Fossil Forests of Ocú, Panama

Abstract. *Silicified woods, the remains of mid-Tertiary tropical forests, are abundant in the vicinity of Ocú, Panama. Initial identifications reveal plant taxa not previously recorded as fossil woods. The plants identified can be found today in moist forests of tropical America, but not in the savanna-like vegetation now growing at the fossil site.*

There have been few researches on Tertiary plant fossils of tropical America because of the scarcity of well-preserved remains, and because major centers of botanical research are located in temperate regions. The principal paleobotanical investigator of this area was E. W. Berry, whose floras of middle America, the Caribbean islands, and northern South America are mostly based on impressions of leaves. We have begun a detailed study of a Panamanian fossil flora represented entirely by silicified woods. Our preliminary results may be of interest to botanists and paleontologists because of the widely recognized importance of the isthmian region as a Cenozoic migration route.

The fossils occur in and around the town of Ocú, Herrera Province, in the north-central part of the Azuero Peninsula, a major physiographic feature on the Pacific side of the isthmus. Present vegetation at the collecting sites is savanna-like, comprising mostly grasslands with widely spaced trees and shrubs. The most conspicuous woody plants are *Curatella americana, Byrsonima crassifolia, Xylopia aromatica,* pipers, a clusia, and other shrubs usually associated with degraded soils. Grasses and sedges cover most of the land in a sparse layer. Patches of true forest occur occasionally in areas unavailable for agriculture and inaccessible to cattle.

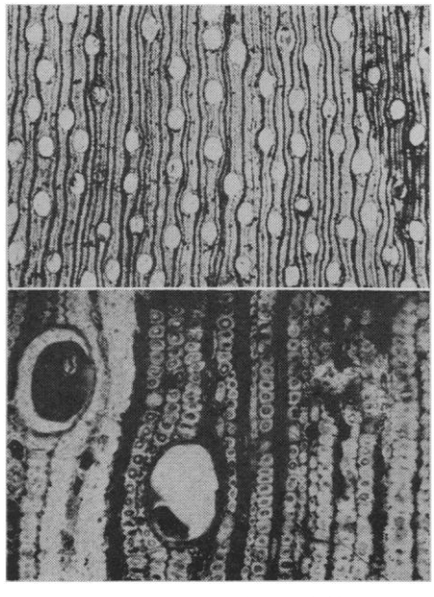

Fig. 1. Transverse section, silicified wood of *Vantanea* (Humiriaceae) from Ocú illustrating preservation of anatomical details (upper, about ×25; lower, about ×100).

Ocú lies in a region mapped by Terry (*1*) as "Oligocene with interbedded or intruded igneous rocks." The fossil woods lie on the surface, associated with volcanic tuffs. As yet, none has been found *in situ,* and it is still uncertain whether these remains are slightly older or somewhat younger than the nearby marine Oligocene sediments. In the absence of more adequate stratigraphic control, we refer to these fossils as "mid-Tertiary."

The fossils, known locally as *chumicos,* are strewn about in pastures and piled up in gullies in such abundance that the townspeople of Ocú use them as decorative building stones. Pieces are angular and range in size from small hand specimens to stumps a foot or more in diameter.

The best-preserved of the Ocú woods show excellent cellular detail in thin section. We have identified genera in Humiriaceae (*Vantanea*), Flacourtiaceae (*Tetrathylacium*), and Hernandiaceae (*Hernandia.*) These are apparently the first records of Tertiary woods from these families. The presence of these genera as fossils indicates that a pronounced floristic and vegetational change has occurred in the Ocú region since the mid-Tertiary. But in other portions of the isthmus, and in nearby North and South America, these same genera still form parts of the extant forest flora. This condition contrasts strongly with the situation among the mammals, where families which existed on the isthmus during the Tertiary Period are no longer present there (for example, Rhinocerotidae), and other families are extinct (for example, Hypertragulidae).

