Reports

Chronology of a Small Glacier in Eastern British Columbia, Canada

Abstract. *The age of trees growing on the moraines of a small, high-altitude glacier in the Canadian Rockies suggests that the date of the maximum post-Pleistocene ice advance was around A.D. 1714, with another later advance about 1832. These two dates are synchronous with the two major periods of recent ice advance in the area.*

A chronological study was made in September 1963 of an unnamed glacier which flows from the north slope of the President Peak (elevation 3140 m) towards the Little Yoho River in Yoho National Park, British Columbia, Canada. This glacier, which will be referred to as President Glacier, is located at 51°31′N, 116°34′W and formerly extended nearly 2 km in a due north direction. The outer edge of the terminal moraine is at an elevation of 2210 m and its maximum northward extent is 1 m south of the high water level of the Little Yoho River. The present ice terminus is at an elevation of 2353 m and is a horizontal distance of 945 m from the terminal moraine. There has been a horizontal shrinkage of nearly half the total ice length. In the past 6 years, President Glacier has slowly retreated and has left a recent recessional moraine around 1 m in height (*1*). The present surface of névé and ice is largely shaded from direct solar radiation, and ice retreat in the future may be slow.

Increment borings were made of all the trees growing on the terminal moraine, on a large inner moraine which occurred upslope between the terminal moraine and the present ice margin, and within the mature forest which surrounds part of the glaciated area. Readings of tree cores were made in the field with a hand lens, and the oldest cores were preserved and later dated with a binocular microscope in the laboratory.

The oldest tree growing on the terminal moraine was a *Picea engelmannii* Parry which was 2.5 m in height with a bole circumference of 0.74 m at a height of 0.05 m above the surface of the soil. This tree started growth in 1744. A mean period between the formation of a moraine and the invasion of tree seedlings of around 30 years was determined for an area 6 km north-northeast of President Glacier (*2*). This area was at a slightly lower elevation, but had a similar tree composition and geologic substrate. If there was a similar tree-invasion period for the President Glacier area, the terminal moraine was formed around A.D. 1714. The oldest tree growing on the large inner moraine was an *Abies lasiocarpa* (Hook.) Nutt. which was 6 m in height, with a circumference of 1.1 m at a height of 0.1 m. This tree started growth in 1862 and, if there was a 30-year period for tree invasion, the inner moraine was formed around 1832.

In the mature forest beyond the glaciated area, a *Picea engelmannii* which was 20 m from the terminal moraine had greatly diminished growth from 1830 to 1843 and another *Picea* at a distance of 100 m had diminished growth from 1826 to 1837. There were no periods of greatly diminished tree growth in the 18th, 17th, or 16th centuries.

Over 40 percent of the surface of the terminal moraine was covered with lichens, mosses, and flowering plants of which *Dryas drummondii* Richards. *D. hookeriana* Juz. and *Salix arctica* Pall. were the dominants. A rudimentary soil, which covered part of the terminal moraine, contained considerable organic matter and unincorporated litter. The maximum diameter of lichens growing on boulders was 0.1 m. There were two prominent lichen species, *Rhizocarpon geographicum* and a white species which could not be identified (*3*). The color of the rocks of the terminal moraine was duller than that of the inner moraine. The inner moraine had less than 5 percent of its surface covered by plants, there being little soil and no organic litter accumulation except in the vicinity of *Dryas* and *Salix* plants. The maximum diameter of lichens on the boulders was 0.05 m.

The incomplete terminal moraine reached a maximum height of only 3 m, while the inner moraine had a maximum height of 50 m and formed a complete semicircle around the lower portion of the glaciated area. This suggests that the inner moraine was formed by a separate ice advance and was not a recessional moraine of the ice advance that occurred about 1714, and which produced the much smaller terminal moraine.

The foregoing evidence suggests that President Glacier had two major independent advances in recent centuries. The earliest was about 1714, probably during the period 1711 to 1724, in which seven other glacial advances have been recorded for Oregon, Washington, British Columbia, and Alberta (*2*). The later advance took place about 1832 during the period, 1830 to 1850, in which ten other glacial advances occurred in the area (*2*). The relationship of these two periods of glacial advance to immediately previous periods of reduced sunspot activity which occurred from 1645 to 1715 and 1798 to 1833 has been noted (*2*).

The oldest tree (*Picea engelmannii*) in the mature forest started growth in 1556 which indicates that no greater ice advance than about 1714 occurred until before the 16th century. There is also geologic evidence which may indicate that the advance in the early 1700's was the first in at least several centuries. The terminal moraine of 1714 was only 3 m in height and contained a small amount of material, which suggests that when the ice advance which produced this moraine occurred, there had been little previous recent scouring of the mountain slopes by ice. The moraine contained several square to rectangular boulders up to 3 m in width which had angular nonrounded edges and corners and were apparently not the result of glacial erosion. These boulders were probably talus boulders which were resting on the slope when the ice advance occurred and which were pushed or carried downslope by the ice without much abrasion to their edges.

The inner (about 1832) moraine contained no large boulders and few rocks which were not partly rounded at their edges. This suggests the rocks of the inner moraine were the result of the glacial erosion which occurred in the 120 years (about) between the first and second ice advance. The large volume of material in the 1832 moraine is further possible evidence that the ice advance at that time followed a century of ice action on the mountain slopes. Examination of the size, shape, and numbers of large boulders in moraines of other glaciated areas in which there were ice advances during the "Little Ice Age" would be helpful in substantiating the use of boulders as an aid in chronological studies.

