ATOLL RESEARCH BULLETIN

---

No. 37

# Pumice and other extraneous volcanic materials on coral atolls

by

M.-H. Sachet

Issued by

THE PACIFIC SCIENCE BOARD

National Academy of Sciences—National Research Council

Washington, D. C.

May 15, 1955

CONTENTS

# Pumice and other extraneous volcanic materials on coral atolls

by
Marie-Hélène Sachet

## Introduction

"Every square inch of land in the atoll is coral ..." Wood-Jones, (1910, p . 57). Statements similar to this, varying only in their colorfulness, accuracy, or detail, together with various generalizations to the effect that atolls are made up entirely of organic limestone, are abundant through the literature of coral islands, in diaries, adventure stories, and scientific reports; and within certain limits such statements are true.

The presence on atolls of volcanic rocks such as pumice and basalt, as well as volcanic soils, has aroused much curiosity and interest.

The most conspicuous and abundant foreign rock is pumice. Examination of the literature reveals its presence in widely separated islands and shows its importance as a "natural resource." We will first cite available information on pumice, its occurrence, uses, significance, and complete this record with mention of other extraneous materials. For the purposes of this review, pumice is taken to mean volcanic ejecta that are vesicular and light enough to float. The author is aware that rocks of significantly different texture and chemical composition may be included, and that the petrologist might desire further restriction of the term, which is impractical here.

## Pumice

### Geographic distribution

Seurat (1903, p. 6), who spent many months in the remote Tuamotu Atolls and the neighboring Gambier Islands, reports the presence of small pieces of pumice on the beaches of South Marutea, one of the easternmost atolls of the Pacific. Pumice is not often reported from the Tuamotus, and is indeed probably not as common there as in various central Pacific groups of atolls; however, the literature on this immense archipelago is especially poor and inadequate.

On the contrary, pumice is reported by many observers in many different islands in the central Pacific and in the Micronesian Atolls.

Van Zwaluwenburg (1941, p. 15) found it on Canton Island, and W. A. Dixon (1877, p. 165) said it was abundant on Malden Island. In 1862, W. W. Gill, a missionary, was collecting idols on Pukapuka (Cook Islands) and wrote (1876, p. 60): "One old man was carrying what seemed to be a large lump of coal with evident ease. This turned out to be pumice stone blackened by long exposure to rain and wind." This piece was deposited by Gill in the museum of the University of Sydney.

The U. S. Exploring Expedition (1838-42) observed pumice in several of the many atolls visited. Dana (1849, p. 77) mentions it on Fakaafo and Howland. Of the latter he says that bits of pumice and pieces of driftwood are scattered all over the island's surface.

The abundance of this pumice at times is extraordinary. Whitmee (1878, p. 108) wrote that in that year, ships met great quantities of it in the vicinity of the Ellice group, and quoted newspaper accounts to this effect. He added: "... the shores of all the Ellice Islands are thick with it. Hundreds of tons have been thrown up on each island." An interesting note here is that the pumice when first observed (April 1878) was free of sea-weeds and barnacles, but these were noticeable by June.

Another important record of pumice in the Ellice Islands is that of Hedley (1896, p. 16) from Funafuti: "Everywhere small pieces of pumice the size of a walnut might be collected on the beaches. The natives say that a few years ago much pumice came ashore, coincident with which the fish from without the lagoon became unfit for food."

Finsch (1914, p. 43) says that he himself saw great quantities of pumice on the strand at Butaritari, Gilbert Islands. P. E. Cloud, Jr. (1952, p. 21) observed and collected it on Onotoa in the same group.

There are few records of the presence of pumice in the Marshall Islands. One of these is by Chamisso (1821, p. 156), one of the most gifted and versatile naturalists to visit Pacific atolls. Another reference is by Grundemann (1887, p. 442) on Ailuk. Still another is by Stone (1951, p. 2) on Arno Atoll. It is quite possible that pumice does not reach these islands as often or as abundantly as it does the Gilbert or Ellice Islands. However it is present now in the Marshall Islands, and F. R. Fosberg observed it in 1951-52 (unpublished) during the Northern Marshall Islands Expedition. During this investigation pumice of several distinct sorts was noted, and specimens were collected on Pokak, Utirik, Ailuk, Jemo, Kwajalein, Ujae, Wotho, and Ujelang atolls. It was ordinarily found as scattered pebbles, usually small, but larger pieces up to the size of man's head also were seen. It occurred in greatest quantities inland on the surface of the ground on Kirinyan Islet, Ujelang, and on Ebeju Islet, Ujae. On Ebeju perhaps a bushel could have been gathered in an area 20 meters square. This was a localized occurrence, though; other similar areas have little or no pumice. Much smaller amounts were scattered on the beaches, as on Jemo, above the normal wave mark; and in several places where dunes and sand spits were being cut away by wind or waves, buried pieces were exposed.

The only record of pumice in the Caroline atolls is from Kayangel Atoll, Palau (Cloud, personal communication, 1953). /But see Addenda, p.20/.

Several records of the presence of pumice are available from Laysan Island, one of the northernmost atolls in the world. H. H. Schauinsland, who spent 3 months on this island in 1896, observed hard seeds, nuts, masses of resin, and rounded pieces of pumice /Bimstein/ in the abundant piles of bird droppings (Schauinsland, 1899, p. 20). In an appendix (p. 89) he enlarged on the subject and noted that he did not find any pumice on the strand during his sojourn, but that it was always present in the center of

the island, partly on the surface, and partly in the guano pits. An interesting sequel to this report is found in the journal of Munro (1946, p. 43). Quoting from his journal on Laysan (June 20, 1891) he writes: "On the dry surface of the lagoon there are lots of small pieces of pumice," but adds, "evidently this was cuttlefish bone disgorged by birds." He reports finding pieces of cuttlefish bone in the gizzards of young albatrosses and other birds.

