peat time of 50 to 75 years is obtained if one divides 150 years (1788 to 1938) by either two or three earthquake cycles. A repeat time of 91 years (1847 to 1938) is obtained if that zone did not rupture in 1880 or between 1897 and 1903. The eastern half of the Shumagin Gap also broke in 1788 and 1847. The gap has not been the site of a great shock since at least 1903. Although the interval that has elapsed since 1903 is somewhat greater than 50 to 75 years, repeat times of historic events along the Nankai trough of southwestern Japan vary by about a factor of 2 (*22*). The repeat time, however, appears to be proportional to the size of the rupture zone and the displacement in the preceding large earthquake (*23*). Since the shocks of 1938 and 1899 to 1903 near the Alaska Peninsula appear to have shorter rupture lengths than those of 1788 and 1847, the experience from Japan suggests that the interval between the last major event and a future large shock will be at the shorter end of the spectrum of repeat times for both the Shumagin Gap and the 1938 zone. Thus, it seems likely that one or more large earthquakes will rupture the Shumagin Gap sometime in the next 10 to 20 years.

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A Temperature and Precipitation Record of the Past 16,000 Years in Southern Chile

Abstract. *Regression equations relating pollen taxa from surface samples to temperature and precipitation are applied to a radiocarbon-dated pollen sequence in a lake core from Alerce. The resulting curves are a measure of the fluctuations of these climatic variables and show similarities to other late Quaternary records from the Southern Hemisphere.*

The climate of the Southern Hemisphere is primarily controlled by Antarctica and its vast ice sheet (*1, 2*). Nearby continents in the belt of the southern westerlies are cooled by outbreaks of polar air and by the Humboldt and Benguela currents, which transport polar water equatorward along the west coasts of South America and Africa. Our understanding of the timing and nature of climatic changes in the Southern Hemisphere during the Quaternary comes largely from the marine record (*3*) and from glacial (*4-6*) and palynological (*7-9*) studies in the temperate latitudes of Australia, New Zealand, and South America; oxygen isotope measurements in the Byrd Station ice core have provided most of the information on climatic events in Antarctica (*10*). Apparent in these data is the need to quantify in detail the variations in temperature and precipitation. We attempted this by applying multivariate statistics to a 16,000-year pollen sequence in southern Chile.

We first derived a pair of regression equations relating taxa of the modern pollen rain to mean January (summer) temperature and annual precipitation, as estimated from meteorological records at stations distributed over some 14° of latitude (Fig. 1) (*11*). At 26 composite sites 20 taxa were tied to temperature and at 24 sites to precipitation (*12*). The equations were then applied to the fossil pollen in a lake core at Alerce (41°25'S, 72°54'W), just south of the Chilean lake district at the northern extreme of the Valdivian rain forest (*13*). Sediments in the lake were deposited after the wastage of ice of the Llanquihue Glaciation (*9*).

To remove the effect of sample size, pollen data are expressed in terms of the relative frequency of the 20 taxa. Multiple forward stepwise regression shows that 11 taxa explain 91 percent of the variance in the temperature data, with a standard error of estimate of 0.99°C (15 percent of the range of the surface temperatures). Likewise, 11 taxa explain 94 percent of the variance in mean annual precipitation, with a standard error of estimate of 509 mm (14 percent of the range of the surface values).

We further transformed the surface data set before performing the regression in order to give each variable a mean of zero and a standard deviation of unity. The same result can be obtained from analogous equations in which unscaled percentage data are used as the predictor variable; however, when data for lower parts of the core are expressed in terms of deviation from surface means, it is easier to identify significant departures from the surface data set. Although tem-

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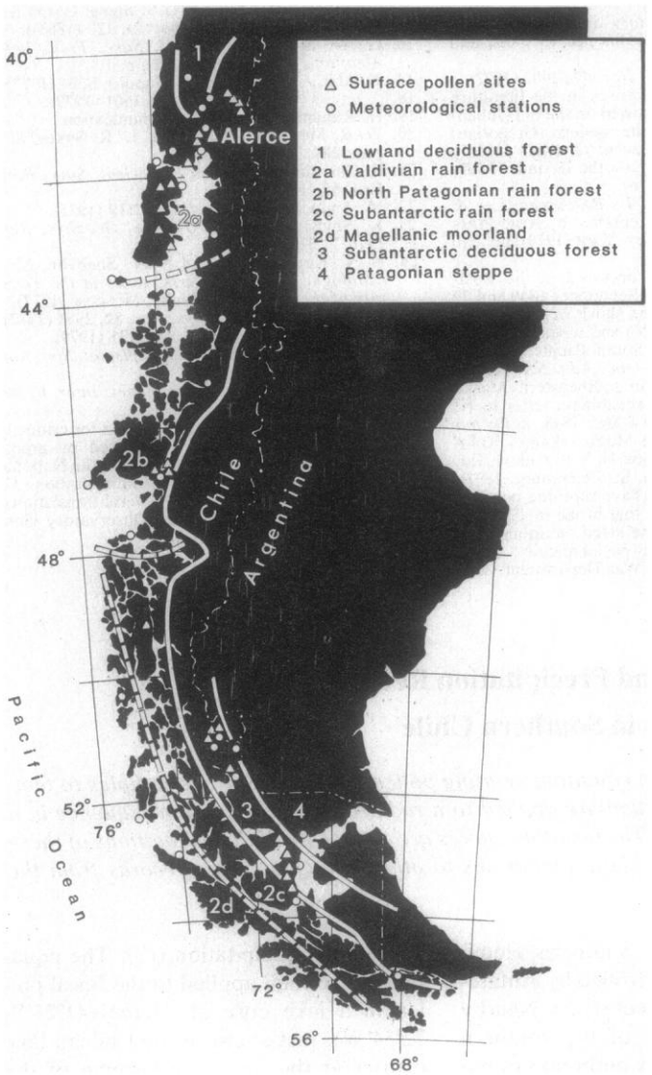

