nsec intervals from -5 to $+5$ μsec. No data lying outside of ± 5 μsec were plotted since no 100 nsec intervals outside this range contained more than one point. The central 100-nsec interval contains nine points with an r.m.s. of 35 nsec. Because the probability of noise or lunar surface returns occurring at these rates within a given 100 nsec time interval is so low, it can be concluded with a high degree of confidence that the observed signals within this interval are indeed from the retro-reflector package. The uncertainty of ± 7.5 m in the range obtained on the night of 1 August can therefore be improved to ± 5 m by the results obtained on the night of 3 August.

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2 September 1969

Age of the Bay of Biscay: Evidence from Seismic Profiles and Bottom Samples

Abstract. *Paleomagnetic data and marine magnetic surveys suggest that the Bay of Biscay was created by rifting due to an anticlockwise rotation of the Iberian peninsula. The period during which movement occurred is not known precisely, but a rotation, amounting to 22 degrees, appears to have taken place in post-Eocene time. To provide independent evidence on the age of the rift, bottom samples from the Biscay abyssal plain have been related to the distribution of seismic reflectors within the sediments. The investigation shows that a large part of the Bay of Biscay was in existence in late Cretaceous times and that the data can be interpreted in terms of some early Tertiary rotation. However, the amount of possible Tertiary opening is appreciably less than the paleomagnetic results suggest. In view of the fact that reflectors of Middle-Upper Miocene age can be traced as undisturbed horizons across the bay, all tectonic movements must have ceased by the early Miocene.*

The hypothesis, put forward by Wegener (*1*) and others, that the Bay of Biscay formed as a result of an anticlockwise rotation of the Iberian peninsula relative to the rest of Europe has recently received some support from paleomagnetic studies (*2–5*) and from the fanlike pattern of linear magnetic anomalies between the French and Spanish continental slopes (*6*). Girdler (*2*) found a consistent difference of 38° (± 16°) in the declinations in rocks of Permian, Triassic, and early Jurassic age from north and south of the Pyrenees, which can be accounted for by a 40° rotation of Iberia in late Mesozoic and Tertiary time about a point near 44°N, 1°W. According to bathymetric charts, this same amount of movement is necessary to open up the Bay of Biscay, if the 500-fathom (900-m) contour is taken as the boundary between ocean and continent. There is some area of overlap in fitting northern Spain against France in the eastern part of the bay, but this is probably due to outbuilding of the French continental slope by thick accumulations of sediment deposited during the Tertiary (*7*).

The paleomagnetic data of Van Dongen (*3*) and Van der Voo (*4*) based on measurements made in Spain indicate a similar amount of rotation. The former, working with rocks from the eastern Pyrenees, proposed a 30° rotation after Permian time, whereas the latter, using observations from the Meseta, advocated a post-Triassic movement. Watkins and Richardson (*5*) have examined some late Eocene volcanic rocks near Lisbon and have suggested that the Bay of Biscay was partially open during the Eocene and that a 22° rotation occurred sometime later in the Tertiary.

In view of these conclusions, particularly those of Watkins and Richardson which imply that the bay is of fairly recent origin, it seems appropriate to consider some results of a study of the stratigraphy of the sediments of the abyssal plain which forms the floor of much of the Bay of Biscay. We have examined the relation of some cores and dredge samples to several hundred kilometers of seismic reflection profiles, recorded with an air-gun profiler (*8*), in order to determine the age of various parts of the abyssal plain sediments and thus to provide some independent evidence on the age of the Bay of Biscay. The positions of the seismic lines are indicated in Fig. 1. Figure 2 shows the locations and ages of bottom samples, both published (*9–11*) and unpublished (*12, 13*), from the plain and continental slope.

The reflection records indicate that the sediments of the abyssal plain are well stratified and that they are probably composed of many turbidite layers interbedded with finer-grained material, an assumption strongly supported by the core data and by the pronounced leveling effect of sedimentation close to small seamounts (Fig. 3). We have divided the sequence into three units which can be recognized over a wide area. The uppermost section (the upper turbidites) is about 300 m thick and is made up of many closely spaced reflectors. The middle "homogeneous zone" is approximately 200 m thick and generally lacks strong reflectors in the frequency range in which the recordings were made (60 to 150 cycles per second); this suggests that the sediments are more lithologically uniform than those above and below. The lowest formation (the lower turbidites) is primarily composed of several closely spaced strong reflectors.