It would seem that the two observers may have seen and reported the same thing. It is interesting to note that they both believed it to be pumice at the time. Since we have no idea what regurgitated cuttlefish bone may look like, it seems difficult to settle the question at this point. It is unfortunate that no one thought of bringing back a bit of the material. However, it is quite possible that Mr. Munro should not have distrusted his 1891 observations and that both he and Schauinsland did observe pumice scattered on Laysan. The fact that some of it had gone through the albatrosses' stomachs does not necessarily mean that it was not pumice. Schauinsland (1899, pp. 20, 89) remarked that these birds will swallow anything and that they may pick up the rounded pebbles intentionally "to help their digestion."

Much later (in 1912) Elschner visited the Leeward Hawaiian Islands and recorded (1915, p. 35) pumice on Laysan, Pearl and Hermes Reef, Lisianski, and Midway.

One of the most intriguing observations of pumice is that made at the time of the visit of the Austrian ship Novara in 1858, to the atoll of Sikaiana or Stewart Island. Both Scherzer (1862, p. 607) in the "Narrative" of the voyage, and Hochstetter (1866, pp. 157-158) in the "Geology," mention the abundance of pumice on Faule, one of the two larger islets of the atoll. Hochstetter pointed out that the pumice was "finely porous and brown, and floats on water." Trying to ascertain the thickness of the pumice beds, Hochstetter examined the sides of a water-hole about 18 feet in diameter, found in the middle of the forest. The rims of the hole were of "compact coral conglomerate," and the pumice lay all around but only superficially, in the humus layer covering the coral rock.

Guppy (1887, p. 140) mentions that during the surveying voyage of the "Fly" much pumice was found in various places along the eastern coast of Australia. This is reported by Jukes (1847) in his narrative of the voyage. The "Fly" visited a low coral island, Raine Islet, and Jukes (1847, p. 128) observed pumice there, embedded in the coral sandstone forming the island.

Beyond Australia, westward in the Indian Ocean, we find pumice recorded in the Cocos-Keeling Islands by several authors. The earliest such reference is by Keating (1840, p. 378) who said: "Large quantities of pumice-stone have been found on all the islands." Later pumice was recorded by Guppy (1889, pp. 284-287), who spent ten weeks on Cocos-Keeling in 1888, and by Wood-Jones (1910, pp. 170-171), who lived for fifteen months on the main atoll as a doctor and included his observations in his book "Coral and Atolls."

Further west we have records of pumice from the Chagos Archipelago: Moresby (1844, p. 309) wrote: "Masses of pumice-stone are constantly found

on the beach of the islands, ....' One piece in Captain Moresby's possession, measures 37 by 27 inches, and weighs 8 lbs. 12 oz." Finsch (1887, p. 42) and Wilson (1889, p. 144) observed pumice in 1884 on the beaches of Diego Garcia in the same group.

The last region in the Indian Ocean from which we have records of pumice is that of the long chain of atolls of the Maldive and Laccadive archipelagoes. Because of their proximity to India, of the activity of the British civil servants, Navy officers, and naturalists, and because several great scientific expeditions studied these islands, we have more information on them than on most atolls, and those scattered in time.

In 1892-94, a party on the ship "Investigator" surveyed the Laccadives, and Alcock (1902, p. 175), a naturalist on the 1892 campaign, reports that two of the ship's officers discovered a bed of pumice a little inland of the north end of Cardamum (Kardamat) Island. Unfortunately, he did not hear of it until the ship had steamed away. Oldham (1895, pp. 6-7) mentions this occurrence and seems to imply that he himself saw this pumice bed, but apparently at a later date. "The northern point of the island is formed by a spit of sand on which I found a quantity of pumice, extending inland for about fifty yards from the extreme point; it is strewn all over the surface, and varies in size from a marble to half a foot in diameter." The "Investigator" party also found pumice pebbles on the bottom of the Bay of Bengal (Alcock, 1902, p. 153).

Ellis (1924, p. 9) recorded pumice from the Laccadives. In 1899-1900, J. S. Gardiner visited the Maldives, Minicoy, and the Laccadives, and with his two associates, gathered vast amounts of information and extensive zoological and botanical collections. The results for the main part were included in two large volumes published in 1901 to 1906. Gardiner (1906, p. 582) found pumice on many of the atolls. In another paper (Willis and Gardiner, 1901, p. 113) Gardiner mentions finding a little pumice among foraminiferal sand on Hulele Island, Male Atoll. Soon after Gardiner, Alexander Agassiz visited the Maldives (1901-02) and published his account, accompanied by a volume of valuable photographs (1903 b). He recorded (pp. 63, 69) the presence of abundant windrows of pumice on the beaches of two atolls, South Malosmadulu (Embudu Islet) and North Malosmadulu (Medu Islet).

The latest information on pumice in the Maldives was collected during the John Murray Expedition of 1933-34 and is recorded in Sewell's accounts. On Horsburgh Atoll (Sewell, 1936 b, p. 116) lines of small pumice fragments were observed on the sandy sea beach of Goidu Islet.

On Addu Atoll (Sewell, 1936 a pp. 77, 79, 82) pumice occurred on several of the islets (Putali, Mulikadu, Maradu) inland from the sandy lagoon beaches. On Putali (p. 77) "Running along the whole length of the northern part of the island, about 10 yards to the east of the steep bank that now forms the east bank of the lakes [elongated ponds running parallel to the lagoon edge], there is a well-marked line of rounded, water-worn pieces of pumice." Sewell goes on to quote Gardiner's and Oldham's observations, and concludes that this pumice must come from Krakatau: "if this be so, then since 1885 or thereabouts the inner beach of the island has advanced towards the lagoon by some 10 yards, and sand spits have been built out into the lagoon and have cut off the lake ...."

