yield curve of a nuclide with mass ~300 should not be inconsistent with the fission-derived Xe spectrum in chondrites. Probably one peak will remain at the 82-neutron shell near mass 140 or 145. The second peak will then be at mass 155 to 160. With a width of some 30 mass units, the two peaks will blend to a large extent. $Xe^{134}$ and $Xe^{136}$ will be on the upward slope of the peak. A yield ratio of ~1.4, as observed in chondrites, is not inconsistent with this picture.

If the progenitor of fission Xe in chondrites was indeed a superheavy element, it may be possible to characterize this element more closely by further trace element correlations. Little can be said from the present data except that the correlation of $Xe_f^{136}$ with Xe and Hg is somewhat better than that with Au, In, Tl, Pb, Bi, Te, I, and Cs. Enstatite chondrites, though low in both $Xe_f^{136}$ and $Xe^{132}$, are high in these eight elements (as well as $Xe^{129}$ from the decay of extinct $I^{129}$) and hence fall consistently above the correlation line (for example, Fig. 3). Only on $Xe_f^{136}$-Xe and Hg-Xe plots (Figs. 1 and 4) do they and the C4 chondrites seem to follow the trend of the other meteorites. [The mercury content plotted here is the tightly bound component released above 450°C (*21*), which is more likely to be indigenous than the more abundant, low-temperature component.] The Hg-Xe correlation is badly marred by four aberrant points in the upper left and lower right of the diagram. Possibly these deviant points are due to contamination or to low Hg retentivity in very fine-grained meteorites. We tentatively assume that some explanation of this sort applies and that the correlation is real. But the reverse possibility must be kept in mind.

It is difficult to draw any quantitative conclusions from the apparent correlation of Hg and Xe. The condensation behavior of these two elements is less well understood than that of most others (*13*); little more can be said than that both are outstandingly volatile. The most simpleminded interpretation is that the progenitor was a congener of Hg or Xe. The latter possibility is unlikely, however. Trapping efficiencies of heavy noble gases from the solar nebula seem to have been no greater than $10^{-4}$ to $10^{-5}$ (*13*). Even if the efficiency was as high as $10^{-2}$ for element 118, a rather high abundance in the nebula would be required to account for the observed $Xe_f^{136}$. This, in turn, would imply a minimum half-life in the range of $10^8$ to $10^9$ years according to Eq. 3. Moreover, element 118 would presumably be trapped in the same mineralogical sites as Xe, in which case its decay product, $Xe_f^{136}$, should diffuse at the same rate as $Xe^{132}$, contrary to observation.

These objections do not apply to eka-mercury, element 112. From the graph given by Nilsson *et al.* (*19*), the half-lives for $\alpha$ decay and spontaneous fission of element $112^{296}$ can be estimated to be $\sim 10^6$ and $10^{13}$ years, with an uncertainty of several orders of magnitude in either direction. Its $\alpha$-decay daughter, $110^{292}$, would decay predominantly by spontaneous fission ($t_{1/2} \approx 10^5$ years), its half-life for $\alpha$ decay being close to $10^8$ years. Nonetheless it would be premature to identify the progenitor of $Xe_f^{136}$ with element 112 on the basis of a simple chemical analogy. We can state with some confidence that the progenitor was highly volatile, but inasmuch as boiling points and heats of vaporization tend to decrease with increasing $Z$ in the right-hand portion of the periodic table, elements 113 to 117 and element 119 cannot be ruled out. A more specific identification of the progenitor must hence be postponed until its geochemical character is established in more detail, from a study of the distribution of $Xe_f^{136}$ among various meteoritic phases (*27, 28*).

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28. After this work was submitted for publication, we learned that M. Dakowski (*Earth Planet. Sci. Lett.*, in press) has independently suggested superheavy elements as progenitors of $Xe_f^{136}$ in both chondrites and achondrites.