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References and Notes

1. Peter Read, Kelowna, B.C., personal communication.
2. J. R. Bray and G. J. Struik, *Canad. J. Botany* **41**, 1245 (1963).
3. I thank Dr. M. E. Hale for the lichen identification and Mr. and Mrs. G. Hartley and Mr. and Mrs. P. Read for aid in measuring the distance of ice retreat.

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Radioactivity in the Atmospheric Effluents of Power Plants That Use Fossil Fuels

Abstract. *Analysis of the fly ash produced by combustion of pulverized Appalachian coal has shown that a 1000-megawatt coal-burning power plant will discharge into the atmosphere from about 28 millicuries to nearly 1 curie per year of radium-226 and radium-228. An oil-burning plant of similar size will discharge about 0.5 millicurie of radium per year. Comparison of these data with data on the release of fission products from nuclear-powered generating stations shows that when the physical and biological properties of the various radionuclides are taken into consideration, the conventional fossil-fueled plants discharge relatively greater quantities of radioactive materials into the atmosphere than nuclear-powered plants of comparable size.*

Our interest in the distribution of naturally occurring radionuclides has led us to analyze samples of ash from coal and oil consumed in the production of electrical energy. Six samples of fly ash were obtained from the electrostatic precipitators of boilers burning six different batches of pulverized semibituminous coal from Appalachian mines. In addition, three samples of the solid residues formed when fuel oil was burned were obtained from the breechings of smoke stacks carrying the combustion products from boilers fired with South American oil. These ash samples were analyzed radiochemically for the radionuclides Ra^{226}, Ra^{228}, and Th^{228} by methods adapted from those of Petrow *et al.* (*1*).

The results of these analyses are shown in Table 1. It is interesting that for coal ash, the near equality of the Ra^{228} and Th^{228} content indicates that secular equilibrium exists and that the levels of activity for both nuclides must be supported by an equivalent amount of Th^{232} activity. However, for petroleum ash, the ratio of Th^{228} to Ra^{228} is 1.4, near the value of 1.5 which would be expected for transient equilibrium supported by a Ra^{228} parent. The data indicate that for coal, the whole thorium series is contained within the matrix whereas, for petroleum, radium has been leached selectively from the substrate.

Large, coal-burning central power stations burn pulverized coal, the combustion products of which, both gaseous and particulate, are discharged into the atmosphere through smoke stacks. In the plants from which our samples were obtained, mechanical filters and electrostatic precipitators are used to reduce the fly-ash content of the exhaust gases, and it is estimated that 97.5 percent of the fly ash produced is thus collected when the equipment is properly maintained. The remaining 2.5 percent is discharged directly into the atmosphere. For the purpose of this report, it was assumed that the fly ash so collected is representative of the chemical composition of the dust that passes into the atmosphere.

A 1000-megawatt power station will consume about 2.3 million tons of semibituminous coal per year (*2*). If we assume that the coal has an ash content of 9 percent, of which 2½ percent is discharged into the atmosphere, it can be calculated that such a coal-burning station will discharge about 4.5×10^9 g of fly ash into the atmosphere each year. On the basis of our analytical data, this fly ash will contain about 10.8 mc of Ra^{228} and 17.2 mc of Ra^{226}.

In coal ash, the radioisotopes originate from traces of U^{238} and Th^{232}. On the basis of the measured Ra^{226} and Ra^{228} content of the ash, and with the assumption that the coal has a 9-percent ash content, U^{238} and Th^{232} are present in coal in concentrations of 1.1 and 2.0 parts per million, respectively. The activity of U^{238} is 0.4 pc/g, while that of Th^{232} is about 0.2 pc/g. Anderson reported comparable concentrations of Ra^{226} in British coal (*3*).

A power station in which dust collection equipment is not used will discharge about 80 percent of the ash into the atmosphere. If such a plant has a capacity of 1000 Mw, it will annually discharge about 350 mc of Ra^{228} and 550 mc of Ra^{226}.

Oil-burning plants normally discharge nearly all of the combustion products into the atmosphere. A 1000-Mw station will consume about 460 million gallons of oil per year. If it is assumed that the oil has an ash content of 0.05 percent a total of 7.3×10^8 g of fume will be discharged, the total radium content (Ra^{226} plus Ra^{228}) of which would be about 0.5 mc (Table 1).

The amounts of radium just mentioned, and the associated radionuclides of the uranium and thorium series do not add significantly to the other sources of natural radioactivity to which humans are exposed. Because of the insolubility of fly ash, one would expect that radium inhaled in fly ash would be present in higher concentrations in the lungs than in other soft tissues. The lungs from three adult New York City residents were found to contain, 1.0, 1.2, and 1.0 pc of Ra^{228}, 0.8, 0.7, and 0.7 pc of Th^{228}, and 0.2, 0.2, and 0.5 pc of Ra^{226}. Data on the radium content for other soft tissues are not available in New York City but Hursh *et al.* (*4*) have reported that the concentration of Ra^{226} in soft tissues other than lung, in subjects from Rochester, N.Y., ranges from 0.05 to 0.1 pc/kg, wet weight, compared to a mean of 0.3 pc/kg wet weight in the lungs of our subjects. In contrast, the normal concentrations of Ra^{226} in bone was reported by Hursh to be 3.4 pc/kg wet weight. The radium in bone is due primarily to the normal occurrence of this element in soil (*5*) from which it passes metabolically into plants and animals.