WILLIAM L. STERN
RICHARD H. EYDE
Division of Plant Anatomy, Smithsonian Institution, Washington 25

Reference

1. R. A. Terry, *Calif. Acad. Sci. Occasional Papers No. 23* (1956).

5 April 1963

Radiogenic Strontium-87 as an Index of Geologic Processes

Abstract. *The abundance of radiogenic Sr^{87} relative to Sr^{86} at the time of crystallization has been determined for 45 rocks. The total range in the ratio Sr^{87}/Sr^{86} is less than 2 percent. Ratios for recent lavas range from 0.702 to 0.711. Oceanic basalts are closely grouped at 0.703, whereas ratios for continental volcanic rocks spread from 0.702 to 0.711. Among the volcanic rocks, ranging from basalt to rhyolite, no correlation was found between original ratio and rock type. Older mafic and felsic rocks that include both plutonic and extrusive types also cover this same range in original Sr^{87}/Sr^{86} ratios; however, there is a definite trend with geologic time. Precambrian rocks give values as low as 0.700. The data indicate that Sr^{87}/Sr^{86} of the weathering crust has changed 1.1 percent in 3000 million years, while the ratio in the mantle has changed no more than 0.5 percent.*

This report follows the general discussions previously outlined by Gast (*1*) and by Hurley *et al.* (*2*) on radiogenic strontium in the earth's crust. (See their reports for development of theory and review of previous work.)

In this study, analyses of 86 samples make possible the determination of initial Sr^{87}/Sr^{86} ratios of 45 rock units. Two important points come to light that differ with the results of Hurley *et al.* The absolute values of the Sr^{87}/Sr^{86} ratios are considerably lower, and significant variations of initial ratios with geologic time are outlined.

The isotope dilution analyses were done on a 6-inch, Nier-type mass spectrometer utilizing single-filament surface ionization. Unspiked strontium isotopic compositions were determined with four different mass spectrometers. These include the 6-inch and three different mass spectrometers of 12-inch radius-of-curvature, 68° deflection with 60° sector magnet, using both single-filament surface ionization and triple-filament ionization.

Figure 1 illustrates the data obtained for one sample of reagent strontium with the four instruments. There is a wide range in values, particularly between the two modes of ionization; however, the best fit line through the points follows the theoretical first-order pattern of isotopic fractionation within the mass spectrometers. If the ratio Sr^{86}/Sr^{88} is assumed not to vary in na-

ture, it is possible to correct for instrument fractionation by a process of normalization. All Sr^{87}/Sr^{86} ratios in this paper are normalized to correspond to Nier's (*3*) Sr^{86}/Sr^{88} ratio of 0.1194. The range in observed Sr^{86}/Sr^{88} for 51 samples measured with a single filament is 0.1165 to 0.1190, with a mean of 0.1179. For 35 samples measured with a triple filament, the range is 0.1194 to 0.1207, with a mean of 0.1200. The 95-percent confidence level of the corrected Sr^{87}/Sr^{86} ratios is approximately $\pm$ 0.001. Natural variations of the ratio Sr^{86}/Sr^{88} below about 0.2 percent cannot be precluded; hence an additional uncertainty of $\pm$ 0.001 is possible. Errors resulting from the calculation of initial Sr^{87}/Sr^{86} from the present-day data are negligible except in a few samples which are noted in the tables.

The rubidium-poor achondrite Pasamonte which has been analyzed by Gast (*4*) and in this laboratory places the original Sr^{87}/Sr^{86} ratio in achondrites firmly at 0.6983, if the Sr^{86}/Sr^{88} ratios are normalized to 0.1194. Results for 16 volcanic rocks of either historical or geologically recent age are given in Table 1. Owing to the long Rb^{87} half-life, no measurable radiogenic Sr^{87} has accumulated in these rocks since their time of eruption. The Sr^{87}/Sr^{86} ratios range from 0.702 to 0.711 (Fig. 2). Oceanic volcanics group tightly around 0.7027. Continental volcanics show a spread of about 1.5 percent with several samples as low as the oceanic rocks. There is no clear-cut difference between the values found in mafic versus felsic volcanics.

A sample of seawater and a modern mollusk give a value of 0.708 for Sr^{87}/Sr^{86} (Table 2). Four limestone samples indicate the increase in radiogenic strontium in sea water through geologic time. There has been about a 1-percent change in Sr^{87}/Sr^{86} of seawater, which is in agreement with the results of Gast (*5*).

The older mafic rocks that have been studied vary considerably in their original Sr^{87}/Sr^{86} ratios, with a general decrease in value with increasing age (Table 3). Granites and gneisses show a relatively wide range in original ratios (Table 4).

