancement and associated diffractions (between arrows, at approximately 0.47 s depth). This is considered as a relatively strong indication. For location, see Fig.4b.

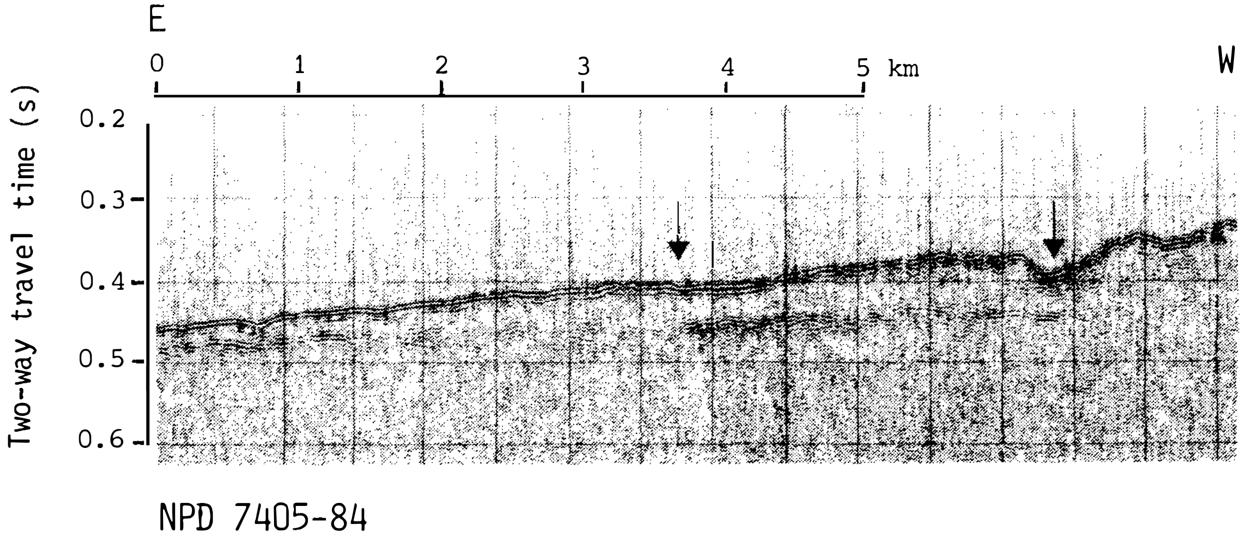


Fig.6. Poor quality data from Leirdjupet, southeast of Bjørnøya, showing a strong amplitude anomaly (between arrows). Despite the data quality, this is an indication with a high degree of confidence. For location, see Fig.4b.