A reflector marking the top of a succession of stratified sediments clearly older and distinct from the lower turbidites is found in the area of two small seamounts named Gascony and Cantabria (Fig. 1), features which appear to be made up of gently folded sediments, faulted in places. Figure 3 shows this horizon (labeled reflector 1) beneath the southern flank of Cantabria Seamount. Unfortunately, it can only be followed for a short distance under the abyssal plain since it soon becomes covered by thick, highly reflective turbidites that appreciably reduce penetration. A similar horizon occurs under Gascony Seamount, which we believe is reflector 1, since it is a smooth interface and exhibits well-developed stratification below. It also gives strong echoes and lies beneath the lower turbidites (site 2 profile, Fig. 3). The only interface older than reflector 1 and its associated layered sediments reported from this area is a rough "basement" surface, probably volcanic, 1 km beneath reflector 1 under the northern slope of Gascony Seamount, which has been found on deeply penetrating recordings made with the French Flexotir seismic profiling system (*14*). We have detected this "basement" reflector only near the edge of the abyssal plain, west of 9°W, on the *C-9* profile in Fig. 1.

Examination of all the air-gun recordings indicates that in small areas of the Bay of Biscay it is possible to sample most of the succession described above with conventional corers or dredges, since different parts of the sedimentary sequence occur close to the sea floor as a result of erosion or mild structural movements, or both. Figure 3 shows short sections where reflectors normally found deep within the sediments lie at or very near the sea bottom.

Site 1 is situated in Theta Gap where the Biscay and Iberian abyssal plains join. The connection is made by a system of narrow channels which have been cut (*10*, *15*) by turbidity currents as they accelerated and became erosive in falling about 200 m from the Biscay into the Iberian plain. Blocks of indurated ooze obtained in a dredge haul at site 1 by Laughton and others in 1960 have been dated as Middle to Upper Miocene in age (*10*). Since the channel cuts deeply into the upper turbidites, at least part of this succession must be of Miocene age.

At site 2 the lower turbidites have been brought to the sea floor by mild anticlinal warping and erosion on the southern slope of Gascony Seamount. Two strong reflectors in the lower turbidites produce well-defined topographic benches, one of which was sampled with a gravity corer. Unfortunately, the core was short (1.7 m) and failed to penetrate a Quaternary pelagic cover (*13*).

Details of a core and some dredge samples from site 3 on Cantabria Seamount have been described by Jones and Funnell (*11*). A gravity corer brought up samples of an indurated Upper Cretaceous (Maestrichtian) coccolith ooze from the level at which reflector 1 outcrops. Evidently, reflector 1 records an important change in the sedimentary regime in the Bay of Biscay at or very close to the boundary between the Mesozoic and the Tertiary.

Using the bottom samples in conjunction with the reflection profiles, we can reach some limited conclusions about the history of the Bay of Biscay. The upper turbidites on every seismic profile appear to be structurally undisturbed and can be traced from near the base of the continental slope off

