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Deep Seismic Reflection Results from the Gulf of Mexico: Part I

Abstract. *Deep sounding seismic reflection data show undeformed reflectors at depths down to 11 kilometers beneath the continental rise and abyssal plain and 7 kilometers in basins of the lower slope. Weak reflectors are visible beneath the salt of the Sigsbee Scarp and within salt ridges separating the lower slope basins.*

We report here results of a deep sounding common-depth-point (CDP) seismic reflection survey across a portion of the lower slope, Sigsbee Scarp, continental rise, and abyssal plain in the northern Gulf of Mexico. This powerful tool for the investigation of deep geologic structure has heretofore been used almost exclusively by the petroleum industry. It promises much to the marine geologist and geophysicist.

The CDP method was adopted by the petroleum industry in the early 1960's because this technique made it possible to attenuate multiple reflections and random noise. With the CDP technique it is possible to achieve an increased signal-to-noise ratio by summing several reflectors from what are theoretically common points in a vertical plane. The shot point and receiver geometry determine the number of reflection records to be summed. Typically, the number of summed input records is 6, 12, or 24, or, in some instances, 48 or 96. In industry terminology, the number of input traces is denoted as 6-fold, 12-fold, and so on, or 600 percent coverage, 1200 percent coverage, and so on, respectively.

Digital recording of marine seismic data was introduced into the petroleum industry at about the same time as the CDP method. By 1966, 85 percent of U.S. marine seismic data were digitally recorded (*1*), which facilitated CDP processing and simultaneously provided a mechanism for the application of sophisticated noise suppression techniques.

The CDP method and ancillary digital signal enhancement techniques have proved to be powerful tools for obtaining data on deep, detailed geological structure on land and offshore. On the continental shelves, multichannel digital seismic reflection instrumentation has yielded reflections from depths of 8 to 10 km, depths which are significantly greater than the depths of penetration of single-channel analog instrumentation. The petroleum industry, however, has shown little interest in areas of deeper water. The industry also tends to consider seismic reflection data confidential. As a result only a few deep-water CDP cross sections have been published (*2, 3*).

The geologic structure of the deeper parts of the Gulf of Mexico is well suited for CDP investigation. Little is known about details of structure and stratigraphy below depths of about 2 to 3 km beneath the sea floor, the maximum penetration of single-channel seismic reflection analog instrumentation. Multiple bottom reflections obscure primary reflections deeper than 2 to 3 km subbottom on the slope and deeper than 5 to 8 km subbottom in the abyssal plain. Seismic refraction investigations (*4*) have provided information on the gross framework of the region but no detailed structural information. Salt underlies some areas of the Gulf such as the lower slope off Texas and Louisiana (*5*). Single-channel reflection data have provided little information about the nature of salt deformation and possible subsalt reflectors because of the poor quality of deeper reflectors.

Our investigation consisted of two CDP lines resembling in plan an inverted "V" (Fig. 1). The survey was conducted on board the University of Texas Marine Science Institute R.V. *Ida Green*, and the data were processed at the University of Texas Medical Branch, Galveston.

Penetration was excellent. The deepest observed reflector was located near the southern end of line SS-2. It was received 6.5 seconds after the bottom reflection. A relatively strong deep reflector was recorded 4.5 to 5.0 seconds after the bottom reflector beneath all of the abyssal plain–continental rise portions of both lines. Sediment-filled basins separated by salt ridges (*5, 6*) underlie the lower slope. The usefulness of the CDP method is evident in this region. Multiple reflections which interfere with primary reflections deeper than about 2 seconds subbottom are strongly attenuated, permitting resolution of the primary reflections at depths of 4 to 5 seconds in some cases (Fig.

Table 1. Layer velocities, layer thicknesses, depths beneath the sea floor, and expected reflection arrival times calculated from seismic refraction data (*7*) for the northern Gulf of Mexico.

Layer velocity (km/sec)	Calculated reflection time (sec subbottom)	Layer thickness (km)	Depth (km subbottom)
1.9	0.0	0.5	0.0
2.2	0.53	2.0	0.5
3.2	2.34	2.5	2.5
3.8	3.91	2.0	5.0
4.8	4.96	4.0	7.0
6.6	6.63	5.0	11.0

2). Short, discontinuous reflectors can also be seen within the salt.

