Hydrocarbon Potential in the Makran Offshore Area*

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Abstract

During the past ten years the Makran offshore area has attracted considerable attention of national and international scientists, exploration, and petroleum companies to have a better understanding of the peculiar geological and oceanographic setting and to considerably broaden the geological knowledge about Pakistan's EEZ off the Makran margin and its resource potential.

The morphological structure of the Makran, which is strongly influenced by deformation during the subduction processes, is very complex. On the continent and on the upper part of the slope, there are five to seven E-W striking, folded, and elevated accretionary ridges which have been thrust northward, these ridges are separated by ponded slope basins filled with turbidites and hemipelagic sediments, which are horizontal or dip downslope. The large part of the accretionary wedge is well exposed on the continent. A morphologically characteristic deep-sea trench associated with active convergent margins does not exist in Makran.

The Makran continental margin is in an area of high biological productivity in the surface water controlled by monsoonal upwelling. This is one of the causes for the formation of an oxygen minimum zone resulting in a high accumulation rate of predominantly marine organic matter in the marine sediments. Seismic data collected recently from the Makran offshore area provided preliminary identification of some hydrate deposits both at and underneath the sea floor. A bottom-simulating reflector (BSR), caused by the impedance contrast at the base of the gas hydrate zone was observed off Makran at about 400 m below the sea floor in the single channel seismic profiles. The presence of the hydrate indicates that large volumes of methane are being generated at depth in these regions. Offshore, gas expulsions and turbid waters are reported to occur in places along the Makran continental shelf and slope area. Localized presence of small gas seeps/vents has been noted at the seabed, which perhaps is related to the presence of mud diapir or mud volcano structures in the Makran upper slope sediments. Mud charged with methane gas and traces of heavier hydrocarbon oozes through active mud volcanoes along the Makran Coast, which is of special interest in relation to probable oil deposits. Geological, geophysical, and geochemical studies of the Makran zone may eventually lead to delineating the potential resources of the area including petroleum deposits.

In recent years, methane hydrates have been considered a potentially vast energy source because of their widespread occurrence in permafrost regions and in most of the world's oceans. It is estimated that the total amount of organic carbon in hydrate gas probably is more than twice that in all fossil fuels on earth. Once extraction proves to be economical, hydrate might replace the oil and gas needs. In the future it seems that the Gas Hydrates could be used for commercial purposes such as automobiles and for industry, if the technologies to exploit the methane commercially are developed. This will be regarded as a great achievement of scientists and technologists of the future generations.

Introduction

Recently, in the U.S.A. intellectuals have put together their hand with geoscientists and showing their interest in Gas Hydrates. Natural gas hydrates (crystalline solids composed mostly of methane and water) are present in marine sediments on the continental slope and rise. There are two essential conditions for the presence of gas hydrates viz. high hydrostatic pressure (> 50 bar) and low ambient temperature at the sediment water interface (< 7°C). The chemistry of hydrates consists of a lattice of water molecules enclosing gas molecules (usually methane, but also higher-order hydrocarbon), and at least three structures have been identified (Sloan, 1998). It is reported that methane in hydrates is commonly of biogenic origin, but thermogenic methane also occurs in hydrates, vented to shallower depth through subsurface conduits (MacDonald et al., 1994). Kvenvolden (1988) mentioned that estimates of total hydrate volumes vary widely, but even the relatively conservative estimate shown 10^4 Gt (gigaton) of methane carbon (1 Gt = 10^{15} g), exceeds estimates of organic carbon from all other sources, with the exception of dispersed carbon in the lithosphere. It is further confirmed that estimate of total organic carbon % is double from known fossil fuel sources (Kvenvolden, 1988).

The Makran coast occupies nearly 670 km of the 990 km long coastline of Pakistan. Geology of the Makran offshore area is as uniquely interesting and intricate as that of mountainous area in the Himalayas and northern areas of Pakistan. The Makran Subduction Zone, which has been subjected to folding and faulting, is interlained by sediments of undetermined thickness and age. From Jiwani in the west to Sonmiani in the east, the Makran margin is marked by fascinating geological features including the mud volcanoes (surface indicators of gas hydrates) which dot the coastline. It is well established that gas hydrates occur also in the offshore region of Makran, although their distribution and extent were not well known earlier (White, 1979, 1982). Mud charged with methane gas and traces of heavier hydrocarbon oozes through active mud volcanoes along the Makran coast, which is of special interest in relation to probable oil deposits. Geological, geophysical, and geochemical studies of the Makran zone may eventually lead to delineating the potential resources of the area including petroleum deposits.

The Makran continental margin is in an area of high biological productivity in the surface water controlled by monsoonal upwelling. This is one of the causes for the formation of an oxygen minimum zone resulting in a high accumulation rate of predominantly marine organic matter in the marine sediments (von Rad et al., 1995). Seismic data provides preliminary identification of some hydrate deposits both at and underneath the sea floor (Figure 1). Seismic exploration techniques frequently detect not the hydrates themselves, but they often detect the bottom of the hydrate deposit and the beginning of a zone of free methane. A bottom-simulating reflector (BSR), caused by the impedance contrast at the base of the gas hydrate zone was observed off Makran at about 400 m below the sea floor in the single channel seismic profiles (Roeser et al., 1997).

Methane hydrates are a type of natural formation that contains large amounts of methane, which is also known as natural gas, and water, in the form of ice. They are crystalline solids that form under moderate pressure (for instance, at water depths greater than 530 meters in the low latitudes and 250 m in high latitudes e.g., in the Arctic) and at temperatures that are low but above the freezing point of water.

Scientific information and data collected on board German research vessel R.V. Sonne (1993, 1997-98), provided greater insight into various geo-environmental conditions of the Northern Arabian Sea. A joint collaborative research programme PAKOMIN between BGR Germany and National Institute of Oceanography, Pakistan envisaged to investigate the influence of the oxygen minimum zone (OMZ) on the sedimentation at the continental margin off Pakistan. The objective of the co-operative program was the execution of the MAKRAN Program. The co-operative program had the main topic "Tectonic evolution and Fluid Transport in the Makran Accretionary Wedge (Pakistan)" and will considerably broaden the geoscientific knowledge about Pakistan's EEZ off the Makran margin and its resource potential. The project promotes the understanding of the structure and origin of the Makran accretionary wedge and the fluid/gas transport in "cold seeps and offshore" mud volcanoes, as well as the assessment of the hydrocarbon potential of this area (Figure 2).

The Pak-German geological and geophysical research programme in the Arabian Sea was executed in three cruises. During these cruises with R/V Sonne reflection seismic, gravimetric, magnetic, sediment echographic (PARASOUND), and bathymetric measurements (HYDROSWEEP) were carried out to investigate the structure of the submarine part of the accretionary wedge. Hydroacoustic and gravity data were continuously recorded while within the Pakistan EEZ. During these cruises the Pak-German scientists investigated the Makran accretionary wedge off Pakistan in detail to search for submarine gas seeps, vents of fluids, gas hydrates, and the detailed sampling of "cold seep" sites within the Makran accretionary complex. Detailed sea floor sediment sampling (coring/grabbing), heat flow measurements, in-situ qualitative and quantitative gas, and interstitial water sampling at cold seeps were also carried out.