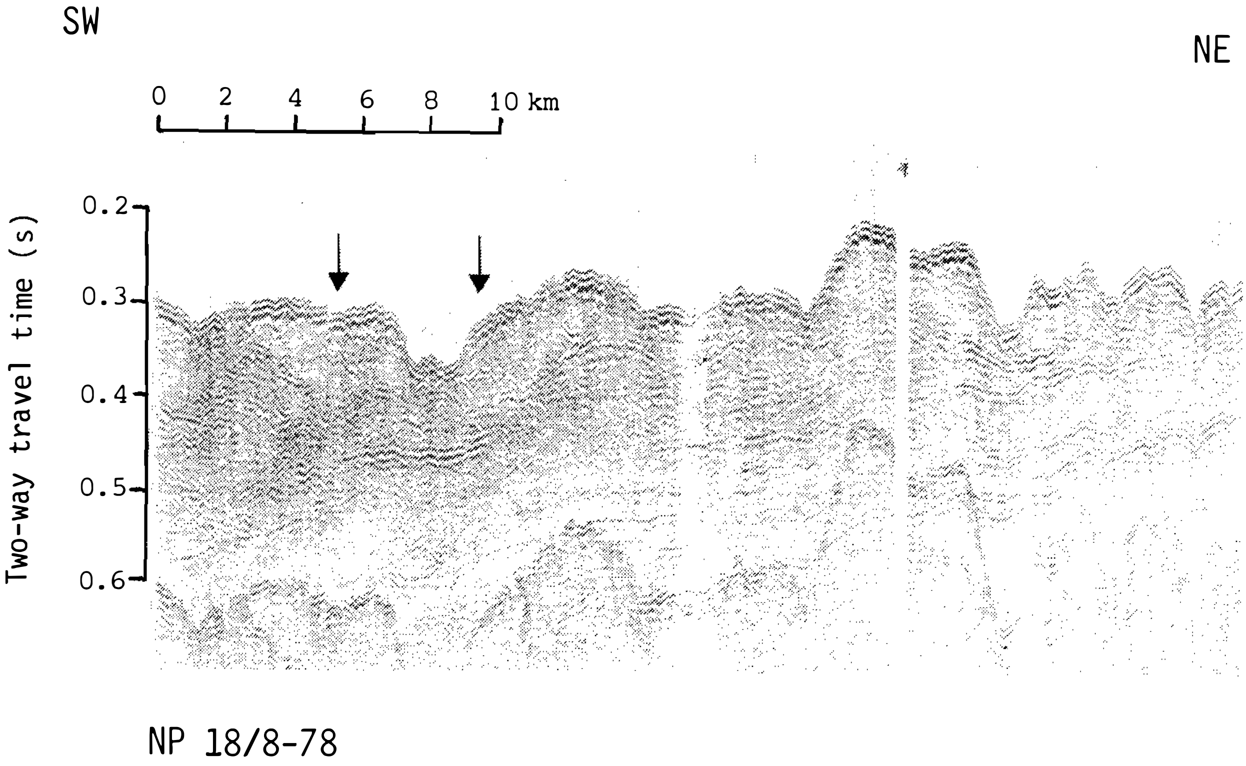


Fig.7. Amplitude enhancement (between arrows, approximately 0.46 s depth) NW of Bjørnøya. The data set is of generally good quality, but the indication is considered weak. The irregular sea floor topography and disordered reflector pattern also introduce some uncertainty. For location, see Fig.4a.

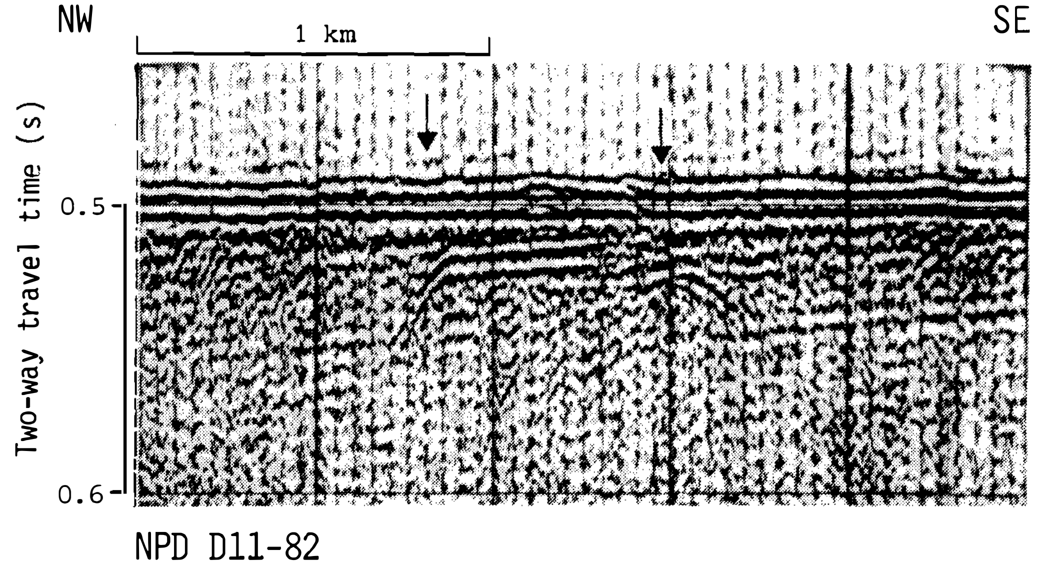


Fig.8. Sparker record of intermediate quality in Bjørnøyrenna, E of Spitsbergenbanken. Shallow gas is indicated by an amplitude anomaly (between the arrows, approximately 0.02 s depth). Note also phase shift and diffraction pattern at the edges of the anomaly. For location, see Fig.4c.

