References and Notes

1. H. H. Hyman, *Science* **145**, 773 (1964); H. Selig, in *Halogen Chemistry*, V. Gutmann, Ed. (Academic Press, New York, 1967), p. 403.
2. P. A. Agron, C. K. Johnson, H. A. Levy, *Inorg. Nucl. Chem. Lett.* **1**, 145 (1965).
3. S. G. Malm, F. Schreiner, D. W. Osborne, *ibid.*, p. 97.
4. R. D. Burbank and S. S. De Bala, in preparation.
5. We use the term "bridging" in the sense of an electrostatic interaction stronger than a van der Waals contact.
6. R. J. Gillespie and R. S. Nyholm, *Quart. Rev. London* **11**, 339 (1957); R. J. Gillespie, *J. Chem. Educ.* **40**, 295 (1963); R. J. Gillespie, in *Noble-Gas Compounds*, H. H. Hyman, Ed. (Univ. of Chicago Press, Chiago, 1963), p. 333; R. J. Gillespie, *Angew. Chem. Int. Ed. Engl.* **6**, 819 (1967).
7. N. Bartlett, F. Einstein, D. F. Stewart, J. Trotter, *J. Chem. Soc.* **1967A**, 1190 (1967).
8. G. R. Jones, R. D. Burbank, N. Bartlett, *Inorg. Chem.*, in press.
9. R. D. Burbank and N. Bartlett, *Chem. Commun.* **1968**, 645 (1968).

9 January 1970

Differential Isotopic Fractionation in Benthic Foraminifera and Paleotemperatures Reassessed

Abstract. *Different species of benthic Foraminifera taken at the same level in an Atlantic core yielded different oxygen isotopic values. It was therefore impossible to deduce paleotemperature values. In addition, pelagic and benthic species showed the same isotopic variations, an indication that pelagic and benthic species reflect only the variation of oxygen-18 composition of the ocean.*

During a cruise of the French research vessel *J. Charcot*, the top of Charcot seamount (45°19′N, 10°31′W), which is at a depth of 2665 m and is 2300 m above the Atlantic abyssal plain, was cored.

The core consists throughout its entire length (0.80 m) of calcareous grayish ooze with about 20 percent clays and heavy minerals. The coarse fraction ($> 80\ \mu m$) is a nearly pure foraminiferal ooze, with pelagic as well as benthic forms. A detailed study of the core has shown that this sediment is Quaternary in age, that it is not reworked, and that the sedimentation rate, obtained by ^{14}C measurements, is about 1.85 cm/1000 years (*1*).

The oxygen isotopic composition of the tests of different foraminiferal species has been studied throughout the core. The pelagic species *Orbulina universa, Globorotalia truncatulinoides,* and *Globorotalia hirsuta*, the benthic species *Planulina wuellestorfi*, a mixture of four species of *Pyrgo* (*myrrhina, depressa, serrata, fisheri*), and a mixture of other calcareous benthic species have been analyzed.

To eliminate the organic matter, the following method proved to be satisfactory (Table 1): (i) grinding the tests; (ii) bathing them for 72 hours in Clorox (sodium hypochlorite) at room temperature; (iii) rinsing four times with deionized water; and (iv) drying at 60°C.

The purified carbonate was then reacted according to McCrea's classical method (*2*). The 8- to 15-mg samples and the 100 percent phosphoric acid were degassed under vacuum for at least 24 hours and were then reacted at 25.2°C in a thermostatic bath while the samples were being continuously shaken. The CO_2 was condensed with liquid nitrogen, released by warming up with a mixture of acetone and Dry Ice, and analyzed with a mass spectrometer, Atlas M 86.

Results are expressed as

$$\delta = \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} \times 1000$$

where R is the isotopic ratio $^{18}O/^{16}O$ or $^{13}C/^{12}C$ and the standard is the Chicago PDB-1 standard. All the correction factors mentioned by Craig (*3*) were applied to the results. The reproducibility of the measurements is better than 0.1 per mil.

The results are shown in Fig. 1. It is immediately apparent that the six curves obtained are almost parallel, a group of three curves for the pelagic Foraminifera and a group of three curves for the benthic Foraminifera.

Oxygen isotopic differences among pelagic Foraminifera have been interpreted by Emiliani (*4*) as reflecting the fact that the diverse pelagic species do not live at the same depth and, therefore, not at the same temperature. Evidence from plankton tows equipped with opening and closing nets supports this conclusion (*5*), but the same explanation cannot apply to the benthic species. If the isotopic composition of foraminiferal tests were affected only by temperature and the oxygen isotopic composition of the water, different species of benthic Foraminifera that lived in the same environment would have the same isotopic composition and only one curve would be obtained all along the core for the benthic forms. We obtained, however, three markedly different curves, and the differences between *Pyrgo* sp. and *Planulina wuellestorfi* reached more than 1 per mil.