Preliminary Scientific Results

The preliminary scientific results of the Pak-German cruise represented a substantial step forward for a better understanding of the long-time storage and migration mechanisms of natural gasses present in enormous quantities in ‘gas hydrate’ in marine sediments offshore Pakistan. Though the gas hydrates were reported earlier by White (1982 and 1983) but their extent and widespread presence offshore Makran was confirmed by seismic methods during the Pak-German cruise with R/V Sonne SO-122 (Roeser et al., 1997). During the geological cruise of the Makran Margin (SO-130; 1998) when the solid hydrates were brought to the surface and put into hot water, the methane gas was released. A rough approximation was made about the extent of gas hydrates field which is 200 km long, 100 km wide, and 600 meters thick (Delisle, in press). The presence of numerous gas seeps at water depths of typically 300 m and 600 to 800 m was established. The escaping gas, dissolved in the seawater migrates laterally and can be traced for distances of tens of kilometers from the seep region. By towing a camera-TV sled at a distance of 2 m above the sea floor, various locations were detected, where gas is leaking from the sediments (Figure 3). These spots are made visible by white and black mats on the sea floor, formed by bacteria, which are fed by the gas flow emerging from the sediments. The geochemical analysis of the recovered sediments confirmed high gas concentrations. The seeps are apparently the result of gas hydrate melting processes, induced by uplift of marine sediments out of the pressure and temperature field, where gas hydrates can exist.

In essence, gas hydrates offshore Pakistan are slowly melting today in zones of shallow water depth under the influence of warm bottom waters while new gas hydrates are being formed ocean ward in deeper levels within the sediment.

A surprising result of this research is the confirmation that unlike in other geologically similar marine sediment accumulations around the Pacific and Atlantic Oceans, methane losses are largely confined to the shallow water regions. Outflow of gas, where the sediments of the continental slope meet the abyssal plain, is rather limited. This fact is tentatively attributed to the low permeability of the more than 600 meter thick gas hydrates layers, which largely prevent the upward migration of fluids or gasses. One inactive 60 meter high mud volcano at about 300 meter water depth was discovered. Sediment samples taken from its centre cone proved that the former conduit is now completely frozen up by gas hydrates.

Hydrates are plentiful in nature, both underwater and under permafrost. They are a potential source - possibly a very important source - of energy for the future. However, little is currently known about cost-effective ways to turn hydrates into an energy resource. The worldwide amount of carbon bound in gas hydrates is frequently estimated to total twice the amount of carbon to be found in all known fossil fuels on Earth. Additionally, conventional gas resources appear to be trapped beneath methane hydrate layers in ocean sediments. (Dillon, 1992; Dillon et al., 1995; Dillon, 1995).

Scientists are only just beginning the study of methane hydrate deposits. In the U.S., deposits have been confirmed on all areas of the continental shelf and under Alaskan permafrost. Similar deposits have been confirmed in many locations throughout the world e.g., Vancouver Island, Nankai Trough, offshore Japan, offshore Costa Rica, offshore Peru, and the Black Sea (Tabrez and Inam, 1998a and 1998b). On melting, the gas hydrate liberates a considerably expanded amount of methane. Theoretically, one cubic centimeter of pure methane hydrate should yield about 164.0 cubic centimeters of methane and 0.8 cubic centimeters of water. In nature, however, other molecules are frequently mixed in with the methane. It is more typical to get 158.0 or so cubic centimeters of methane from a cubic centimeter of hydrate.

For purposes of producing natural gas from hydrates, the concentration of hydrates within a formation is important. It would be much more expensive to produce hydrates that are, for instance, evenly distributed at low percentages throughout a shale formation than it would be to produce from a formation with a very high percentage concentration in one place, possibly with free methane trapped beneath it.

Most natural gas hydrate is formed from biogenic methane, excreted by bacteria that eat organic matter that has been washed into (or died in) the ocean. This type of hydrate is concentrated where there is a rapid accumulation of organic detritus and also where there is a rapid accumulation of sediments (which protect detritus from oxidation).

There are reports that gas trapped below hydrate deposits is currently being produced in Siberia. The economics of hydrate resource recovery may be significantly different for countries like Japan and India, which have very few energy resources, which are concerned about the price and national security problems presented by imported energy, and which see a potential for significant economic gains if they could tap a domestic energy resource. Both Japan and USA had significant research programs underway in late nineties.

Discussion

A moderate to steep slope was observed in the PARASOUND record obtained by R/V Sonne, with a few NE-trending steep fault or slump scarps interrupted by flat terraces at 420 and 530 m water depth. Abundant minute micro-seepage with a diameter of 1-4 cm probably tiny gas bubble tubes caused by bubble ebullition at saturation methane concentrations in aerobic sediments occur almost continuously at the upper slope between 350-400 m. Fewer, but much larger (up to a meter) seepage craters covered by blackish precipitates and whitish bacterial mats are found on the terrace around 420 m and along the adjacent slope down to 530 m, especially at small escarpments (von Rad et al., 1996).

BSR's, caused by the impedance contrast at the base of the gas hydrate zone, can be clearly recognized about 400 m below the ocean floor in the single channel seismic profiles studied by White (1982, 1983) and Rouser et al., (1997). In the Makran Margin, well developed BSR's occur on lines SO 122-04A (Figure 4) and SO 122–13 (Figure 5) between 0.5s (TWT) and 0.7s (TWT) below the sea floor. In the area between these two seismic lines some published profiles do show BSR'S (Lehner et al, 1982; White and Louden, 1982; Minshull et al., 1992). In the west of about 65° 'E gas hydrates may exist in the frontal 50 km of the Makran accretionary complex. It is noted that seismic bright spots on line N 1804 (Lehner et al., 1982) below the summits of the two most seaward anticlinal ridges of the Makran accretionary complex. They are direct indicators for accumulation of hydrocarbons (Roeser et al., 1997).

The Makran continental margin is an area having the prerequisite conditions for the formation of an oxygen maximum zone (OMZ) resulting in a high accumulation rate of predominately marine organic matter in the sediment. Geological setting and oceanographic condition leads numerous-induced fluid vents discharging methane bearing waters, as well as the corresponding mineralization and cementation, were observed and sampled during Pak-German cruises (SONNE-90/1993 and SONNE-130/1998) of the Arabian Sea. Samples analyzed at BGR laboratory of fluids from on shore mud volcanoes confirmed that the dominant associated CH_4 is of bacterial origin (e.g. Chandragup mud volcano: $\delta^{13}c$ CH_4 - 63‰, Fuher, 1997). The submarine vents also contained predominantly CH_4 generated by CO_2 - reducing bacteria (von Rad et al., 1995; Berner et al., 1996).

