bodies for Newcastle disease virus. The birds showed susceptibility to a challenge dose of virulent Newcastle disease and laryngotracheitis viruses on the 28th day. Eight serial passages of lung suspensions of mice inoculated with the hemagglutinating agent by insufflation did not produce evidence of pneumonia or disease.

The hemagglutinating agent was readily propagated in monolayers of HeLa and pig kidney cells. A mild cytopathogenicity was detected by the 48th hour. Hemadsorption of guinea pig erythrocytes, as described below, was observed by the 48th hour without macroscopic changes in the cell sheets, but adsorption was more pronounced after the 144th hour of incubation.

Immune and hyperimmune sera (*1*) to related viruses were tested for neutralization of the hemagglutinating agent grown in embryonating eggs. Serial tenfold dilutions of the agent were mixed with an equal volume of a heat-inactivated (56°C for 30 minutes) serum diluted 1:10 in tryptose broth and held 1 hour at room temperature. Each mixture was inoculated into each of three 9-day-old embryonating chicken eggs, which were incubated at 35°C for a maximum of 6 days. Infectivity end points were determined by mortality after the 24th hour and the presence of hemagglutinins in the fluids of the surviving embryos. No neutralization of the hemagglutinating agent was demonstrated by antisera of influenza types A and B, mumps, fowl plague (strain Brescia and strain "N"), or Newcastle disease, laryngotracheitis, cello, or Crawley viruses. It was interesting to note that hyperimmune sera prepared with the fluids infected with the hemagglutinating agent in rabbits and chickens did not neutralize the homologous agent.

The hemadsorption test described by Vogel and Shelokov (*2*) and Shelokov *et al.* (*3*) was applied to tissue cultures of HeLa cells infected with the Montana strain of Newscastle disease virus and the hemagglutinating agent. After incubation at 37°C for 144 hours, 0.2 ml of a 0.4 percent guinea pig erythrocyte suspension was added to the washed infected cell sheet. Both agents hemadsorbed chicken, horse, bovine, and guinea pig erythrocytes. However, erythrocytes from guinea pig blood were adsorbed more heavily than those from the blood of the other species.

The hemadsorption-inhibition test showed that hyperimmune sera to the hemagglutinating agent and to Newcastle disease virus specifically inhibited hemadsorption of the homologous virus. None of the sera used in the chicken embryo neutralization tests described above inhibited hemadsorption of the new agent in tissue culture. In addition, parainfluenza 1 and 2 and infectious bronchitis virus immune sera failed to show evidence of inhibition of hemadsorption of guinea pig erythrocytes to the infected tissue culture cells (*3*).

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References and Notes

1. Antisera used in this study were obtained through the courtesy of several investigators as follows: influenza A and B and mumps, from Dr. E. Lennette, California Public Health Laboratory, Berkeley; fowl plague, strains Brescia and "N," from Dr. J. E. Williams, Animal Disease Eradication Division, Agricultural Research Service, Washington, D.C.; Crawley virus, from Dr. J. F. Crawley, Connaught Medical Research Laboratories, University of Toronto; *Mycoplasma gallisepticum*, from Dr. H. E. Adler, University of California, Davis; and cello, from Dr. V. J. Yates, University of Rhode Island, Kingston. Antisera of parainfluenza 1 and 2 were purchased from Microbiological Associates, Bethesda, Md. All other antisera were prepared by us.
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2 June 1960

Age Determination by X-ray Fluorescence Rubidium-Strontium Ratio Measurement in Lepidolite

Abstract. X-ray fluorescence analysis of several lepidolites whose rubidium and strontium concentrations had already been determined by neutron activation and stable isotope dilution, or both, indicates that this technique can be used for rapid nondestructive reconnaissance rubidium-strontium studies, and that an x-ray analysis method comparable in accuracy to isotope dilution can probably be developed for dating Precambrian lepidolites, as the simple technique presently used has many obvious possibilities for improvement.