Oceanic basalts and several recent continental volcanics have values of Sr^{87}/Sr^{86} within experimental error of 0.7027. This is the value that we have tentatively assigned to the present-day source region of oceanic basalts (possibly the mantle). If the earth and achondrites are of the same age and

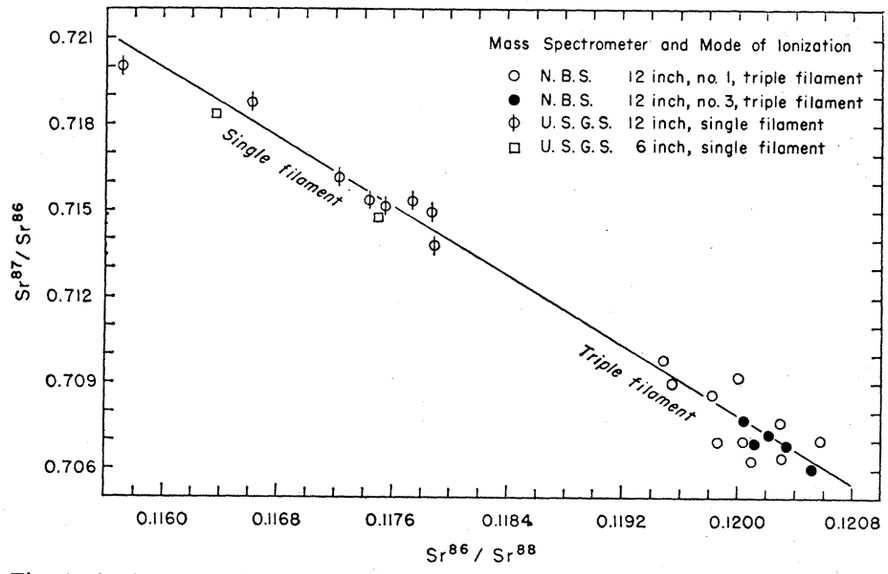

Fig. 1. Analyses of reference strontium nitrate (United Mining and Chemical Corp. Lot B 857).

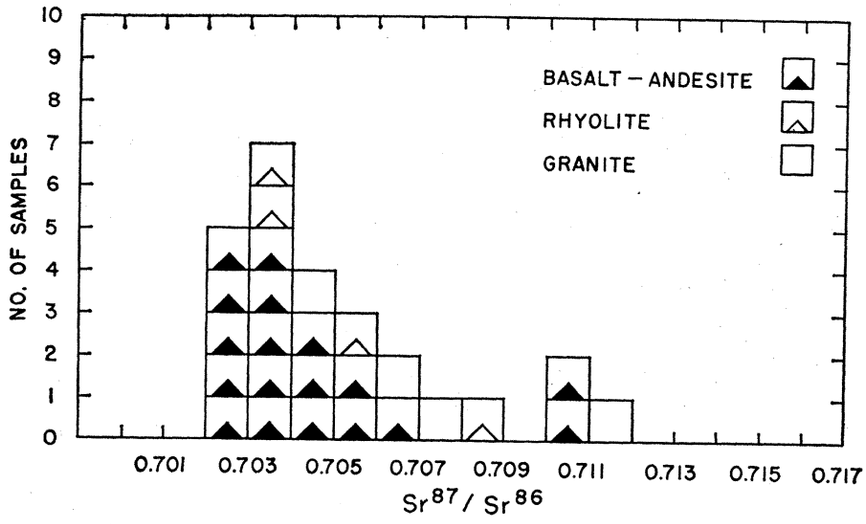

Fig. 2. Initial Sr^{87}/Sr^{86} ratios of rocks less than 250 million years old.

Table 1. Sr^{87}/Sr^{86} ratios of historic and recent volcanic rocks. All analyses by x-ray fluorescence ($\pm$30%) by H. J. Rose, Jr., and Zell Peterman, U.S. Geological Survey, Washington, D.C., except No. 11 by isotope dilution.

