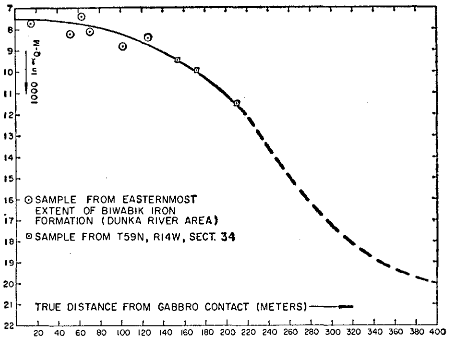

Fig. 1. Relation of oxygen isotope fractionation between quartz and magnetite to true distance (*2*) from Duluth gabbro contact.

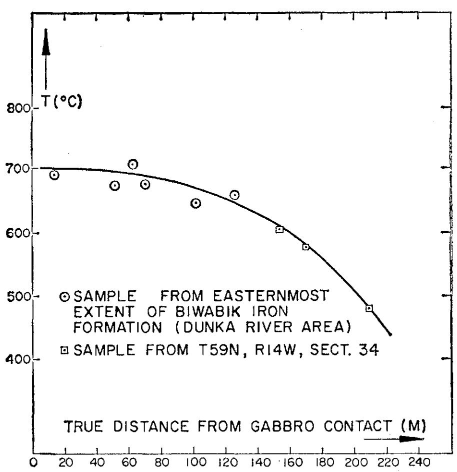

Fig. 2. Relation between temperature (inferred from reference *3*) and true distance from the Duluth gabbro contact (*2*).

to both prograde and retrograde metamorphism are observable in the most highly metamorphosed iron formation. This suggests that isotopic equilibrium was approached within a given small system at the temperature maximum for that system. The magnitude of the retrograde gradient suggests that, near the contact, measured oxygen isotopic fractionations between quartz and magnetite may be about one unit too high to correspond to maximum temperatures of metamorphism (*9*).

Table 1 lists oxygen isotope data from a reconnaissance study of the eastern part of the Biwabik iron formation. There is an abrupt change in oxygen isotope fractionation between 2 and 3 km from the contact. This may be compared to the rapid series of mineralogical changes reported by French (*10*) in the same distance interval.

Because the metamorphic aureole produced by the Duluth gabbro is quite narrow, it is possible to observe significant systematic variations in fractionation within the cores of drill holes which extend through the gabbro into the underlying iron formation or which are located so close to the basal gabbro contact that this contact can be accurately projected. Data from these cores are given in Table 2. In Fig. 2, 1000 ln α_{Q-M} is plotted versus true distance of the sample from the gabbro (*2*).

Two things may be noted about Fig. 2. First, the gabbro contact intercept of the quartz-magnetite fractionation is 7.5, which corresponds to an experimentally measured temperature of approximately 700°C (*3*). Arbitrarily subtracting 1.0 for retrograde metamorphism would increase this temperature to about 750°C. This is a rather high contact temperature (*11*) and it lies in the most accurately determined portion of the experimental system. Also, $d \ln \alpha_{Q-M}/dD$ is small near the gabbro contact intercept and becomes larger at some distance from the intercept. Fig. 2 shows that a temperature-distance plot with temperatures taken from O'Neil and Clayton (*2*) would have the same shape. These curves are convex in the opposite sense to that predicted for the intrusion and cooling of a simple tabular body (*11*). Such a shape and contact temperature might result from the periodic addition of heat to the system over an interval of time rather than in a single brief episode.

Our work suggests that quartz-magnetite fractionation can yield valuable information about the physical conditions under which metamorphic rocks formed, even though retrograde effects are by no means negligible. If the anomalous shape of Fig. 2 results from repeated addition of heat to the system, a direct comparison between Jaegers' model (*11*) and Fig. 2 of the distance at which the temperature has dropped to half its contact value should result in a maximum estimate of the thickness of the marginal portion of the Duluth gabbro complex. Such an estimate gives a value on the order of 500 meters.