An accurate determination of seismic velocities from our reflection data is possible only in the portions of the data recorded less than 1 or 2 seconds after the arrival of the bottom reflector. Without good velocity determinations, depths cannot be calculated. Earlier investigators (7), however, have determined velocities and calculated the thicknesses of major rock units in this area from seismic refraction data. Table 1 lists layer velocities, layer thicknesses, depths beneath the sea floor, and expected reflection arrival times calculated from refraction data. The recorded reflection times are in good agreement with the calculated reflection times.

The deep reflector recorded 6.5 seconds after the arrival of the bottom reflection in the abyssal plain–continental rise portion of line SS-2 probably correlates with the 6.6 km/sec layer observed in refraction investigations. The velocity, 6.6 km/sec, suggests that this layer is basaltic oceanic basement. Weak, discontinuous reflectors about 6.0 seconds subbottom near the southern end of line SS-1 may also be basaltic crust.

A good reflector was observed throughout the abyssal plain–continental rise region. It has a two-way travel time of about 5 seconds subbottom where it fades into the noise near the base of the Sigsbee Scarp (about 2 seconds below the bottom of Fig. 3). This reflector may correlate with the top of the 4.8 km/sec reflector which Ewing *et al.* (8) inferred to be the top of an evaporite sequence of late Paleozoic or Mesozoic age. The lack of deformation of this reflector indicates that the central portion of the Gulf of Mexico has been tectonically stable since its deposition.

Figure 3 shows the portion of line SS-1 where faint reflectors are visible beneath the salt. The salt was not penetrated by Deep Sea Drilling Project (DSDP) hole 92, but overconsolidation of sediments and pore water five times as salty as seawater near the bottom of the hole suggest the presence of salt (9). The genesis of the feature is not clear. Amery (2) suggested that it consisted of laterally flowing salt overlying relatively horizontal strata. Our data do not support this interpretation. Plotting subsalt reflectors at depths calculated with the use of a velocity appropriate for salt results in irregular northward-dipping reflectors. A velocity sig-

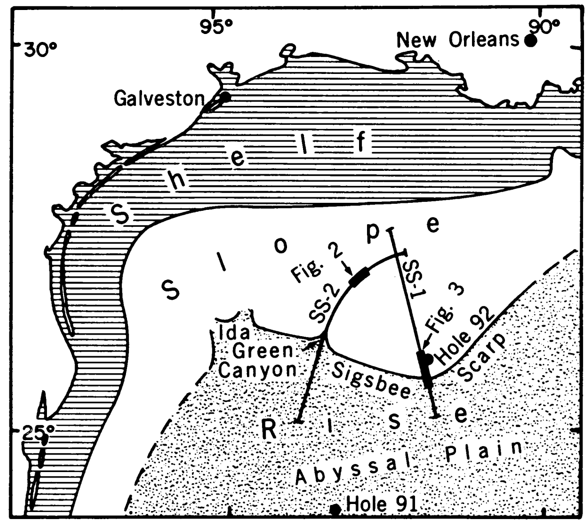

Fig. 1. Northwestern Gulf of Mexico showing the location of seismic reflection lines SS-1 and SS-2 relative to the continental shelf, the continental slope, Sigsbee Scarp, Ida Green Canyon, the continental rise, and the abyssal plain. Heavier portions of the reflection lines indicate the locations of data shown in Figs. 2 and 3.

