U.S. Geological Survey
[Reports-Open file series]

U. S. Geological Survey

Open File Report 80-88

The Appearance and Distribution of the Gas-Hydrate Reflector off the Southeastern United States

by

Charles K. Paull

and

William P. Dillon

Woods Hole, MA 02543

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature.

U. S. Geological Survey

Open File Report

The Appearance and Distribution of the Gas-Hydrate Reflector off the Southeastern United States

by

Charles K. Paull

and

William P. Dillon

Woods Hole, MA 02543

A strong reflector parallel to the bottom is observed in seismic-reflection profiles off the southeastern United States. This reflector occurs at a subbottom depth of about 400-700 meters (m) in water depths of about 800-3800 m. Because it is approximately parallel to the sea floor, it is known as the bottom-simulating reflector (BSR). The BSR is independent of reflectors that represent sedimentary strata and can cross such reflectors. The BSR is believed to be caused by the impedance contrast at the base of a gas-hydrate-cemented layer. Such a layer could act as a seal, trapping hydrocarbon gas and creating an energy resource. Indeed, the gas-hydrate may be a future resource in itself, when methods are devised to extract the gas that is bound into it.

The U.S. Geological Survey has collected more than 10,000 km of multi-channel common-depth-point (CDP) seismic-reflection profiles and 15,000 km of single-channel seismic-reflection profiles off the east coast of the United States south of Cape Hatteras. Many of these reflection profiles were collected in the Cape Hatteras to Blake Outer Ridge areas (Figs. 1, 2) where the BSR occurs. This report illustrates the appearance and distribution of the BSR on a few of these profiles (Figs. 2-8). Presence of the BSR in profiles off the southeastern United States has also been noted by Markl and others (1970), Hollister, Ewing, and others (1972), and Tucholke and others (1977).

Bottom-simulating reflections probably result from the contract between an upper, high-velocity zone of gas-hydrate-cemented sediment and a zone in which no such cementation occurs and seismic velocities are lower. The strength of the seismic return can be enhanced by free gas bubbles below the boundary, which can reduce further the seismic velocities. A gas-hydrate, also known as a clathrate, is an icelike crystalline lattice of water molecules in which small gas molecules such as methane, ethane, and H_2S become trapped. Gas hydrates appear to be stable under the temperature and pressure conditions of the deep sea (Claypool and Kaplan, 1974; Miller, 1974) and have a strong tendency to form under conditions where water and sediment are saturated with gas. Deep Sea Drilling Project holes 102, 103, and 104 (Fig. 1) have demonstrated that gas is present in large quantities in the Blake Ridge sediments. Cores from these drill holes released large amounts of gas for several hours after exposure on the deck of the drilling ship. This slow release of gas is consistent with breakdown of gas-hydrates. The gas was predominantly methane (CH_4) and contained traces of ethane (C_2H_6) and hydrogen sulfide (H_2S) (Hollister, Ewing et al., (1972). Because gas-hydrates are stable under conditions of high pressure and low temperature, and because sediment temperature increases as depth increases along the geothermal gradient, gas-hydrates cannot form below a certain depth. The base of the gas-hydrate follows a temperature-pressure surface that represents the position of its phase stability. In the study area, the BSR is observed to dome up around diapirs (Fig. 7), which are interpreted to be salt domes by Grow and others, (1977). As salt is a good thermal conductor, heat flow through these diapirs presumably is higher than heat flow in the surrounding sediments. The presence of salt is also an inhibitor to clathrate formation (Tucholke and others, 1977); thus, the observed doming supports both the cathrate and salt-diapir interpretations.

The BSR is frequently of high amplitude, which indicates a strong acoustic-impedence contrast and therefore large changes in density and/or seismic velocity at this boundary (Fig. 4). Interval velocities determined from velocity analyses (Fig. 8) of seismic profiles show that the boundary marks a strong velocity inversion.

Very low seismic velocities observed beneath the BSR (Fig. 8) also support the interpretation that the BSR reflects a gas-hydrate. These low velocities, which are less than that of sea water, are interpreted to result from presence of free gas bubbles trapped beneath the gas-hydrate. Bubbles amounting to only a small percentage of the interstitital water volume can produce low velocities (Brandt, 1960; Levin, 1962). The contrast of high-velocity gas-hydrate-cemented sediment with low-velocity gas-filled sediment (Stoll and others, 1971) would account for the large acoustic-impedance change and large reflectivity at this boundary.

In drilling on the Blake Ridge, an abrupt decrease in drilling rate has been observed near the presumed depth of the BSR (Hollister, Ewing, et al., 1972). However, this correlation requires a sediment velocity of less than 2.0 km/sec, which is less than that expected in a gas-hydrate-cemented zone (Stoll and others, 1971), suggesting that if there is a gas-hydrate zone in this area, then the BSR was not penetrated in these wells. Abundant siderite was found near the bottom of hole 102, and hole 104 ended in a hard ankerite nodule, both possibly due to diagenetic processes. Our evidence does not support the hypothesis that a thin layer of authigenic minerals is the cause of the BSR. Although a reflection could be produced by a thinly cemented layer the velocity structures observed require considerable thicknesses of high-velocity material above the reflector and low-velocity material below, which cannot be explained as a result of a thin layer of authigenic minerals. Therefore, we conclude that the BSR results primarily from a gas-hydrate layer, although it could be enhanced by the authigenic boundary.

