The abundances of various nuclei up to the iron group show a good agreement with their production estimates in explosive nucleosynthesis (*14*). The heavier nuclei can, however, be produced in a variety of processes, *s*, *r*, or *p* processes, from the seed nuclei of the iron group (*15*). The relative abundance of VVH/VH nuclei in some *s* process models, for example, is higher by a factor of 4 as compared to that in *r* process synthesis. Under suitable conditions, nuclei beyond the iron group ($Z \approx 30$) could also be formed in explosive nucleosynthesis or other freeze-out processes that follow nucleosynthesis (*14*). The VVH/VH ratio therefore is a good indicator of the processes dominating the production of VVH nuclei since for the various processes there is a wide variation in the expected VVH/VH ratio. The absence of a wide variation in the VVH/VH ratio in cosmic rays with time therefore suggests that these nuclei are not produced in a variety of processes; rather, the nuclei are probably produced in a single process that yields a VVH/VH ratio of $\approx 1.3 \times 10^{-3}$. It seems remarkable to us that this ratio has remained the same in cosmic rays in the past. This observation indicates that most of the heavy cosmic rays originate in sources of similar heavy element composition and in similar nucleosynthetic processes.

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Kerogen Recycling in the Ross Sea, Antarctica

Abstract. *Analyses of the stable isotopes of the organic carbon and microscopic examination of the sediment particles suggest that up to 90 percent of the organic matter in Ross Sea sediments is derived from the igneous and ancient metamorphic and sedimentary rocks that are being glacially eroded on the Antarctic continent and transported seaward.*

The nondescript, insoluble, organic material found in most sedimentary rocks is defined as kerogen. Kerogen is the major reservoir of organic carbon on the earth's surface, containing over three orders of magnitude more carbon than all the other organic carbon reservoirs combined. The mode of purification used for kerogen testifies to the inertness of the material: the rock is dissolved away from the carbonaceous matter through the use of hydrochloric and hydrofluoric acids (*1*). This chemical and presumably biological inertness suggests that much of the kerogen in ancient sediments that are being weathered and transported to the sea may be redeposited with relatively little alteration. If this is true, then the kerogen and the various elemental and mineralogical constituents found in sediments may represent several weathering and redeposition cycles. For each cycle a new portion of kerogen formed by the maturation of contemporaneous organic matter may be added to the amount already formed in previous cycles. Because of the complex nature of kerogen, it has been difficult to determine whether an incremental accumulation with time has occurred. For Holocene sediments found in temperate and tropical environments the problem has been the masking of the recycling process by the tremendous mass of recently living land-derived organic matter. However, this is not a problem in polar regions where terrestrial ecosystems are practically nonexistent. We report here on a study of the amounts and isotopic composition of the organic carbon in sediments of the Ross Sea, Antarctica, which shows that much of the sedimentary organic carbon is derived from the rocks being eroded by glaciers on the Antarctic continent.

Sediment cores were collected along the edge of the Ross Ice Shelf during cruise 51 of R.V. *Eltanin* in February 1971. At that time, in the middle of the austral summer, the shelf extended to about 78°S. Surrounding the Ross Sea to the southwest extends the Transantarctic Mountain chain composed of a complex mixture of sedimentary, metamorphic, and igneous rocks of Precambrian to Late Cenozoic age. Glaciers spread from many of the valleys of this mountain chain down into the Ross Sea and give rise to the Ross Ice Shelf, the largest feature of its type on the earth's surface.

The primary core used in this study, core 51-18, was taken about 160 km northeast of McMurdo Sound at the edge of the ice shelf. We examined the size fraction greater than 74 μm under a microscope to estimate the relative amounts of the various types of organic and nonorganic derived particles. The widths of the bars in Fig. 1A indicate the relative amounts within one constituent category. These widths are not comparable from category to category. The amounts and stable carbon isotope compositions of the total organic carbon (~ 95 percent kerogen) were determined (*2*) on the size fractions smaller than and larger than 250 μm. These are given in Fig. 1B and Table 1.