E. C. PERRY, JR.
BILL BONNICHSEN
Department of Geology and Geophysics, University of Minnesota, Minneapolis

References and Notes

1. F. F. Grout, and T. M. Broderick, *Minn. Geol. Surv. Bull.* No. 17 (1919); J. W. Gruner, "The mineralogy and geology of the taconites and iron ores of the Mesabi Range, Minnesota," *Iron Range Res. Rehabilitation,* 1946 (Minnesota Geological Survey, Minneapolis, 1946); D. A. White, *Minn. Geol. Surv. Bull.* No. 38 (1954); J. N. Gundersen and G. M. Schwartz, *Minn. Geol. Surv. Bull.* No. 43 (1962).
2. True distance is used to mean perpendicular distance from the sample to the plane of the gabbro contact.
3. J. R. O'Neil, and R. N. Clayton in *Isotopic and Cosmic Chemistry* (North-Holland, Amsterdam, 1964).
4. B. M. French, *Science* **146**, 917 (1964); thesis, Johns Hopkins University.
5. H. L. James and R. N. Clayton in *Petrologic Studies, Buddington Volume,* A. E. J. Engel, H. L. James, B. F. Leonard, Eds. (Geological Society of America, New York, 1962), pp. 217–233.
6. R. N. Clayton and T. K. Mayeda, *Geochim. Cosmochim. Acta* **27**, 43 (1963).
7. C. R. McKinney, J. A. McCrea, S. Epstein, H. A. Allen, H. C. Urey, *Rev. Sci. Instr.* **21**, 724 (1950).
8. E. C. Perry and B. Bonnichsen, Abstr. in *Trans. Amer. Geophys. Union* **47**, 212 (1966).
9. We have expressed fractionation as 1000 $\ln\alpha_{Q-M}$ where $\alpha_{Q-M} = (O^{18}/O^{16})_Q/(O^{18}/O^{16})_M \simeq \delta_Q - \delta_M$. The quantity δ is defined as

$$\left(\frac{(O^{18}/O^{16})_{\text{sample}}}{(O^{18}/O^{16})_{\text{standard}}} - 1\right)(1000).$$

The standard for this study is standard mean ocean water [H. Craig, *Science* **133**, 1833 (1961)].
10. French (*4*, fig. 79 in thesis). Our sample control is not adequate to give accurate quartz-magnetite isotope fractionations corresponding to French's tightly spaced isograds. Tentative values are: (i) appearance of ferrohypersthene and of crystalline graphite, 10; (ii) appearance of hedenbergite, 15; (iii) appearance of grunerite, 18.
11. J. C. Jaeger, *Amer. J. Sci.* **255**, 306 (1957).
12. Support from NSF grants GP 366, GP 2861, and GP 5071. H. L. James suggested the problem. Erna Beiser made most of the mass spectrometric determinations.

9 May 1966

Shallow Structure of the Straits of Florida

Abstract. *Continuous seismic profiles of the Straits of Florida indicate that north of 26°30'N the trough was formed mainly by sediment upbuilding along the margins. South of this latitude the straits may be due in part to faulting.*

The Florida peninsula is located on the eastern margin of a broad submarine platform known as the Florida Plateau (*1*). To the east and south of the Florida Plateau is the Straits of Florida, an arcuate trough 700 km long and 90 to 145 km wide (Fig. 1). Depths along the axis of the Straits of Florida range from 2200 m south of Dry Tortugas to 740 m west of Little Bahama Bank.

Structural and erosional origins have been postulated for the Straits of Florida and the other troughs in the Florida-Bahama region. Agassiz (*1*) suggested that submarine erosion by the Gulf Stream was responsible for the formation of the Straits of Florida. Hess (*2*) interpreted the troughs in the Bahamas as drowned river valleys and the banks between the troughs as having been formed by upgrowth of reefs