Strontium in specimens of the mineral lepidolite has been shown to consist, in general, almost completely of the radiogenic isotope strontium-87, formed through the transmutation of radioactive rubidium-87 (*1*). Thus it is possible to determine the geological "ages" of lepidolites by determining total-Rb/total-Sr ratios alone, without isotopic analysis of the strontium.

Rubidium forms no minerals of its own, proxying for potassium in crystal structures; generally, the K/Rb ratio is in the range 200 to 300 (*2*). However, Rb is enriched in pegmatites, and K minerals in this environment may contain the element as a major constituent. The pink to purple lithium-bearing mica lepidolite, $([K,Rb]Li[Al(OH,F)_2]-Al(SiO_3)_3)$, can contain up to 4 percent Rb, and, in contrast, contains less than 500 parts of Sr per million, the amount depending on age. Hence the analytical problem for lepidolite age determination consists in accurately measuring Rb/Sr ratios ranging from about 90 to above 2500.

L. H. Ahrens *et al.* (*3*) attempted to determine lepidolite age ratios by optical spectrography, but were unable to achieve sufficient accuracy for Rb to make the method generally useful. Recently, however, several groups of workers (*4, 5*) have achieved ratio determinations accurate to 5 percent or better by using the stable-isotope dilution technique, in which Rb and Sr concentrations are measured mass spectrometrically; and analysts at the Harwell installation have shown (*6*) that comparable accuracy can also be achieved by neutron activation analysis.

Stable isotope dilution analysis involves chemical and ion-exchange element separation, preparation of calibrated tracer isotope solutions, and the use of a mass spectrometer, while activation analysis requires the availability of a neutron source of high intensity, a radiochemical laboratory, and counting equipment. Both techniques are difficult and costly. Thus, there is a need for a rapid, inexpensive method of measuring Rb/Sr ratios, if only to make it easier to select samples worth studying by the other techniques.

X-ray fluorescence spectroscopy appeared to merit consideration for use in this application, because it is a rapid, nondestructive technique; hence, the present investigation was begun. A suite of samples whose Rb and Sr contents had previously been determined by isotope dilution and activation was available (*7*). Thus the Rb/Sr ratios determined for these "standards" by x-ray fluorescence could be compared against the ratios previously determined for them by the two established methods.

The x-ray spectrometer used was a General Electric XRD-5. Samples were bombarded by 50 kv CuKα radiation at 50 ma. A LiF crystal followed by a 0.010 inch Soller slit was used for spectrum analysis. The detection system consisted of an argon-methane gas-flow proportional counter run at 1.825 kv, and a Berkeley scaler. Samples were ground to a fine flour in a small steel ball mill which had been precontaminated, and packed into aluminum holders for analysis. The samples were thick compared to the depth of pene-

Table 1. Comparison of data obtained by x-ray fluorescence and isotope dilution methods of Rb/Sr ratio determination in four lepidolites. Samples are from an intercalibration suite (7).

	L-12 Bikita	L-13 Ingersoll	L-14 Varutrask	L-15 Pala
		Isotope dilution data		
Age (million years)	2635 ± 100	1660 ± 70	1785 ± 50	107 ± 7
Rb/Sr (atoms)	92–100	145–157	144,144	2100–2600
Sr (weight ppm)	345 ± 15	80 ± 5	136 ± 10	6.9 ± 0.5
		X-ray fluorescence data		
Count/100 sec (av. for two runs):				
30° background	1153	1113	1146	1130
26.62° (Rb)	137,219	52,325	78,766	76,049
25.14° (Sr)	3064	1724	2010	1533
22° background	1174	1278	1205	1228
Derived net count rate:				
Rb count	136,050	51,155	77,595	74,880
error	±250	±160	±190	±185
Sr 298*	1417	365	562	94
Sr 238	1303	322	496	30
Sr 273a	1379 ± 52	352 ± 42	541 ± 45	74 ± 40
Sr 273b	1390 ± 65	320 ± 55	544 ± 58	69 ± 53
Rb/Sr 298	96	139	138	797
Rb/Sr 238	104	159	156	2490
Rb/Sr 273a	99 ± 4	146 ± 17	143 ± 12	1010†
Rb/Sr 273b	98 ± 5	159 ± 27	142 ± 16	1085‡

* 238, 273, and 298 are Rb/"Rb-tail" correction ratios; see text. † +1360, −385. ‡ +3585, −475.

tration of the incident radiation, and the total area of 14 mm by 20 mm was immersed in the beam, which was not homogeneous in density.