Fig. 1. Locations of Alerce, surface-pollen composite sites, and meteorological stations in relation to vegetation regions (*13*) in southern Chile.

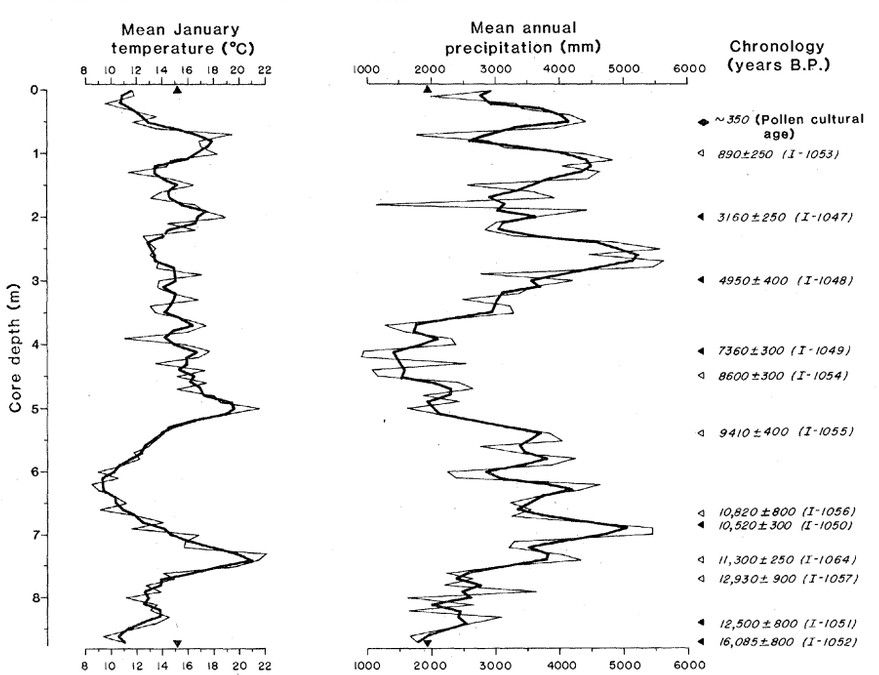

Fig. 2. Mean January temperature and mean annual precipitation for the past 16,000 years at Alerce. Bold lines represent three-point moving averages of the data. The triangles on the temperature and precipitation scales denote modern mean values, closed triangles on the right denote ^{14}C-dated levels in the Alerce core, and open triangles denote ages from nearby sites (*13*) that are pollen-stratigraphically correlated with Alerce.

perature and precipitation values are derived from these no-analog levels, the standard errors doubtless overestimate the accuracy of the prediction.

Application of these equations to the pollen sequence at Alerce (Fig. 2) shows that, for much of the past 16,000 years, mean January temperature was within 2.0°C of the present value of 15.2°C, while at the beginning of the record it was clearly lower. This early cool interval was followed by a short episode warmer than today which reached a peak about 11,300 years before present (B.P.). A second cool interval ensued, becoming pronounced at about 10,000 B.P.; it too was followed by a warm episode that peaked between 9410 and 8600 B.P. Since these predicted temperature maxima are more than 2.0 standard deviations above the mean temperature (12.5° ± 1.9°C) given by the surface data set, the absolute temperatures are unrealistically high; but the pollen spectra do indicate exceptionally warm conditions. After the second warm peak, cooling set in, and successive minima were reached between 4950 and 3160 B.P., between 3160 and 800 B.P., and during recent centuries. This cooling trend was interrupted twice, at about 3000 and 350 B.P., by temperatures higher than at present.

The precipitation record at Alerce consists of periods when amounts were about equal to the present 1900 mm and periods when they were as much as twice the present value. Again, the highest predicted values are more than 2.0 standard deviations above the mean precipitation (1885 ± 1164 mm) from the surface data set. Thus, as with the temperature maxima in the lower portion of the record, we question the accuracy of these high values, but conclude that precipitation at Alerce was much heavier than today. The maxima roughly correspond with the temperature minima: the earliest peak is at 10,520 B.P., encompassing the period from 11,300 to 9400 B.P.; the most pronounced peak coincides with the cool interval from 4950 to 3160 B.P.; the next is centered after 3160 and before 890 B.P.; and the last occurs between about 350 B.P. and the present. Temperature and precipitation are not closely related in the surface data set (r = .41) and show a high degree of independence in the Alerce section (Fig. 2).