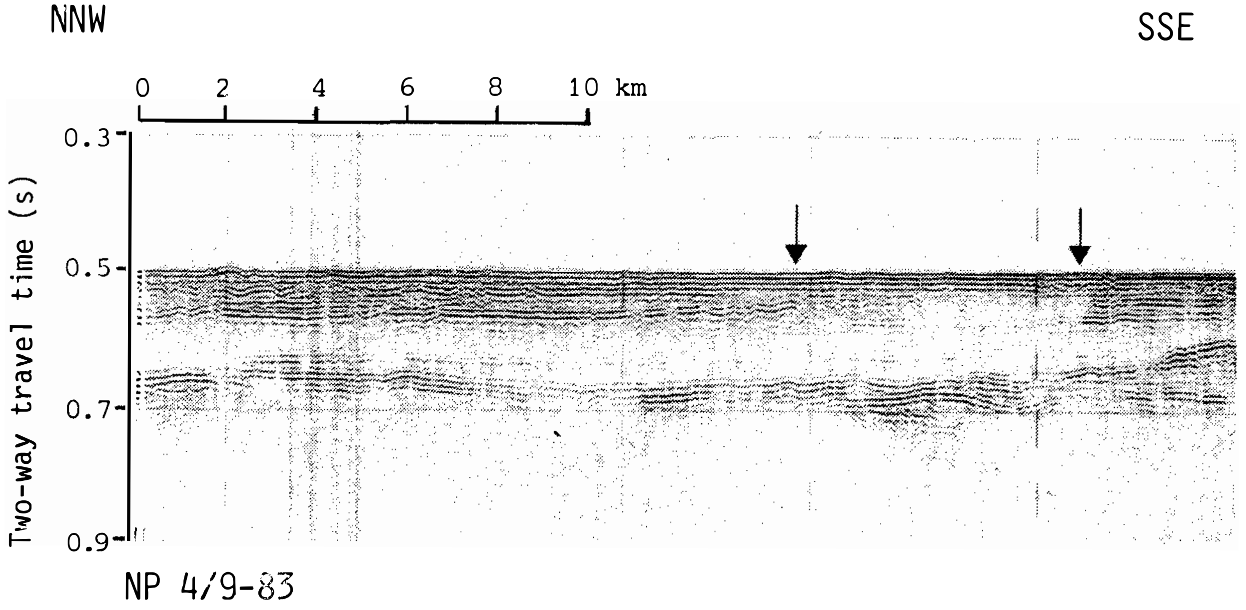


Fig.9. High quality data from outer Storfjordrenna showing several features interpreted as shallow gas indications, both in the unlithified sediments and in the upper bedrock. Acoustic blanking probably causes the generally white appearance of the record between approximately 0.55 s and 0.65 s. It is particularly distinct in the upper part of the record, between the arrows, at 0.5 s depth. Variation in the lower reflector probably results from gas in the upper bedrock. For location, see Fig.4a.

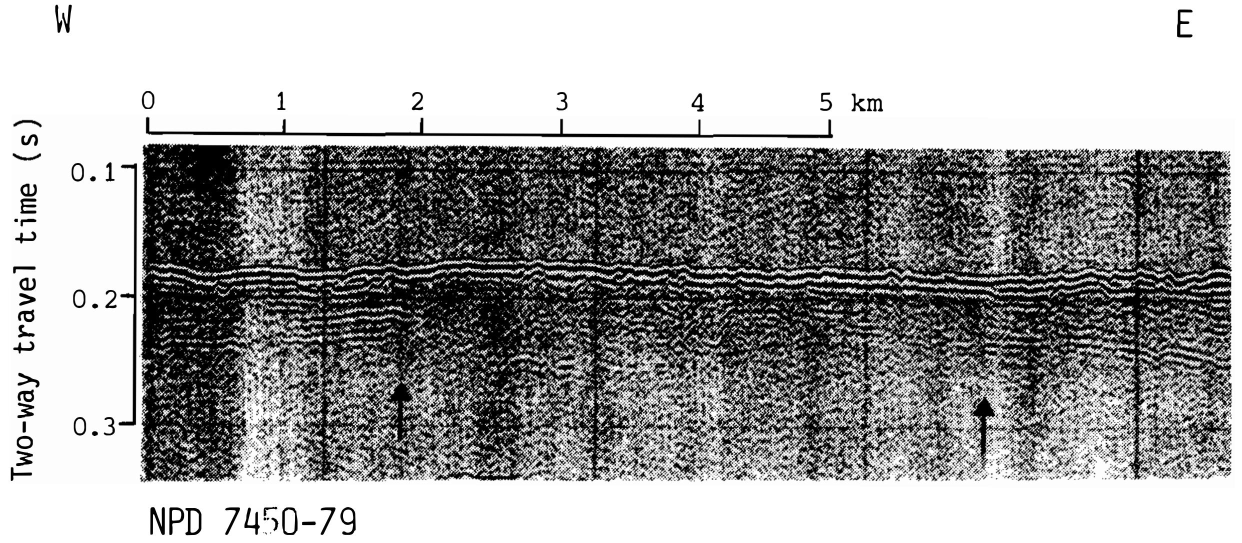


Fig.10. Low quality data from Spitsbergenbanken, northeast of Bjørnøya showing a weak indication of gas blanking (between the arrows). For location, see Fig.4b.