No records were found of the occurrence of pumice on the Western Indian Ocean atolls.

Very little information is available on the atolls and low coral islands of the Gulf of Mexico and the Caribbean Sea, and there are no records of pumice on them. However, in this connection, it is interesting to note that Guppy (1917, p. 6) mentions pumice pebbles found in beach drift in the West Indies.

## Probable origin and transport

Although the occurrence of pumice on coral atolls has, at times, greatly puzzled the observers -- especially when found far inland on the islets -- it has been generally accepted without argument that the pumice had been floated by the ocean after eruptions of distant volcanoes, carried about by currents, and deposited on the beaches of low islands in the same manner as other drift material.

Elschner (1915, pp. 35-36) wrote:

> "We can produce two sources of this pumice in the last decades. The Sunda Straight sustained great changes at the time of the eruption of the volcano Krakatoa, as immense quantities of pumice stone were thrown out, which were then washed ashore on the reefs and beaches of the different coral islands in the central Pacific Ocean; for instance, on Nauru, all over the Marshall Islands and the Mortlock atolls, etc., also in the northern part of the Pacific, pumice stone pieces, even though small quantities, were found drifting and washed ashore.
>
> "In the year 1906 ...., Captain Schlemmer at that time in charge of the phosphate works on Laysan Island (which have since ceased to exist) mentioned in his diary that he observed that a quake was to be felt and on the following days the sea was full of drifting pumice stone pieces. On his trip from Laysan Island to Honolulu he observed these pumice stone pieces as far as in the neighborhood of the main group near Kauai.
>
> "Appearance inland
>
> Seabirds, especially frigate birds, during their flight, pick up floating particles on the water and swallow them, so that the discovery of the pumice stone in the interior of the island is to be explained on the principal that undoubtedly the birds vomited these pieces.
>
> "The appearance of pumice stone in this neighborhood in March and April, 1906, is interesting; it documents the last traces of volcanic activity, which formerly were here of an imposing degree. At the mentioned time eruptions of the Hawaiian volcanoes did not take place and the occurrence of drifting stone, limited to this part of the group, was therefore of a local nature, that is, it most probably was caused by a quake of the ocean bottom in this neighborhood."

Yamanari (1935, p. 17) reports that after the eruption of a submarine volcano in 1934, large quantities of pumice drifted around in the seas near the Minami-Satsuma Islands.

The great quantities of pumice found on Sikaiana are perhaps more easily explained than if they occurred in the Tuamotus, for example. Sikaiana, a seldom described atoll, lies near many volcanoes, those of New Britain, the Solomon Islands, and the Santa Cruz Islands, to mention the nearest ones. Whichever of these the pumice came from, it did not have to travel very far and could be thrown up on the islands when great quantities of it were still floating together, before being scattered over greater expanses of the sea.

The question of how far and how long pumice can float was taken up by H. B. Guppy. He was fascinated by the factors responsible for the dispersal of plants; therefore he took great interest in the study of drift material and wrote two books on the subject. In another of his works (Guppy, 1887, pp. 137-144), he devoted a whole chapter to the drifting of pumice quoting many of the sources mentioned here and giving much information on the presence of pumice on high island beaches and at sea.

> "The pumice ejected during the volcanic outbreak at Blanche Bay in New Britain in May, 1878, was carried eastward by the drift-currents, and literally deluged the shores of the Solomon Group, both impeding navigation and temporarily suspending the beche-de-mer fishery .... Mr. Wilfred Powell, who was present at the time of the eruption in New Britain, states that Blanche Bay and a great part of St. George's Channel were so thickly covered with pumice that it was impossible for a boat or even a vessel to work its way through ....
>
> "Several agencies assist in the dispersion of a field of floating pumice. In the first place, the trituration or wear and tear of the fragments, a process by which they soon obtain the form of rounded pebbles, considerably reduces their size .... In the course of time the winds and waves scatter the floating fragments, and arrange them in long streaks a mile or more in length and some 25 or 30 yards in width .... Finally .... solitary fragments are scattered over the surface of the ocean where they may float for many years until their sodden condition causes them to sink. It is not unusual to find in the tow-net in the mid-Pacific a solitary stone, which has become so sodden that it has not sufficient buoyancy to float in fresh water.
>
> "The length of time that pumice will float in sea-water is a matter that bears on the distribution of this material over the various oceans. Judging from an experiment I made in the Western Pacific, pumice may float for several years before it becomes sufficiently sodden to sink to the bottom. I kept floating in seawater for two years and nine months three rounded pieces of andesitic pumice, which I originally obtained in the tow-net whilst cruising in the Solomon Islands. Although they had evidently been a long time in the water before

I got them, since they floated heavily and had the discolored appearance of old drift-pumice, the only evident alteration in their buoyancy produced by my experiment was that one piece which floated in fresh-water, when I first obtained it, now sank ...."