No.	Rock type	Location	Date of eruption	Rb (ppm)	Sr (ppm)	Sr^{87}/Sr^{86} observed
1	Basalt	Hawaii	1959	10	250	0.7024
2	Basalt	Hawaii	1959	10	250	0.7032
3	Basalt	Hawaii	1959	10	250	0.7032
4	Basalt	Iceland	1924	10	100	0.7028
5	Basalt	Iceland	1730	10	100	0.7023
6	Andesite	Japan	1946	30	200	0.7052
7	Basalt	New Zealand	1886	10	200	0.7047
8	Andesite	Mt. Etna	1886	10	800	0.7029
9	Tephrite	Mt. Vesuvius	1944	180	700	0.7068
10	Rhyolite	California	Recent	200	100	0.7036
11	Obsidian	California	Recent	132	73.6	0.7030
12	Basalt	Idaho	Recent	50	100	0.7108
13	Basalt	Idaho	Recent	10	100	0.7100
14	Basalt	Arizona	1066	10	500	0.7030
15	Basalt	New Mexico	Recent	30	600	0.7037
16	Basalt	Colorado	Recent	30	500	0.7048

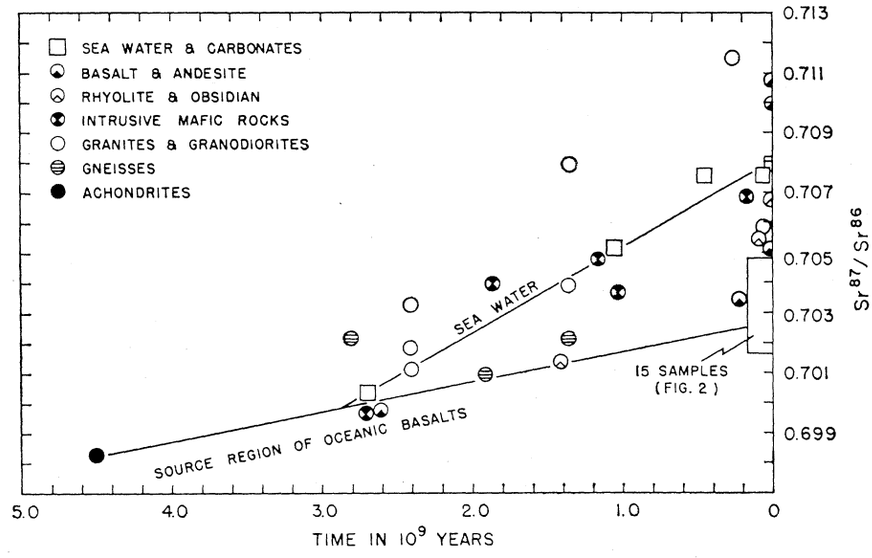

Fig. 3. Initial Sr^{87}/Sr^{86} ratios of rocks ranging from recent to 3000 million years in age.

Table 2. Sr^{87}/Sr^{86} ratios of seawater and limestones; m.y., million years.

No.	Type of sample	Location	Age	Sr^{87}/Sr^{86} observed
17	Seawater	Gulf Stream	Modern	0.7081
18	Mollusk shell	Delaware coast	Modern	0.7075
19	Limestone	Haiti	Eocene	0.7076
20	Limestone	Texas	Ordovician	0.7077
21	Limestone	New York	>1,050 m.y.	0.7052
22	Limestone	South Africa	>2,650 m.y.	0.7004

Table 3. Analytical data and original Sr^{87}/Sr^{86} ratios of Pleistocene or older mafic rocks. All values for Rb and Sr by isotope dilution, except No. 23, by x-ray fluorescence.

No.	Type	Location	Age (m.y.)	Rb (ppm)	Sr (ppm)	Sr^{87}/Sr^{86} present	Sr^{87}/Sr^{86} original
23	Basalt	California	0.1	10	1100	0.7047	0.7047
24	Basalt	Wyoming	10	8.2	337	0.7022	0.7022
25	Diabase	Virginia	180	21.5	187	0.7079	0.7069
26	Basalt	California	220	72.4	464	0.7050	0.7035
27	Anorthosite	Minnesota	1000	0.93	492	0.7037	0.7037
28	Diabase	Arizona	1140	55.0	297	0.7144	0.7048
29	Basalt	Minnesota	1800	55.3	750	0.7097	0.7040 ± 0.002
30	Greenstone	Minnesota	2600	3.5	106	0.7063	0.6998 ± 0.0015
31	Anorthosite	Ontario	2600	9.3	162	0.7061	0.6997 ± 0.0015

Table 4. Analytical data and original Sr^{87}/Sr^{86} ratios of pre-Pleistocene felsic rocks.

