Coiling Direction of Globigerina pachyderma as a Climatic Index

Abstract. An interdependence between the geographical distribution of dextral and sinistral populations of the planktonic foraminifer, *Globigerina pachyderma,* and sea surface-temperatures is demonstrated. It is inferred that changes in dominant coiling direction at lower levels in sediment cores from the North Atlantic record southward shifts of isotherms during the last ice age.

Variation in coiling direction of planktonic foraminifera has been studied by Bolli (*1*), by Vašíček (*2*), and by Ericson, Wollin, and Wollin (3). Vašíček (*2*) and Nagappa (*4*) have utilized their findings on this subject in making stratigraphic correlations between various oil wells. Ericson, Wollin, and Wollin have charted the geographical distribution of populations of *Globorotalia truncatulinoides* (d'Orbigny) in top samples from sediment cores taken in the North Atlantic Ocean. From evidence that the pattern of distribution of these populations has persisted for some thousands of years, probably since the end of the last ice age, they infer that there must be something about the local environment which works to the advantage of those individuals which coil in the preferred direction. However, just what this selective condition of the environment may be is far from clear from the pattern of distribution of *G. truncatulinoides.*

In the case of *Globigerina pachyderma* (Ehrenberg), on the other hand, an interdependence between surface water temperature and coiling direction is evident from Fig. 1, which shows percentages of right and left coiling in top samples from sediment cores taken in the Arctic Ocean, the North Atlantic Ocean, and connecting seas. The percentages have been determined from counts of at least 100 tests in each sample. The position of 7.2°C isotherm in April (*5*) is also shown.

A similar relationship between coiling and temperature has been found in the South Atlantic Ocean. Although not enough samples have been studied to define a boundary line, it is apparent that left coiling is strongly dominant in samples from the vicinity of Antarctica and south of latitude 50°S, while right coiling is dominant in samples from points farther north.

To conceive of any mechanism by which temperature could act selectively upon coiling direction is difficult, to say the least.

The explanation may be, as suggested by Ericson, Wollin, and Wollin (*3*), that the advantage enjoyed by individuals having the preferred coiling direction is not due to a direct reaction between the geometry of the tests and the environment, but rather to genetical linkage between coiling direction and some other characteristic of the animal which, in the case of *Globigerina pachyderma,* determines temperature tolerance.

Coiling ratios in samples from lower levels in the cores show that left coiling has been strongly dominant from top to bottom of all cores taken within the present province of left coiling, and that in cores from the right-coiling province there have been several reversals in the dominant direction. In short, during late Pleistocene time the boundary between the provinces of right and left coiling was never much farther north than it is now, but at other times it was a good deal farther south. Changes in the ratio of coiling directions in a typical core, R9-7, from the right-coiling province are shown graphically in Fig. 1, together with a curve of climatic change inferred from variation in abundance of all other species of planktonic foraminifera in samples taken at 10-cm intervals. The record suggests that there has been a relatively recent shift of isotherms to the north and that the immediately preceding time of cold climate was, in turn, preceded by a rather short interval, recorded at 50 and 60 cm in core R9-7, during which the April 7.2°C isotherm was at or near its present position.

In general, the distribution of other species of planktonic foraminifera in the cores is in harmony with the supposition that the changes in coiling of *Globigerina pachyderma* are influenced by temperature. For example, no species of *Globorotalia* occur at any level in cores taken in the Norwegian, Greenland, and Arctic seas, and these species are poorly represented in top samples of cores from more