The origin of the great amounts of pumice found on Cocos-Keeling Atoll was also discussed at length by Guppy (1889, pp. 284-286):

"I shall refer more than once in these papers to the part which the pumice derived from the great Krakatoa eruption of 1883 has taken in reclaiming land from lagoon. Narrow inlets have been obliterated and the shallow water around the lagoon has been in places filled up by fields of floating pumice that drifted inside the reefs. The Krakatoa pumice, readily known by its white and fresh appearance and its unsodden texture, is to be found at present in great quantity on the beaches .... but there is another kind of this material, apparently elsewhere derived, though of somewhat similar composition, which is found inside the raised weather margins of the islands, and extends for some 20 paces or more amongst the trees. It is of much greater age; and whilst its outer surface is darkened by weathering, its interior is often sodden and half-rotten. There is also a black and heavier pumice, formed of a more basic lava, which is known (rightly or wrongly) amongst the residents as the Tomboro pumice, and is found amidst the vegetation 15-20 paces in from the weather beaches. It varies in size from a walnut to a coco-nut; and, unlike the two felspathic kinds of pumice above referred to, it withstands decay, so that although it has been known in the island for half a century and more, its internal substance is still unaltered ....

"Wherever, in these islands, a layer of old pumice overlies the sandy soil near the beach, an abundance of volcanic minerals, especially magnetite, occurs in the soil. By means of a magnet, a number of fine particles of magnetite can be collected from a saucer filled with the white calcareous sand that is found between the tide-marks upon the beaches .... The local evidence would seem to show that they [the grains of magnetite with their occasionally attached semifused feldspar crystals] are derived from the decay of pumice that is stranded in such large quantities on these beaches, especially since I found them in greatest abundance in the sandy soil underlying an old bed of pumice. Their large mean size, viz., half a millimetre, and the specific gravity of the mineral, would seem to favour this opinion. It should, however, be noted that during the night following the great eruption in the Sunda Straits, some 700 miles away, fine pumice dust fell over the Cocos-Keeling Islands in such quantity that on the succeeding morning it was found covering the deck of a schooner, that lay at anchor in the lagoon, with a layer a quarter of an inch deep ...."

Wood-Jones (1910, pp. 170-171) also discussed the origin of the Cocos-Keeling pumice:

> "On the seaward beaches is thrown the flotsam and jetsam that reaches the group from the outside world, and one of the principal items,-one that has in many places caused a considerable alteration in the character of the islands - is pumice. The greater part of the pumice found in the group arrived after the eruption of Krakatua; being washed up in 1883 in vast quantities. This pumice, lightest of all the wreck that the sea has piled up, has been carried for varying distances into the island from the seaward beach, and shows, as an index, the limit of surf action in the island building that has been reached in twenty three years. It occurs in great quantities as rounded sea-worn masses, some being a foot or more in their long axis, but the majority varying from the size of marbles to that of cricket balls. Besides the Krakatua pumice, which lies to-day mostly on the seaward beaches, and for a few paces into the island itself, there is older pumice which may be found almost anywhere in the breadth of the dry land. Pumice has been arriving from somewhere ever since the first appearance of land in the atoll ring, and has, during the period of its stay, undergone much decomposition. The Krakatau pumice is almost uniformly grey, and is fresh and clean: but pumice exists far from the sea that has become impregnated with foreign substances, and is in many places entirely fragmented. The various stages of pumice degeneration may be traced from the sea beach to the interior of the island. Some of the pumice has never been grey, and rounded blocks of a black and cinder-like substance are here and there found in parts of the island where pumice has been most freely washed ashore. This pumice does not appear to belong to any one particular period, for it is found to-day on the beaches, and in the islands, but its composition wherever found appears to be the same, and, on fracture, its internal part is always shining and fresh-looking, if it be picked up on the beach or far in the center of an island."

Wood-Jones, like Guppy, was interested in plant and animal dispersal and devoted a chapter of his book to this and related subjects. In it, he went back to the subject of pumice (pp. 290-291) and said of Krakatau pumice: "This pumice has been touring the ocean for over twenty years, and still, in the Sunda Straits, some set of current will send whole masses to sea, and a ship will steam for half an hour through the bobbing white balls of pumice which are launched upon an indefinite, and an irresponsible journey." Of the pumice older than that attributed to Krakatau he says: "This is most probably the pumice set adrift in the April of 1815, when the unparalleled eruption of Tomboro - the great volcano of Sumbawa took place." He adds: "The blocks of pumice set adrift by the eruptions have been navigating the Eastern seas ever since ...."

Visitors to Diego Garcia, Chagos Archipelago, were undoubtedly correct in believing the pumice they observed to be a product of the 1883 eruption: by a happy coincidence, two naturalists, Finsch and Wilson, stopped at Diego Garcia (then a coaling station) in 1884 and published their observations on the atoll. Finsch, (1887, p. 42) observed pumice on the lagoon strand and on the outer shore "in great quantity." Later, his ship encountered great drifting masses of pumice at sea. R. F. M. Wilson (1889, p. 144) spent only an hour on the atoll and mentions large quantities of pumice: "There must be tons of it lying on this beach." At sea, he also observed it, but in "wreaths." The Nautical Magazine in the last months of 1883 repeatedly warned its readers of the changes in the Sunda Strait and said (p. 852): "In some parts of the Straits the pumice stone is 7 ft. to 8 ft. deep."

Another instance in which the source of pumice was rightly identified as Krakatau is reported from Rameswaram Island, at the northwest end of "Adam's Bridge" in the Gulf of Mannar, between India and Ceylon, by Foote (1889, p. 835):

> "As we walked eastward along the beach our attention was attracted here and there by the quantity of pumice stone thrown up. Not a vestige of pumice was seen along the beach when I visited it in 1882, but now it abounded, having been drifted from the straits of Sunda after the terrible eruption of Krakatao in 1883. The pumice fragments were of all sizes, from a pin's head up to a child's head, and most of them showed signs of their long sea voyage, in the form of incrustations of nullipores of serpulae or of flustrae and other equally lovely polyzoa, together with serpulae of several species. Many specimens showed also adherent young valves of a very pretty white and crimson species of Spondylus. It was impossible not to be struck by the great number of zoological, geographical, and geological facts recorded by these interesting specimens."