The BSR closely parallels the sediment-water interface and shows cross cutting relationships with other reflectors, which are presumably related to the bedding planes (Figs. 3-7). Seismic reflections from the units above and below the BSR are different, especially where the BSR is stronger. The unit above the BSR is usually acoustically transparent and causes very weak or essentially no seismic reflections, whereas reflections from beneath the BSR are usually strong and closely spaced. The change in reflection character across the BSR is sufficiently obvious for it to be clearly visible on both true-amplitude and gain-ranging-amplification displays (Fig. 4); thus, it is not an artifact of the automatic gain control. The subbottom depth of the BSR varies as a function of the overlying water depth. In the vicinity of the Blake Outer Ridge, the BSR has not been identified in water deeper than 3750 m where it is at 0.6 seconds (two-way travel time) subbottom. The shallowest observation of the BSR is in water 750 m deep where it is 0.4 seconds (two-way travel time) beneath the sea floor.

Areas of major surface erosion correspond to areas where the BSR is weak or broken. In these areas, the geothermal gradient would be depressed, causing a downward migration of the hydrate stability field which could proceed below the level where the sediment is uniformly saturated with biogenic gas. This depression of the geothermal gradient may explain the patchy and intermittent nature of the BSR under eroded areas. In contrast, the hydrate stability field in areas of deposition would migrate upward in the sediment (Fig. 4). This migration could provide additional free gas to assure gas saturation in the sediment near the phase boundary. The breakdown of hydrates causes the release of large amounts of gas, as water in the hydrate form can contain more than 50 times the volume of gas that it will hold in saturation (Cieslewicz, 1971).

Large gas traps may exist in places where a significant amount of closure exists beneath the BSR surface. For example, the Blake Outer Ridge is sealed along both its flanks by a hydrate layer (Fig. 3). It also has topographic relief so that both landward and seaward closure exist (Fig. 4). A tremendous amount of free gas could be trapped within this structure that conceivably could be exploited.

The gas-hydrate layer itself represents a potential resource if a method could be devised to tap it. Gas, which is present in great concentration in gas-hydrates, could be released by changing the pressure-temperature conditions and adding the necessary heat of crystallization. The amount of heat necessary to break down a gas-hydrate represents about 5%-30% of the energy available in the gas released (G. Holder, oral communications, 1979). Therefore, a net energy gain can be realized.

REFERENCES CITED

Brandt, H., 1960, Factors affecting compressional wave velocity in unconsolidated marine sand sediments: Journal of the Acoustical Society of America, v. 32, no. 2, p. 171-179.

Cieslewicz, W. J., 1971, Some technical problems and developments in Soviet petroleum and gas production: Mines Magazine, November, p. 12-16.

Claypool, G. E., and Kaplan, I. R., 1974, The origin and distribution of methane in marine sediments, in Kaplan, I. R., ed., Natural gases in marine sediments: New York, Plenum Press, p. 99-139.

Grow, J. A., Dillon, W. P., Sheridan, R. E., 1977, Diapirs along the Continental Slope off Cape Hatteras: (Abstract) Society of Exploration Geophysics, Annual International Meeting and Exposition, Calgary, Alberta, Canada, p. 57.

Hollister, C. D., Ewing, J. I., et al., 1972, Initial Reports of the Deep Sea Drilling Project, Volume XI: Washington (U.S. Government Printing Office), 1077 p.

Levin, F. K., 1962. The seismic properties of Lake Maracaibo: Geophysics, v. 37, p. 35-47.

Markl, R. G., Bryan, G. M., and Ewing, J. I., 1970, Structure of the Blake-Bahama Outer Ridge: Journal of Geophysical Research, v. 75, p. 4539-4555.

Miller, S. L., 1974, The nature and occurrence of clathrate hydrates, in Kaplan, I. R., ed., Natural gases in marine sediments: New York, Plenum Press, p. 151-177.

Pratt, R. M., and Heezen, B. C., 1964, Topography of the Blake Plateau: Deep-Sea Research, 1966, v. 11, p. 721-728.

Stoll, R. D., Ewing, J. I., and Bryan, G. M., 1971, Anomalous wave velocities in sediments containing gas hydrates: Journal Geophysical Research, v. 76, p. 2090-2094.

Tucholke, B. E., Bryan, G. M., and Ewing, J. I., 1977, Gas-hydrate horizons detected in seismic-profile data from the Western North Atlantic: American Association of Petroleum Geologists, Bulletin, v. 61, no. 5, p. 698-707.

Figure 1: Bathymetric map showing the region off the southeastern United States and northern Bahamas. Box indicates the section of the map shown in Figure 2. Locations of Deep Sea Drilling Project (DSDP) wells on the Blake Outer Ridge are indicated by stars and identified by number. Contours are in meters from Pratt (1964).