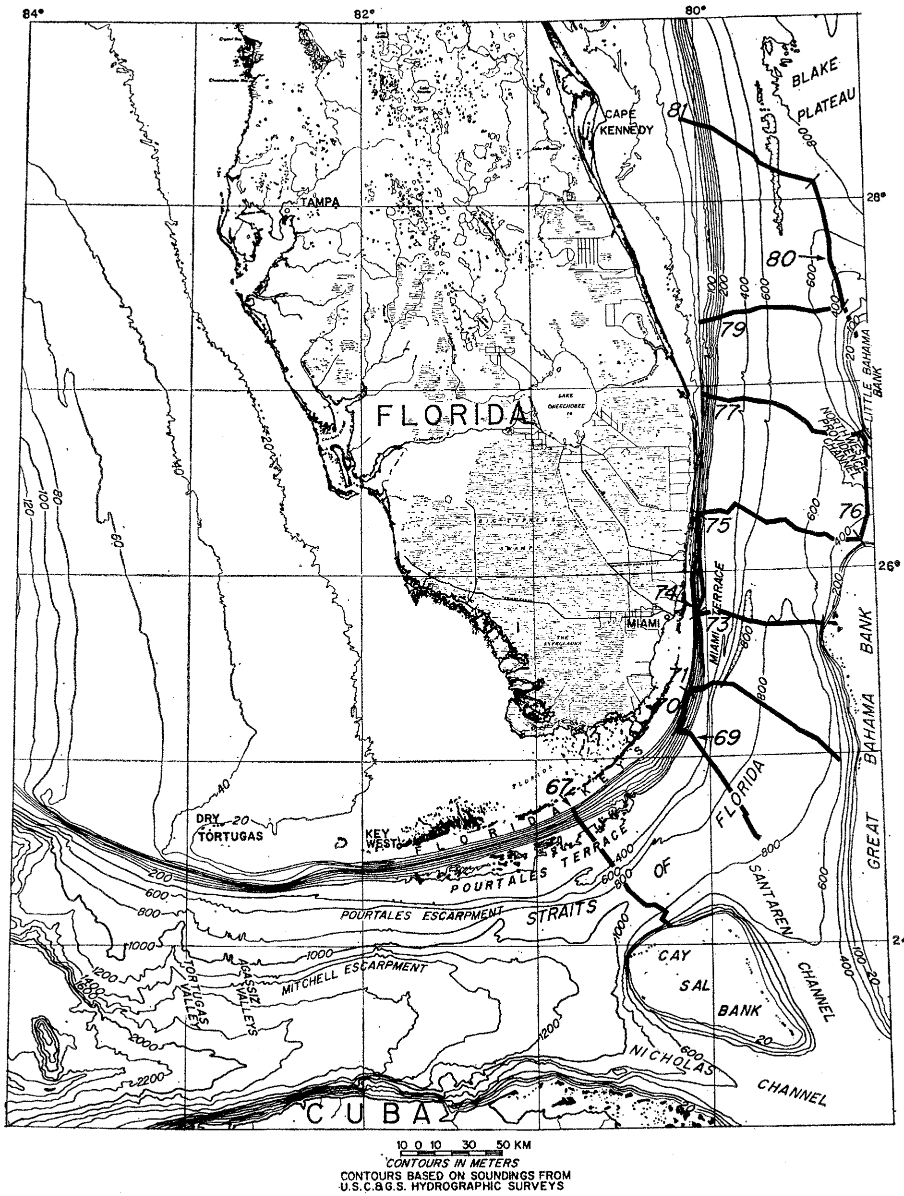

Fig. 1. Bathymetric chart of the Straits of Florida showing the location of the seismic profiles illustrated in Fig. 2. Base map from Uchupi (*14*).

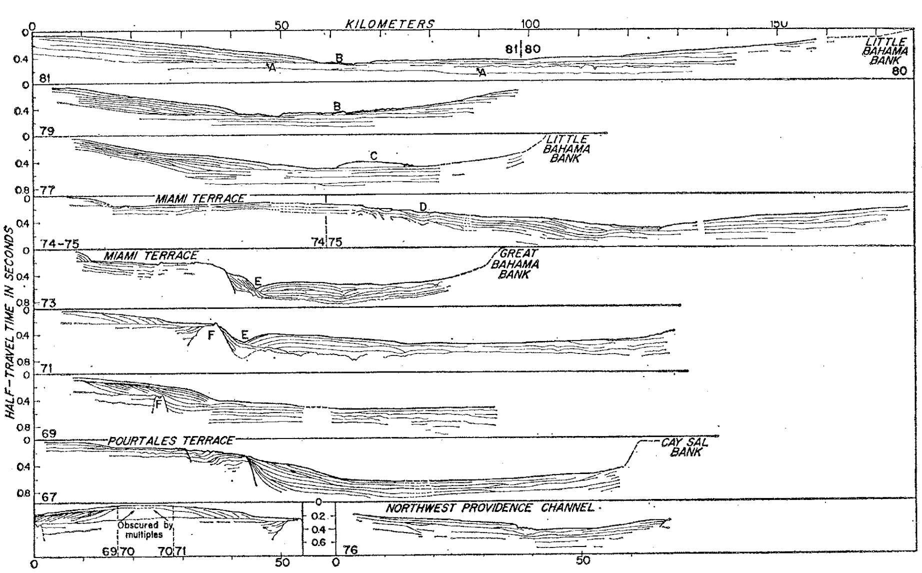

Fig. 2. Continuous seismic profiles across the Straits of Florida. The profiles have a vertical exaggeration of 10 ×. Areas marked by letters *A* to *F* indicate the special features described in the text. For location of profiles see Fig. 1.

along the valley sides and deposition behind the reefs. Newell (*3*) suggested that the banks were formed by carbonate deposition on a subsiding basement, and that the troughs represent areas of less active deposition. Pressler (*4*), Sheridan *et al.* (*5*), and Talwani *et al.* (*6*) stated that faulting may have played a significant role in the formation of the Bahama troughs and the Straits of Florida. Jordan, Malloy, and Kofoed (*7*), Kofoed and Jordan (*8*), and Kofoed and Malloy (*9*) ascribed some of the topographic features on the western and northern sides of the Straits of Florida to faulting.