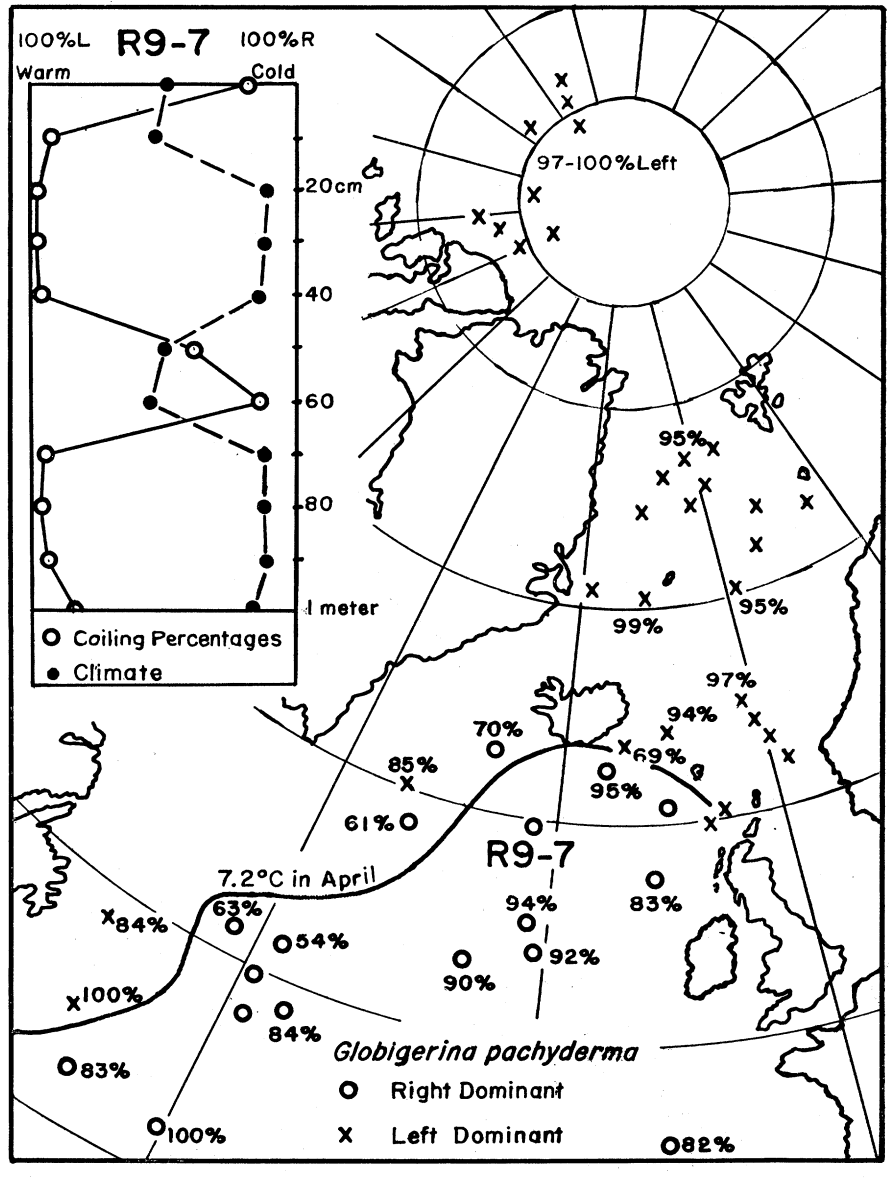

Fig. 1. Distribution of dextral and sinistral populations of the foraminifer, *Globigerina pachyderma,* in top samples of sediment cores and the position of the 7.2°C surface temperature isotherm in April.

southerly stations within the province of left coiling. They are abundant, however, in the tops of cores from the province of dextral coiling. The same association is maintained in the time dimension of cores from the province of dextral coiling; species of *Globorotalia* are well represented in sediments layers where the coiling of *Globigerina pachyderma* is dominantly dextral, but they are absent or rare where the coiling is sinistral.

By determining similar vertical changes in coiling percentages of *G. pachyderma* in cores from more southerly stations not shown on the chart it will probably be possible to determine approximately the former position of the boundary between right and left dominant populations, and by inference the most southerly position of the April 7.2°C isotherm during the peak of the last glaciation. This information will make possible an estimation of the amount of temperature lowering that occurred in this part of the North Atlantic during the last ice age.

In the meantime, the present data are at least suggestive. The absence of any zone of right coiling at lower levels in the cores from the province of left coiling implies that this part of the North Atlantic during the late Pleistocene has not at any time been much warmer than it is now. Evidence that the boundary between right- and left-coiling populations was farther south during the last ice age favors the conclusion that continental glaciation was accompanied by general cooling of North Atlantic waters, and particularly within this critical region, rather than by marked change in pattern of circulation. This conclusion supports the hypothesis that Pleistocene refrigeration was a result of reduction in total radiation from the sun and not a consequence of some purely terrestrial cause (*6*).

DAVID B. ERICSON
Lamont Geological Observatory, Columbia University, Palisades, New York

References and Notes

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6. This report is Lamont Geological Observatory contribution No. 355. The investigation is being supported by National Science Foundation grant No. NSF-G6540. I am grateful to Maurice Ewing, director of the Lamont Geological Observatory, who made available the material described in this communication. O. L. Bandy, University of Southern California, has informed me that he has a paper in press which also deals with the coiling of *Globigerina pachyderma*. According to Bandy our respective papers will supplement rather than duplicate each other.

9 April 1959

Virus versus Gene Change in Maize

In maize the *Rrr* kernels from a standard RR♂ × rr♀ (*R*, self-colored aleurone; *r*, colorless aleurone) are dark-colored. However, Brink (*1*) has found that when plants of genotype RR^{st} (R^{st}, stippled aleurone) are test-crossed on *rr*♀, the resulting kernels which receive *R* (from their RR^{st} parent) have aleurone which is weakly-colored mottled. We might indicate these kernels as *R′rr*; the prime indicates *R* of RR^{st} origin, without commitment whether *R′* is different from *R*.