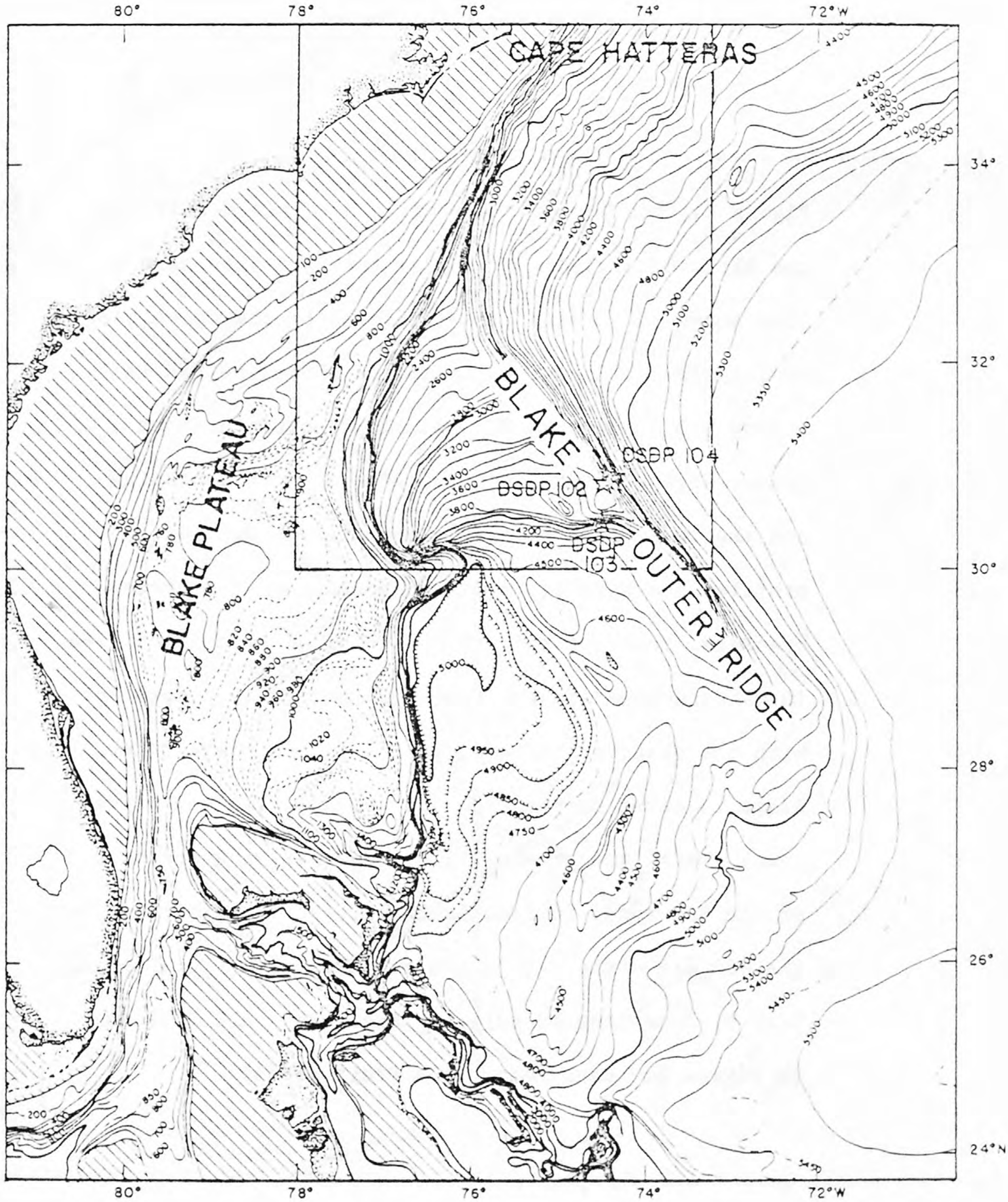
CAPE HATTERAS
BLAKE PLATEAU
BLAKE OUTER RIDGE
DSDP 104
DSDP 102
DSDP 103
80°
78°
76°
74°
72°W
34°
32°
30°
28°
26°
24°N

Figure 1

Figure 2: Location of the profiles collected near the the Blake Outer Ridge by or for the USGS (the dashed line shows where data were collected by the University of Texas). Bold pattern indicates where the BSR is strong and of high amplitude; dotted pattern shows areas where the BSR identification is more tentative and the reflection is of low amplitude. Sections of profiles shown in other figures are indicated by the brackets. The fact that the BSR has not been identified in water depths greater than 3800 meters is consistent with the observation that the BSR on the Blake Outer Ridge is never deeper than 5.6 seconds (Two-way travel time) (Markl and others, 1970). However, the strength of the BSR tends to fade laterally, so the limits of the BSR are often determined subjectively. V. A. a and V.A. b, locations of velocity analyses A and B shown in Figure 8. Bathymetry from Pratt (1964).