Of the pumice observed in the Maldives and Laccadives during his expedition Gardiner (1906, p. 582) says: "On the shores of many of the islands there are lines of pumice, which the natives state were washed up about 1885, and would hence have probably owed their origin to the eruption of Krakatoa in 1883. In addition half-decomposed pumice is found, in places at some considerable distance inland, which evidently belonged to an earlier period." Ellis (1924, p. 9) in an account of the Laccadives, quotes Gardiner's suggestion that pumice found in the Maldives came from Krakatau, and adds that in the Laccadives, large beds of pumice were reported after 1883, "which have now entirely disappeared. Only scattered pieces much water-worn are now found." Sewell (1936 a, p. 77) also attributed the origin of the pumice observed on the Maldives to the eruption of Krakatau in 1883 (see p. 4 of this paper).

The 1883 eruption, however, despite its violence and the sensation it caused, was not the only source of pumice found in the Indian Ocean: Moresby (1844, p. 309) found pumice in the Chagos Islands when he surveyed the archipelago in 1836-37.

Most authors quoted here attribute the origin of the pumice directly to volcanic eruptions. This is undoubtedly the usual case, but it seems conceivable that some of this material might be launched onto the sea by the action of the waves undercutting the slopes of some of the numerous volcanic cones found in the Pacific. Some of this bobbing pumice may well have spent a good part of its time as part of a volcano's slope, before being freed and set adrift in the cone's erosion.

Lacroix (1939 a, p. 610) discussing the pumice collected by Seurat in South Marutea (Tuamotus) remarked that this chemical-mineralogic type of rock was known in the South Pacific only from Easter and Tutuila Islands and suggested an origin for it in a hypothetical submarine volcano that might have existed in some part of this vast region. It is not clear whether he had in mind an underwater eruption or a cone that extended above the surface and was subsequently cut away by the waves, but he probably meant the latter. In any event, it does not seem necessary to postulate the existence of such a volcano, because it is quite possible for pumice to float from Easter Island or elsewhere to S. Marutea.

The possibility should not be overlooked that some of this material, for example the coarse, black variety found by Fosberg in the Marshalls, might not be pumice at all but clinkers from the furnaces of coal-burning ships. Such have been reported cast up on the shores of Lake Michigan by Dr. Helen Foster and Mr. Gilbert Corwin (conversations, 1954). This may be determined for the Marshall Islands material by future petrological studies.

## Chemical and petrological nature

An obstacle to the discussion of the origin of pieces of pumice found on atolls is the fact that few have ever been studied for their petrological character and chemical composition. Recent unpublished analyses of such material will be found in an addendum to this paper, p. 21.

Lacroix based his remarks (1939a) on several analyses including one by Raoult of South Marutea material (Lacroix 1928, pp. 44-45. This is as follows:

| | Percent |
|---|---|
| $SiO_2$ ..... | 69.40 |
| $Al_2O_3$ ..... | 15.29 |
| $Fe_2O_3$ ..... | 0.46 |
| FeO ..... | 1.73 |
| MgO ..... | 0.11 |
| CaO ..... | 1.86 |
| $Na_2O$ ..... | 5.30 |
| $K_2O$ ..... | 3.91 |
| $TiO_2$ ..... | 0.32 |
| $P_2O_5$ ..... | 0.06 |

| | Percent |
|---|---|
| $H_2O$ (+) ..... | 1.57 |
| $H_2O$ (-) ..... | 0.36 |
| MnO ..... | 0.07 |

Lacroix described this material as a rhyolithic pumice, "formed of volcanic glass with elongated cavities, which contain a few hexagonal plates of biotite" as the only crystalized minerals. He remarked that its chemical composition showed in any case that it could not be pumice from Krakatau. He pointed out a similarity with the trachyte from nearby Pitcairn Island, suggesting that the pumice might not have come from too far away.

The pumice from Funafuti was examined by Cooksey (1896, p. 77):

> "Pumice Pebbles. -- Pebbles of pumice stone, the largest of which resemble a walnut in size, all much water worn and rounded, were collected from various places on the outer circumference of the Atoll, and possibly occur on all of these islets. They possess a fibrous texture, and contain macroscopic crystals of sanidine. The colour varies from light to dark grey, one or two having a brown or greenish tinge.
>
> "An analysis of one which was much rounded by attrition, and possessed a very light grey colour, gave the following percentage composition:--

| | |
|---|---|
| Hygroscopic moisture ... ... | .09 |
| Loss on ignition ... ... | 2.29 |
| $SiO_2$ ... ... | 66.50 |
| $Fe_2O_3$ ... ... | 3.21 |
| $Al_2O_3$ ... ... | 16.84 |
| CaO ... ... | 3.03 |
| MgO ... ... | 1.03 |
| $K_2O$ ... ... | 5.44 |
| $Na_2O$ ... ... | 2.53 |
| $P_2O_3$ ... ... | trace |
| | 100.96 |

> "A partial analysis of another pebble of a darker shade gave 60.37% of $SiO_2$."

Cooksey noted that the figures in this analysis agreed very closely with results of analyses of material from the 1883 Krakatau eruption but thought

this volcano too far away to be a likely source of the pumice in Funafuti.

Uses: Agricultural and abrasive.

In the Gilbert Islands the U. S. Exploring Expedition learned that pumice was gathered by the inhabitants and pounded up to fertilize the soil of the taro pits; in addition, Wilkes (1845, vd. 5: p. 81) writes: "the coconut trees are fenced round, and pounded pumice is mixed with the soil near their roots. This stone is collected by the women, who are frequently to be seen in numbers on the beaches, after westerly winds, picking it up in small baskets."