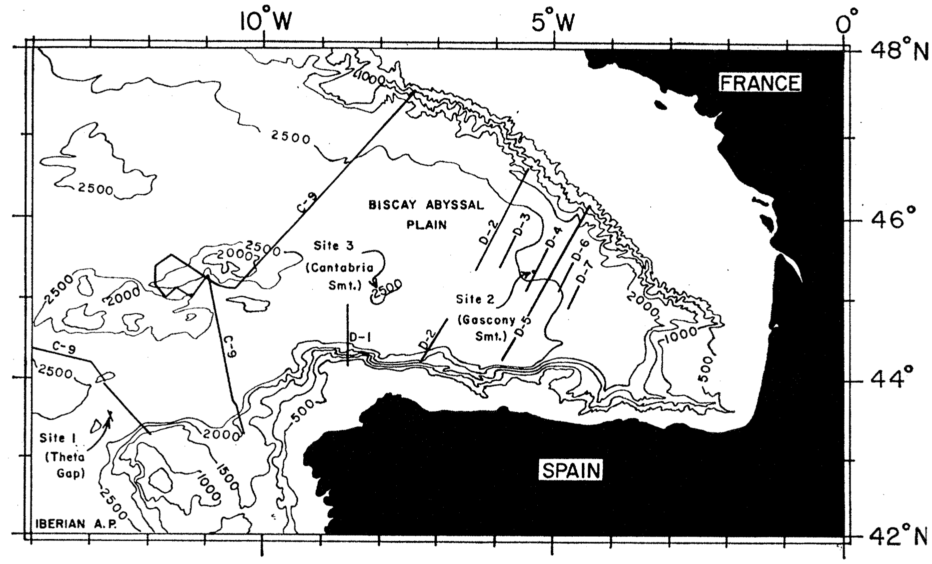

Fig. 1. Positions of air-gun reflection profiles recorded from R.V. *Robert D. Conrad* in 1965 (line *C-9*) and R.R.S. *Discovery* in 1966 (lines *D-1* to *D-7*) shown on a National Institute of Oceanography (Great Britain) bathymetric chart of the Bay of Biscay. Contour values are in fathoms. The locations of bottom sampling sites are indicated.

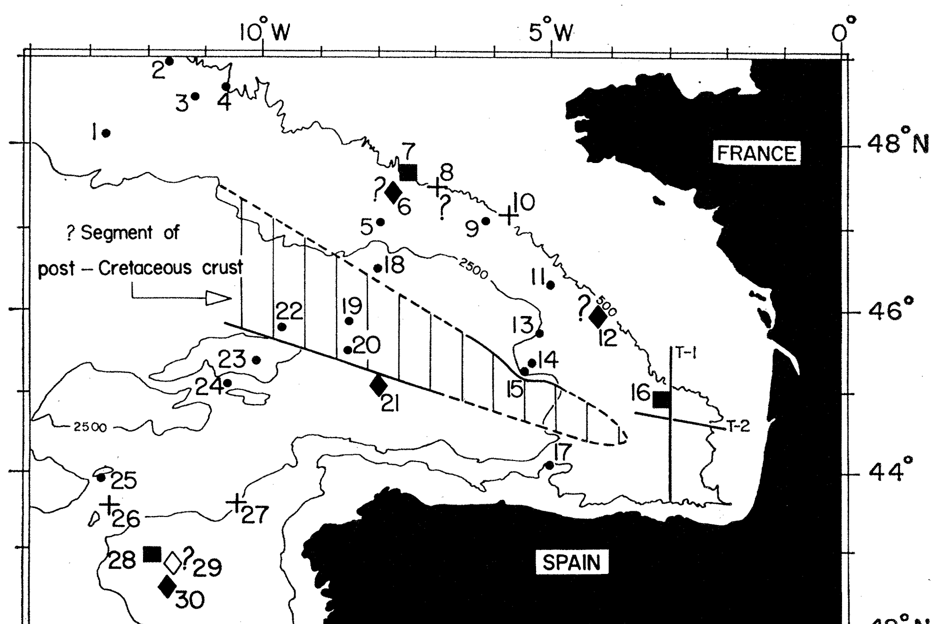

Fig. 2. Locations of bottom samples. Ages are denoted as follows: Quaternary (filled circles); Miocene (crosses); Paleocene or Eocene (filled squares); Upper Cretaceous (filled diamonds); and Lower Cretaceous (open diamond). Reflection profiles recorded by Damotte *et al.* (*14*) are shown along tracks *T-1* and *T-2*.

northern Spain to the bottom of the continental slope off western France. The implication is that the Bay of Biscay was fully opened by the Middle or Upper Miocene and has remained free from tectonic activity since that time. Except for the mild folding that formed Gascony Seamount, which involved the lower, but not the upper, turbidites, there must also have been a long period of quiescence before the influx of the upper turbidites because the available profiles indicate that the lower turbidites are also undistorted over a wide area of the bay. As we failed to acquire a sample of the latter at site 2, we have, at present, no precise knowledge of the length of this period.

That at least part of the bay was in existence in late Cretaceous time is indicated by the presence of reflector 1 in the vicinity of Cantabria and Gascony seamounts. However, we are unable to follow reflector 1 across the entire Bay of Biscay, for it is apparently absent in a segment of the abyssal plain about 12° wide between these two fea-