20 February 1969

## Glaciation in Southern Argentina More than Two Million Years Ago

Abstract. *In southern Argentina till beds interbedded with lava flows were deposited by ice that extended at least 40 kilometers east of the present crest of the cordillera. The flow covering the oldest till bed is 3.2 ± 1 million years old. The flow that constitutes the present surface and covers the youngest till bed, is 1.7 ± 0.5 million years old.*

In 1944 Feruglio described an exposure in southern Argentina where till and fluvioglacial material were interbedded with lava flows (*1*). Feruglio noted the great erosion since the volcanism had ceased but, because isotopic dating had not been developed, he was able to describe the glaciation only as "ancient." I visited this exposure in March 1968 and conclude that Feruglio was correct in his identification of till. The material is unsorted, a few of the pebbles are striated, and granitic

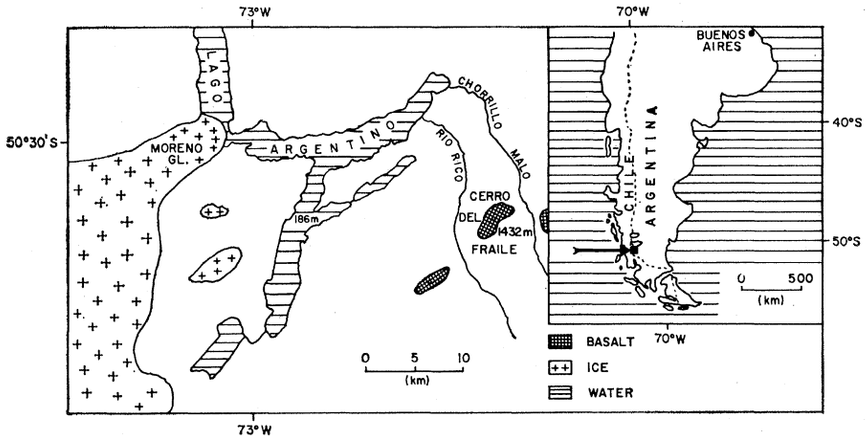


Fig. 1. Location map.

Table 1. Potassium-argon dates from whole-rock samples of basaltic lava flows from Cerro del Fraile. Sample KA-68-25 from uppermost flow; sample KA-68-26 from basal flow. Constants used for calculations of dates: $K_{\lambda\beta} = 4.72 \times 10^{-10}$ year, $K_{\lambda\epsilon} = 0.585 \times 10^{-10}$ year, $K^{40} = 1.19 \times 10^{-4}$ (atomic abundance of natural potassium).

| Standard cubic centimeters of radiogenic $Ar^{40}$ per gram of sample $\times 10^{-8}$ | Ratio of radiogenic $Ar^{40}$ to $Ar^{40}$ total | K (%) | Age (year) $\times 10^6$ |
|---|---|---|---|
| | *Sample KA-68-25** | | |
| 10.89 | 0.25 | 1.56 | $1.7 \pm 0.5$ |
| 9.87 | .24 | 1.56 | |
| | *Sample KA-68-26** | | |
| 6.23 | .10 | 0.65 | $3.2 \pm 1$ |
| 14.0 | .21 | .66 | |

* Analyses by Isotopes, Incorporated, Westwood, New Jersey.

boulders, some as much as 2 m in diameter, can only have been transported by ice from the nearest outcrop in the cordillera 40 km to the west.

The hill, now known as Cerro del Fraile (Fig. 1), at latitude 50°33′S, longitude 72°40′W, was referred to by Feruglio as that lying between the Río Rico and the Chorrillo Malo. It forms a part, detached by erosion, of the escarpment bounding the south side of the glacially carved depression that contains Lago Argentino (186 m above sea level). Slopes are as much as 30° where the bedrock consists of Upper Cretaceous sediments (so identified by Feruglio from their fossil content), which extend from near lake level to about 1020 m above sea level; slopes are vertical on the capping lava flows and mostly steep on the interbedded tills but vertical where the till is indurated (Fig. 2A). The total thickness of lava, till, and alluvium is about 180 m. Most of the summit platform, which extends for about 4 km from northeast to southwest, slopes gently toward the west. An eroded volcanic plug is situated on the eastern edge of the hill and rises above the general level of the summit platform to 1432 m above sea level.

The capping of lava flows and interbedded tills is best exposed on the west side of the hill (Fig. 2A). Figure 3 shows the stratigraphy at the only point where I saw the unconformable contact between the Cretaceous strata and the overlying beds. All the fluvial units are confined to the lower part of the section; higher up, lava flows are interrupted only by till beds. A sample of the lowest lava flow, which covers the oldest till unit and is covered by water-laid cobbles, has been dated by whole-rock K/Ar analysis at $3.2 \pm 1$ million years. The whole-rock K/Ar age of the uppermost flow is $1.7 \pm 0.5$ million years (Table 1).