Hartzer, a missionary (1900, p. 43) writes in almost the same words, and so does Kurze (1887, p. 68). Such observations on the taro-pits have been made or quoted by others, such as Meinicke (1863, p. 405) and Finsch (1893, p. 52). Gulick (1862, p. 413) also described the careful tending of the taro-pits but said that soil was brought to them in baskets and shifted. He did not mention pumice. Probably both were added to the various leaves, which were shredded and thrown into the pits. A similar instance is found in Grundemann (1887, p. 442): According to him, on Ailuk in the Marshalls, soil and leaves were thrown into the pits, and pumice, when available, was ground up and added. This is the only record of this practice in the Marshall Islands. Similarly Cloud's observation of the use of pumice as fertilizer on Kayangel Atoll, Palau (personal communication, 1953), is the only record for the Caroline Islands.

In spite of its abundance on the Ellice Islands, pumice does not seem to have been used there as in the Gilberts. It might be pointed out here that the Gilbert Islands are the most densely populated of all atolls and at the same time one of the driest and most sterile of the inhabited atolls and at the same time one of the driest and most sterile of the inhabited atoll groups. In this connection it is noteworthy that pumice is used as fertilizer in another densely populated group, the Maldive Islands. Gardiner (Willis and Gardiner, 1901, p. 121) says that on Suvadiva, plantains are grown in pits dug to below high tide level "and on Kondai [islet of Suvadiva] I saw a man put in a basket a pumice from the beach; this appeared on enquiry to be a regular custom of the island."

In addition to its role in atoll agriculture, pumice is often used on these limestone islands as an abrasive: In the Gilberts, Finsch (1914, p. 254) says that pumice was used to polish and smooth wood, shell, and coral. In Ujae (Fosberg, unpublished observations 1951-52), the Marshallese called it by the name "tilan," and they said they used it like sandpaper. A large piece of a black, coarse-grained, hard variety was seen in use as a whetstone for machetes on Bock Islet, Ujae.

Ecological significance

Very little factual information is available on the ecological significance of pumice on atolls. Several authors have discussed it, following three main lines of speculation: One is the possible role of pumice in the dissemination of animals from one shore to another. Another is the information that pumice has been supposed to furnish on ancient shorelines. The most important is the possible influence of pumice on the growth of plants.

Some of the above-mentioned authors, such as Whitmee and Guppy, have spoken of pieces of pumice incrusted with marine animals such as annelids, cirripeds, bivalves. Wood-Jones (1910, p. 291), after his discussion of the origin of stranded pumice (see p. 8 of this paper) added: "the blocks of pumice ... have visited many shores in the course of their travels, and have constituted a mighty fleet of passenger vessels for the use of Nature's colonists." In some cases pumice may play a certain role in the dissemination of marine forms, but it seems that Wood-Jones exaggerated the "mightiness" of the effect.

Guppy's chapter on pumice drift (1887, pp. 137-144), in spite of some hasty and regrettable assertions (a footnote on p. 143 says that "the trees of the center of a coral islet grow from seeds ejected by the fruit-pigeons), contains a wealth of facts and is one of the few compilations and discussions of the intriguing problem of stranded pumice. The author attempts to clarify the ecological significance of this material. Unfortunately he had a tendency, at times, to let his keen observations be colored by the theories dear to him. Thus, in his notes on the distribution of pumice pebbles on islets (Guppy, 1887, p. 141), he mixes facts and assumptions:

> "I shall subsequently point out, that as we cross a coral islet from its weather or newer portion, the pumice pebbles become fewer and more decayed, until they finally disappear in the leeward or older part of the islet. Such a fact proves that this material has not been swept over the surface of the islet by a single wave, such as those which follow earthquakes, but that, whilst the islet has been growing sea-ward with the reef in the course of ages, pumice has at widely different times been stranded on its shores. The decayed pumice pebble, that now lies among the trees in the interior of the islet, remains where the ebbing-tide left it long ago. The same explanation is also applicable to the pumice pebbles found on coral islets and reefs that have experienced some degree of elevation. Doubtless the "great sea wave" produced by an earthquake has sometimes distributed the pumice pebbles lying on the beach over the surface of the islet; but if it will be found, as I believe, to be generally true, that the pebbles get fewer and more decayed as we proceed into the interior, we must look to some other agency than that of the "great sea wave." In some coral islands which are placed in unprotected positions in the Pacific, pumice pebbles are found only in the interior and not on the beach. It would seem most probable that the force of the wind during storms would be sufficient to sweep the light pumice pebbles off the beach and amongst the bordering vegetation.
>
> "All the evidence goes to show that in a comparatively dry climate and on porous soil stranded pumice may resist for ages the disintegrating effects of the atmospheric agencies."

Guppy goes on to describe the distribution of the pebbles on coral islets in the Solomons and shows them to be fewer and more decom-

posed toward the interior, disappearing eventually on the lee side.

> "Those obtained within 20 or 30 paces from the beach floated buoyantly in the sea, but out of those found at distances greater than 100 yards, more than half sank. The pumice pebbles furthest from the beach were evidently of greater age and had been exposed for a longer time to the wet."

No doubt, on certain islands -- possibly on some of those examined by Guppy -- older pumice brought by one of the variously caused "great waves", which may at times completely cover low coral islets, is partly removed from the beaches by subsequent lesser storms and later happens to be surrounded by younger pumice, left stranded in windrows by the ordinary tides. (See quotation of Gardiner on p. 9 of this paper). This does not necessarily mean that the islet has become larger, offering more space for new pumice. The contours and total area of islets do change of course, and if an islet became larger, it might be from its seaward side, but the aspect and distribution of pumice are not sufficient to permit a reconstruction of the change. However, in certain special locations and when other evidence is available, pumice pebbles arranged in lines, well inland, may indicate a change in shoreline. Stone (1951, p. 2), writing of Arno Atoll, Marshall Islands, says "The progressive widening of Arno Island, although now slow, is known to the people there because inland and parallel with the beach they find rows of pumice pebbles such as occur along the present beach." (See also quotation of Sewell on p. 18 of this paper).