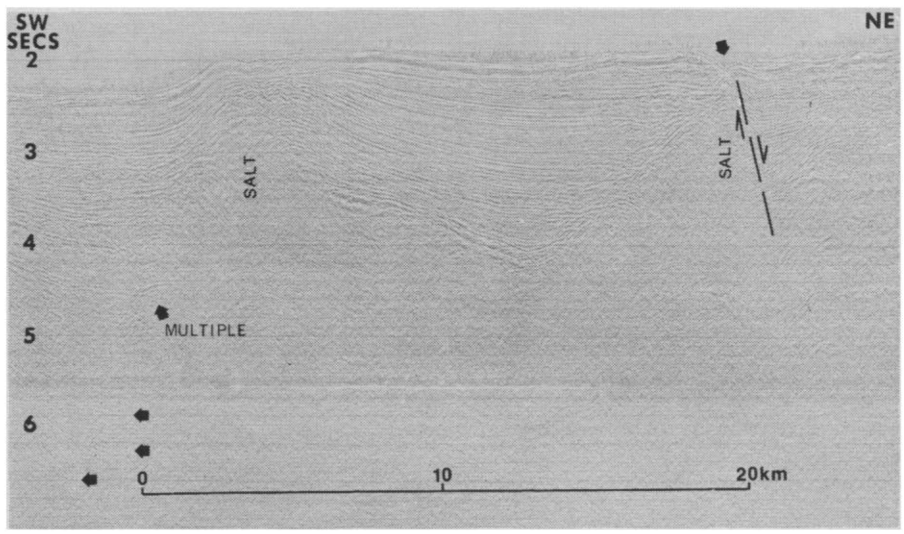

Fig. 2. Features from north to south along line SS-2 are as follows: shallow basin, inferred fault, salt ridge, basin, salt ridge, and deep (about 4 seconds two-way subbottom travel time) basin, all on the lower slope. Arrows indicate deep reflectors, the attenuated bottom multiple, and the surface expression of a fault.

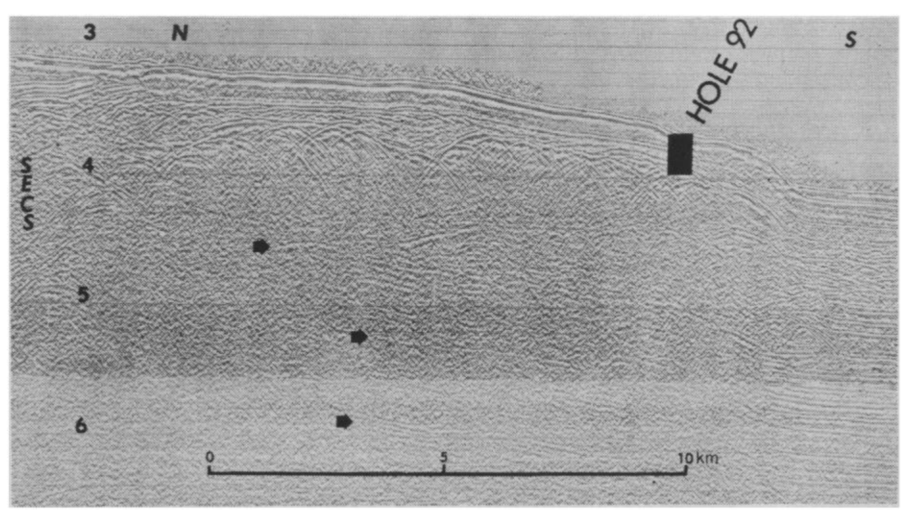

Fig. 3. Features from north to south along line SS-1 are as follows: lower slope, DSDP hole 92, Sigsbee Scarp, and the continental rise. Note the tongue of salt forming the Sigsbee Scarp and subsalt reflectors (arrows). Subsalt reflectors have not been reported from single-channel seismic reflection surveys.

nificantly lower than that of pure salt can be found such that reflectors remain roughly horizontal and can be correlated with reflectors beneath the adjacent continental rise. This suggests that another mechanism, possibly a submarine landslide or slumping incorporating significant quantities of salt, may be a better explanation of this feature.

Both lines SS-1 and SS-2 show a change in the number of good reflectors per unit depth in the continental rise–abyssal plain region. The lower portion of the section contains relatively fewer reflections than can be explained on the basis of the decreasing of signal-to-noise ratios with greater depth. Near the Sigsbee Scarp, the change occurs at about 2.5 seconds subbottom. A similar phenomenon was observed in single-channel reflection data north of DSDP hole 91. Worzel and Bryant (*10*) correlated the upper zone of numerous reflectors with a zone of interlayered turbidites and abyssal sediments found in DSDP cores. The zone consists of rocks of Pleistocene and Upper Pliocene age. Within the upper zone, our data show subzones in which the reflectors are wavy, anastomosing, and locally discontinuous. Structural discontinuities are limited to the subzones and do not extend into suprajacent or subjacent strata. We suggest that periods of alternating sea-floor erosion and deposition caused the irregularities in the reflectors.