The first order $K\alpha_1\alpha_2$ doublets at 25.14° (strontium) and 26.62° (rubidium) were used for the analysis; actual background was measured at 30° and 22° and background values for the Sr and Rb angles were obtained by interpolation. In a single analysis, after peak-top identification, 100-second counts were made at each position, that is, 30-background, Rb, Sr, 22-background; then the process was repeated.

The first-order SrKα doublets lies, in lepidolites, in a "hanging valley" between the RbKα and Kβ peaks. Even for lepidolites very rich in strontium, such as the 2600-million-year-old Bikita specimen, the number of "Rb-tail" counts falling at the Sr position is an appreciable fraction of the Sr count rate, and the background count rate is of the same order of magnitude. The situation for a young sample, such as the approximately 100-million-year-old Pala lepidolite, appeared at first sight to be hopeless, as the expected Sr count rate is less than one-tenth the background and overlap count rate total. The possibility of using the second or third order lines, where Rb and Sr are better separated, was investigated but given up, both because of the overlap of Sr and Fe peaks, and because of the great attenuation of the Sr count. Rb-Sr overlap at the first order was reduced somewhat by replacing the original 0.020 inch Soller slits with 0.010 inch slits.

The following procedure was adopted for computing Rb/Sr ratios: (i) It was assumed that equal numbers of Rb and Sr atoms give equal numbers of counts at the detector; this assumption is expected to be erroneous by only a few percent. (ii) Identical 25.14° and 26.62° background corrections were used for all samples. These were based on eight 100-second counts each, at 22° and 30°. If matrix effects are present, such averaging will introduce error; but the results obtained show already that any such effect must be quite small within this group of samples. Background correction numbers for the Sr and Rb angles were obtained from the data taken at 22° and 30° by straight-line interpolation. As the line may be slightly curved, some bias may have entered here. (iii) Rb was determined by subtracting the assumed 26.62° background from the total count. The Rb to Rb-background count ratio was always high (>50). (iv) Sr was computed by subtracting both the background contribution and the computed contribution of "Rb-tail" counts to the total count at 25.14°.

A "Rb-tail" correction was computed with the isotope dilution Rb/Sr ratios and the observed x-ray fluorescence Rb count rates to calculate the number of Sr counts expected both for the Bikita and Pala samples, and subtracting each number, plus interpolated background, from the total 25.14° counts. For Bikita, the "Rb-tail"/Rb ratio thereby obtained was 1/298, while for Pala it was 1/238.

A direct measurement of the overlap in a Sr-free RbCl sample gave an intermediate ratio, 1/273. Since no decision is yet possible as to which method is preferable, four sets of Sr-concentration data are given in Table 1. The first three are based on the three determinations of Rb-tail/Rb ratio just described. Thus, in the data on strontium labelled "Sr 298" the Bikita sample was used as the sole standard and the other three specimens as unknowns; in the "Sr 238" set the Pala sample alone was used as a standard, Bikita becoming an unknown; and for the "Sr 273a" line the tail correction comes from the RbCl experiment so that all the lepidolites are unknowns. In computing the "Sr 273b" line the tail ratio 1/273 was also used, but for the background at 25.14°, values based on the 22° and 30° data for each particular sample were used.

The isotope dilution and neutron activation data for these samples are also summarized in Table 1. Only analysis ranges are given; further details are given in the paper already referred to (7). In summary, the samples have been analyzed by from two to four groups by isotope dilution and by one group by neutron activation, with the agreement shown. All of the x-ray fluorescence data are in sufficiently good agreement with the isotope-dilution determined ratios to be useful for reconnaissance analysis purposes, and for the three ancient lepidolites, the x-ray fluorescence ratios appear to approach the isotope dilution analyses in quality.

