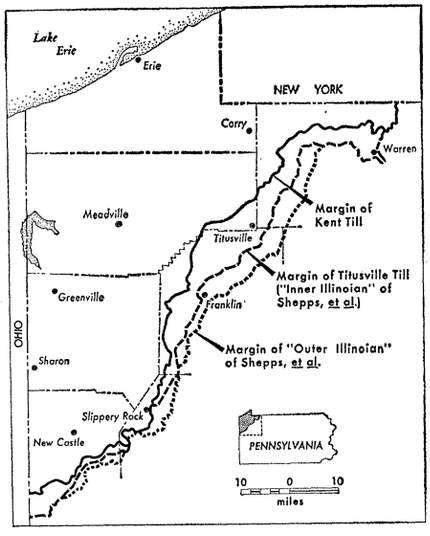

Fig. 1. Glacial boundaries in northwestern Pennsylvania (*2*); 1 mile = 1.6 km.

corded in detail (*5*). The Titusville Till is the surface material between the eastern boundary of that till and the boundary of the Kent Till (Fig. 1). It is overlain by the Kent Till west of the Kent margin. The Titusville Till is usually underlain by sand or gravel ranging from a fraction of an inch to 15 feet in thickness, which in turn lies upon bedrock or upon till of an as yet unknown age.

The Titusville Till is correlated with the Mogadore Till (*6*) of the Akron, Ohio, region and with the Millbrook Till (*7*) of the Killbuck glacial lobe. Its age corresponds almost exactly with that of till previously called "Illinoian" near Lake Geneva, Wisconsin, reported by Black as being 31,800 ± 1,200 years old (*8*) and correlated by him as "Farmdale of Shaffer," a till at the surface in NW Illinois (*9*), which has recently been given the rock-stratigraphic name of Winnebago Till (*10*).

The Kent Till, which is considerably younger than the Titusville Till, has a minimum age of 14,000 years on the basis of dating of marl in a kettle hole near Corry, Pennsylvania (*11*) and is probably correlative with Shelbyville or other tills of Tazewell age in Illinois (*10*), or it may be just slightly younger. The Kent Till is considerably younger than the Titusville Till because there was a pre-Kent and post-Titusville episode of weathering. Organic material beneath tills at Otto, New York, about 65 miles northeast of Titusville, are dated at 52,000 and 63,900 years (*12*) and are therefore older than the peat at Titusville. It is tempting to speculate that the lower of the two upper tills at Otto (Muller's unit 7, *12*) may be correlative with the Titusville Till. The Titusville Till is younger than any of the pre-Farmdalian tills so far dated by Dreimanis in southern Ontario (*13*). The Titusville Till is younger than a pre-Farmdalian till of the Scioto glacial lobe at Gahanna, Ohio, which has been dated (*14*) at 46,600 ± 2,200 years. The relation of the Titusville Till to "early Wisconsin" till near Sydney, Ohio, described by Forsyth (*15*) is uncertain. The Titusville Till may be of about the same age as the Fayette drift of southeastern Indiana described by Gooding (*16*).

In terms of the classification proposed by Frye and Willman (*10*) for the Lake Michigan lobe drifts, the Titusville Till is correlative with the Winnebago Till of northern Illinois (formerly called "Farmdale"), which is pre-Shelbyville of the Woodfordian and pre-Farmdalian and late Altonian in age. The Titusville Till is not Illinoian, but provides evidence for a widespread pre-Farmdalian post-Sangamonian glaciation in the Grand River lobe in western Pennsylvania and northwestern Ohio.

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Temperature Dependence of Carbon Isotope Composition in Marine Plankton and Sediments

Abstract. *Samples of marine plankton collected in high-latitude areas of the South Atlantic where surface water temperatures are near 0°C show a carbon-12 enrichment of 6 per mill relative to samples collected where temperatures are about 25°C. The organic carbon in sediments in the Drake Passage and Argentine Basin also shows a carbon-12 enrichment relative to warmer areas.*

Previous studies (*1–4*) of the isotopic composition of the organic carbon in marine organisms included few samples of marine plankton. Since knowledge of the composition of this group is necessary for understanding the variations observed in marine sediments and petroleum, the work described in this paper was undertaken.