That Guppy does not realize the true relationship between topography of an islet, soil and vegetation is well shown in his next topic: He assumes (Guppy, 1887, p. 143) that soil gets thicker and richer from seaward to lee side of an islet because "we pass ... from its newest to its oldest portion" and therefore pumice has had more time to form soil, has been completely decomposed, and indeed, cannot be found anymore on the lee side. Actually there may never have been as much pumice in the center and on the lee side of this islet as on the seaward side. Vegetation does change as one goes from seaward to the more protected side of the islet, but this change is brought about by the topography and structure of the islet and the diminution in the effects of wave, wind, spray, etc. The vegetation in turn, together with these same factors, determines the variation in the abundance of soil, which is indeed often thicker in the center, or toward the lee side of an island, or the lagoon side of an atoll islet. But this zonation of soil and vegetation is quite independent of the presence of pumice. It is possible, of course, that given a uniform pumice layer over an islet to begin with, the pumice might decompose somewhat faster near the center of the islet than on the seaward side, because a thicker and faster forming soil and humus layer in this center would provide a greater abundance of the substances that cause the decomposition of the pumice pebbles.

While Guppy tried to prove the beneficial influence of pumice on the vegetation of a coral islet, other authors took it quite for granted. Scherzer (1862, p. 607) says:

> "Another geological peculiarity is the occurrence of heaps of pumice-stone. These are found about the size of walnuts over the entire interior of Faole at those places which the swell of the waves cannot reach even in the stormiest weather, where they occur in such immense quantities (though there are no traces of them on the sand or shingle of the actual beach) that we may take for granted that the convulsion which brought them here must have occurred in times long gone by, the more so as this superposed pumice-stone exercises a marked and obvious influence upon the vegetation of the island. So far as its soil consists of heaps of fragments of coral and mussel-shells, the cocoanut palm reigns almost alone, whereas as soon as the pumice-stone region is reached, there begins an exceedingly luxuriant growth of lofty forest trees with huge trunks and umbrageous foliage, and an astonishing abundant flora of species apparently peculiar to these Atoll Islands."

This correlation of vegetation with substratum, also mentioned by Hochstetter, may be somewhat illusory, since the coconut palms were probably planted by the natives in a ring around the islet, and the luxuriance of the mixed forest, which includes breadfruit trees, is not too unusual in a very wet atoll such as Sikaiana. Yet the observations by Scherzer and Hochstetter are very interesting. It would certainly be worthwhile to find out now, almost 200 years later, what the soil of Faule Islet is like and whether any traces remain of the abundant pumice layer observed by the naturalists of the "Novara."

## Other noncalcareous rocks

Various extraneous materials other than pumice are found on atolls: these are various stones, muds, etc., found among the roots of drift trees, or supposedly brought by them, other pieces of rock or even masses of coal or soil imported by men for various reasons, and finally the mysterious "basalt blocks" described from various islands.

The latter are of special interest on Rose Atoll, in American Samoa. This very small, uninhabited, and isolated island may have been first landed on by members of the U. S. Exploring Expedition (1838-42). Dana (1849, pp. 77-78) says that the officers on the Vincennes observed blocks of compact cellular basalt on Rose, lying 200 yards inside the line of breakers. Wilkes (1845, vol. 2, p. 64) adds that "they were from twenty to two hundred pounds weight, and were found among blocks of coral conglomerate." Unfortunately, Dana himself did not land on Rose, being on another ship. Couthouy (1842, p. 138), who was probably there, says that the volcanic boulders were found on the sandy lagoon bottom and were similar in appearance and mineral structure to the rocks forming the mass of Samoa and Tahiti and that one of them weighing about 20 pounds was picked up in 4 feet of water among small rolled blocks of coral conglomerate. At least one member of the landing party of the "Vincennes" published his own account of the discovery, although his book is not part of the official edition of the Expedition results; Pickering (1876, p. 235) writes:

> "For the first time on a coral-island, the mineral kingdom was represented; several blocks of vesicular lava being met with by our party; in all instances resting upon the coral-shelf, not imbedded. Two or three of these blocks were seen by myself, the largest weighing perhaps twenty pounds. From the mineral composition, they had evidently been derived from some volcanic island; and there seemed no means of transportation, unless entangled in driftwood. This actually takes place at the Tarawan coral-islands; where Mr. Hale found a native name for "Basaltic stones in the roots of trees drifted" to those shores."

Much has been made, in later works, of the discrepancy between the various accounts, as to the location of the boulders. And when A. G. Mayor, visiting Rose Atoll in June 1920, failed to find them "after diligent search" (Mayor 1924), it was generally assumed that the U. S. Expedition had mistaken blackened coral boulders for vesicular volcanic rock. This error is not hard to make, but it should be kept in mind that Couthouy and the officers of the Vincennes were not without experience of atolls, darkened coral boulders, etc., having visited a large number of the Tuamotus before reaching Rose. Later L. P. Schultz, a member of the U. S. Navy surveying expedition to the Phoenix and Samoa Islands (U. S. S. Bushnell), spent 11 days on Rose Atoll in June 1939, and found pieces of compact olivine basalt on the reef (a dozen or more, the largest the size of a man's head) and confirmed observations of the "Vincennes" party thereby reopening the question of the origin of the material (Schultz 1940, p. 48 and unpublished data). His specimens of it are deposited in the U. S. National Museum, where they are currently being studied.