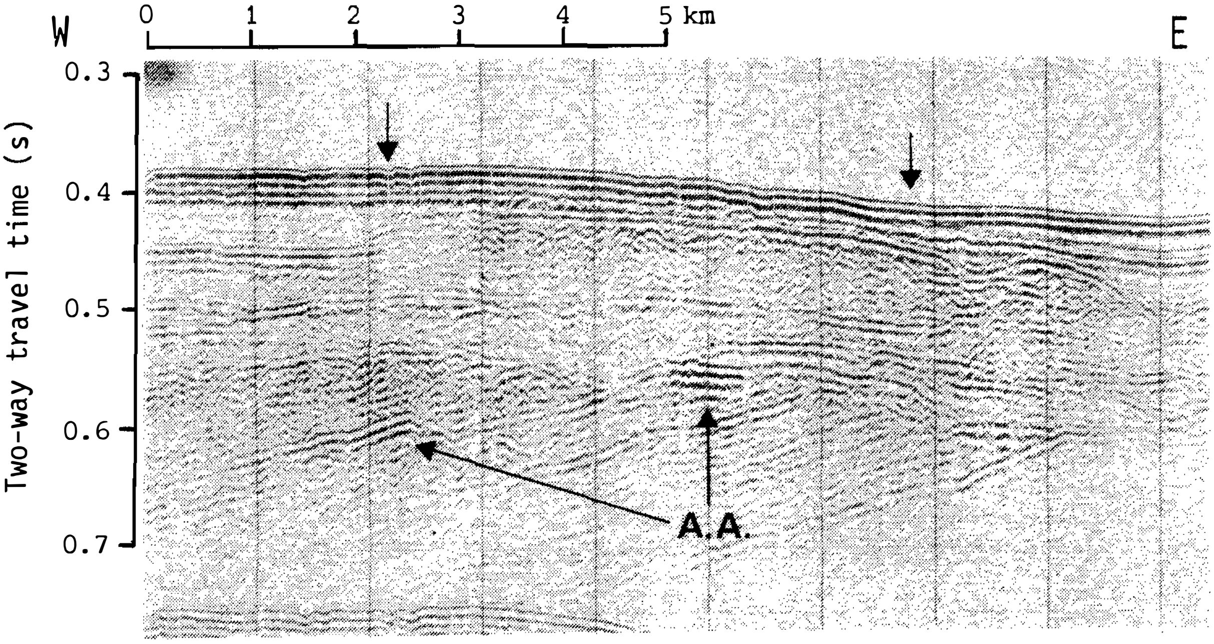


Fig.11. High quality data from outer Storfjordrenna showing gas blanking (between the arrows) in the unlithified sediments and an amplitude anomaly (A.A.) (centre of the record) in the top bedrock reflector (the upper regional unconformity). Another, slightly weaker anomaly, can be seen to the west. For location, see Fig.4a.

Pockmarks.

Direct gas leaks into the water column have not been observed on the existing data from the northern Barents Sea, neither in the sparker data used in this study, nor in the 3.5 kHz echo-sounder data recorded by NP in the region. However, pockmarks have been recorded in two areas. These are strong indications that gas is, or at least has been ascending through the sea floor. Solheim and Elverhøi (1985) reported a pockmark field southeast of Hopen, and Solheim (in prep.) has recorded pockmarks in Erik Eriksenstredet between Nordaustlandet and Kong Karls Land (enclosed map).

Southeast of Hopen, the pockmarks are small (15-20 m diameter) and shallow (less than 1 m), but locally ocurring in high concentrations. The field is situated in an area of thin (less than 10 m) unconsolidated sediment cover, resting on dipping Mesozoic sedimentary strata. The Erik Eriksenstredet pockmarks are smaller (5-10 m diameter), widely spaced and have almost no topographic expression. They occur in a region of somewhat thicker, but varying sediment cover (10-25 msec). Underlying bedrock is dipping Mesozoic strata in the southern part and probably Upper Paleozoic carbonates in the northern part, closer to Nordaustlandet (Elverhøi and Lauritzen 1984).