Twenty-five samples of plankton were collected from widely different geographical locations (Table 1) with a ½-meter net with a mesh aperture of 202 μ by workers on Vema cruise No. 18 in 1962 and Eltanin cruises No. 12 and No. 13 in 1964. Samples Nos. 11 and 12 were immediately passed through a glass fiber filter and dried. All the others were kept frozen until analyzed. Samples 1–10, 13, and 22, analyzed at Jersey Production Research Company (JPR) were filtered as described. The remaining samples, analyzed in the Geochemistry Laboratory at the Lamont Geological Observatory, were dried at reduced pressure. Most of the samples had a dry weight over 100 mg; the Antarctic samples were about 1 g or more. One of us (A.H.B.) carefully examined parts of these samples and made the estimates listed in the table on the relative amounts, by weight, of phyto- and zooplankton. No land-derived organic debris was detected.

Homogenized portions of the dried organisms were subjected to combus-

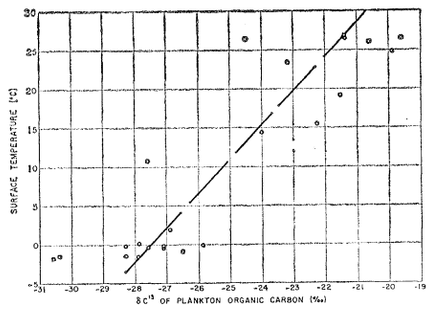

Fig. 1. The isotopic composition of the total organic carbon of marine plankton plotted against the temperature of the surface water at the source of the sample. The curve is the estimated best fit of the points (slope: 0.23 per mill per deg C).

tion (*1*), and the purified CO_2 was analyzed in a Nier-McKinney type mass spectrometer (*5*). The results are reported relative to the Chicago PDB standard in terms of δC^{13}, defined as:

$$\delta C^{13}(\text{in per mill}) = \frac{(C^{13}/C^{12})_{\text{sample}} - (C^{13}/C^{12})_{\text{standard}}}{(C^{13}/C^{12})_{\text{standard}}} \times 1000$$

The compositions of the samples were related to the Chicago PDB standard at JPR through a lub oil (−29.4 per mill vs. PDB) and at Lamont through a sample of powdered charcoal (−24.6 per mill vs. PDB).

The isotopic compositions of the 25 plankton samples show a range of −18 to −31 per mill, considerably beyond the range of −8 to −18 per mill for marine organisms reported by Craig (*1*). The one sample of plankton analyzed in his study had a value of −12.9 per mill. Sackett and Thompson (*3*) report a range of −19.6 to −23.2 per mill for six samples collected in Mississippi Sound and two values of −12.8 and −16.8 per mill for samples from the Gulf of Mexico with appreciable amounts of "near-shore" marine plant forms. Most evidence seems to indicate that a real difference exists between the isotopic organic carbon composition of marine plankton and other marine organisms. The reason for this difference is not yet known.

A correlation between isotopic composition and temperature of the water in which the plankton lived is indicated in Fig. 1. Nine samples collected from water with a temperature of about 25°C have an average composition of −21.7 per mill, whereas 12 samples collected from water of about 0°C have an average composition of −27.9 per mill. The temperature dependence shown by these data is in the same direction and has about the same magnitude as that for isotope exchange equilibrium (*1*) and for kinetic isotope effects (*6*) between carbon compounds.

Within the cold-water group two observations are important. First, plankton samples Nos. 17 through 22, consisting mainly of phytoplankton, are not significantly different from the other samples containing appreciable amounts of zooplankton. This indicates that the relative amounts of phytoplankton and zooplankton do not determine the isotopic compositions of these samples. Second, the benzene extractable fraction is very high, 26 to 51 percent, and is somewhat proportional to the enrichment of C^{12} in each sample. This fraction is a measure of the lipid carbon, generally 5 to 10 per mill enriched in C^{12} relative to the nonlipid carbon in plants (*7*). For Nos. 20 and 25 the isotopic composition of the benzene unextractable fractions were (calculated) −26.9 and −28.2 per mill, respectively, an indication that excessive lipids alone cannot account for the observed C^{12} enrichments. Thus, it appears that this enrichment of C^{12} in cold-water plankton is due to a greater fractionation of carbon isotopes at lower temperatures during photosynthesis, or to some unknown factor, rather than to a species effect or to the lipid content of these organisms.