No.	Type	Location	Age (m.y.)	Rb (ppm)	Sr (ppm)	Sr^{87}/Sr^{86} present	Sr^{87}/Sr^{86} original
32	Obsidian	New Mexico	1	152	4.3	0.7095	0.7080
33	Obsidian	Wyoming	13	221	17.9	0.7121	0.7055
34	Granite	Washington	15	50.2	365	0.7046	0.7045
35	Monzonite	Colorado	55	210	517	0.7068	0.7059
36	Granite*	Massachusetts	250	94.2	762		0.7115
37	Granite*	Arizona	1330	285	147		0.7080
38	Gneiss	Colorado	1350	32.1	246	0.7097	0.7022
39	Granite*	Colorado	1350	255	168		0.7039 ± 0.002
40	Rhyolite	Arizona	1400	244	145		0.7016 ± 0.002
41	Gneiss	Montana	1900	82.3	505	0.7141	0.7010
42	Granite*	Ontario	2400	81.0	480		0.7012
43	Granite*	Minnesota	2400	137	418		0.7033
44	Granite*	Minnesota	2400	176	338		0.7019 ± 0.002
45	Gneiss*	Minnesota	2800	103	372		0.7022

* More than one sample of each rock (see appendix); rubidium and strontium concentrations are averages, age and original Sr^{87}/Sr^{86} obtained from plot of Sr^{87}/Sr^{86} versus Rb^{87}/Sr^{86}.

origin, a line between this point and the point for achondrites (Fig. 3) defines the trend of the development of radiogenic strontium in the source region of oceanic basalts. None of the old samples falls significantly below this line, and three are closely grouped. These are the Ely Greenstone (sample 30) of the Keewatin of Minnesota, anorthosite (sample 31) from the Keewatin at Bad Vermilion Lake, Ontario, and Bulawayan Limestone (sample 22) from the belt of ancient rocks in Southern Rhodesia. The slope of this line indicates a Rb/Sr ratio in the source region of oceanic basalt of about 0.021.

The investigations of Horstman (*6*) and Turekian and Kulp (*7*) indicate a Rb/Sr ratio for surface rocks of 0.25. A crust 3000 million years old with this Rb/Sr ratio would have a maximum ratio for present-day Sr^{87}/Sr^{86} of approximately 0.73. The radiogenic strontium that developed in the primeval crust, however, has been continuously diluted throughout geologic time by new material being brought up from the mantle that is characterized by a low Rb/Sr ratio. Basalts are particularly effective in this dilution process because their strontium concentrations are high and their Sr^{87}/Sr^{86} ratios are low. This dilution combined with a probable lower Rb/Sr ratio of the deeper crust are probably sufficient to lower the present Sr^{87}/Sr^{86} ratio of the crust to about 0.71 or 0.72.

Granitic and continental basaltic rocks with original ratios of 0.704 to 0.711 cannot be simple differentiates from a source similar to that of Hawaiian basalts. The possibility of such an origin with subsequent contamination of the magma with radiogenic crustal strontium cannot be ruled out, however.

With the exception of certain volcanic rocks, the continental rocks, on the average, approximate seawater in Sr^{87}/Sr^{86}. This is exactly the pattern that is expected if these rocks are reworked continental material. If they are derived from reworked crustal material, this material has undergone a high degree of homogenization. Homogenization is accomplished through the weathering cycle and through subsequent metamorphic processes; otherwise highly radiogenic initial values for Sr^{87}/Sr^{86} (> 0.71) would be expected through localized melting of old sedimentary or metamorphic rocks. Granites with high initial ratios appear to be few, if not wanting.

A second hypothesis is that these

continental rocks originate either deep within the crust or in the mantle beneath the continents in a region in which the Rb/Sr ratio approximates that of basalt, and the isotopic composition of strontium is inhomogeneous but tends to be more radiogenic than in the source region of oceanic basalts (*8*).