The same phenomenon has been observed in another core taken on the outer edge of the Atlantic continental shelf, at a depth of 1040 m, 138.6 miles off the Pointe du Raz (47°47′N, 8°06′W). At a level rich enough in benthic forms to allow measurements on separate species, considerable differences in isotopic composition were observed: *Uvigerina mediterranea*, +4.16 per mil; *Cibicides pseudoungerianus*, + 3.40 per mil; *Quinqueloculina* sp. and *Pyrgo* sp., + 3.24 per mil.

In another core, Shackleton (*8*) mentioned a difference of 1.5 per mil between two benthic forms, but he attributed it to a mixture between two levels.

Tarutani, Clayton, and Mayeda (*7*) have shown that ^{18}O is concentrated in magnesium calcites, relative to pure

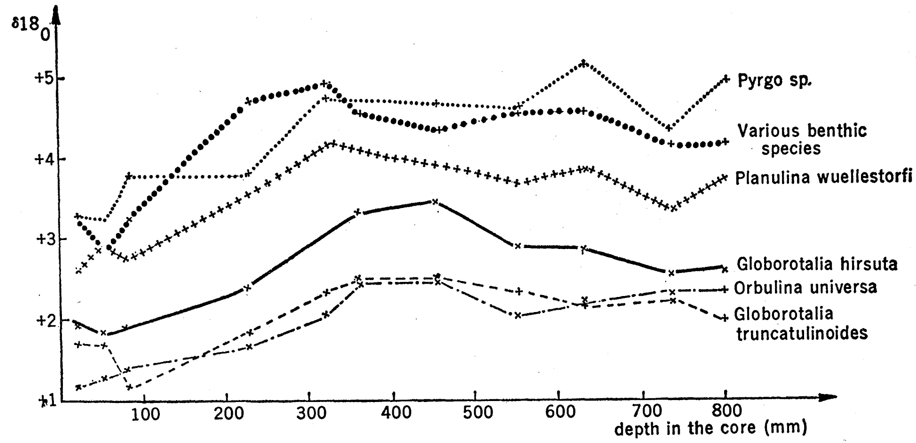

Fig. 1. Variations of $\delta^{18}O$ in three benthic and three pelagic species of Foraminifera in the core.

Table 1. Elimination of organic matter in *Orbulina universa* by Clorox treatment.

Time in Clorox (hours)	*Orbulina universa*			
	Before grinding		After grinding	
	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$
0	+3.44	+2.34		
	+4.65	+2.40		
48	+2.00	+2.43	+1.94	+2.26
	+1.99	+2.45	+1.90	+2.29
72	+1.98	+2.22	+1.89	+2.29
	+1.86	+2.38	+1.92	+2.28
120	+2.02	+2.26	+1.93	+2.33
	+1.87	+2.20	+1.91	+2.14

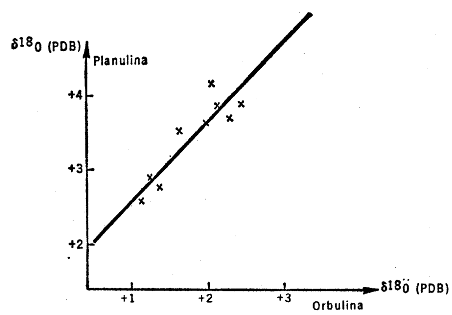

Fig. 2. Correlations between $\delta^{18}O$ for *Planulina* and *Orbulina* in the core.

calcite, when it is precipitated in the same conditions. The ^{18}O content increases 0.06 per mil for each mole percent of $MgCO_3$ in calcite. On the basis of the values given by Tarutani *et al.* (*7*), the isotopic effect might be explained if *Pyrgo* sp. contains 10 to 15 percent more $MgCO_3$ than is contained in *Planulina wuellestorfi*; a similar effect might be obtained for $SrCO_3$.

To determine if the isotopic differences noticed in our benthic Foraminifera were due to differences in chemical composition, we measured the magnesium and strontium content of the foraminiferal shells. The results show that the magnesium and strontium contents of the different species of benthic Foraminifera are of the same order as those of pelagic Foraminifera and that they are insufficient to account for the observed isotopic effect (less than 0.12 percent for $SrCO_3$ and less than 1.1 percent for $MgCO_3$).

From our results and on the assumption that the isotopic composition of seawater is +0.1 per mil for deep Atlantic water (referred to standard mean ocean water), the isotopic temperatures have been calculated. If this assumption is correct, none of the benthic species present in the first 35 mm of the core shows concordance with the environmental temperature, as the true temperature in this region is 2.8° to 3.2°C (*8*) and the calculated isotopic temperatures are 4.2°C for *Pyrgo* sp., 4.4°C for diverse benthic forms, and 6.6°C for *Planulina wuellestorfi*.