In Table 2 are given the isotopic organic carbon compositions for the tops of several cores of sediments from the high latitudes of the South Atlantic. Since the contribution of land plants to the areas where these cores were taken is highly improbable, the organic carbon in these sediments pre-

Table 1. Isotopic organic carbon composition of plankton. Z, zooplankton; P, phytoplankton.

Sample No.	Location		Surface temp (°C)	Description*	Organic carbon			
					Total		Benzene extractable	
					Dry wt (%)	δC^{13}†	%	δC^{13}
				Pacific Ocean				
1	6°37′N	88°24′W	26.7	Z(P)		−21.7		
2	10°47′S	138°11′W	26.8	Z(P)		−21.4		
3	14°32′S	150°02′W	26.4	Z(P)		−24.5		
4	39°09′S	157°29′E	14.4			−24.0		
				Atlantic Ocean				
5	28°00′N	68°09′W	26.5	Z(P)		−21.4		
6	27°08′N	68°03′W	23.4	Z(P)		−23.2		
7	26°56′N	68°22′W	24.8	Z(P)		−19.9		
8	22°27′N	82°44′W				−20.6		
9	20°48′N	66°30′W		Z(P)		−23.3		
10	19°33′N	66°30′W	26.2			−23.1		
11	18°28′N	60°00′W	26.0	Z(P)		−20.6		
12	13°48′N	67°37′W	26.5	Z(P)		−19.6		
13	41°42′S	56°35′W	10.7	Z(P)		−27.6		
14	59°23′S	31°16′W	−0.4	Z(P)	35	−27.6	30	
15	59°58′S	46°47′W	−0.1	Z(P)	21	−25.9	26	
16	60°30′S	54°31′W	+0.1	Z+P	34	−27.9		
17	60°34′S	28°37′W	−0.9	P(Z)	22	−26.5	38	
18	60°41′S	34°57′W	−0.6	P(Z)	9	−27.1	31	
19	60°48′S	31°02′W	−1.5	P(Z)	20	−30.4	47	
20	61°07′S	40°08′W	−0.2	P(Z)	11	−28.3	29	−31.7
21	61°40′S	34°59′W	−1.5	P(Z)	14	−28.3	41	
22	61°55′S	62°27′W	+1.8	P(Z)		−26.9		
23	62°00′S	40°48′W	−0.5	Z+P	33	−27.1	38	
24	64°05′S	40°40′W	−1.6	Z+P	33	−27.9	47	
25	64°58′S	52°01′W	−1.8	Z+P	33	−30.6	51	−33.0

* Parentheses around symbols for phytoplankton or zooplankton indicate that they constitute a minor fraction with respect to the zooplankton or phytoplankton, respectively. Z+P indicates approximately equal proportions of each. † δC^{13} values are the averages of duplicate analyses; the standard deviation was 0.2 per mill.

Table 2. Isotopic organic carbon composition of the top of some sediment cores.

Core No.	Location		Water depth (m)	δC^{13} organic carbon (per mill)
	S	W		
	Argentine Basin			
V14–47	50°46′	49°09′	1689	−25.5
V14–51	56°37′	34°48′	3698	−23.3
	Drake Passage			
V15–130	57°51′	60°10′	3477	−26.0
V18–72	60°29′	75°57′	4695	−24.2
V18–81	63°46′	69°49′	3540	−24.7
V18–93	59°29′	64°47′	3834	−24.0

sumably came from the marine organisms thriving in the overlying surface waters. The average value for these sediment samples is −24.6 per mill, an indication that the sedimentary organic carbon in this area is also enriched in C^{12} relative to the organic carbon deposited in warmer areas, δ being about −20 per mill (*3*, *4*). Thus it now appears that the isotopic carbon composition of marine organic sediments can be controlled by two major factors: the amount of terrestrially derived organic carbon, δ being about −27 per mill (*3*), or the amount of cold- or warm-water marine plankton preserved in the sediments, or both.