Table 1. Comparison of the amounts and stable isotopic compositions of the organic carbon in the fractions of core 51-18 smaller than 250 μm and larger than 250 μm.

Interval (cm)	>250 μm			<250 μm		
	Percentage of fraction	Organic carbon (%)	δ^{13}C organic carbon (per mil)	Percentage of fraction	Organic carbon (%)	δ^{13}C organic carbon (per mil)
0–5	7	0.23	− 24.2	93	0.73	− 27.0
5–10	22			78	0.56	− 26.6
10–15	9	0.12	− 22.9	91	0.61	− 25.8
					0.58*	− 25.9*
					0.23†	− 24.0†
15–20	5	0.24	− 25.1	95	0.50	− 26.2
20–25	5	0.32	− 23.5	95	0.29	− 24.7
25–30	12	0.23	− 22.0	88	0.30	− 23.7
30–35	18	0.14	− 22.5	82	0.29	− 22.6
35–40	20			80	0.33	− 23.9
40–45	10	0.10	− 25.7	90	0.40	− 25.9
45–50	0			100	0.73	− 27.8
50–60	0			100	0.71	− 26.5
60–70	0			100	0.65	− 28.9

* < 149 μm. † 149 to 250 μm.

Three distinct lithofacies can be distinguished in core 51-18 on the basis of the relative abundances of the various terrigenous and pelagic constituents. The lower portion of the core contains a diatom ooze (70 to 45 cm), more specifically a siliceous lutite with very abundant diatoms and sponge spicules and minor amounts of fine sand-size quartz grains. Pelagic sedimentation was predominant during this time interval, with lesser amounts of terrigenous clastics being derived from Antarctica. The interval from 45 to 20 cm is characterized by significant amounts of igneous and metamorphic rock fragments and indurated shale chunks. Most of these clastic particles are of coarse sand size, but a few pebbles are scattered throughout the interval. Coarse quartz sand is abundant, consisting of a mixture of well-rounded to highly angular grains. Dark shards of volcanic glass are a minor constituent. Fossil remains are scarce in this section and consist of a few diatoms, radiolarians, and sponge spicules. This section reflects the rapid deposition of clastic constituents derived from both glacial and fluvial marine origins.

From 20 to 10 cm, the sediments are similar to those immediately below, but there is a reduction in the abundance of large clastic particles, particularly the shale. An increase in the component of pelagic fossil remains (diatoms, radiolarians, and sponge spicules) indicates a reduction of the deposition rate.

The upper 10 cm differ from the rest of the core in the absence of shale fragments and diatoms. The predominant particles are sand-size quartz grains and rock fragments accompanied particularly in the top 5 cm by abundant radiolarians and sponge spicules that reflect the modern environment of the Ross Sea.

The δ^{13}C composition of the organic carbon (kerogen) in low- and middle-latitude marine sediments ranges from greater than −20 per mil for open marine sediments to less than −28 per mil for river and estuarine sediments, the extremes reflecting a composite of the compositions of the plants growing in the particular areas or drainage basins (*3*). High-latitude open marine sediments in the Arctic (*4*) and the Antarctic (*5*, *6*) show considerably lighter δ^{13}C values, averaging about −25 per mil. These light values are presumably due to the increased isotope fractionation that occurs during carbon fixation at low temperatures by phytoplankters indigenous to polar waters (*5*).

For core 51-18, the δ^{13}C values for the kerogen in both fine (< 250 μm) and coarse (> 250 μm) fractions over the five 5-cm intervals from 20 to 45 cm are positive by several per mil relative to present-day values. A major climatic change during that period of time is not a reasonable explanation as the presence of unsupported ^{228}Th (^{228}Th not supported by an equivalent amount of its radioactive parents ^{228}Ra and ^{228}Ac) [half-life, 1.9 years; (radioactivity of ^{228}Th)/(radioactivity of ^{232}TH) = 1.44 ± 0.05] in the 0- to 5-cm interval suggests very rapid sediment deposition with the entire section represented by the core having been deposited during historical times (we assume here that there is no nondetectable discontinuity in sedimentation).