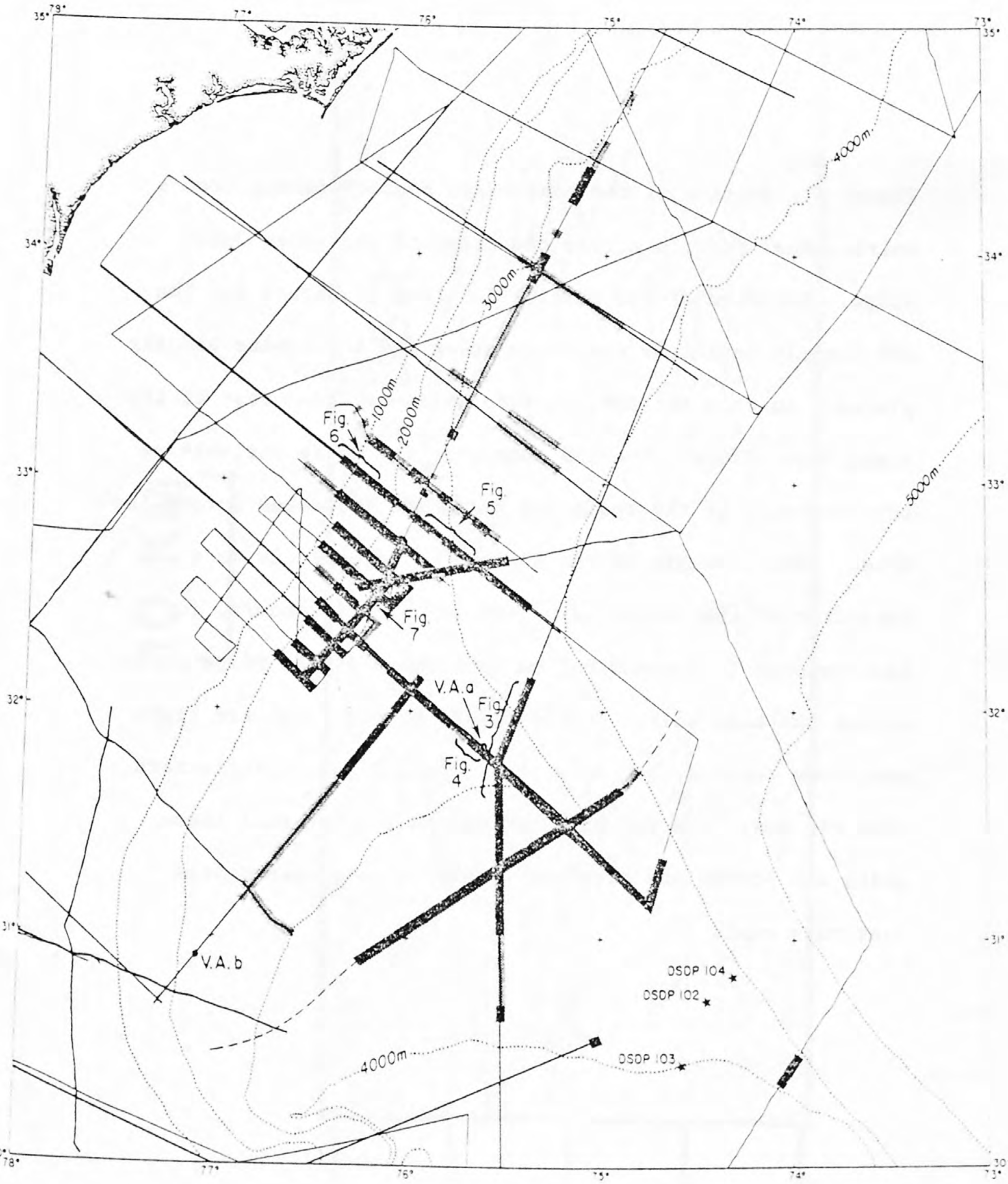

Fig. 6
1000m
2000m
3000m
4000m
5000m
Fig. 5
Fig. 7
V.A.a
Fig. 3
Fig. 4
V.A.b
DSDP 104
DSDP 102
DSDP 103
4000m

Figure 2

Figure 3: Section of the near-trace monitor record from a multichannel profile across the crest of the Blake Outer Ridge. Location of the profile is shown in Figure 2. The BSR clearly parallels the ridge crest and intersects bedding planes. In this section, closure exists at the crest of the Blake Outer Ridge. The BSR character is quite variable as the intensity of the reflector fades and increases across the crest. The strength of the BSR may be in part due to the character of the sedimentary beds in which it occurs, for its response is symmetrical on both sides of the ridge crest within the same unit. On the flanks of the ridge are high-amplitude returns, not only along the BSR but on reflectors that dip away from the BSR, perhaps indicating that these units are porous and have gas trapped within them by the clathrate seal.

