Antarctic Science 5 (2): 207–210 (1993)

A bottom simulating reflector on the South Shetland margin, Antarctic Peninsula

E. LODOLO, A. CAMERLENGHI and G. BRANCOLINI

Osservatorio Geofisico Sperimentale, P.O. Box 2011 I-34016 Trieste Opicina, Italy

Abstract: Multichannel seismic data acquired over the northern Pacific margin of the Antarctic Peninsula, have shown the presence of high-amplitude sub-bottom reflections across part of the South Shetland accretionary prism. Detailed seismic data analysis, such as true amplitude signal recovery, reflection coefficient determinations and closely-spaced semblance velocity analysis, have been carried out in order definitely to assign this bottom simulating reflector to the base of the stability field for methane hydrate. This represents the first evidence of gas hydrate layers in the Antarctic Peninsula region.

Received 9 September 1992, accepted 3 February 1993

Key words: bottom simulating reflector, gas hydrates, Antarctic Peninsula, South Shetland trench

Methods and geological setting

Strong, high-amplitude sub-bottom reflections have been identified on two multichannel seismic lines on the continental slope of the South Shetland trench, off the Pacific margin of the Antarctic Peninsula. The lines were acquired by R/V *OGS-Explora* during the 1989/90 Antarctic cruise of the Italian "Programma Nazionale di Ricerche in Antartide" (PNRA) utilizing two air-gun arrays of 15 guns each with a total volume of 45 litres. Thirty fold data were recorded using a 120-channel, 3000 m long analogue streamer. The sampling interval was 4 ms. The hydrophone group interval was 25 m and the shot spacing 50 m. Processing steps on the lines included,

a) spherical divergence and absorption compensation,

b) trace editing and despiking,

c) shot gather adjacent trace sum applying a differential normal move out,

d) normal move out and common-depth-point stack using stacking velocities derived from semblance analyses and constant velocity-stack analyses,

e) deconvolution after stack, and

f) trace mixing and time-variant filtering.

The South Shetland trench (Fig. 1 inset) appears to mark a zone of convergence between the continental domain of the South Shetland microplate and the ocean floor to its north-west (Guterch *et al.* 1985, Pelayo & Wiens 1989, Larter 1991). During the Cenozoic the margin south-west of the Hero fracture zone has evolved from active to passive as successive segments of the Antarctic-Phoenix ridge have collided with the trench which formerly existed along the Pacific margin of the Antarctic Peninsula. Subduction stopped in each collision zone at the time of collision because the trailing flank of the ridge crest and the overriding lithosphere at the trench were both part of the Antarctic plate. Between the Shackleton and Hero fracture zones, however, spreading stopped at the Antarctic-Phoenix ridge 4–2 m.y. ago, before the ridge crest had reached the trench (Barker 1982, Larter & Barker 1991). It has been suggested that continued sinking of the subducted slab and roll-back of the hinge of subduction along this segment of the margin have caused extension in Bransfield Strait, to the south-east of the South Shetland Islands, and hence continued convergence at the trench (Barker 1982, Barker & Dalziel 1983).

The multichannel seismic line, IT9043, crossing the whole South Shetland forearc from the continental shelf to the trench (Fig. 1), shows the deformed units (with poor seismic response) of the sedimentary accretionary complex where a strong, high-amplitude reflector that approximately parallels the sea floor (bottom simulating reflector, BSR) has been detected, and is interpreted as the base of the stability field for methane hydrates (Stoll *et al.* 1971).

Seismic evidence for the presence of gas hydrate

a) A well-defined, high-amplitude and nearly continuous reflector, interpreted as a gas hydrate BSR, has been identified in bottom sediments on line IT9043 (Fig. 2), where it is particularly strong and continuous. It is also present on line IT9044.

b) The sub-bottom depth of the BSR generally increases with increasing water depth, and shows the characteristic relationship (Kvenvolden & McMenamin 1980) of increased thickness of the hydrate stability zone (HSZ) with increasing pressure (Fig. 3). Sub-bottom two-way time of the BSR in line IT9043 varies from 640 ms at the shallowest water depth surveyed (about 1200 m) to 900 ms at a depth of 4350 m in the vicinity of the trench. Local discontinuities of the reflector (Fig. 2, CDP 4700–4750) could be caused by structural discontinuities, discontinuous