The most plausible explanation is that both coarse and fine fractions for the five 5-cm sections of the 20- to 45-

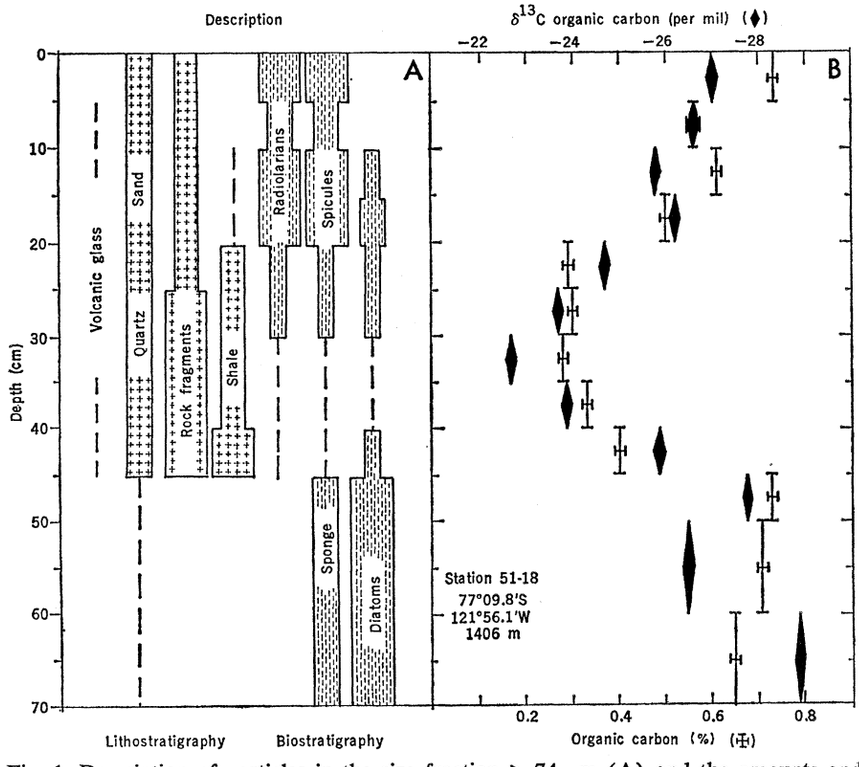

Fig. 1. Description of particles in the size fraction > 74 μm (A) and the amounts and isotopic compositions of carbon in the fraction < 250 μm (B) for various intervals of sediment core 51-18.

cm interval contain appreciable amounts of shale and rock fragments reduced to various particle sizes by the grinding action of glaciers. These components contain isotopically heavy kerogen which must constitute an appreciable fraction of the total kerogen. One may estimate the amount of this contribution by using an expression which relates the percentage of carbon and the $\delta^{13}C$ values of each component and the fraction (F) of recycled material, for example,

$$[(\%C)(\delta^{13}C)]_T = F[(\%C)(\delta^{13}C)]_R \times \{(1-F)[(\%C)(\delta^{13}C)]\}_A$$

where the subscript T refers to the total fine fraction, the subscript R refers to recycled material, and the subscript A refers to authigenic material. Using values of 0.7 percent and -27.2 per mil, respectively, for the amount and isotopic composition of the authigenic material and 0.23 percent and -22.3 per mil, respectively, for average values of the coarse material for the 20- to 35-cm sections, the fine fractions of the 20- to 25-cm, 25- to 30-cm, and 30- to 35-cm intervals contain 85, 86, and 90 percent, respectively, recycled kerogen. These estimates are only approximate as the $\delta^{13}C$ compositions of the coarse fractions are quite variable. It is only because some of the coarse fractions in this core have anomalously heavy isotopic values that the kerogen contribution is recognizable.