These plankton isotopic compositions suggest another plausible explanation for the carbon isotope composition of petroleum—average being about δ −28 per mil (*8*). This explanation is that many oils may have been formed with little carbon isotope fractionation from organic carbon of the composition now found in cold Antarctic waters. If some factor other than temperature determines the composition of marine plankton, then perhaps present-day isotopic compositions of cold-water plankton were present in ancient warm seas where most organic carbon sources of petroleum were presumably deposited.

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Polyploidy and Environment in Arctic Alaska

Abstract. *The frequency of polyploidy in the angiosperm flora of the Ogotoruk Creek–Cape Thompson area of northwestern Alaska is correlated with edaphic environmental gradients in the area. These results, when placed in a historical and ecological context, help to clarify the problem of increasing frequency of polyploidy with latitude in the northern hemisphere.*

The observations that the frequency of polyploidy in angiospermous plants increases along a south-to-north latitudinal gradient in Europe (*1*) and that the polyploid members of a euploid complex sometimes occupy environments different from those of their diploid relatives (*2*) have led some workers to claim that polyploidy enables plants to occupy extreme environments. Subsequent investigations (*3*) have not generally supported this conclusion, though some workers maintain (*4*) that the Arctic and sub-Arctic regions are exceptions. The high frequencies of polyploid taxa in these regions have been linked alternatively to the observation (*5*) that polyploids had a marked advantage in colonizing bare ground after the retreat of the Pleistocene ice sheets. With this line of reasoning it is presumed that at more northerly latitudes the initial high frequency of polyploids colonizing the previously glaciated land surface has been largely unaffected by the influx of diploid migrants that have, in later postglacial time, significantly reduced the polyploid frequency in such areas at lower latitudes, the reasons given being an insufficient period of time for migration to occur and the present climatic regime (Reese, *3*).

Both these approaches to the problem of polyploidy and plant distribution require explanations in terms of supposed special genetic attributes in polyploids, but such explanations may provide only partial solutions. Many workers appear to have overlooked the fact that the distribution of polyploids is affected by such things as their time and place of origin, migration routes, past and present climates, location of refugia, and all the other factors (including genetic make-up) that affect plant distribution. The present trend (*6*) of studying the distribution of polyploids within a broader phytogeographical framework should lead to a more complete understanding of the problems.

In 1962, we began cytological studies of the angiosperm flora of the Ogotoruk Creek–Cape Thompson area (68°06′N;165°46′W) of northwestern Alaska. In this report we relate the polyploid frequency of the angiosperm flora to the history and ecology of the area and discuss some of the problems raised above in the light of our data.

The Ogotoruk Creek Valley covers about 110 km^2 of extensive tundra flats and low mountains up to slightly more than 325 m. Mudstone, sandstone, dolomite, limestone, chert, and argillite of Mississippian to Cretaceous age are the most common bedrocks. The area was unglaciated, but unconsolidated Quaternary sediments 6 to 18 m thick cover about 50 percent of the area (*7*).

The climate is typical of the western Arctic; winter temperatures reach −40°C and mean summer maximum temperatures are above 10°C only during July. Precipitation averages about 20 cm, most of it occurring in summer. Snowfall is light and is redistributed into extensive beds of snow by strong winds which average 36 km/hr in the winter. Wind velocities during summer average 22 km/hr (*7*). Permafrost extends to depths over 300 m, and its upper boundary lies close to the soil surface (*7*).

Temperature and precipitation are relatively constant throughout the valley, and plant distribution depends primarily on edaphic factors. Soil texture varies considerably from the lowlands, where fine-grained mineral fractions and organic materials predominate, to the slopes and ridgetops where 20 to 40 percent of the soil mass consists of coarse angular rock fragments (*8*). Other soil characteristics are correlated with the topographic and textural gradients. Soil moisture is high in the lowlands, low on the slopes and uplands (*9*). Permafrost at depths of less than one-half meter maintains low soil temperatures on the valley floor, while on steeper topography, permafrost is deeper (about 2 m) and soil temperatures are higher (*10*). Frost action is correlated with fine-grained soils, low temperatures, and high soil moisture, and is, therefore, most intense in the Quaternary sediments of the valley floor (*8*, *11*). In summary, cold, wet, organic, or fine-grained mineral soils of lowland areas in which permafrost and frost action play important roles