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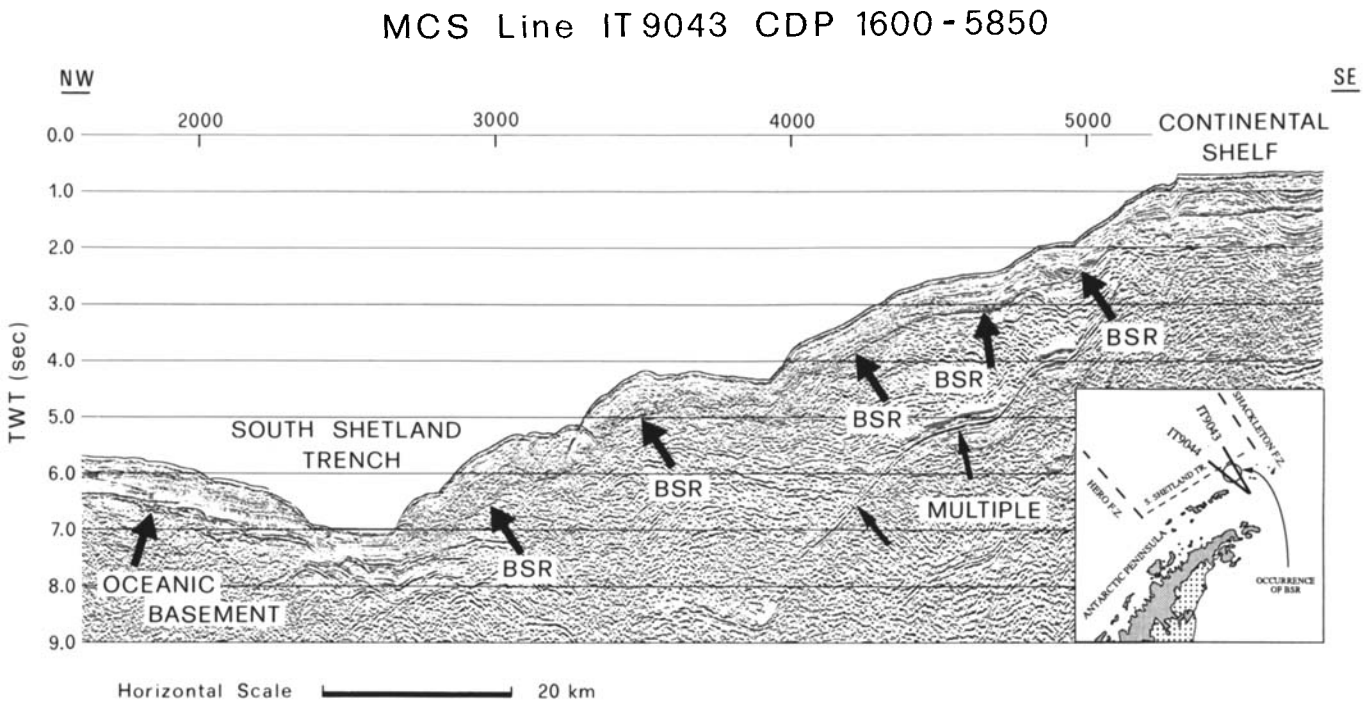


Fig. 1. Thirty-fold seismic reflection profile IT9043 across the Pacific margin of the South Shetland Islands, where a well-developed BSR has been recognized (reflector that parallels the sea floor from 2.0–4.0 sec two-way time). From SE–NW, the profile crosses the South Shetland continental margin, showing a small fore-arc basin, the accretionary sedimentary prism generated by the convergence between the Phoenix and Antarctic plates, the trench filled by a relatively thick and apparently little disturbed sequence, and the outer swell, where the oceanic crust of the subducing slab is covered by pelagic and hemipelagic sediments. Vertical exaggeration is about 7:1 at the sea floor.