Approximately 1000 km of continuous seismic lines were recorded in the Straits of Florida with a precision graphic recorder; a 10,500-joule sparker was used as a sound source for determining the shallow structure of the Straits. Reflections from the bottom and sub-bottoms were received by a five-hydrophone array towed behind the ship. The sections shown in Fig. 2 were drawn from the original recordings obtained in the field.

Profiles 80 and 81 extend from near the northwestern edge of Little Bahama Bank to Cape Kennedy (Figs. 1 and 2). The structures shown by these profiles are depositional in origin and were formed by upbuilding and progradation in a seaward direction. Progradation and upbuilding from the mainland and Little Bahama Bank are essentially equal. Data from other profiles farther north and from the JOIDES (Joint Oceanographic Institutions Deep Earth Sampling Program) borings (*10*) suggest that the irregular reflector that ranges in depth from 0.30 second on the northwest to 0.60 second on the southwest (*A*, profiles 80 and 81) may mark the top of the Cretaceous strata. If this assumption is correct, profiles 80 and 81 show a maximum upbuilding of 1 km (if the velocity of sound is 2 km/sec in the sediments), and a progradation of about 50 km from the mainland and 100 km from Little Bahama Bank during the Cenozoic. Progradation toward the center of the Straits of Florida appears to have extended to the present edge of the Gulf Stream.

It is possible that the irregular surface of the reflector marking the top of the Cretaceous strata may be due to erosion by the Gulf Stream. If so, in the past the stream was wider than it is at present. The small mounds (*B*, profiles 80 and 81) may represent coral mounds, because sediments from this zone contain appreciable quantities of coral fragments.

Prograding and upbuilding, similar to that illustrated by profiles 80 and 81, can also be seen in profiles 79 and 77. The isolated mounds west of Little Bahama Bank (*B*, profile 79) may be coral mounds, but this has not been verified by sampling. The sediment rise, midway along profile 77 (*C*), is the tip of the northwesterly trending slope off Great Bahama Bank. Profile 76 in Northwest Providence Channel, between Little and Great Bahama Banks, indicates that the present slopes of the channel were formed by sediments prograding toward its axis. The other profiles (74 and 75, 73, 71, 69, 67) show a terrace in various stages of burial. In profiles 74 and 75, and 73, the sediments have partially buried the terrace along its western edge. Extensions of stratigraphic data from wells near Miami (*11*) suggest that the core of this terrace, known as Miami Terrace, may consist of shallow water Suwanee limestone (Oligocene strata) or the Hawthorn formation of Lower Miocene age. Along profiles 75 and 74 (*D*) sediments have completely buried the slope flanking the terrace on its seaward side. In this profile, deposition from the Bahamas side of the Straits of Florida is as great as that from Florida.

Farther south (see profiles 73 and 71), the slope flanking Miami Terrace on the east is covered by a thin veneer of sediments and is separated from a broad sedimentary ridge to the east by a narrow depression (*E*, 73 and 71). This sedimentary ridge, between the 800-m contours, extends to latitude 26°N where it grades into the western side slope of the Straits of Florida (Fig. 1). It appears to have been formed by sediment progradation in a southward direction with some outbuilding to the east and west. Profiles 73 and 71 clearly show that the depression west of the ridge is non-depositional in origin, not erosional as suggested by Kofoed and Malloy (*9*).

Along profile 71, Miami Terrace consists of a prominent ridge on the east (*F*) without any internal reflectors, and a filled trough to the west. Due to its high reflectivity, and from considerations of the regional geology, Rona and Clay (*12*) suggested that the ridge consists of limestone; possibly it is a coral reef. The filled basin west of the ridge is partially capped by sediments prograding toward the ridge. In profile 69 both the inner basin and the ridge are buried under a thick sedimentary prism. South of the Florida Keys (profile 67), the terrace (Pourtales Terrace) is again exposed. Irregularities on the surface of this terrace appear to be due to folding and faulting. There is also some indication of drag folding along the slope, flanking the terrace on its seaward side. This slope is covered by a thick mantle of sediments, most of which appears to have been deposited from the mainland side of the Straits of Florida.