The only possible explanation is that the composition of the test is partly due to the biological activity of the animal. Craig (*9*) has shown that the isotopic composition of the carbon of foraminiferal tests does not reflect equilibrium with dissolved carbon but shows utilization of metabolic CO_2.

Assuming that metabolic CO_2 has an isotopic composition similar to that of the organic matter of the plankton, characterized by $\delta^{13}C = -14$ per mil, Craig concludes that 30 percent of the carbon in foraminiferal tests has a biological origin. If so, part of the oxygen could also have a metabolic origin, which would explain the observed small depletion of ^{18}O.

The contribution of metabolic CO_2 apparently varies with the different species, as is shown by the fact that we obtained different curves. The parallelism of the curves (Fig. 1) shows, however, that this contribution is constant for any given species. Apparently, it will be possible to calculate temperatures from the isotopic data only after a very careful study of the biological framework of the foraminiferal tests.

The oxygen isotopic composition of a benthic species (*Planulina wuellestorfi*) and a planktonic species (*Orbulina universa*) at each level of the core is compared in Fig. 2. The excellent correlation ($r = 0.889$) indicates that both benthic and pelagic Foraminifera are sensitive to the same phenomenon, most likely oxygen isotopic variations of the seawater (*6*).

This conclusion is substantiated by the fact that the slope of the regression line (Fig. 2) is very near 1. If the isotopic composition of seawater affects the isotopic composition of benthic as well as pelagic Foraminifera and if, in addition, temperature had an influence on the pelagic species, the slope of the regression line would be less than 1.

We conclude that temperature is not responsible for the variations of the isotopic composition of pelagic foraminiferal tests; instead, the variations of the isotopic composition of oxygen of the ocean are responsible for the variations affecting both the benthic and the planktonic species. As a result, the curves that show the variations of oxygen isotopic composition of foraminiferal tests all along the core give very useful paleoclimatological indications only if interpreted in terms of ice cap melting. Until more information is obtained on the participation of metabolic CO_2, it seems to us to be impossible to make a true correlation between $\delta^{18}O$ and temperature of crystallization of the foraminiferal tests.

JEAN CLAUDE DUPLESSY
CLAUDE LALOU
ANNIE CLAUDE VINOT
Centres des Faibles Radioactivités, Centre National de la Recherche Scientifique, 91 Gif-sur-Yvette, France

References and Notes

1. G. Delibrias, J. C. Duplessy, R. Chesselet, C. Lalou, A. C. Vinot, paper presented before the 8th Congress of the International Quaternary Association, Paris, 1969. Carbon-14 measurements on foraminiferal tests have given the following ages: 0 to 35 mm = 3800 ± 120 years; 65 to 95 mm = 5470 ± 130 years; 210 to 240 mm = 15,000 ± 200 years; 305 to 335 mm = 18,800 ± 500 years; 415 to 435 mm = 26,500 ± 1200 years; 646 to 691 mm = > 35,000 years.
2. J. M. McCrea, *J. Chem. Phys.* **18**, 849 (1950).
3. H. Craig, *Geochim. Cosmochim. Acta* **12**, 133 (1957).
4. C. Emiliani, *Amer. J. Sci.* **252**, 149 (1954).
5. J. I. Jones, *Micropaleontology* **13**, 489 (1967); W. H. Berger, *Deep-Sea Res.* **15**, 31 (1969); *ibid.* **16**, 1 (1969).
6. N. Shackleton, *Nature* **215**, 15 (1967).
7. T. Tarutani, R. N. Clayton, T. K. Mayeda, *Geochim. Cosmochim. Acta* **33**, 987 (1969).
8. P. Tchernia, personal communication; F. C. Fuglister, *Atlantic Ocean Atlas of Temperature and Salinity Profiles and Data from the International Geophysical Year of 1957–1958* (Woods Hole Oceanographic Institution, Woods Hole, Mass., 1960).
9. R. Revelle and R. W. Fairbridge, *Geol. Soc. Amer. Mem. 67* (1957), vol. 1.
10. We thank Y. Le Calvez for help in identifying the foraminiferal species; Jacques Labeyrie for useful discussions of the problem; P. Martineau for help in the preparation of the samples; E. Brichet for the chemical analyses; and Professor Emiliani for his review of our text and his useful suggestions.

13 November 1969; revised 15 January 1970

Toxic Factor Produced by a Granulosis Virus in Armyworm Larva: Effect on Apanteles militaris

Abstract. *The internal parasitoid* Apanteles militaris *is affected by a proteinaceous toxic factor in the hemolymph of granulosis virus–infected armyworm larva. The hemolymph, after centrifugation to remove the virus particles and inoculation into the larval hemocoel, is still toxic to the parasitoids.*

Tanada and Hukuhara (*1*) separated the two strains of a granulosis virus of the armyworm *Pseudaletia unipuncta* (Haworth) (Lepidoptera: Noctuidae) on the basis of differences in synergistic property and virus particle size. The synergistic virus strain