It should be noted that systematic side scan sonar investigations have only been carried out in these two regions in the northern Barents Sea. From the geological setting in the surrounding regions, we consider it likely that pockmarks exist over larger parts of the Barents Sea, in particular in the deeper troughs, where fine grained mud increase the preservation potential of the features.

CONCLUSIONS

At this state of information, the following main conclusions can be drawn:

- Several areas of the northern Barents Sea (north of 74^0 N) have seismic anomalies that may indicate the presence of shallow gas. The majority of the gas zones are mapped in the southwestern part of the study area, but this may partly be a function of data coverage.
- Two types of gas indications are important in the study area; amplitude anomalies (bright spots) and gas blanking. Most of the mapped indications are of the former type.
- Most of the shallow gas indications are found in the sedimentary bedrock. Seismic anomalies within the unlithified sediment cover are only found in the southernmost area and along the western continental shelf edge. The latter area has large unlithified sediment thickness and the potential for shallow gas may be higher than shown in this study.
- The shallow seismic data base in the northern Barents Sea is of insufficient quality and has too poor areal coverage for adequate regional shallow gas mapping. There is a great need for better data, preferably multichannel data with high resolution and penetration down to at least 1000 m.

Table 2. Shallow gas indications.

LEGEND:

Type of indication: 0=Bright spot
1=Blanking

Geology: U=Unlithified sediments
B=Bedrock

Indication confidence: 0=Weak
1=Medium
2=Strong

Data quality: 0=Poor
1=Intermediate
2=Good

Depth to top gas (from sea floor) in two-way travel time (s). Water depth in metres. For indications of large areal extent, start and stop positions are given, while the approximate centre position is given for less extensive indications.

POSITION	DEPTH TO TOP GAS	WATER DEPTH	TYPE OF INDICATION	INDIC. CONF.	GEO-LOGY	DATA QUAL.	INST./ LINENO.	S.P./ TIME
N74 49.97 E16 49.87	0.11	300	0,(1)	0-1	U	0	NPD 7450-79	S170- 245
N74 49.92 E23 12.20	0.01	128	1 (Fig.10)	0	B	0	"	S3895- 3980
N74 09.44 E17 10.11	0.04	218	1	0	B	0	NPD 7410-80	S370- 395
N74 39.60 E21 13.04	0.04	293	0,1	0-1	B	1	NPD 7440-80	S695- 725
N77 44.85 E26 16.67 N77 44.82 E25 58.05	0.01- 0.04	150- 165	1 [1]	0	B	1-0	NPD 7745-80	S4135- 4285
N78 21.17 E25 59.70	0.04	240	0	1-2	B	0	NPD 2600-80	S5980- 6040
N78 40.05 E34 00.09	0.08	315	0 (Fig.5)	2	B	0	NPD 3400-80	S3675- 3758
N78 42.80 E34 30.36	0.12- 0.07	263- 308	0	2	B	0-1	NPD 3430-80	S5270- 5354
N74 30.01 E25 46.00	0.06	338	0	0-1	B	0-1	NPD 7430-81	S3815- 3870
N73 33.73 E22 59.58	0.10	450	0	0-1	B	0-1	NPD 2300-81	S0138- 0155
N74 02.90 E22 59.97	0.03	450	0	0	U	1	NPD 2300-81	S1205- 1245

POSITION	DEPTH TO TOP GAS	WATER DEPTH	TYPE OF INDICATION	INDIC. CONF.	GEO-LOGY	DATA QUAL.	INST./ LINENO.	S.P./ TIME
N74 11.60 E22 59.90	0.07	375- 315	0	1	B	1	NPD 2300-81	S1510- 1615
N74 06.02 E16 24.85 N74 04.71 E16 32.62	0.18- 0.12	353- 315	0	0	B	0	NPD D10-81	S0300- 0407
N73 35.32 E22 59.20	0.09	450	0	1	B	1-0	NPD D12-81	S0383- 0400
N76 00.6 E15 28.8 N75 37.7 E16 57.0	0.11- 0.07	203- 390	1,0 [2]	0	U	1-0	NPD D17-81	S0000- 0925
N75 52.03 E17 09.09 N75 59.12 E16 21.25	0.03- 0.02	315- 368	1,0 [2]	1	U	1	NPD D18-81	S27900- 28385
N76 01.56 E17 17.42	0.01	300	1	0	B,U	1	NPD D19-81	S1685- 1755
N76 30.20 E15 19.60 N76 37.03 E14 29.48	0.02- 0.10	113- 210	1,0 [2]	1	B	0	NPD D20-81	S15205- 15725
N75 02.8 E29 13.6	0.02	368	0 (Fig.8)	2	B	1	NPD D11-82	S57630- 57645
N74 47.7 E30 32.7	0.07	383	0	0	B	1	"	S58560- 58600
N74 38.2 E31 22.5	0.07	263	0	2	B	1	"	S59160- 59210
N74 53.0 E32 45.6	0.03	158	0	2	B	1	NPD D12-82	S1680- 1710
N76 44.2 E23 07.6 N76 51.4 E22 27.9	0.04	150- 105	1 [2]	1	B	1	"	S38400- 38840
N75 25.7 E32 27.6 N75 21.5 E32 48.0	0.03	285- 255	1	0	B	1	NPD D13-82	S26100- 26350
N75 54.7 E32 26.3	0.03	323	1	0	B	1	NPD D14-82	S1800- 1850