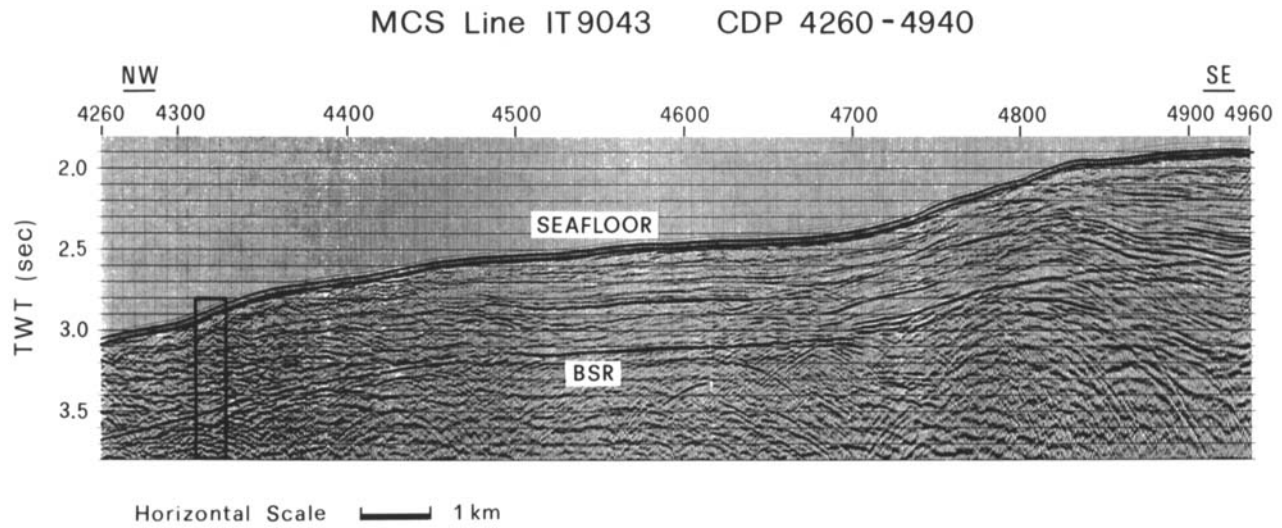


Fig. 2. Part of MCS line IT9043 in which the entire continental slope from trench to shelf break shows evidence of the BSR in the sub-bottom. Frame on the seismic section refers to the trace display in Fig. 4.

gas zones near the base of the HSZ, or ground water or gas chemistry variability that render the base of the HSZ geometrically more complex than elsewhere.

c) The BSR (Figs. 2 & 4) is almost always a single symmetrical pulse, which indicates a simple interface (Hyndman & Spence 1992) consistent with the long-term pressure/temperature stability of the HSZ and its base (Dillon & Paull 1983).

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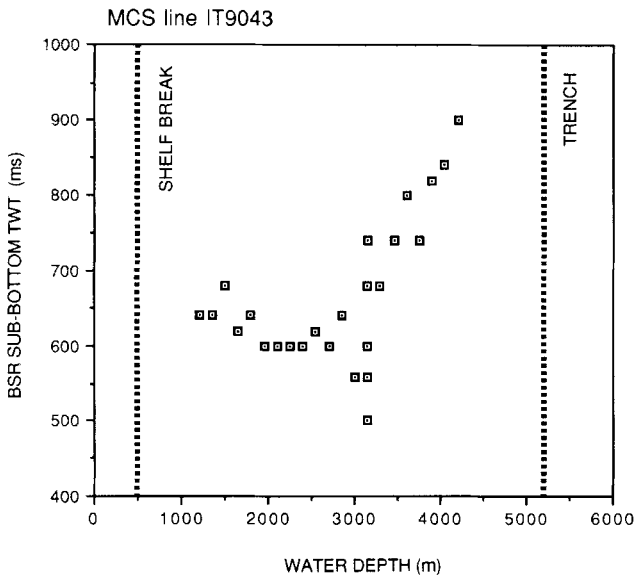


Fig. 3. Plot of sub-bottom two way travel time of the BSR versus water depth along the continental slope, from shelf break to trench. Two different trends can be identified: approximately constant BSR sub-bottom two-way time at shallow water depths, and increasing BSR sub-bottom two-way time with depth in deeper water.

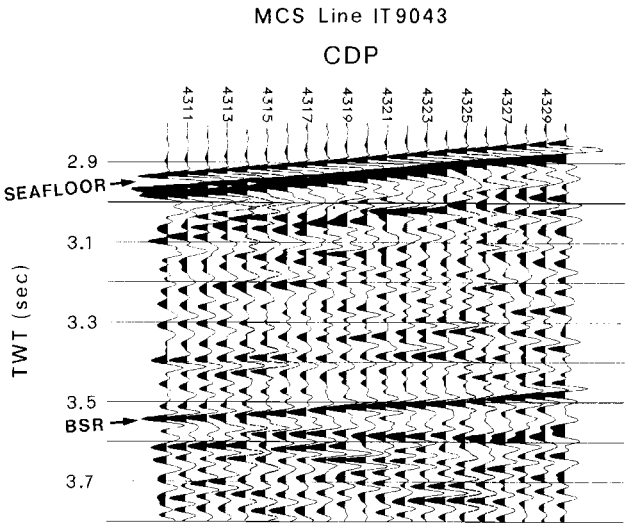


Fig. 4. Display of 21 CDP traces that include the sea floor reflection and the BSR (location of traces in Fig. 2). Reflection amplitude has been corrected for spherical divergence.

d) The BSR crosses reflections that reflect the position and orientations of sedimentary layers. It must therefore be younger and superimposed upon the acoustic structure of these sediments.