Plumes of bacterial CH_4 (characterized by isotope analyses) which were detected within the OMZ and extended over more than 20 km at round 600 to 800 meter depth horizontally from the accretion into the open water column (Berner et al., 1996): The horizontal and vertical distribution of CH_4 in ocean waters off Pasni, Ormara, and Karachi transects are shown in Figure 6, Figure 7, Figure 8, and Figure 9.

A plume (Methane Gas), with concentration decreasing is observed at average depth of 600 m, from the slope of the accretion in the north to site location in the south off Pasni Transect. The horizontal extension is around 25 km. In the offshore Ormara region the extent is more than 25 km laterally at around 500 m water depth into the open ocean. At Karachi Transect two CH_4 plums at 300 and 800 m are easily noted which have shorter extensions of 5 to 8 m into the water column, under water (TV-sled) observations of gas seeps between 650 and 500 m water depth all transects. Especially in the southwest of Ormara, it is detected that high CH_4 concentrations within a 1 km wide canyon ("Calyptogena Canyon") cutting into the accreted sediments contained pelecypods of type culyplogena sp. which are known to be associated with active gas seeps (Figure 10). Same vent fauna have been reported with many "cold seeps" at accretionary prisms. Such as Oregon Margin (Suess et al., 1985). These include Calyptogena and Solemya (pelecypods) and tube worms of the Vestimentifera group (Lamellibrachia and Escarpia; Gerlach, 1994) and Poginophora. They derive their energy from the oxidation of methane to CO_2 and H_2S to elemental sulphur and sulphate (von Rad et al., 1996). The gas seeps/expulsions may be associated with deep faults cutting into the sediments and probably resemble migration paths for sedimentary hydrocarbons.

The preliminary results obtained so far thus indicate good prospects for a potentially vast energy source in the Makran offshore area as it is estimated that the total amount of organic carbon in hydrate gas probably is more than twice that in all fossil fuels on earth. Once extraction proves to be economical, hydrate might replace the oil and gas needs. In the future it seems that the Gas Hydrates could be used for commercial purposes such as automobiles and for industry, if the technologies to exploit the methane commercially are developed. This will be regarded as a great achievement of scientists and technologists of the future generations. However, there is lot more research to do in this relatively new field of petroleum exploration and to achieve better results both R&D organizations and the petroleum industry need to work together. The geoscientists of the National Institute of Oceanography are presently working on the recently acquired seismic data with the exploration geologists of the leading petroleum exploration company of Pakistan. It is expected that this collaboration of the R&D institute and the industry would result in the delineation of potential hydrocarbon fields in the Makran offshore area and may thus lead to the economic prosperity of the country.

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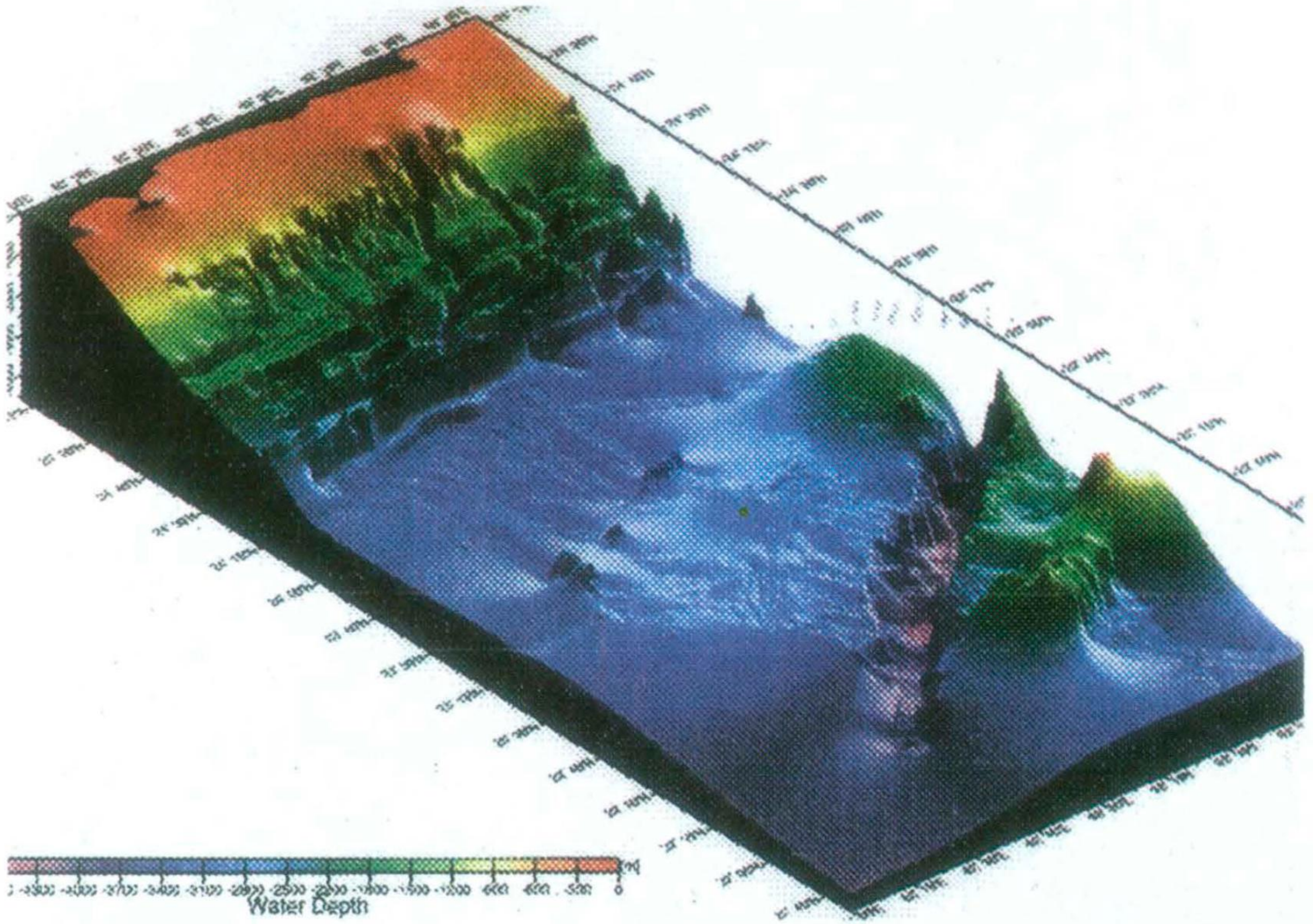

Figure 1. 3D view of Makran offshore area where seismic data obtained on board R.V. Sonne identified some hydrate deposits at and underneath the sea floor.