Where the contact between till and overlying lava is exposed (Fig. 2B), the till has been baked red to a depth of 30 to 50 cm. Whether at least some of the flows were extruded beneath the ice, as suggested by Feruglio, is uncertain. In places, a homogeneous fine-grained layer, pebble-free but penetrated from below by large boulders, separates unsorted till from the over-

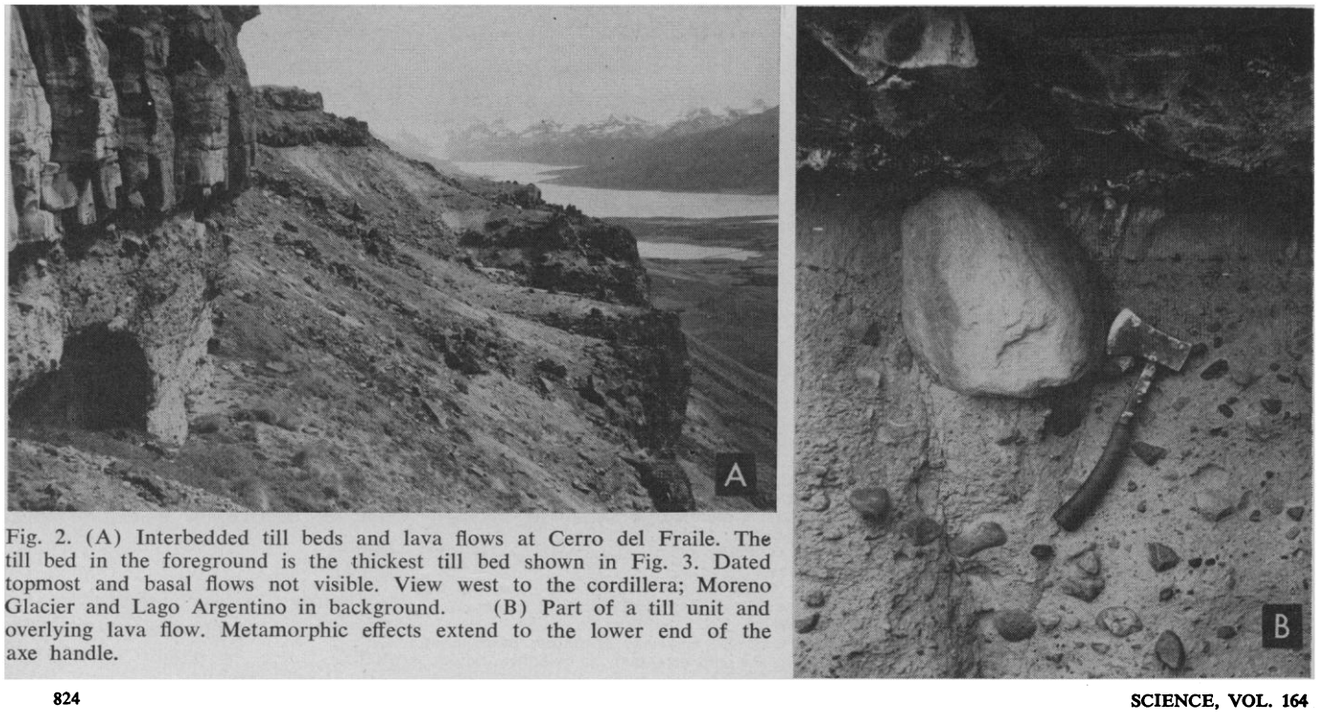


Fig. 2. (A) Interbedded till beds and lava flows at Cerro del Fraile. The till bed in the foreground is the thickest till bed shown in Fig. 3. Dated topmost and basal flows not visible. View west to the cordillera; Moreno Glacier and Lago Argentino in background. (B) Part of a till unit and overlying lava flow. Metamorphic effects extend to the lower end of the axe handle.

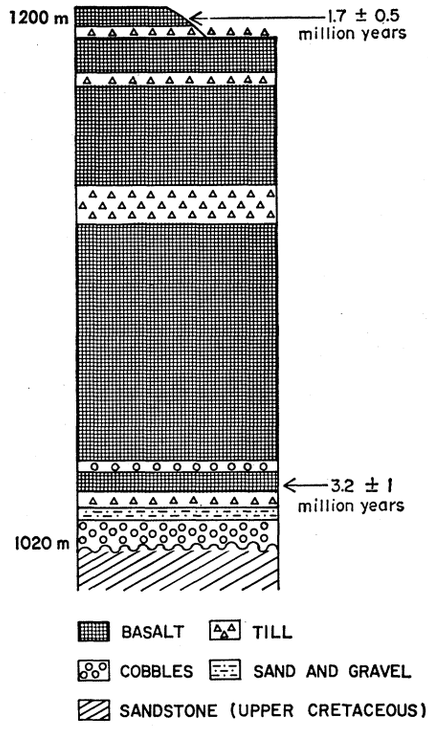


Fig. 3. Stratigraphic section of interbedded till, alluvium, and lava flows at Cerro del Fraile. Ages determined at positions indicated.