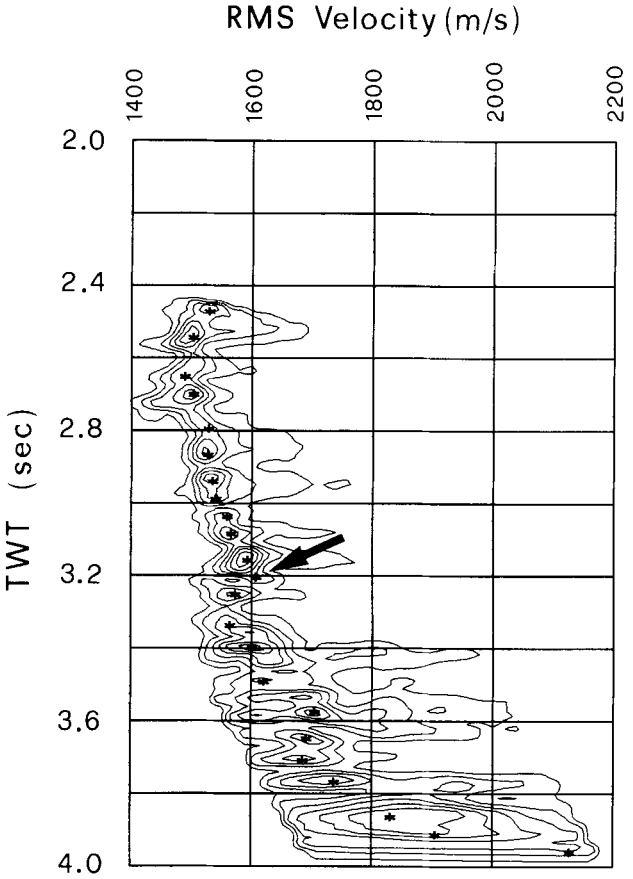


Fig. 5. Semblance plot generated by summing CDP gathers, showing RMS velocities picked between CDP 4500 and 4700 (see Fig. 2). Variations of 10 m s^{-1} have been applied in the normal-move-out computation to obtain greater resolution. Asterisks show the interpreted RMS velocity trend from the sea floor to about 1.5 sec two-way time below it; the peak in semblance at *c.* 3.2 sec two-way time (arrow) represents the BSR.

e) True amplitude traces (Fig. 4) indicate a consistent negative polarity of the BSR with respect to the sea floor reflection. This is consistent with high acoustic velocity gas hydrate-saturated sediments, at least at the base of the HSZ, overlying lower velocity sediments in which free gas, trapped by the overlying hydrate-sealed zone, can be anticipated (Sloan 1990).

f) The amplitude of the BSR (Fig. 4) is larger than any other sub-bottom reflector, and has a laterally continuous character consistent with the base of an HSZ.

g) The reflection coefficient of the sea floor, calculated by comparing the amplitude of the sea floor reflection with the amplitude of the sea floor multiple on near-normal incidence traces (to avoid complications due to variation in amplitude with offset), gives values ranging from 35–40%. Because the amplitude of the BSR is about 50%

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of the primary sea floor reflection, we conclude that the reflection coefficient of the BSR must be large. Significant reflection coefficients (up to 50% of the sea floor) can be anticipated at a HSZ base/gas-rich contact.

h) Detailed, closely-spaced velocity analyses, carried out over a short section where the BSR is strong, approximately flat and the geological structure is relatively uniform (from CDP 4500 to CDP 4650 on seismic line IT9043), show that the hydrate layer is well resolved (Fig. 5), and has a calculated interval velocity of about 2400 m s^{-1}. Semblance velocity analyses, carried out at *c.* 2 km intervals throughout the area where the BSR is detectable, show lateral variations associated with the reflector, even though the deformed structure in many areas prevents accurate velocity determinations.

The effect of sediment diagenesis contrast could furnish a possible alternative cause of strong BSRs: the cementation of sediments that occurs with the opal-A to opal-CT transformation, causes an increase in both density and seismic velocity and consequently a high-amplitude, and normal-polarity with respect to the sea floor, response on the seismic sections (Londsale 1990). Thus the BSR found on line IT9043 cannot be referred to opal transformation within the sediments.

Conclusion

A bottom simulating reflector beneath the continental slope of the Pacific margin of the Antarctic Peninsula exhibits seismic and geometrical characters of the base of a gas hydrate zone (Minshull & White 1989). We conclude that the gas hydrate, and possibly trapped gas, occurs in the sub bottom sediments here. Our limited seismic coverage prevents the mapping of the areal extent of the BSR and associated layers of possible pore-filled gas.

To our knowledge this is the first identification of gas hydrate in this area.

Acknowledgement

This manuscript has been critically reviewed by Michael D. Max at SACLANT Udersea Research Centre, La Spezia, Italy, and Graham Westbrook (University of Birmingham). Robert Larter (British Antarctic Survey, Cambridge) provided comments and suggestions that greatly improved the original manuscript. Funds for this study were provided by Programma Nazionale di Ricerche in Antartide (PNRA), Ministero dell'Univeristà e della Ricerca Scientifica e Tecnologica.

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