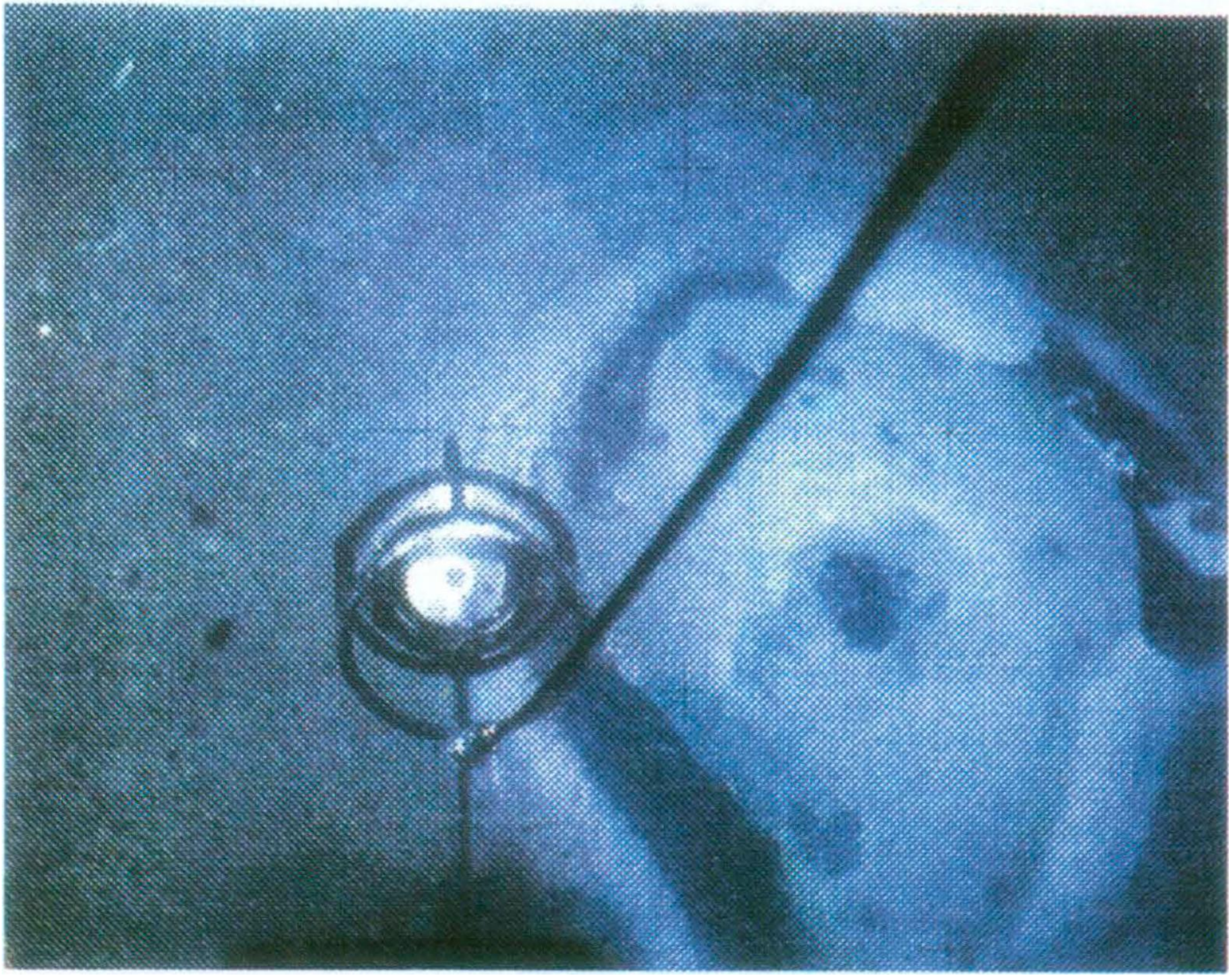

Figure 2. Offshore mud vent photographed in the Makran offshore area during the Pak-German research programme.

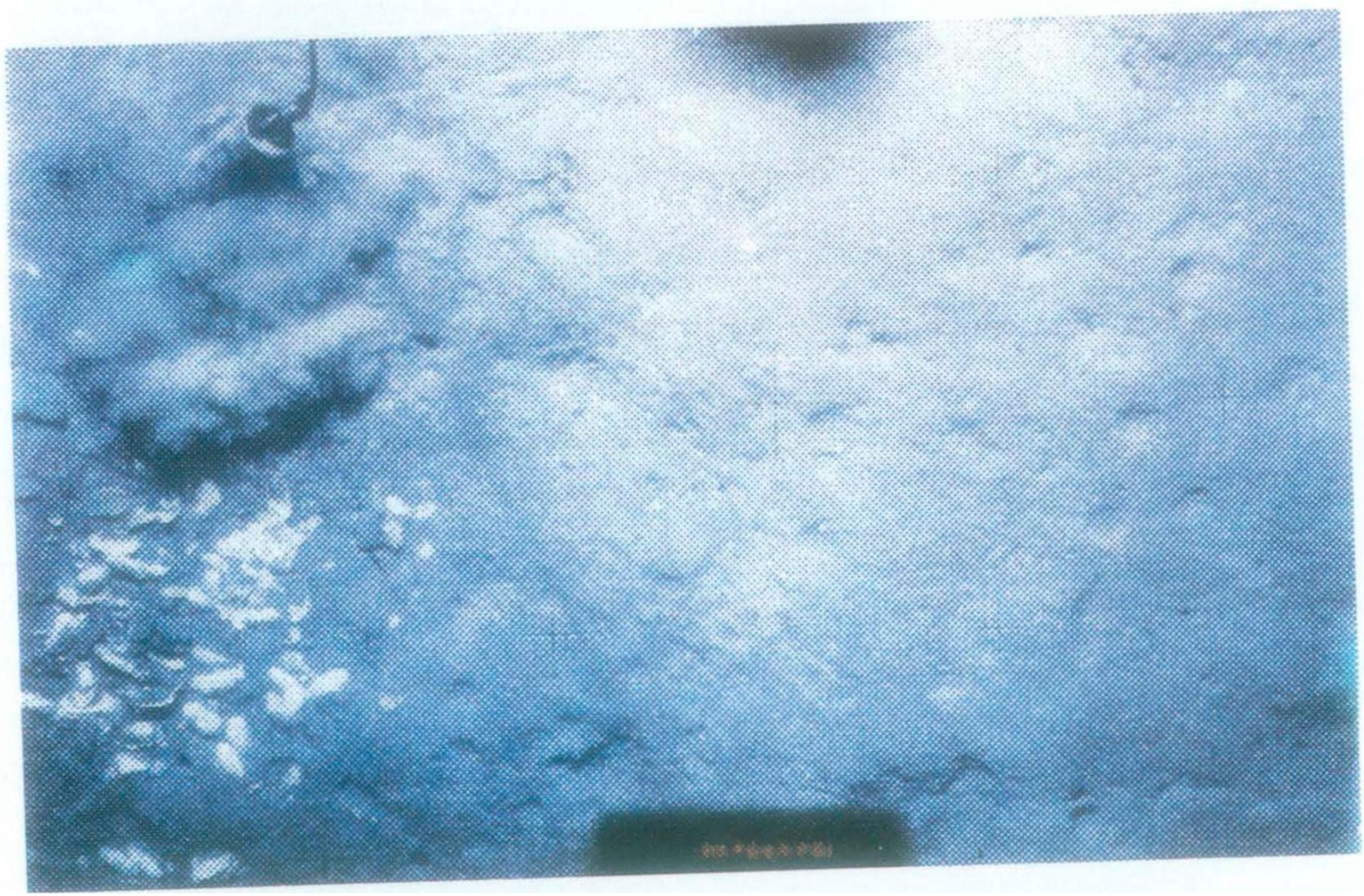

Figure 3. Seafloor photographed in the Makran offshore area during the Pak-German research programme where gas was observed leaking from the sediments.