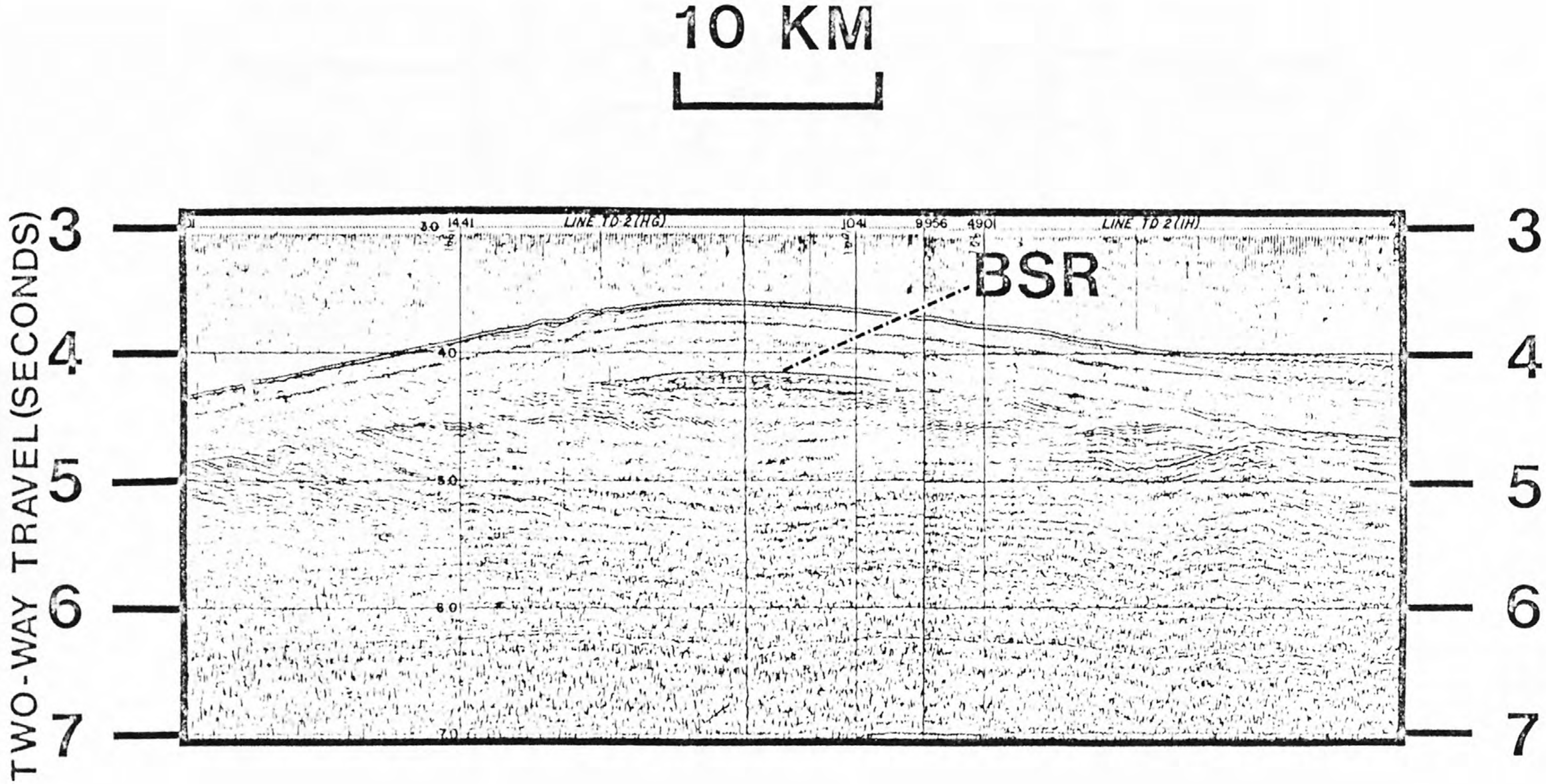

Figure 3

Figure 4: Two displays of the same section of CDP profiles BT-1 (Fig. 2). Both sets of data are 48-channel records with 36-fold processing. The section below is a true-amplitude display; the section above has automatic gain control (AGC) applied. The BSR closely follows the bottom and is strong on the east side of the profile, but its presence becomes questionable toward the west where it fades. The change in the character of the seismic units above and below the BSR is clear in both displays, implying that the character of the reflectors is not an artifact of the AGC. The unit above the BSR is essentially acoustically transparent, whereas stronger returns appear beneath the BSR.

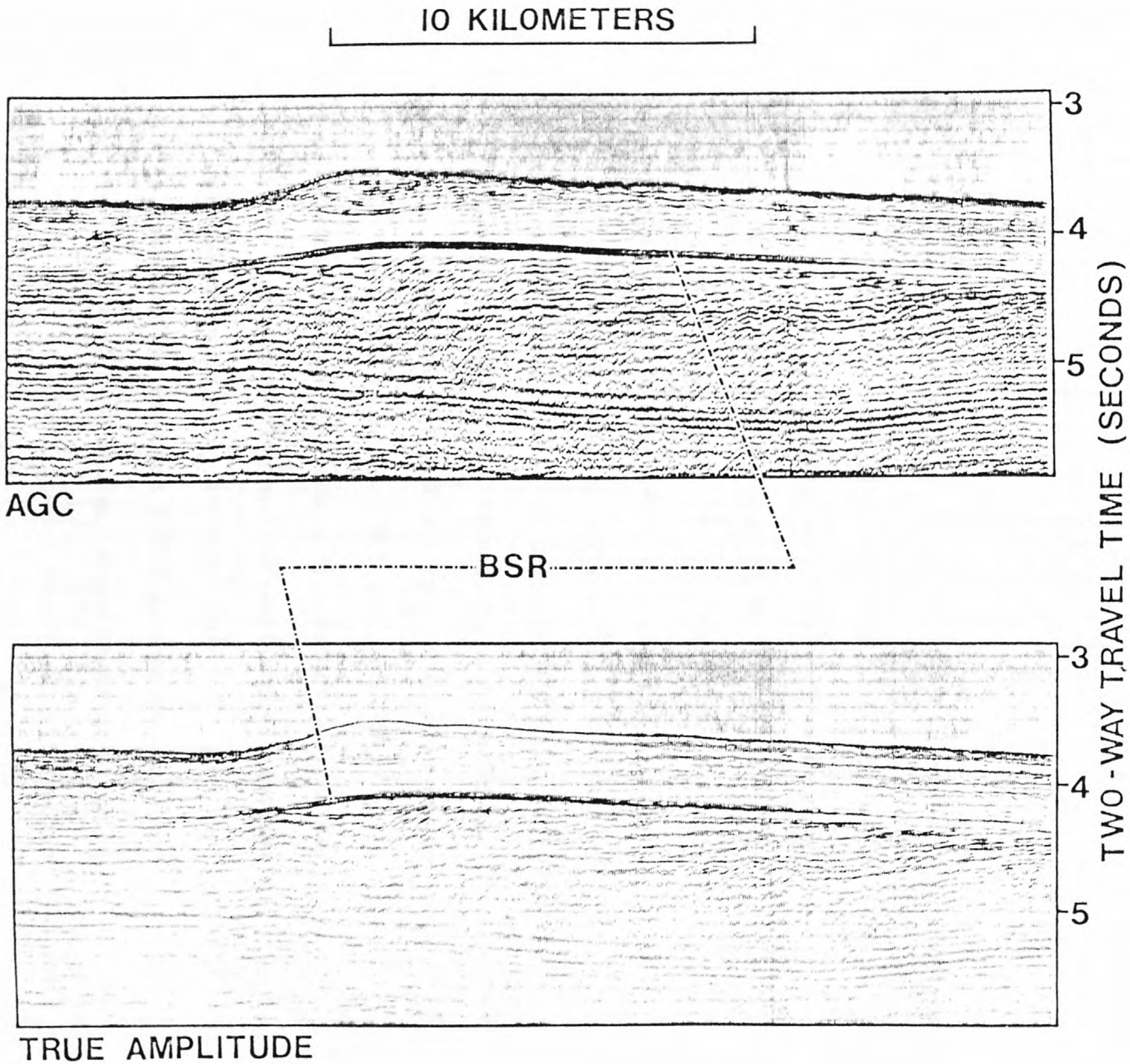
10 KILOMETERS
3
4
5
AGC
BSR
3
4
5
TRUE AMPLITUDE
TWO-WAY TRAVEL TIME (SECONDS)

Figure 4

Figure 5: Part of a CDP profile whose location is shown in Figure 1. Automatic gain has been applied. The BSR is strong and distinct on the left and right sides of the photo, but it is weak in the middle of the photograph where the true dip of reflectors is landward. Horizons A, B, and C are believed to be sedimentary beds that have a true dip toward land. These horizons appear to pass through the BSR but show weaker reflections above the BSR than below it. Free gas may be trapped within the beds sealed against the near-bottom layer of gas-hydrate-cemented sediment. The continuity of reflectors through the cemented zone probably reflects low original porosity in these units, making them less susceptible to hydrate cementation.