Appendix

Historic and Recent Volcanic Rocks

1. Vesicular basalt, 4 Dec. 1959 eruption of Iki-12, Hawaiian Islands, H. A. Powers, No. G-2811.
2. Vesicular basalt, 11 Nov. 1959 eruption of Iki-1, Hawaiian Islands, H. A. Powers, No. G-2807.
3. Vesicular basalt, 29 Nov. 1959 eruption of Iki-10, Hawaiian Islands, H. A. Powers, No. G-2810.
4. Vesicular basalt, 1924 lava from southwest side of Askja volcano, Iceland, G. T. Faust, No. I-8.
5. Porphyritic, vesicular basalt, 1724-1730 flow near Lake Myvatn, Iceland, G. T. Faust, No. I-12.
6. Pyroxene andesite, 1946 eruption of Sakura-Jima, Japan, R. A. Bailey.
7. Basaltic cinder, 1886 eruption of Tarawera, New Zealand, R. A. Bailey.
8. Pyroxene andesite, 1886 eruption of Mt. Etna, Sicily, R. L. Smith.
9. Leucite tephrite, 1944 eruption of Vesuvius, Italy, R. L. Smith.
10. Gray vesicular glass, Little Glass Mountain, Medicine Lake, Modoc County, California, H. A. Powers, No. 52-P-123.
11. Obsidian, as above, B. R. Doe.
12. Gray basalt, Highway flow from North Crater, Craters of the Moon, Idaho, H. A. Powers, No. 62-P-81.
13. Gray basalt, Indian Tunnel flow from Big Crater, Craters of the Moon, Idaho, H. A. Powers, No. 62-P-119.
14. Vesicular basalt, Kana-A flow, Sunset Crater, Arizona. Tree-ring date sets eruption at 1066, D. E. Livingston, University of Arizona.
15. Vesicular basalt, Capulin, New Mexico, H. A. Powers, No. 54-P-153.
16. Porphyritic basalt, junction of Eagle and Colorado rivers, Dotsero, Colorado, H. A. Powers, No. 54-P-152.

Sea Water and Limestones

17. Seawater, Gulf Stream, Atlantic Ocean, J. L. Harris.
18. Mollusk shell, modern, Rehoboth Beach, Delaware.
19. Very pure marine limestone, Eocene, Haiti, S. S. Goldich, No. HLC-6.
20. Clean limestone from the Ellenburger Group, Llano County, Texas, Lower Ordovician, S. S. Goldich, No. MH-21-5-445.
21. Marble, Balmat, New York, pre-Grenville, B. R. Doe, No. fd 7-3.
22. Dark-gray carbonaceous Bulawayan Limestone, Southern Rhodesia, Lamont Geological Observatory, No. R-9.

Pleistocene or Older Mafic Rocks

23. Olivine basalt, Sawmill Canyon, Mt. Pinehot quadrangle, California, Pleistocene, G. B. Dalrymple, No. 509-49-5, University of California, Berkeley.
24. Basalt flow, Yellowstone Park, Wyoming, Pliocene, B. R. Doe, No. YP-51-71.
25. Standard diabase W-1, Centerville, Virginia, Triassic.
26. Light-gray basalt or andesite, Franciscan of west-central California, R. W. Kistler, No. D-323.
27. Coarsely crystalline, gray-green anorthosite, Silver Bay, Minnesota, S. S. Goldich.
28. Diabase dike, Sierra Ancha Mountains, Gila County, Arizona, P. E. Damon, No. PED-29-61, University of Arizona.
29. Basalt dike, Granite Falls, Minnesota, S. S. Goldich.
30. Ely Greenstone, Tower, Minnesota, S. S. Goldich.
31. Gray-green anorthosite, Bad Vermilion Lake, Ontario, S. S. Goldich, No. RL-33-58 G.

Pre-Pleistocene Felsic Rocks

32. Obsidian, Los Posos, Jemez Mountains, New Mexico, R. L. Smith.
33. Rhyolite, Cougar Creek, Yellowstone Park, Wyoming, Pliocene, F. R. Boyd, Geophysical Laboratory, Washington, D.C.
34. Snoqualmie Granodiorite, Washington, Tertiary, B. R. Doe.
35. Fine-grained quartz monzonite, Eldora, Colorado, S. R. Hart, Department of Terrestrial Magnetism, Carnegie Institution of Washington.
36. Coarse-grained, gray granite, Clinton quadrangle, Massachusetts, three whole-rock samples, Richard Goldsmith.
37. Coarse-grained, pink granite, Gila County, Arizona, four whole-rock samples, D. E. Livingston, University of Arizona.
38. Gray, coarsely crystalline granite gneiss from a core, Rocky Mountain Arsenal, Denver, Colorado, R. B. Taylor.
39. Medium-grained gray granite, St. Kevin quadrangle, Colorado, seven whole-rock samples, R. C. Pearson.
40. Rhyolite, Gila County, Arizona, five whole-rock samples, D. E. Livingston, University of Arizona.
41. Augen gneiss, Little Belt Mountains, Montana, E. J. Catanzaro, No. 263.
42. Gray to pink, medium-grained granites, Rainy Lake, Ontario, six whole-rock samples, S. S. Goldich.
43. Medium-grained, gray to red granites, vicinity of Sacred Heart, Minnesota, three whole-rock samples, S. S. Goldich.
44. Ortonville granite, three whole-rock samples, vicinity of Ortonville, Minnesota, S. S. Goldich.
45. Banded red and gray quartz monzonite gneiss, nine whole-rock samples, along Minnesota River in vicinity of Morton, Minnesota, S. S. Goldich.