Dredge samples (*9, 13*) suggest that country rock, forming the foundation of this terrace (as of the Miami Terrace), may be the shallow-water limestones of the Hawthorn formation of Lower Miocene age. Profiles 69, 70, and 71 clearly show that Pourtales and Miami Terraces were once continuous, but became separated recently by the emplacement of a large volume of sediments southwest of Miami. Kofoed and Malloy (*9*) suggested that the Miami Terrace was downdropped in relation to the Pourtales Terrace. Evidence cited by them for the existence of a fault is the north-south linearity of the bottom contours southwest of Miami (Fig. 1). Seismic profiles across the location of this proposed fault (profiles 69, 70, 71) reveal no indication of faulting. On the contrary, the surface of the terrace can be traced across the location of the fault zone without any disruption.

Although stratigraphic well data are available from both sides of the Straits of Florida, the wells are too far apart to allow one to attempt to decipher the structure of the straits solely on well data. Consequently, the following speculations on the origin of the straits are based on the seismic profiles. These profiles show that north of 26°30′N the Straits of Florida appear to be the result of differential upbuilding along the margins. No evidence of the fault postulated by Sheridan *et al.* (*5*) has been found in this area. Instead, the lower elevation in the center of the trough may be related to a decrease in sedimentation beneath the Gulf Stream. In contrast, faulting may have played a role in molding the Straits of Florida south of 26°30′N. The steepness of the slopes flanking Miami and Pourtales terraces along their seaward sides, and the presence of drag folds along the slope south of Pourtales Terrace suggest that these features may be fault-line scarps. If faulting produced the slopes flanking the terraces, it probably occurred in Miocene or post-Miocene time, as the cores of both terraces consist of Lower Miocene limestones. It is tentatively suggested that the Straits of Florida were formed on a subsiding basement and that the formation was accompanied by upbuilding along the margins, with sedimentation toward the center restricted by the Gulf Stream.

ELAZAR UCHUPI
Woods Hole Oceanographic Institution, Woods Hole, Massachusetts

References and Notes

1. A. Agassiz, *Bull. Museum Comp. Zool.* **14**, 1 (1888).
2. H. H. Hess, *The Navy-Princeton Gravity Expedition* (U.S. Hydrographic Office, Washington, 1932).
3. N. D. Newell, *Geol. Soc. Amer. Spec. Papers* **62**, 303 (1955).
4. E. D. Pressler, *Bull. Amer. Ass. Petrol. Geol.* **31**, 1851 (1947).
5. R. E. Sheridan, C. L. Drake, J. E. Nafe, J. Hennion, *Geol. Soc. Amer. Spec. Papers* **82**, 183 (1955).
6. M. Talwani, J. L. Worzel, M. Ewing, *Trans. Caribbean Geol. Conf. 2nd*, 156 (1959).
7. G. F. Jordan, R. J. Malloy, J. W. Kofoed, *Marine Geol.* **1**, 259 (1964).
8. J. W. Kofoed and G. F. Jordan, *Southeastern Geol.* **5**, 69 (1964).
9. J. W. Kofoed and R. J. Malloy, *ibid.* **6**, 159 (1965).
10. E. Uchupi and K. O. Emery, *Bull. Amer. Ass. Petrol. Geol.*, in press.
11. H. S. Puri and R. O. Vernon, *Fla. Geol. Survey Spec. Publ.* **5**, 6 (1964).
12. P. A. Rona and C. S. Clay, *Bull. Geol. Soc. Amer.* **77**, 31 (1966).
13. J. Bush, *Bull. Amer. Ass. Petrol. Geol.* **35**, 102 (1951); D. S. Gorsline and D. B. Milligan, *Deep-Sea Res.* **10**, 259 (1963).
14. E. Uchupi, *Miscellaneous Geological Investigation Map I 475* (U.S. Geological Survey, Washington, D.C.), in press.
15. Contribution No. 1782 of the Woods Hole Oceanographic Institution.

17 May 1966

Nucleotide Sequence of a Yeast Tyrosine Transfer RNA

Abtract. *The nucleotide sequence of a tyrosine transfer ribonucleic acid is described and compared to the known sequence of an alanine transfer RNA. It is possible to construct very similar base-paired models for the two molecules in spite of only limited similarities in sequences. The evidence indicates that the sequence containing guanosine, pseudouridine, and adenosine in the middle of the polynucleotide chain is the anticodon.*

The determination of the structure of alanine tRNA of yeast (*1*) proved that present techniques are adequate to define the sequence of an RNA molecule the size of tRNA. Since the description of the nucleotide sequence of alanine tRNA left a number of questions unanswered about the relation of