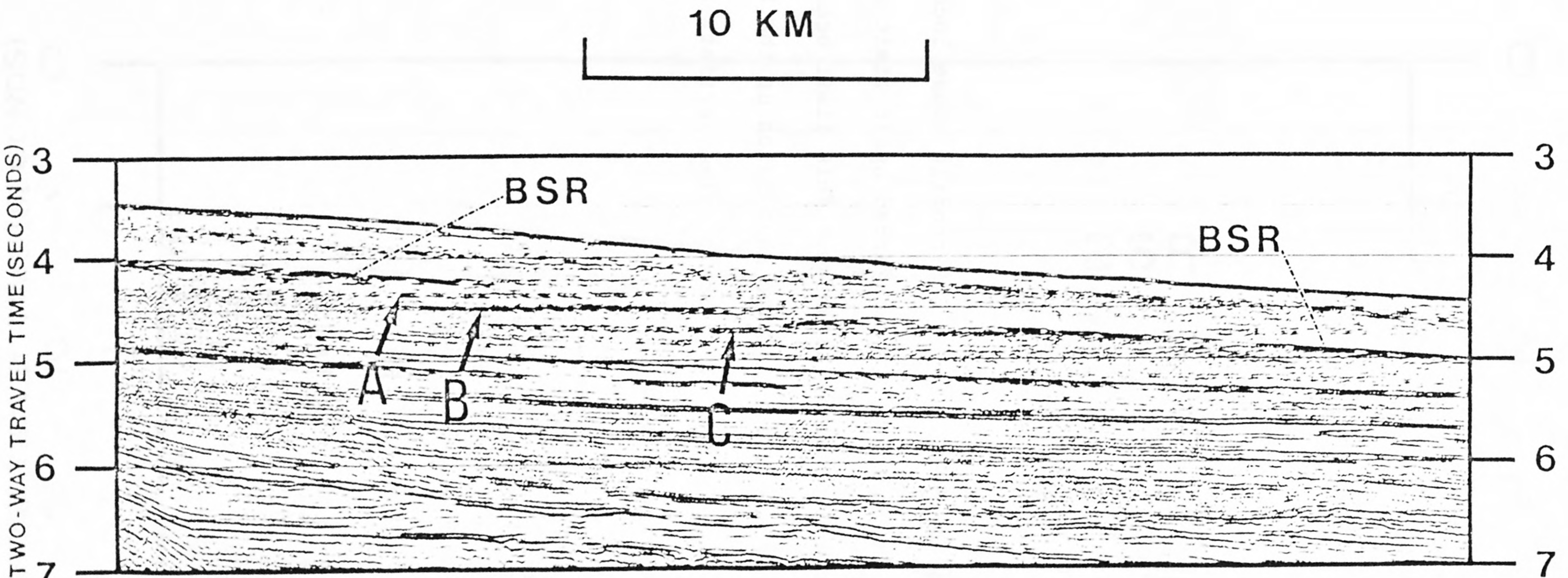

Figure 5

Figure 6: Section of a CDP profile whose location is shown in Figure 2. The inferred updip limit of the BSR is indicated by an arrow. This limit occurs where the thick Tertiary section that makes up the Blake Outer Ridge thins to an abbreviated Tertiary section on the Blake Plateau.