Variations in temperature and precipitation at Alerce closely parallel glacial fluctuations in southern Chile over the past 10,000 years. San Rafael Glacier (46°44′S, 73°55′W), for example, was smaller in 6850 B.P. than today; it later advanced at least three times: between

5000 and 4000 B.P., between 3740 and 500 B.P., and during the 19th century (*14*). The advance between 5000 and 4000 B.P. was the most extensive; the ice front reached some 10 km beyond its present position. These advances can be correlated with the three cool, moist intervals at Alerce subsequent to 4950 B.P.; the greatest advance corresponds with the heaviest precipitation. Elsewhere in the Southern Hemisphere all the observed Chilean neoglacial fluctuations appear parallel only with those in New Zealand (*5*); in Australia and New Guinea, neoglacial advances are thought to have occurred only during the past 4000 years (*4*). Data indicating glacial behavior during the cool and moist interval between 11,000 and 10,000 B.P. in southern Chile are scant (*15*), but relevant findings were reported for the Andes of Peru (*16*), the Carstensz Mountains of New Guinea (*4, 17*), the Arrowsmith Range of New Zealand (*18*), and South Georgia in the Subantarctic (*19*).

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"Atmospheric" Epoxidation of Benzo[*a*]pyrene by Ozone: Formation of the Metabolite Benzo[*a*]pyrene-4,5-Oxide

Abstract. *Benzo*[a]*pyrene deposited on a glass fiber filter reacts rapidly in the dark or light with ambient levels of ozone to yield a mixture of products that display strong direct mutagenicity in the Ames assay. The major stable contributor to this activity has been identified as benzo*[a]*pyrene-4,5-oxide, a DNA-binding metabolite in biological systems, known to be a strong direct mutagen with* Salmonella typhimurium *strain TA98.*

Concern about the possible health hazard of air pollution by combustion-generated particulate organic matter (POM) historically has focused on its polycyclic aromatic hydrocarbon (PAH) content (*1*). Many members of this chemical class, such as benzo[*a*]pyrene (BP), are potent animal carcinogens (*2*) and are predominantly associated with small particles (< 1 μm) that can be inhaled and deposited in lungs of humans (*3*).

Two lines of evidence suggest, however, that the possible health hazard presented by POM is not restricted to the PAH fraction. First, although organic extracts of POM from ambient air and the exhaust from spark ignition engines are known to be carcinogenic, their activity can be significantly greater than would be expected on the basis of their known PAH content (*1, 4*). Second, application of the Ames *Salmonella* mutagen assay to such extracts, as well as those from diesel particulates (*5*) and fly ash from coal-fired power plants (*6*), has demonstrated a significant level of direct mutagenicity (not requiring activation by mammalian metabolic enzymes), which is not ascribable to the promutagenic PAH.

Since the direct mutagenicity of ambient POM is of the frameshift type commonly associated with PAH metabolites (*7*), we suggested that it might be due in part to PAH derivatives formed during combustion, by reactions in the atmosphere subsequent to emission, or by processes that occur during collection of the POM on the commonly employed high-volume glass fiber filters. In experiments with simulated atmospheres, we demonstrated that directly mutagenic nitro derivatives of perylene and BP were produced when the parent PAH was deposited on such filters and exposed to airstreams containing 0.25 to 1.0 ppm NO_2 and traces of nitric acid (*8*).

In addition, production of a directly mutagenic product mixture from the reaction of BP exposed to levels of O_3 commonly encountered during air pollution episodes in many urban areas—for example, 0.1 to 0.2 ppm—was demonstrated (*9*). We now report that the major stable contributor to the direct activity of this product mixture is benzo[*a*]pyrene-4,5-oxide. This highly mutagenic (*10*) K-region epoxide has been identified as a DNA-binding metabolite of BP in several biological systems (*11*).

Chemical and microbiological procedures were carried out under darkroom illumination. Cleaned 8 by 10 inch Gelman AE borosilicate glass fiber filters (of the type commonly used for high-volume collection of ambient particulates) were coated by saturation with, and subsequent evaporation of, a dilute solution of BP (99+ percent) in toluene. Coated filters ($\sim$ 2 mg of BP per filter) were mounted in an apparatus that allowed exposure to a controlled atmosphere, either in the dark or under actinic ultraviolet illumination. Ozone was generated from pure, dry oxygen with a Welsbach model T-408 ozonizer and metered into a flow of filtered, purified air to provide low, stable O_3 concentrations at the filter surface. During a typical 4-hour exposure, the ozone concentration ranged from 190 to 210 ppb at a flow rate of 1.0 cubic foot per minute. Approximately 50 percent of the BP was decomposed in about 1 hour under these conditions in the dark, and approximately 80 percent over the entire 4-hour exposure.

Exposed filters were extracted by ultrasonic agitation in a mixture of methanol, toluene, and dichloromethane (1:1:1) and the extracts were filtered and

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