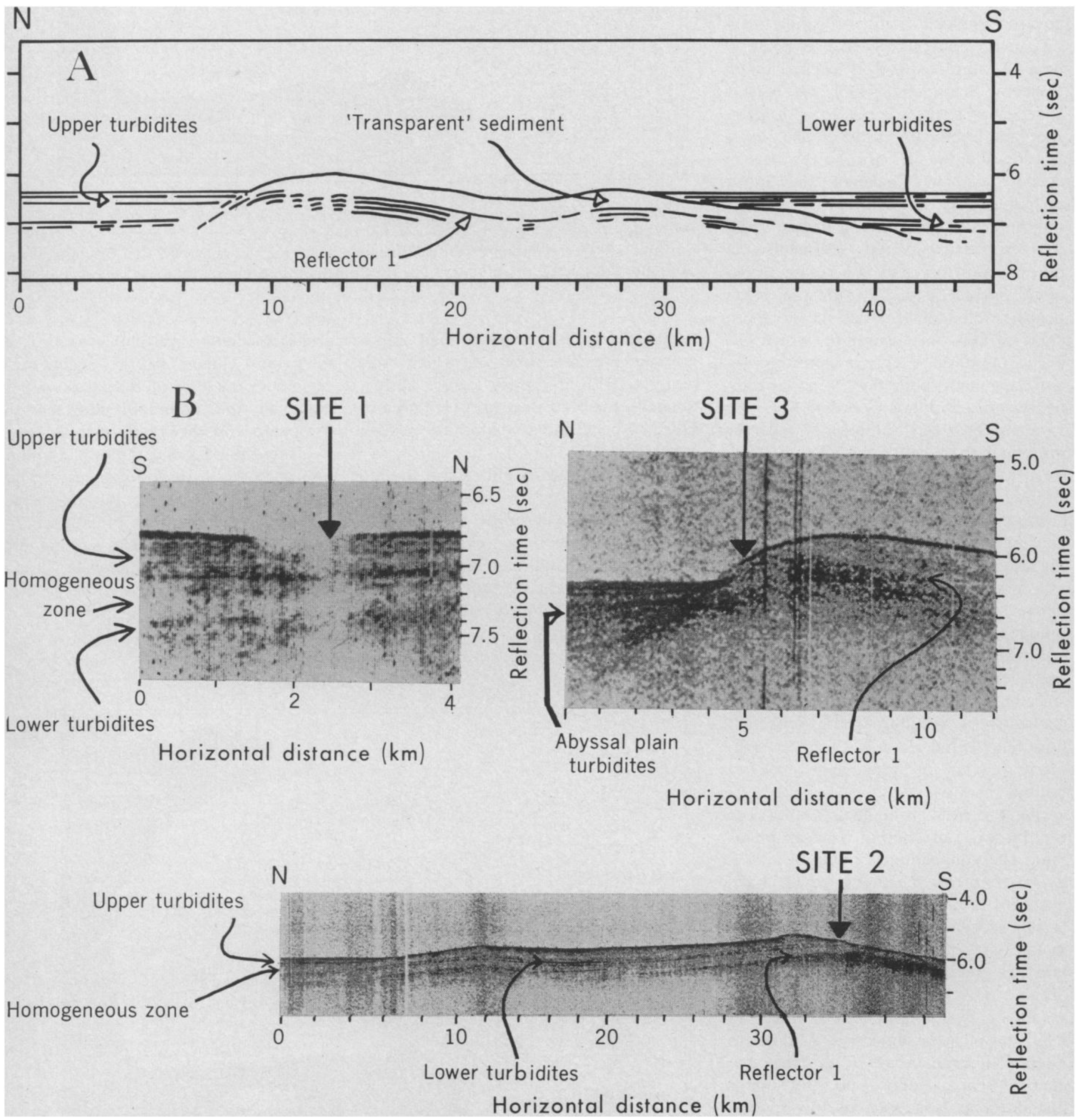

Fig. 3. (A) Line drawing of a seismic profile across Cantabria Seamount from 45°10′N, 7°47′W to 44°50′N, 8°00′W, showing folding and faulting in the layered sediments below reflector 1. The undistorted turbidites of the abyssal plain come to rest unconformably on "transparent" sediment covering reflector 1 on the southern slope. (B) Outcrops of reflectors normally found below the floor of the abyssal plain. Site 1 is in Theta Gap at 43°32′N, 12°37′W. The resolution of reflectors within the channel is poor because of scattering of sound by uneven topography. The deepest part of the channel lies at 7.0 to 7.1 seconds of reflection time. Site 2 is located at 45°20.5′N, 5°21.0′W on the southern slope of Gascony Seamount (profile *D-4*). Site 3 occurs at 45°04.5′N, 8°00.1′W on the northern slope of Cantabria Seamount.