X-ray fluorescence analysis provides an inexpensive, rapid, and reasonably precise method of reconnaissance Rb/Sr ratio and concentration determination; the present technique has a threshold of about 5 ppm for these elements. It appears it may be possible to develop the technique sufficiently to make it feasible to determine Rb/Sr ages by x-ray fluorescence analysis alone (at least for lepidolites of Precambrian age), with an accuracy comparable to that achieved by stable isotope dilution, but with a much smaller expenditure of time and money. The technique also has, of course, the advantage of being nondestructive (8).

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7. These samples are from a Rb/Sr intercalibration suite which was sent to several laboratories throughout the world for analysis. The results are discussed by L. F. Herzog, W. H. Pinson, and P. M. Hurley, *Am. J. Sci.* (in

press) and also, by individual analysts, in (*3*) and (*4*) above. The samples used are: PSU sample L-12 = LN45, Bikita Quarry, Southern Rhodesia; L-13 = L-A106, Bob Ingersoll Mine, South Dakota; L-14 = L-A110, Varutrask Quarry, Sweden; and L-15 = L-A107, Pala Mine, San Diego County, Calif.

8. This work was supported by the Mineral Conservation section of Pennsylvania State University. I wish to thank Dr. Egon T. Degens, Mr. Dieterich Welte, Mr. Werner Deuser, and Mr. Robert Shutt for instruction and assistance. Samples were graciously provided by Prof. Harrison Brown of California Institute of Technology (the M.I.T. supply being exhausted). This report is contribution No. 60-2, College of Mineral Industries, Pennsylvania State University.

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Rates of Submergence of Coastal New England and Acadia

Abstract. Altitudinal and carbon-14 age determinations of in-place *Pinus strobus* stumps of drowned forests at Odiorne Point, N.H., and Grand Pré and Fort Lawrence, Nova Scotia, yield apparent average rates of submergence of 3.1, 14.5, and 20.3 feet per 1000 C^{14} years, respectively. Rate differences are assessed in terms of eustatic rise of sea level, crustal movements, and tidal effects.

Radiocarbon dates for drowned trees along the New England coast have been reported by several investigators (*1–4*), but these determinations only fix the general period of submergence of the coastline. On the basis of earlier work on drowned forests (*5*), one of us (C.J.L.) was able to plan the present study, which provides a measure of the rate of coastal submergence at each of three drowned-forest sites. The initial assumptions of this study were that rising salt water killed the trees from which wood could be dated by C^{14}, that submergence of the forests was progressive at each site, and that the approximate average rates of submergence could be determined from a knowledge of the dates of death of trees at sufficiently different altitudes at each locality.

The drowned forest at Odiorne Point, N.H., near lat. 43°2′ N., long. 70°44′ W., consists of the remains of a coniferous stand whose stumps and fallen trunks are found within a protected cove measuring about 500 feet in diameter. The stumps are rooted in a firm woodland peat, ranging from 2 to 4 feet in thickness, that overlies till and bedrock.

The famous drowned forest at Fort Lawrence, N.S., near lat. 45°50′ N., long. 64°17′ W., has now lost most of its exposed soil and the stumps rooted in it. The site can be reached by following Dawson's directions (*6*). Samples of the forest soil, described by Dawson as "black vegetable mould, resting on a white, sandy subsoil" (*6*, p. 441), proved to be clay loam colored with forest humus to a depth of 6 inches. The "white" layer is underlain by 8 to 9 inches of red sandy loam, which in turn rests on till.

At Grand Pré, N.S., the remains of a forest extend over at least 100 acres of mud flats exposed at low tide on the north side of Boot Island (lat. 45°8′ N., long. 64°17′ W.), near the south shore of the Minas Basin. Stumps are rooted in 15 to 18 inches of gray clay soil that rests upon a pale-red clay layer varying in thickness from 12 to 24 inches, underlain by stony till.