Deep sediment-filled basins of the lower slope are of interest because of their possible hydrocarbon potential. In our area of investigation, these basins range up to 20 km long and are several kilometers wide. Refraction data (*7, 8*) indicate that the velocities probably average between 2.0 and 2.5 km/sec. Hence, sediment thickness in the basins may locally range up to 7.5 km. We have not attempted to analyze the data for indications of natural gas accumulations (*11*), but cursory examination of the data suggests likely possibilities. The largest of the basins lies near the northern apex of our two CDP lines in less than 1.5 km of water. This is within the range of present-day commercial drilling technology.

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Porphyrin Triplet State Probing the Diffusion of Oxygen in Hemoglobin

Abstract. *Laser photolysis study of porphyrin-globin shows that the triplet state of the porphyrin is detectable by its light absorption and that it can be used to determine the rate of penetration of oxygen into the hemoglobin pocket in which the porphyrin is embedded. The oxygen penetration rate does not determine the binding rate of oxygen to iron in hemoglobin.*

The fixation of molecular oxygen to the heme in hemoglobin is expected to depend on the rate of diffusion of the ligand into the heme pocket. To study this diffusion we have made use of the well-known property of oxygen as a triplet-state quencher. The principle of the method was to populate the porphyrin triplet state by nanosecond laser excitation and follow the triplet decay by rapid kinetic spectrophotometry in the presence and absence of oxygen; the enhancement of the decay rate in the presence of oxygen gives a measure of the rate of oxygen diffusion into the heme pocket. Since the hemoglobin triplet is too short-lived for such a study, we investigated instead the corresponding iron-free porphyrin-globin, which has a relatively long triplet lifetime ($> 10^{-4}$ second). We studied the tetrameric porphyrin-globin obtained from human hemoglobin A (in aqueous solution, *p*H 7, 2°C, $10^{-4}M$ in porphyrin) and the corresponding free protoporphyrin IX (in dioxan at 23°C). The globin protecting effect on the porphyrin was expected to appear as a reduction of the triplet quenching constant of the porphyrin-globin compared to that of the free porphyrin.

Transient changes in absorbancy in the solutions irradiated by a laser pulse (*1*) (529 nm, 3×10^{-8} second width at half-maximum) were measured at selected wavelengths. Excitation of degassed solutions of the porphyrin-globin and the free porphyrin, respectively, produced a transient spectrum (Fig. 1), which was attributed to the porphyrin triplet state, populated by intersystem crossing from the excited singlet state. The broad absorption features of the spectrum are character-

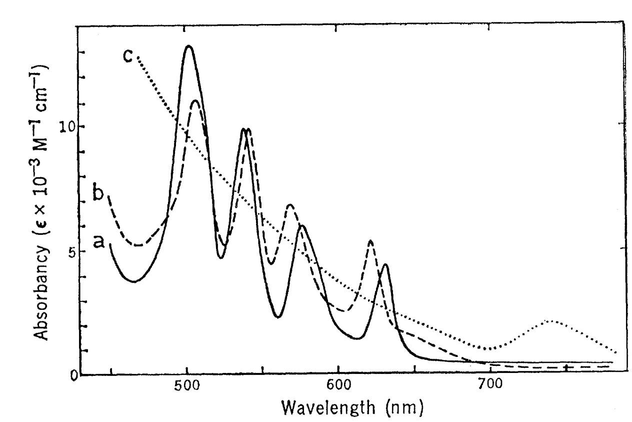

Fig. 1. Curve a: Absorption spectrum of free protoporphyrin IX in dioxan. Curve b: Spectrum of the porphyrin-globin corresponding to human hemoglobin A, in phosphate-buffered aqueous solution at *p*H 7. Curve c: The triplet spectrum obtained on laser excitation of the above compounds.