C. E. HEDGE
F. G. WALTHALL
U.S. Geological Survey, Washington 25, D.C.

References and Notes

1. P. W. Gast, *J. Geophys. Res.* **65**, 1287 (1960).
2. P. M. Hurley, H. Hughes, G. Faure, H. W. Fairbairn, W. H. Pinson, Jr., *ibid.* **67**, 5315 (1962).
3. A. O. Nier, *Phys. Rev.* **54**, 275 (1938).
4. P. W. Gast, *Geochim. Cosmochim. Acta* **26**, 927 (1962).
5. P. W. Gast, *Bull. Geol. Soc. Am.* **66**, 1449 (1955).
6. E. L. Horstman, *Geochim. Cosmochim. Acta* **12**, 1 (1957).
7. K. K. Turekian and J. L. Kulp, *ibid.* **10**, 245 (1956).
8. We are indebted to S. S. Goldich, U.S. Geological Survey, and W. R. Shields, National Bureau of Standards, and to numerous colleagues with the Geological Survey who supplied the samples which made this study possible. Additional samples provided by other laboratories are acknowledged in the Appendix. Publication of this paper authorized by the director, U.S. Geological Survey.

4 March 1963

Ethylene Production in Fading Vanda Orchid Blossoms

Abstract. *The production of ethylene by fading blooms of* Vanda Miss Agnes Joaquim, *determined quantitatively by the perchlorate manometric procedure, was correlated with the degree of fading. A peak production of over 3400 μl per kilogram hour was obtained when 97 percent of the blooms were faded.*

The blooms of the orchid *Vanda Miss Agnes Joaquim* normally fade in senescence, but premature fading may be induced by subjecting the blossoms to certain gases, by pollination, disturbance, or removal of the pollinia. That ethylene probably causes premature fading was indicated when it was induced by exposure of the blooms to illuminating gas, automobile exhaust fumes, and tobacco smoke, all of which contain ethylene, and by placing *Vanda* blossoms and sections of ripe fruits of various plants that produce ethylene together in an airtight container (*1*). Exposure of the normal blooms to 1 part per million of ethylene causes them to fade prematurely (*2*).

From biological assay results (*3*), the production of ethylene by the blossoms of several species of orchids (for example, *Dendrobium* and *Phalaenopsis* spp.), was determined. Similarly, when fading *Vanda* flowers were sealed with green fruits of various plants, the ripening rate of the fruits was accelerated (*1*). Young tomato and African marigold plants sealed in a container with fading blooms displayed symptoms of epinasty, a typical ethylene response; carnation blossoms closed prematurely (an ethylene manifestation commonly called "sleepy" response) in the presence of fading flowers. By biological assay, it was possible to ascertain that ethylene probably is produced by fading *Vanda* flowers. Since brominated charcoal has been found to be effective in preventing the premature fading of normal *Vanda* flowers in the presence of fading blooms (*1*), Lindner's suggestion (*2*) that ethylene produced by the blooms of *Vanda* causes their own

Table 1. Ethylene production in fading *Vanda Miss Agnes Joaquim* blossoms.

After removing pollinia (hr)	Ethylene production (μl/kg hr)	Degree of fading (%)
0	0	0
12	0	5
15	335.21	30
22	508.26	75
25	1016.53	85
28	1638.43	90
30	2582.02	95
32	3442.15	97
34	3359.00	97
36	2851.24	99*
46	1377.07	100†
49	688.53	100‡

* Slightly glassy perianth. † Glassy perianth, and slimy peduncles. ‡ Very glassy perianth, slimy and darkened pediuncles, and odoriferous.