tures. In Fig. 2 this area is shown shaded and terminates at 4°W because Damotte *et al.* (*14*) cite evidence from Flexotir profiles along the tracks shown farther to the east that the continental slope is underlain by reflectors of Cretaceous and possibly Jurassic age. The absence of the Cretaceous reflector 1 on air-gun profiles from the 12° zone can be explained in two ways. It may not be present because that part of the crust is younger than Cretaceous. A second, equally plausible, explanation is that Cretaceous sediments were deposited there but are now too deeply buried by the highly reflecting Tertiary sediments to be detectable by the profiling system. Both interpretations conflict with the data of Watkins and Richardson. The latter precludes any Tertiary opening. The former allows only half the amount of rotation suggested by the paleomagnetic data (*5*). According to present information, the hypothesis of a post-Eocene but pre-Middle to Upper Miocene 12° rotation cannot be discarded. It is necessary to establish whether reflector 1 can be followed from the known Cretaceous outcrop at 45°04.5′N, 8°00.1′W across the 12° zone to Gascony Seamount with a seismic profiler capable of recording the total succession of the abyssal plain. However, there is no evidence for thinning of the sediments in the shaded segment in Fig. 2, which is inconsistent with a more recent age for that area. Indeed, the *C-9* profile reveals the thickest section observed on the air-gun records, showing at least 300 m of sediments below the lower turbidites. The remarkably constant depth of the lower turbidites (7.0 to 7.2 seconds of total reflection time) across the plain from the foot of the Spanish continental slope to Gascony Seamount also suggests that there is no major structural discontinuity along the southern edge of the 12° zone.

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Freezing Tolerance in an Adult Insect

Abstract. *The adult carabid beetle* Pterostichus brevicornis *tolerates freezing under natural conditions. Laboratory tests confirm that winter beetles tolerate temperatures below −35°C, whereas summer beetles die if frozen at −6.6°C. Winter beetles can be cooled to about −10°C before freezing, and they thaw near −3.5°C. Summer beetles thaw at −0.7°C. To avoid freezing damage even in winter beetles, cooling rates must be near 20°C per hour or less.*

Of the multicellular animals that survive freezing, insects provide some of the most striking and best documented examples. However, freezing tolerance in insects has been thought to be almost exclusively confined to the immature forms. In fact, Asahina has stated that "in adult insects . . . bodily freezing always results in fatal injury, even at high subzero temperatures . . ." (*1*).

In the winter of 1966–67 several species of adult ground beetles (Carabidae) were found overwintering in large numbers in partially decayed tree stumps in the vicinity of Fairbanks, Alaska (65°N). When warmed to room temperature, the beetles soon became active and appeared to function in a normal, coordinated manner. Since the adult beetles were apparently surviving exposure at subzero temperatures, a series of studies was initiated to investigate the lower limits of lethal temperature, susceptibility to freezing damage, supercooling points, and whole body thawing points. In addition to these characteristics, the water content of the whole body was determined. *Pterostichus brevicornis* proved to be the most common species and the work reported here pertains to this beetle.

To determine possible seasonal changes, beetles were collected at intervals during the year. Specimens were tested within a few days to a week after collection. Initial work indicated that *P. brevicornis* collected in the winter underwent rapid changes in temperature tolerance and body chemistry when warmed to any temperature above freezing. Because of this fact, until the beetles were tested, they were stored at temperatures close to the average environmental situation at time of collection.

Determination of lower lethal temperature took into account the effect of variable cooling rate, final temperature reached, and time at final temperature. Various warming rates were tried in the initial studies (*2*).

Temperatures were measured with a fine (36 gauge) copper-constantan thermocouple affixed to the dorsal abdomen with a small bit of wax. Specimens were cooled or warmed in insulated vials in a regulated (± 0.3°C) bath. Water contents were determined during the year on representative specimens by drying to constant weight at 90° or 100°C. Studies of temperature and snow cover were also made to determine exposure in the natural situation.

The criteria for survival of lower lethal temperature tests were as follows: the specimen, when warmed to room temperature (23°C), must be capable of directed, coordinated activity such as walking, feeding, and avoidance response, and no paralysis or erratic behavior must be evident. These criteria had to be met for at least 4 days after testing for survival to be judged complete.

Results of cooling tests on beetles from different seasons are given in Table 1. Supercooling points decreased with the onset of cold weather in October and remained near −10°C during the coldest months (December,