Temperatures of Pacific Bottom Waters and Polar Superficial Waters during the Tertiary*

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GEOLOGICAL and paleontological studies of different kinds by various authors have shown quite conclusively that the temperature at the earth's surface in the middle and high latitudes decreased considerably during most of the Tertiary.

The best evidence is paleobotanical, because plants are particularly sensitive to climatic variations, but the successive fossil faunas show the same trend. Although local factors of geographic significance may occasionally produce disturbances, the true picture is quite evident if the available observations are considered and interpreted globally.

Quite understandably, most authors refrain from giving actual figures in degrees centigrade for climatic variations of the past, although this has been done in some cases. Even when actual figures are not published, however, it is often possible to infer them from the published evidence.

The regions that have been best studied from the paleoclimatic point of view are, undoubtedly, North America and Europe. A decrease of about 12°C from Eocene to Pliocene for the coast of California is implied by Smith (*1*). A similar figure is reached by Durham (*2*) for approximately the same region. The decrease of temperature seems to have been rather continuous in this area. Knowlton (*3*), Ruedemann (*4*), and Chaney (*5*) also conclude in favor of a more or less continuous decrease of temperature during all or most of the Tertiary throughout North America.

In western Europe, the decrease of temperature from the Middle Eocene to the Lower Pliocene seems to have been smaller than in North America. The Eocene London Clay has been assigned a mean temperature of 21°C (*6*); the Oligocene Molasse of Switzerland, 20°C (*7*); the Swiss Miocene, about 19°C (*7*); and the German Pliocene floras, about 15°C (*8*).

It seems, therefore, that temperature changed less during the Lower Tertiary and Miocene in western Europe than in North America. However, a somewhat larger decrease of temperature in western Europe during the Tertiary is suggested by Theobald (*9*). The polar seas are believed to have been free of ice in nonglacial times, and a temperature of 5 to 6°C is assigned to the Arctic Sea by Brooks (*10*).

Evidence in support of these views was published recently (*11*). Benthonic Foraminifera of Middle Oligocene age contained in a deep-sea core raised by the Swedish Deep-Sea Expedition of 1947–48 in the eastern equatorial Pacific (*12*) showed an average temperature of 10.4 ± 0.5°C. This result was obtained by the method of oxygen isotopic analysis, based on the temperature coefficient of the equilibrium constant for oxygen isotopic exchange between water and calcium carbonate (*13, 14*). More recently, samples of benthonic Foraminifera of Lower-Middle Miocene and Uppermost Pliocene age from two other cores collected in the same area were treated by the same method. The pertinent data and the results are shown in Table 1.

The age of core 53 is well established as Middle Oligocene because of the presence of typical specimens of *Cassidulina spinifera* Cushman and Jarvis in all samples examined. The age of core 57 is established as Lower-Middle Miocene because of the presence of *Gyroidina zelandica* Finlay, together with *Laticarinina bullbrooki* Cushman and Todd, in the samples that have been analyzed. Oligocene and Miocene sediments were available for coring because submarine erosion

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Table 1. Samples data and temperature values.

Core No.	Location	Depth of the sea bottom (m)	Age of foraminiferal sample	Temp (°C)
58	6°44′N 129°28′W	4440	Uppermost Pliocene	2.2 ± 0.5
57	8°25′N 128°48′W	4607	Lower-Middle Miocene	7.0 ± 0.5
53	15°34′N 127°11′W	4725	Middle Oligocene	10.4 ± 0.5

or slumping had previously eliminated the younger sediments (*15*). The Pliocene sample was obtained from the lower part of core 58 (509 to 513 cm below the top of the core), some 110 cm below the beginning of the Pleistocene. It is, therefore, to be considered of Uppermost Pliocene age.

In Fig. 1, the temperature results have been plotted against a time scale proposed by Holmes (*16*). The Oligocene and Miocene data are represented by a cross, the horizontal segment of which represents the age uncertainty, while the vertical segment represents the experimental error of the temperature determinations (±0.5°C, corresponding to ±3 standard deviations). The temperature value at time 0 is the present bottom temperature in the vicinity of core 58, obtained from Schott (*17*).

A progressive temperature decrease during the Tertiary is quite evident from Fig. 1, although it was probably more complicated than the few points available would suggest.

The possibility exists that the observed temperature decrease may have been produced by increase of the thickness of the water layer. This could have been brought about in two ways: by regional subsidence or by a rise of the water surface. However, all known cases of subsidence in the Pacific basin appear to be strictly local phenomena connected with volcanic intrusions and extrusions, and subsequent isostatic adjustments (*18, 19*). Most of this evidence comes from the western part of the north Pacific (*18*), but some also comes from the eastern part (*19*). None, however, comes from the area where the cores were raised. On the other hand, all that is known about the Pacific basin indicates that most of it is an area of great stability and has been such for a long time. Therefore, subsidence on a regional scale, such as would be needed here, can be excluded with confidence.

A rise of the water surface over all oceanic areas may have been produced by the great Alpine orogenesis, which transformed into land vast areas previously occupied by the sea. However, the volume of the water so displaced would have been some order of magnitude too small to produce the observed temperature variations. Further evidence against both theories is the good correlation between temperature variations in the area here considered and in North America and Europe.