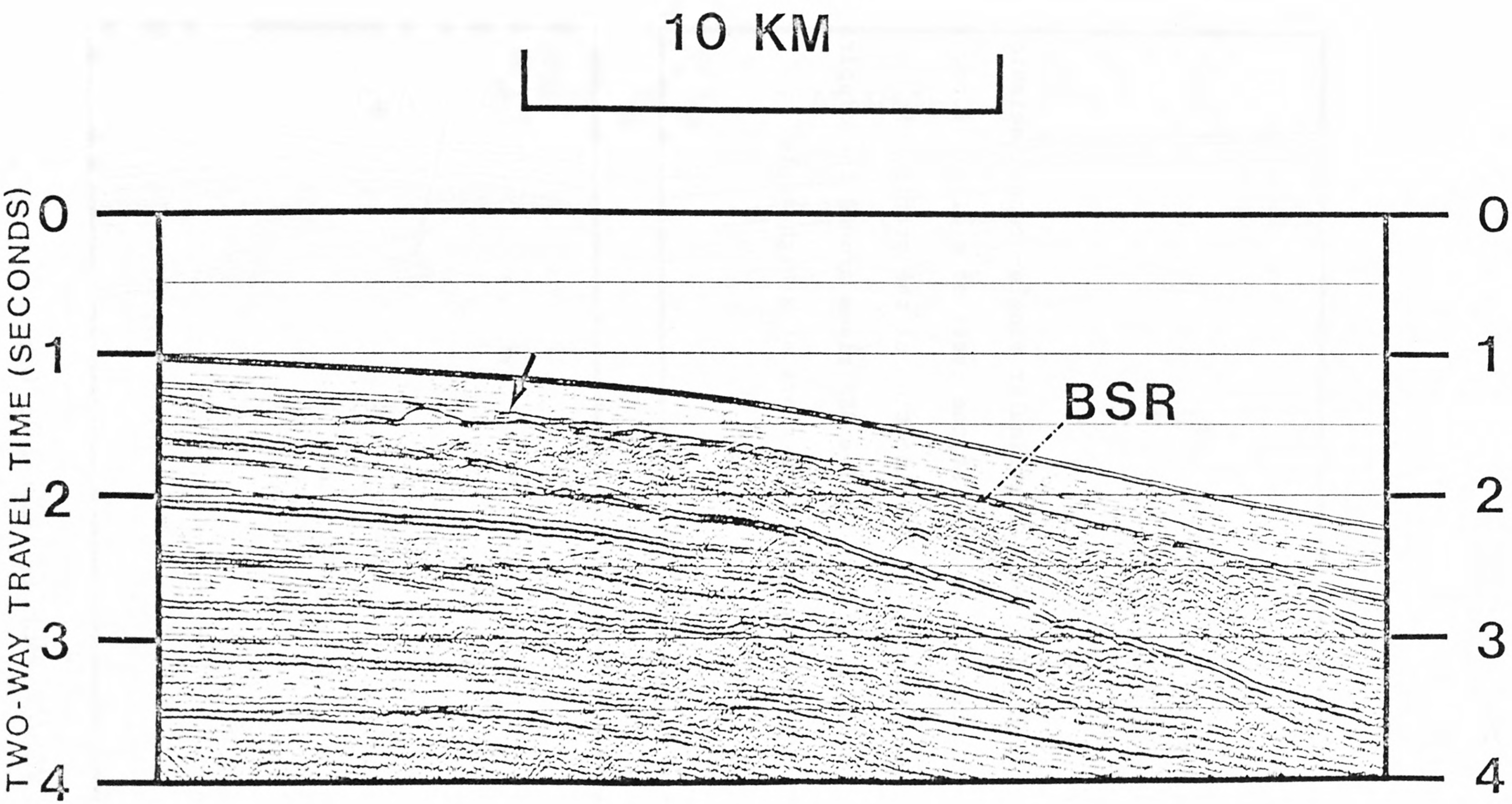

Figure 6

Figure 7: Two perpendicular single-channel seismic profiles that cross at the crest of a diapir (Grow and others, 1977). Location of the profiles is shown in Figure 2. The BSR rises around the diapirs and crosses other reflectors at a high angle.

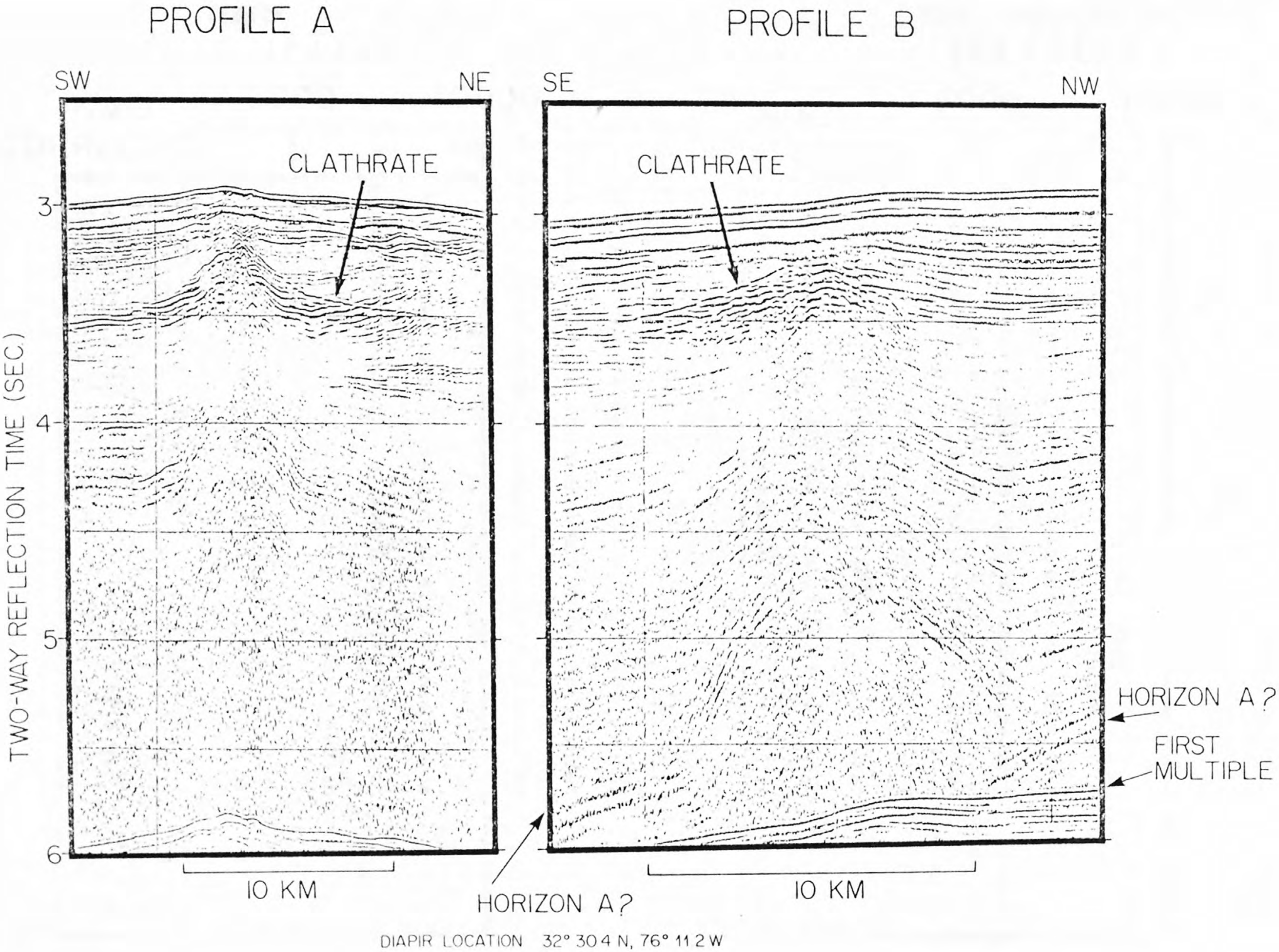
PROFILE A
PROFILE B
SW
NE
SE
NW
CLATHRATE
CLATHRATE
TWO-WAY REFLECTION TIME (SEC.)
3
4
5
6
10 KM
10 KM
HORIZON A?
HORIZON A?
FIRST MULTIPLE
DIAPIR LOCATION 32° 30.4 N, 76° 11.2 W