Brink explains the weakly-colored mottled phenotype of *R′rr* kernels on the assumption that in the RR^{st} parent the R^{st} gene causes *R* to mutate, at a 100-percent rate, to a gene ($R^{r:st}$) for weakly-colored mottling (an effect referred to by Brink as "paramutagenesis"). The R^{st} gene itself is apparently unaffected in RR^{st}. When weakly-colored mottled kernels (*R′rr*) from the test cross of the RR^{st} parent are again test-crossed, the resulting *R′rr* kernels are again weakly-mottled. Brink has therefore concluded that *R* is actually altered in the original RR^{st} parent, since the test-cross progeny (*R′rr*) maintain their light color from one generation to the next. On the other hand, when RR^{st} is self-fertilized, the resulting kernels which have at least two doses of *R′* in their aleurone ($R'R'R^{st}$ or $R'R'R$; $R^{r:st}R^{r:st}R^{st}$ or $R^{r:st}R^{r:st}R^{r:st}$, according to Brink's hypothesis), have aleurone almost as dark as that of standard *RR* plants. Brink has therefore concluded that in the kernels under discussion, his $R^{r:st}$ gene reverts, at a 100-percent rate, almost completely to *R*.

In order to rule out the theory that a virus (or other plasmid element) is causing the changed expression in the *R′rr* kernels, Brink crossed the plants grown from these kernels to standard *RR*♂. The resulting *Rrr* kernels would, of course, be the product of an *R* gamete from the *RR* parent and an *r* gamete from the *R′rr* parent. If the latter (*R′rr*) carried a virus, its *r* gametes might also be expected to carry the virus and to transmit it to the *Rrr* kernels in the cross *R′rr*♀ × *RR*♂. However, these kernels are dark, like *Rrr* of standard origin. Brink has therefore concluded that no virus is involved in the changed expression in *R′rr* kernels (weakly-colored mottled).

However, in my opinion this finding relative to the cross *R′rr*♀ × *RR*♂ does not exclude the possibility that a virus is changing the aleurone from dark red to light in the *R′rr* kernels (those derived from RR^{st}♂ × *rr*♀). Conceivably, two substances, *A* and *B*, are necessary for the continued existence of the virus. Gene R^{st} produces both and supports the virus; *R* produces *A* but not *B*; *r* produces *B* but not *A*. Moreover, we must assume that the virus rapidly disappears in a cell which lacks *A* but that it may live for a longer time in a cell which lacks *B* but has *A*, or may even linger on for several generations, largely in an inactive state, in plants which have only *A*. The virus therefore could not be transmitted by the *r* gametes of a plant that grew from an *R′rr* kernel, but it could be transmitted by the *R′* gametes. If the latter fertilized an *rr*♀ (giving *R′rr* kernels), gene *R* would supply the *A* element and *r*, the *B*. The virus would therefore persist, and the kernels would be light (instead of dark, as they would be in the absence of the virus).

Until further tests, involving properly marked chromosomes have been made, it might be well to suspend judgment on the significance of Brink's RR^{st} case in maize (*2*).

EDGAR ALTENBURG
Rice Institute, Houston, Texas

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2. This study was supported by a grant (C-2393) from the National Institutes of Health, U.S. Public Health Service.

26 March 1959

Reflectivity Spectrum and Optical Constants of Bituminous Coal; Estimation of Aromaticity

Abstract. The spectra of reflectivities, refractive indices, and absorption indices of a bituminous coal vitrain have been determined for the ultraviolet-visible spectral region. The low values for these quantities support the premise that polynuclear condensed aromatics may be present in coal only in small amounts. Aliphatic and amorphous carbons may predominate.

The spectra of specular reflectivities have been determined in the ultraviolet-visible region for Bruceton coal vitrain (*1*), which is 84 percent carbon. Previously, the absorption spectrum in this

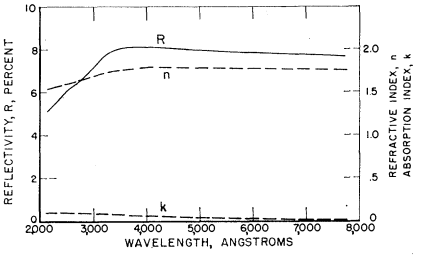

Fig. 1. Ultraviolet-visible spectrum of specular reflectivity and the optical constants, n and k; Bruceton vitrain.