Two other cores taken toward the eastern side of the ice shelf have $\delta^{13}C$ values of -25.9 and -26.1 per mil at the top, with an abrupt decrease to a rather constant -24.5 ± 0.5 per mil down the remainder of the cores. Presumably the recycled kerogen in these sediments is not isotopically heavy, or the amounts are relatively small or constant, or both, for each interval.

We believe that the results reported here are important in providing real evidence that kerogen is being recycled. With the development and use of the new and more sophisticated chemical techniques for studying organic matter in marine sediments, it is important for geochemists to recognize early in their investigations that in one sediment sample they may be dealing with several types of kerogen originally produced at different times and in different environments.

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$$\delta^{13}C = \left(\frac{^{13}C/^{12}C_{sample}}{^{13}C/^{12}C_{PDB}} - 1 \right) 1000$$

where PDB is the Pee Dee belemnite standard.
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Earthquake Prediction: Absence of a Precursive Change in Seismic Velocities before a Tremor of Magnitude 3¾

Abstract. *P-wave velocities in the region near the source of a tremor of magnitude 3¾ were constant to within 2 percent for 41 days before the event; no evidence of a precursive change in velocity was found. Observations of* S-*wave velocities and the ratio of* P-*wave to* S-*wave velocities also showed no precursive changes. In recent studies, premonitory changes in body-wave velocities of about 10 percent and having a duration of 2 to 3 weeks have been reported for crustal earthquakes of this size.*

Premonitory changes in the ratio V_P/V_S (P-wave velocity/S-wave velocity) have been reported for earthquakes in the Garm region of central Asia (*1*), the Adirondack region of New York State (*2*), and southern California (*3*). Typically V_P/V_S is reported to diminish by about 10 percent below its usual value for a certain length of time and then reattain its normal value shortly before an unusually large earthquake. Whitcomb *et al.* (*3*) reported that V_P/V_S diminishes primarily because of a diminution of about 10 percent in V_P.

On 27 March 1973 at 00:48 G.M.T. an unusually large tremor, of magnitude 3¾ (*4*), occurred in the eastern section of East Rand Proprietary Mines (ERPM), 24 km east of Johannesburg, South Africa. The hypocenter of the event was located by using an underground array of ten geophones (*5*) and was found to be about 3 km below the surface and about 150 m above the edge of a mined-out area; the event occurred near the margin of the underground seismic array, and the uncertainty in the hypocentral location is about 100 m. This tremor caused extensive damage underground within a radius of more than 1 km (*6*) and was felt throughout the general Johannesburg area.

According to Whitcomb *et al.* (*3*) the duration of the precursive anomaly in V_P/V_S is related to the magnitude by $\log t = 0.68M - 1.31$, where t is in days. Thus, a precursive anomaly lasting about 17 days would be expected for the event of 27 March.

In the first half of 1973 the Bernard Price Institute of the University of the Witwatersrand, Johannesburg, was engaged in a detailed study of seismicity and tilt in a region about 200 by 350 m in area, 3.1 km below the surface, and 1.2 km west of the focus of the large tremor; this region is referred to as region A. Tremors in region A, ranging in magnitude from -1 to 2.2, served as seismic sources for measuring V_P and V_S in the source region of the tremor of 27 March.

Figure 1 shows the locations of the hypocenter of the large tremor, region A, and six geophones of the underground seismic array. Seismic velocities were monitored along the ray paths from region A to the geophones labeled 42SEV and 58K; hypocentral distances to region A, 42SEV, and 58K are 1.2, 1.1, and 0.7 km, respectively.

The approximate source dimension of the event of 27 March is 3.2 km, so region A and stations 42SEV and 58K are all within the source dimension of this event (*7*).

Figure 2A shows V_P measured over ray paths between region A and stations 42SEV and 58K from 41 days before 27 March to 2 days after. Measured over the ray path to 42SEV, V_P