POSITION	DEPTH TO TOP GAS	WATER DEPTH	TYPE OF INDICATION	INDIC. CONF.	GEO-LOGY	DATA QUAL.	INST./ LINENO.	S.P./ TIME
N75 58.9 E34 30.1	0.14	270	0	1	B	1	NPD D15-82	S16100- 16300
N78 12.1 E33 04.3	0.04- 0.08	165	1,0	1	B	1	NPD D19-82	S1700- 1900
N76 37.0 E34 23.6	0.02	195	1	2	B	0-1	NPD D23-82	S16135- 16235
N74 05.0 E21 19.0	0.05- 0.03	300- 338	0 (Fig.6)	2-1	B	0	NPD 7405-84	S3215- 3528
N74 15.0 E23 30.0	0.01	338	0	1	U	0	NPD 7415-84	S6065- 6103
N73 51.8 E20 06.0	0.05	300	0	0	B	0	IKU D84-173	T015500- 021600
N73 47.0 E21 03.7	0.13	480	0	0	B	0	IKU D84-175	T204000
N73 51.7 E20 54.1	0.06- 0.05	443- 405	0	1	B	0-1	IKU D84-176	T072100- 075350
N74 15.0 E23 23.3	0.08- 0.05	338- 300	0	1	B	1	IKU D85-184	S51618- 51696
N74 10.0 E22 53.5	0.08	368	0	0-1	B	0-1	IKU D85-251	S54323- 54346
N74 38.4 E23 24.8	0.01	143	1	0-1	B	1-0	NP 24/7-71	T1353- 1357-
N74 02.8 E21 13.2	0.05	300	0	1	B	0-1	NP 16/8-77	T2231- 2240
N73 32.0 E15 11.2	0.05	765- 500	1	1	U	2	NP 11/7-78	T0900- 0955
N74 49.3 E17 11.7 N74 50.6 E16 27.5	0.03- 0.15	285- 360	0,1 (Fig.11)	2	B,U	2	NP 3/8-78	T1735- 1953
N76 06.7 E14 20.9 N76 05.0 E15 19.3	0.08	368	0,1	2-1	U	2	NP 18/8-78	T0335- 0535
N75 54.0 E16 26.9	0.07- 0.05	330- 383	0 [2]	0	U,B	2	"	T1415- 1600

POSITION	DEPTH TO TOP GAS	WATER DEPTH	TYPE OF INDICATION	INDIC. CONF.	GEO-LOGY	DATA QUAL.	INST./ LINENO.	S.P./ TIME
N75 11.8 E16 01.5	0.16- 0.10	225- 270	0 [3] (Fig.7)	0	U	2-1	"	T2100- 2120
N77 14.2 E19 53.4 N76 49.2 E19 45.7	0.01- 0.04	143- 158	0,1	1	B	2	NP 6/9-78	T0115- 0505
N76 46.4 E33 31.5	0.03	180	0	0	B	1-0	NP 19/8-83	T0320- 0323
N76 00.6 E16 16.2 N75 40.2 E16 48.0	0.01- 0.16	375- 255	1,0 [4] (Fig.9)	2-1	U,B	2	NP 4/9-83	T0515- 0900

NOTES:

[1] Pull-down in underlying reflector at shotpoint 4220.
[2] Varying amplitude/sporadic reflections.
[3] Associated with a trench/depression in the sea floor.
[4] PDR-data from same location show reduced acoustic transparency in upper sedimentary layer.

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APPENDIX

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