lying lava and suggests a former soil (Fig. 2B). No erratics lie on the surface of the uppermost lava flow which covers only part of the summit platform. The till unit below this flow continues over the rest of the summit platform as a lag concentrate of pebbles and boulders, the matrix having been removed by erosion (Fig. 3). Apparently the uppermost till unit was deposited by the last glacier that covered the hill, and the youngest lava flow has probably never been covered by ice. Perhaps by the time of the deposition of the uppermost till unit the excavation of the present Lago Argentino depression had proceeded far enough to channel much of the ice flowing east from the mountains, leaving the bordering plateau remnants ice-free.

The ages of the oldest and youngest lava flows—3.2 ± 1 and 1.7 ± 0.5 million years—indicate that glaciation in southern Argentina began before 2 million years ago. Glaciation 2 to 3 million years ago has been reported from other temperate parts of the world; in Iceland a till bed is inferred from studies of rock magnetism to be either about 1.9 million or 2.4 to 3 million years old, but other till beds are probably older (*2*); a till bed in the Sierra Nevada, California is about 3 million years old (*3*); and in New Zealand, where apparently ancient tills are known but have not been dated, the earliest major climatic cooling, as shown by the pollen sequence, is thought to have been about 2.5 million years ago (*4*). In Antarctica, glaciers reached the coast more than 2.7 million years ago (*5*) and probably at least 5 million years ago (*6*). A prerequisite for extensive glaciation in southernmost South America would have been the northward surface spread of Antarctic water. Goodell and his co-workers (*6*) believe that cold conditions, during which the 0°C surface-water isotherm was more than 5° of latitude north of its present position, prevailed during the Gauss paleomagnetic epoch (3.35 to 2.35 million years ago) and that the Matuyama epoch was warmer. According to Hays and Opdyke (*7*), however, temperatures fell about 2.5 million years ago, at about the Gauss-Matuyama transition. Ericson and Wollin (*8*) believe that the change to a colder world-wide climate began before 2 million years ago, but that extensive glaciation in temperate latitudes did not start until the Nebraskan glaciation 2 million years ago at the Pliocene-Pleistocene boundary.

Extensive glaciers existed in southernmost South America before 2 million years ago. Because of the imprecision of the dates obtained by whole-rock K/Ar analyses, particularly of the older sample, the age difference between the oldest and youngest till beds is uncertain; thus, it is not known whether one or more glaciations are represented. Furthermore, because the till beds owe their preservation to the covering lava flows, the oldest surviving till bed may not represent the first occasion that the site was ice-covered. The concentration of the fluvial beds near the base of the section perhaps indicates that a glacial climate was less well established when the first flow was erupted than later, but it may merely reflect changes in local topography. More precise dating of these till beds should be possible when studies of the magnetic polarity of the lava flows have been made.

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## Strontium-90: Concentrations in Surface Waters of the Atlantic Ocean

Abstract. *From the large body of analyses of strontium-90 in surface waters of the Atlantic Ocean, annual average concentrations (from 10°N to 70°N) have been compared to those predicted. The data indicate higher fallout over ocean than over land and confirm the rapid rates of down-mixing shown by most studies of subsurface strontium-90.*

With the resumption of atmospheric nuclear testing in 1961, there began several new programs of systematic analysis of strontium-90 or cesium-137 in surface waters of the Atlantic Ocean and its adjacent seas and such programs already operating were expanded. In view of the large body of data, we have collected and collated all the available analyses since 1954, some unpublished and many published only in relatively inaccessible periodicals or reports. These data proved remarkably concordant; this is especially important because of the considerable difficulties involved in the analysis of fallout radionuclides, even in surface seawater. Over 750 analyses from the open-ocean Atlantic were compiled from British, Danish, German, Polish, Russian, South African, and United States sources; after using reasonable criteria of internal consistency and cross-comparability, we have not felt justified in summarily dismissing any data points.

We summarize here the bearing of this body of data on two major problems: (i) the question of the delivery of excess fallout over the ocean, compared to that over land (*1–6*); and (ii) the question of the extent to which fallout $Sr^{90}$ has penetrated to the "deep Atlantic," that is, below the main thermocline (*3, 4, 7*). Previous discussions of both these points have rested almost exclusively on relatively