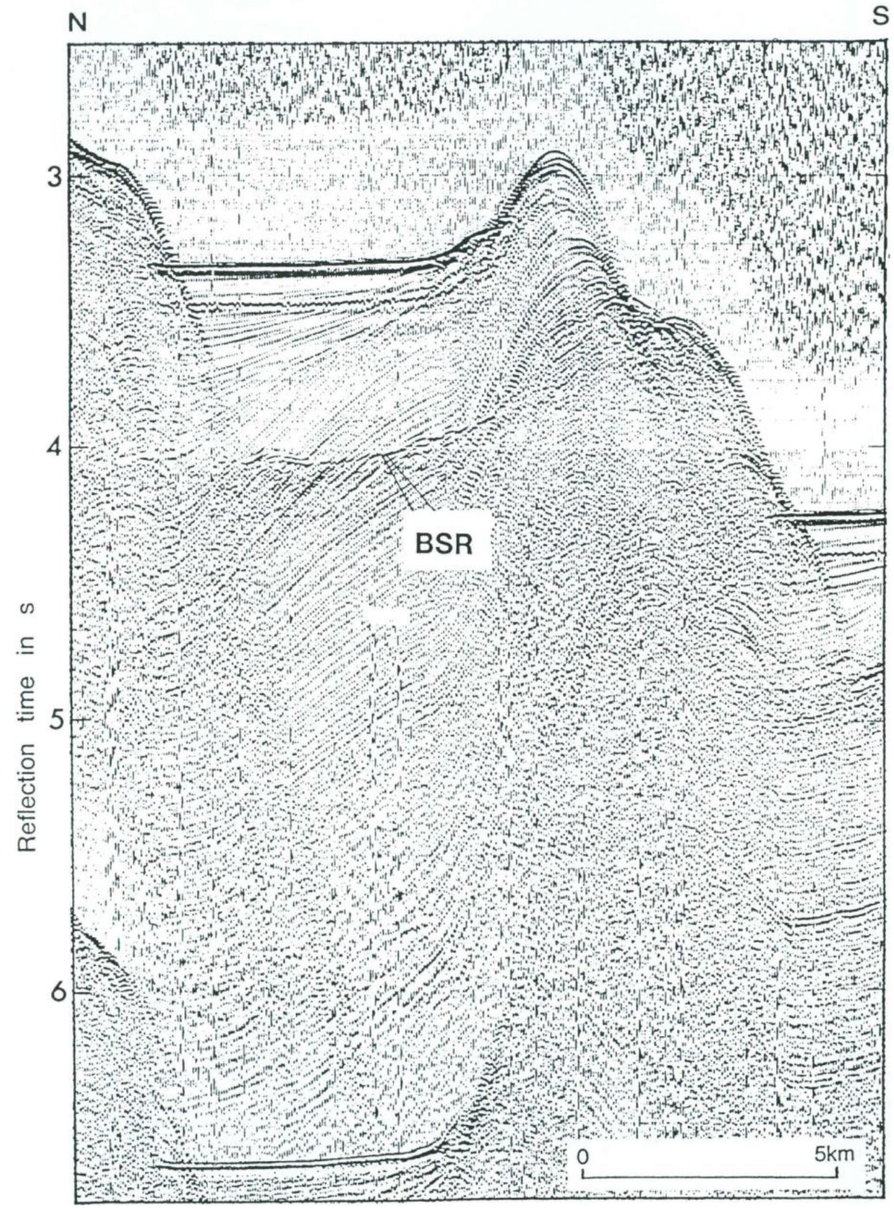

Figure 4. Part of the single-channel monitor record of the seismic reflection profile SO-122-04A showing the BSR at the front of the Makran accetioary margin (after Roeser et al., 1998).