Samples for C^{14} dating were cut from stumps of four white pine (*Pinus strobus*) trees at each of the three sites. The altitudes of the bases of the stumps were determined by standard leveling techniques. Stump altitudes were related to mean sea level, as determined from tide-table data and the observed high-tide mark for the date of the field work at each site. The precise altitudes, relative to mean sea level, of the dated stumps are not critical to the determinations of rates of submergence; only the relative differences in altitudes between stumps at each site are critical. These last altitude values are believed accurate to ± 0.4 foot.

The wood used for C^{14}-age determinations reported in the present paper was taken from the outer rings of the highest and lowest stumps at each site. It was free from contamination by borers and other organisms. Stump-base altitudes and C^{14} ages are shown in Fig. 1. The following speculations about the data are offered.

1) If the rates of coastal submergence were constant at each of the three sites between 4450 and 3200 years before the present (B.P.), the average rate of submergence at Odiorne Point corresponds closely to the approximate average rate of postglacial rise of sea level (Fig. 1), as determined from data presented by Shepard and Suess (*7*, Fig. 1). Crustal stability at Odiorne Point during this time interval would thus be implied, but later upwarping would be required, because the stumps are some 12 feet closer to present sea level than the materials that were dated in Shepard and Suess's study (Fig. 1). Also, the apparent average rate of submergence in the Fort Lawrence–Grand Pré area would amount to roughly three times that which would have been induced by the rate of postglacial rise of sea level determined from Shepard and Suess's data. The greater rate of submergence could probably best be explained as resulting from slow crustal downwarping in the Nova Scotian region, simultaneous with sea-level rise. The possibility that the Nova Scotian submergence rate reflects wholesale tree death during part of the time interval, and is attributable to the breaking of barriers between ocean and forests or to a rapid displacement of the crust, is improbable (*5*, p. 614). Relatively long periods of time were involved in the killing of successively higher trees by the rising salt water (*5*). Another consideration is that greater submergence rate might in some way be related to a progressive increase in tidal range, as continued submergence brought ocean waters farther and farther into the Fundy embayment (*8*, p. 580).

2) If submergence at each site coincided with eustatic oscillations of sea level of the type suggested by Fair-

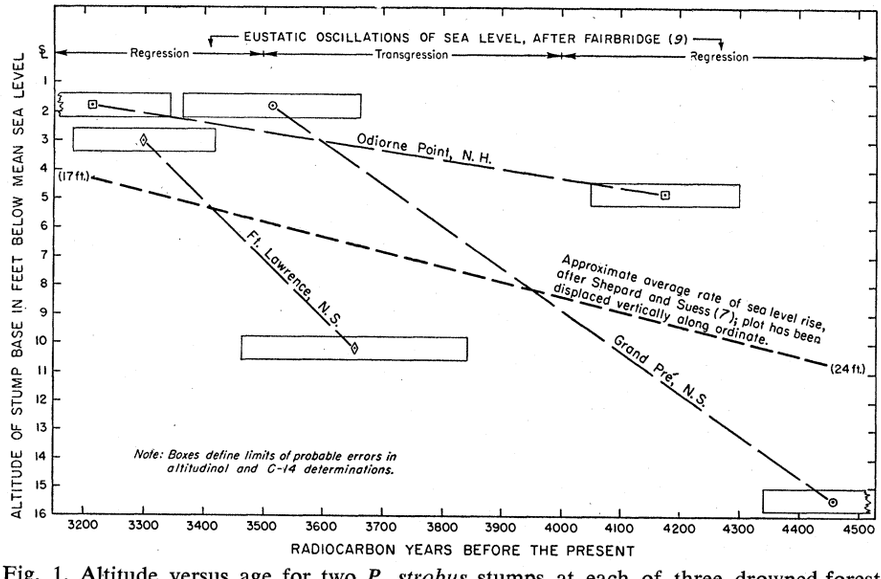

Fig. 1. Altitude versus age for two *P. strobus* stumps at each of three drowned-forest sites, and apparent average rates of site submergence.