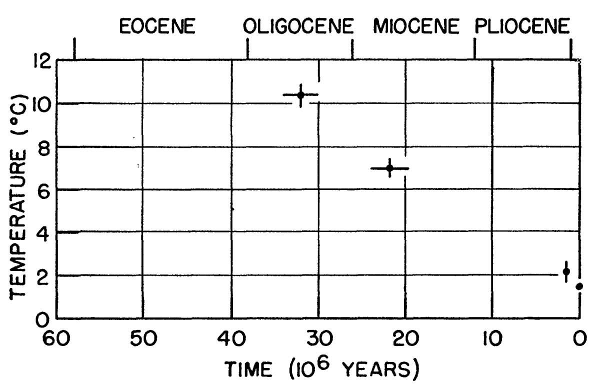

Fig. 1. Temperature change of Pacific abyssal waters during the Tertiary.

The temperature of abyssal waters in the open oceanic basins at all latitudes is conditioned by the temperature of surface waters in the polar areas. It cannot be either lower or appreciably higher, apart from possible adiabatic effects. This uniformity is maintained by superficial water masses that sink to the bottom in the high latitudes and flow toward the lower latitudes as deep currents.

Today, the formation of bottom water is somewhat obstructed by the low salinity of the surface waters at high latitudes, and it takes place only when surface temperature and salinity combine in such a way as to produce water masses of particularly high density (*20*). During the Tertiary, however, the surface salinity of the polar water was certainly much closer to the average than it is now, and the formation of bottom water was easier in spite of the higher temperatures. Therefore, the temperatures of surface polar waters and abyssal waters of open oceanic basins were maintained at close values by the same mechanism now operating, and the temperature data shown in Table 1 are a good estimate of the surface temperatures in the polar areas at the times indicated.

Clearly inadmissible is the reversal in deep-sea circulation in nonglacial times suggested by Chamberlin (*21*), with formation of bottom water at low latitudes and flow of the same toward the poles along the ocean bottom. A temperature difference of only a few degrees centigrade between surface waters in the high and low latitudes would have been sufficient to prevent this phenomenon, even admitting a salinity difference as high as 2 percent.

The circulation of the ocean and atmosphere was probably somewhat different when no ice was present in the polar areas. In the Northern Hemisphere, warm currents reached farther north and, when possible, entered the Arctic basin. In the Southern Hemisphere, the polar water mass was absent or restricted to a narrow belt around Antarctica, and the Antarctic convergence was also absent or considerably displaced southward. Consequently, the temperature gradient along the meridians, in the middle and high latitudes, was much smaller than now, and so were other gradients, such as salinity and isotopic composition.

With regard to the atmospheric circulation, the shallow anticyclones now existing above both polar areas were certainly absent, and the raising wings of the subtropical circulation cells were displaced toward the poles. This again contributed to reduce the climatic differentiation between lower and higher latitudes.

Finally, the bottom water formed in the high latitudes in the absence of ice had an isotopic composition identical or very close to the average, as suggested by Epstein and Mayeda (*22*).

A temperature decrease of some 8°C from the Middle Oligocene to the end of the Pliocene in the deep waters of the equatorial Pacific reflects and emphasizes the general temperature trend during the Tertiary, which resulted in the ice age. The environmental uniformity of the oceanic depths and the thermic inertia of the oceanic mass reduce the possibility of short time, less important temperature variations being recorded and enhance the value of the paleotemperature measurements here presented as a basis for general discussion.

It is unfortunate that more paleotemperature data from the ocean bottom are not available, particularly from the Eocene, Upper Miocene, and Lower Pliocene. The type of material that is needed, however, makes rather remote the probability of securing additional, suitable samples in the near future.

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Contemporary Science and the Poets

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In recent years, the relationships between science and poetry have attracted a considerable quantity of literary criticism. "No poet today," say Levy and Spalding (*1*), ". . . can ignore science. The atmosphere of rational thought that has come with the new knowledge of the physical world, envelops him whether he is conscious of it or not. It is now part of his social heritage, and his poetry draws on it for sustenance." Douglas Bush (*2*, p. 151) makes this sweeping statement: "All modern poetry has been conditioned by science, even those areas that seem farthest removed from it." Dudley (*3*) points out that the science content of a poem may be adulterated but insists that there is a science content.

> No doubt the science in literature is often outdated, distorted or misapprehended, but so great a factor in the pattern of modern life must find imaginative as well as theoretical and technological expression.

Such statements are certainly ego-gratifying for the practicing scientist. Of course, his work has permeated to the heart of modern poetry. Why should not the new biochemical-genetical findings, for example, dominate any poetic myth-making concerned with the durability (or frailty) of man? Generalized theories of gravitation should naturally find their way into poetic metaphor. Is it possible to think about space, about time, without considering these new concepts? We know that the judicious application of certain of the findings of fundamental science has, in the last 50 years, gone far to reshape the way in which our lives are spent. The poets, a human kind of barometer, should be quick and sensitive to register the impact of each fresh discovery, each major theoretical advance. It remains only for the practicing scientist to read the modern poets to discern, mirrored back at him, all of his scientific progress; it should be there, now subtly, now obviously, but there nevertheless.

Another critical view exists, however, that sounds quite different. It is to be sure, a minority view and, one would gather, an unpopular one. J. Isaacs gives it expression (*4*, p. 75):

> I have gone through dozens of volumes and read and re-read hundreds of poems hoping to confirm the belief to which I have referred, that scientific imagery permeates modern poetry, that the poets have been forced by modern science to alter their modes of feeling and expression. Alas! it just isn't true.

So great a divergence of opinion between literary critics about a matter involving science makes it of interest to examine at least some of the poets cited by both groups to determine, if possible, just how the situation strikes a practicing scientist. It may be that modern poetry is influenced to a far-reaching extent by modern science. It may also be that there is no modern science in the works of modern poets, or perhaps the actual situation is somewhat between these two extremes.

At the outset, it might prove of value to state, from the point of view of a scientist, what is not meant by the modern science content of modern poetry. Pos-