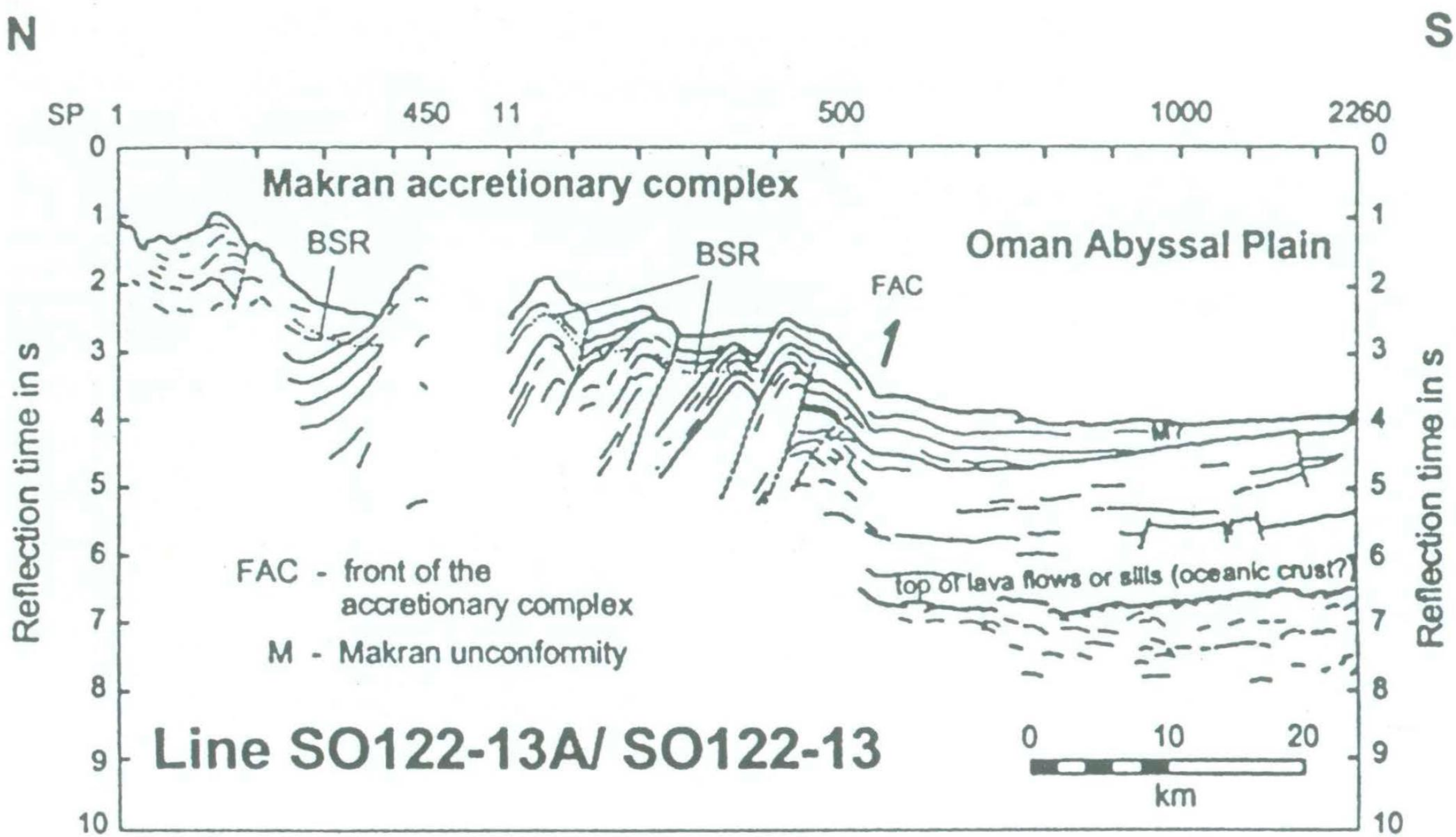

Figure 5. Line S0-122-13/13A across the Makran accretionary wedge, with reflection seismics (after Roeser et al., 1998).

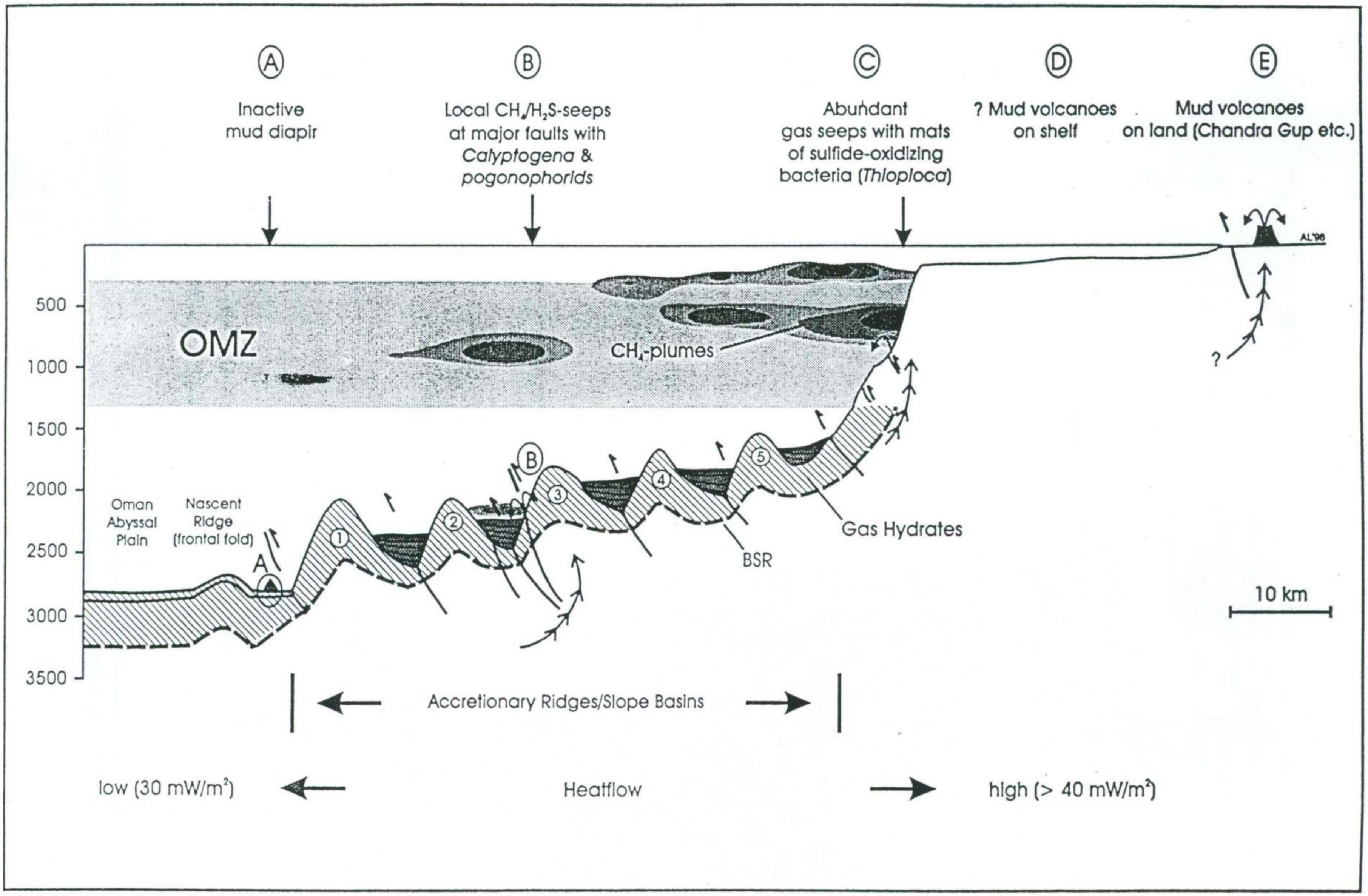

Figure 6. Schematic cross section of the Makran accretionary margin with locations of gas seeps and distribution of methane in water column (after von Rad et al., 1998).