Figure 7

Figure 8: Sections of two velocity analyses (VA), both from 48-channel CDP data collected and processed by Geophysical Services, Inc., during the same field program as each other. A is a VA from profile BT-1 at shot point (SP) 2261, and B is a VA from profile BT-8 at SP 584. Locations of the two VA's are indicated in Figure 2. The BSR is strong in area A. The root-mean-square (RMS) velocity functions are best indicated by the line that best fits the points of high coherence. The RMS velocity function A shows an inversion just below 4 seconds at the time-depth of the BSR. This velocity inversion is typical of areas where the BSR is strong. By comparison, the VA shown in B comes from an area where the BSR has not been identified and shows a normal RMS velocity function, constantly increasing as depth increases.

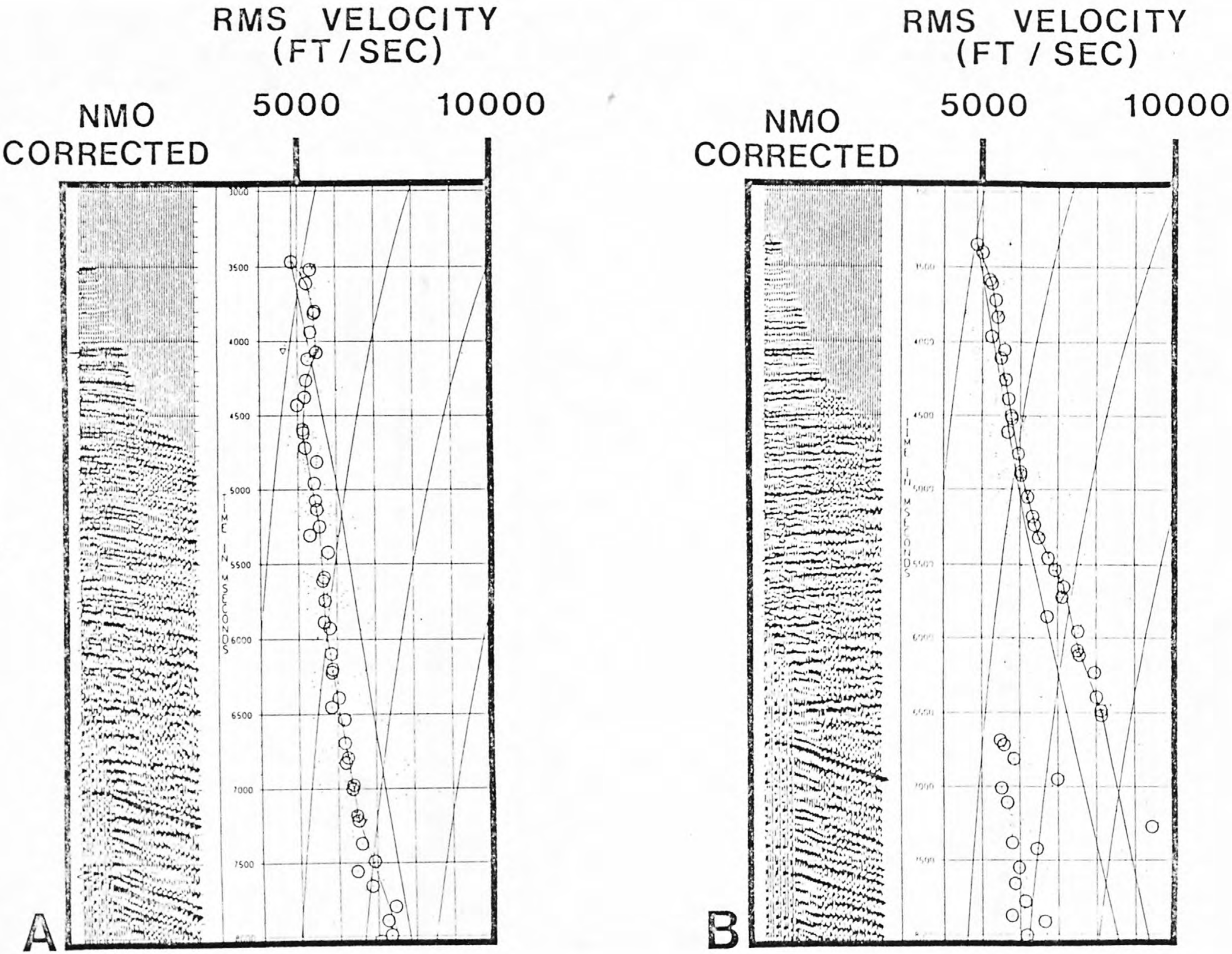
RMS VELOCITY
(FT/SEC)
5000
10000
NMO
CORRECTED
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
TIME IN MSECONDS
A
RMS VELOCITY
(FT / SEC)
5000
10000
NMO
CORRECTED
B

Figure 8