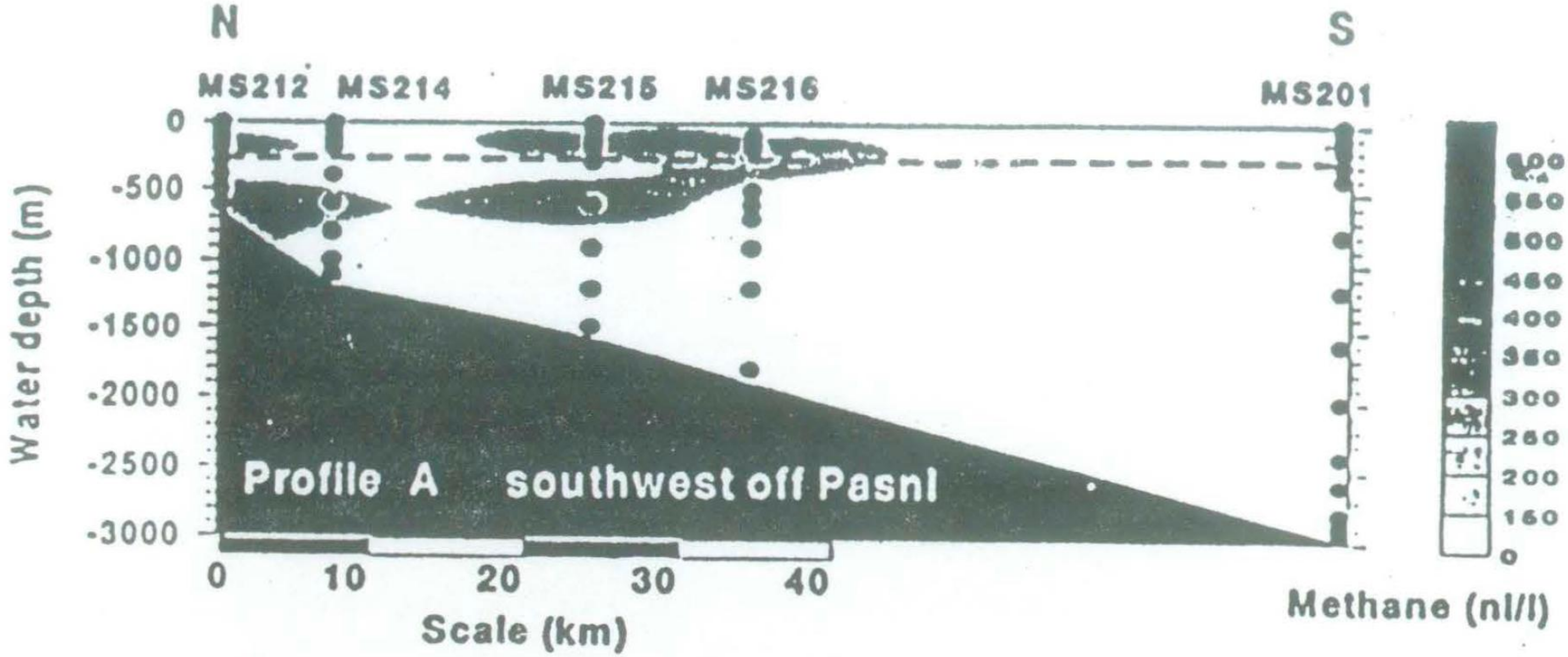

Figure 7. Methane concentration in water column off southwest Pasni (after von Rad et al., 1998).

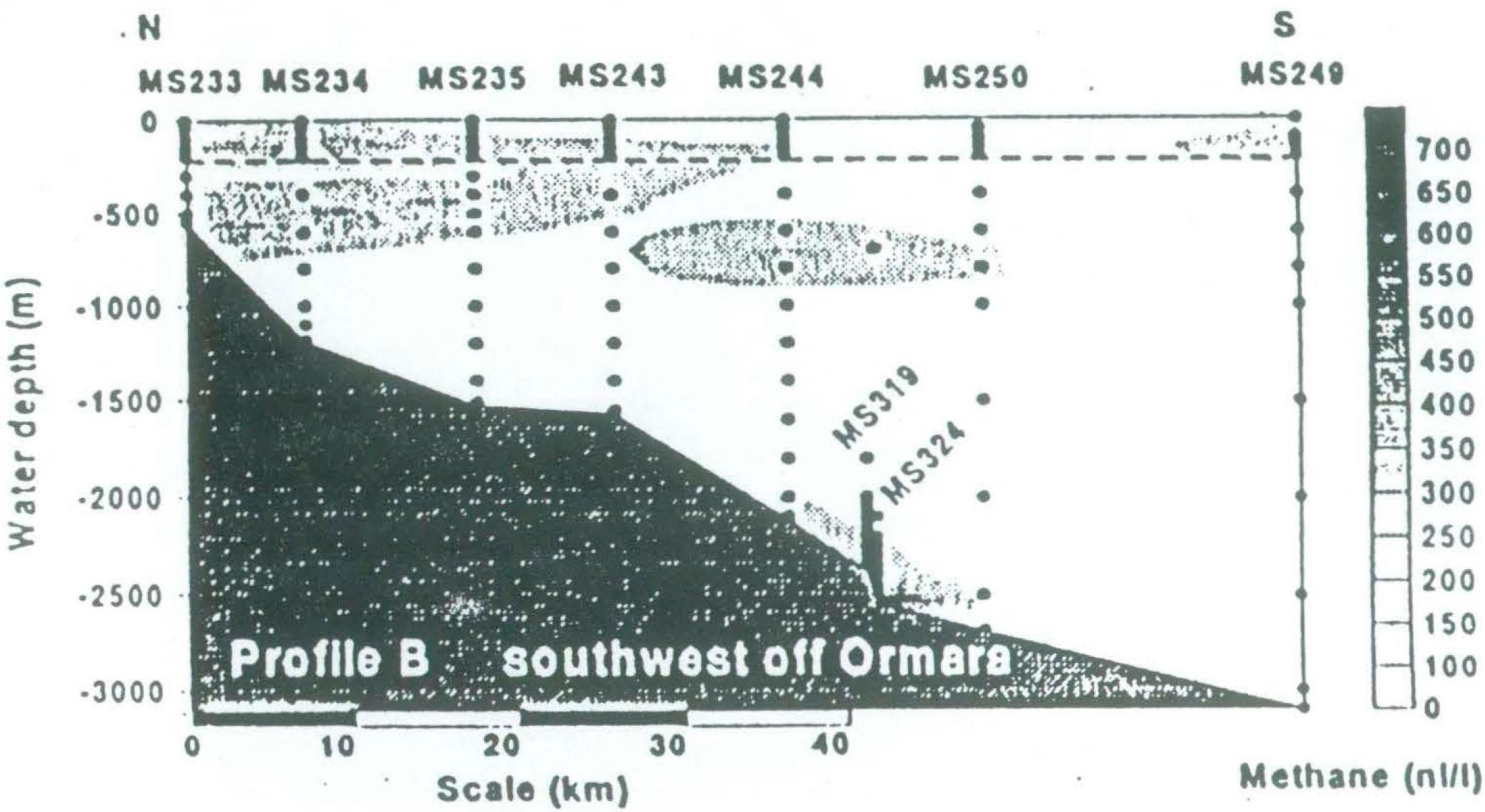

Figure 8. Methane concentration in water column off southwest Ormara (after von Rad et al., 1998).

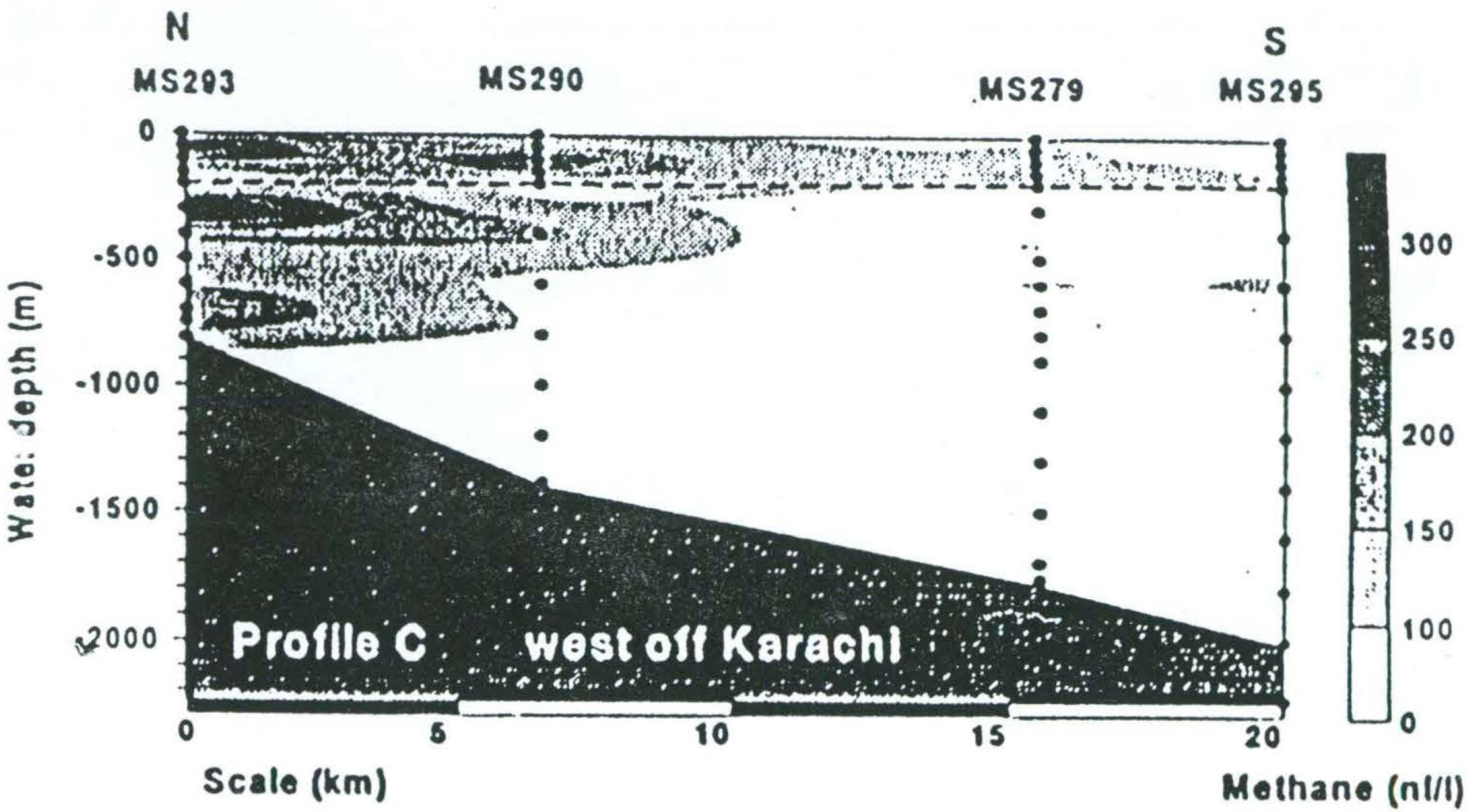

Figure 9. Methane concentration in water column west off Karachi (after von Rad et al., 1998).

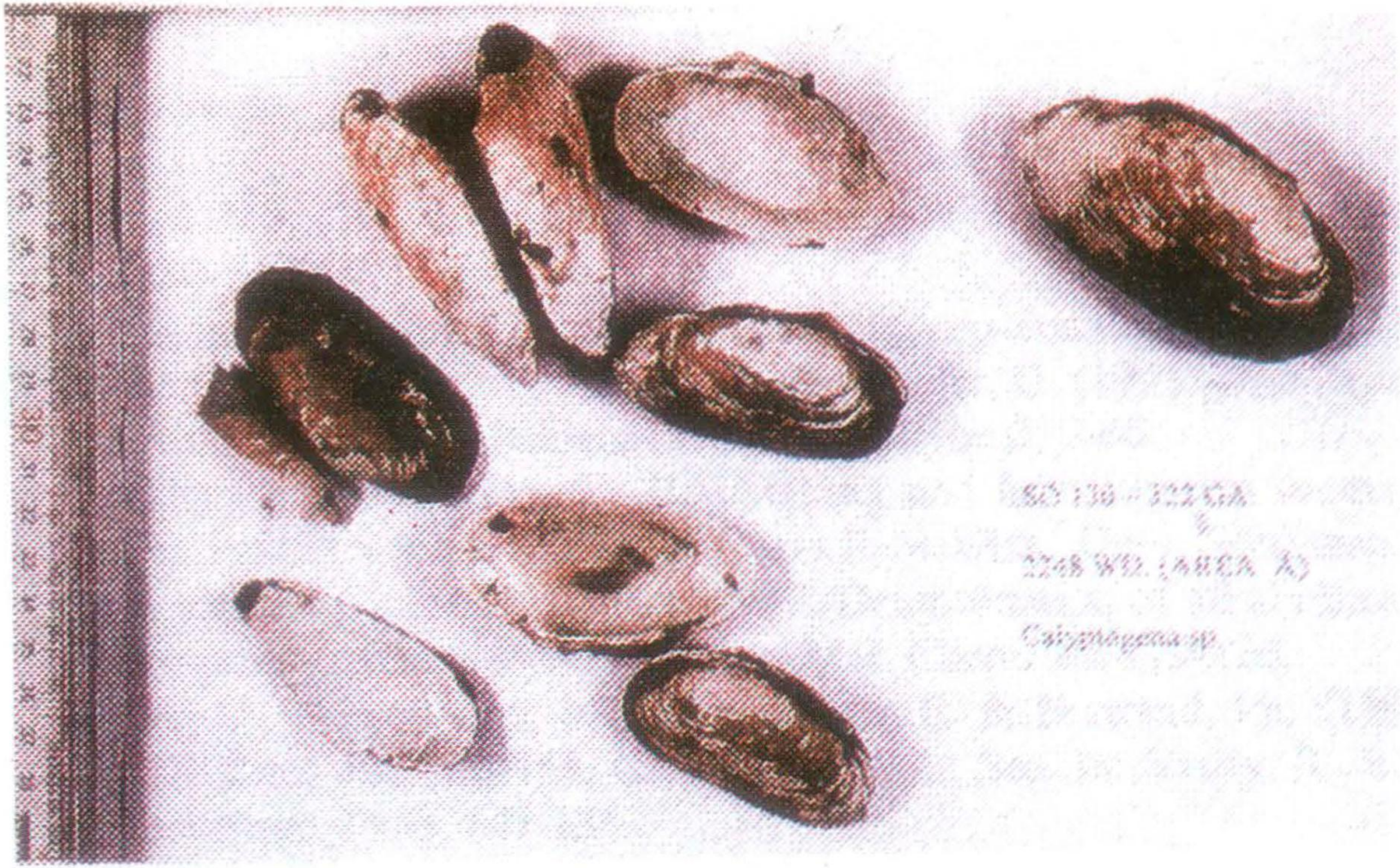

Figure 10. Calyptogena (pelecypod) known to be associated with offshore gas seeps, photographed in the Makran offshore area during the Pak-German research programme.