Another occurrence of mysterious volcanic material is reported by Agassiz (1903 a, p. 350) on Andema [Ant] Atoll: "On Panemur, the westernmost island of the group, large coral boulders form the outer edge of the reef flat, with here and there a few fragments of volcanic rock ...." Unfortunately, Agassiz did not always make clear whether he was writing an eye-witness account, and we cannot be sure of this record as yet. The proximity to Ant of volcanic Ponape might help to explain the presence of the rocks, besides making it rather easy to confirm their existence.

One last record of "basalt" on an atoll was discovered with great excitement in the narrative of Captain John Cameron (1923, p. 397): He described "great basaltic stones" on Caspar Rico [Pokak Atoll, Marshall Islands], one of them "fifteen feet and six inches long, five feet and four inches wide, and three feet thick," and speculated on the hazards of their transport from some high island. Great expectations were raised when the Northern Marshall Islands Expedition explored the desolate atoll in the summer of 1952. No megaliths were found, but a lot of blackened coral boulders and remnants were (Fosberg, 1955 p. 28).

A different type of volcanic rock is recorded by Guppy (1889, pp. 286-287) from Cocos-Keeling Atoll. He writes:

> "Near the middle of the breadth of Horsburgh Island /islet of Cocos-Keeling/, and about 300 yards from the sea, there was, when these islands were first occupied, some sixty years and more ago, a huge volcanic bomb about four feet in height. It was somewhat dome-topped, and was imbedded about six inches in the soil. By the islanders this large mass of foreign rock, with its unknown history, was regarded with much mystery. It lay concealed in the midst of an ironwood forest of great antiquity, where it must have lain for ages; and its burnt-up appearance seemed to support the prevailing opinion that it was some meteoric stone ... Pieces have been taken away by the inhabitants .... the result of this practice being that at the time of my visit in 1888 only a few fragments, none much more than a foot in size, remained to illustrate the description given to me by Mr. Ross. They were, however, sufficient to disclose to me that this mysterious stone was a huge volcanic bomb of a dark reddish cellular lava, possessing a comparatively solid outer crust. The cellular fragments floated buoyantly on the sea; but the more solid parts of the outer crust, on which I also experimented, sank. Nevertheless, as the greater part of the original mass, according to the description given to me, was evidently cellular, I had no doubt in forming the opinion that the whole bomb originally floated."

The observant natives of atolls, who have been collecting pumice stones drifting onto their beaches, have also made much use of drifting logs especially on such islands as the Marshalls or Gilberts, where the supply of usable timbers for canoes and other constructions are pitifully small. They discovered that the roots of some such trees held stones and blobs of earth or mud and carefully collected and utilized these, as well as the wood. This was observed in the Gilbert Islands by Hartzer (1900, p. 48) who says that the large trees often hold pieces of resin like those found in the New Zealand forest, and stones of fine basalt, which are much esteemed and used to make weapons. Dana (1849, p.77) saw some large logs on Enderbury, Phoenix Islands, and in the Gilberts, which carried stones in their roots, and reported that on the latter islands these stones were usually basaltic or volcanic and much prized for use as whetstones, pestles, and hatchets (see also quotation of Pickering, p.16 of this paper).

Darwin himself (1852, p.461) discusses such occurrences and mentions that on North Keeling, Captain Ross /owner of the island at the time of the Beagle's visit/ had found and preserved a green stone, rather larger than a man's head, embedded in the conglomerate. Darwin supposed it to have arrived on this seldom-visited atoll caught in the roots of a tree. Wood-Jones actually saw such occurrences on Cocos-Keeling and explains (1910, p.290) that buttresses -- common in many tropical trees -- are especially suited for such transport: "I have seen a 'buttressed' tree come ashore in the atoll: from whose base a wheelbarrow-load of fine red earth might have been collected ... From the roots of such a tree I have taken small stones..."

Eilers (1935, p.151) says of the natives of Songosor [Sonsorol, Western Carolines] that they use volcanic stones found in drift wood to smooth fibers used for plaiting.

In Micronesia, at least black mud found among such roots was often use to dye fibers. Thilenius (Thilenius and Hellwig 1927, p.204) reports such a custom on Tobi.

Earlier Chamisso (1821, p.155) wrote of the Marshallese:

> "They receive, in a similar manner, another treasure, hard stones fit for whetting. They are sought for in the roots and hollows of the trees which the sea throws up: iron and stones belong to the chiefs, to whom they must be delivered, on payment of a reward ...."

When the desired stones or soils were not available, the natives of the Caroline atolls, who did much voyaging and trading with high island peoples, imported them. Chamisso (1821, p.104) describes with some emotion, how Kadu, a native of Woleai whom the "Rurick" met in the Marshalls and took along for part of the voyage, "never neglected carefully to collect pieces of iron, broken glass, and everything overlooked by us, which might be valuable to his countrymen, he looked on the shore at Oonalashka, chiefly for stones, which might serve for whet-stones ..."

Girschner (1912, p.157) reports that on Namoluk, red earth imported from Ponape was used as a dye. On Pulusuk and Satawal, Damm et al. (1935, p. 81) mention similar imports from Truk. Finally E.G. Burrows (1949, p.12) found a single igneous boulder on Falalap Islet, Ifalik Atoll in 1947-48, which the natives told him had been brought by canoe in ancient times to be used as a whetstone.

Oldham (1895, p.6) reports that he saw pieces of volcanic stone and a green stone on the north end of Chitkak Island (Laccadives), which the natives had brought from the ballast of a steamer wrecked on Byramgore Reef.

This is not the only instance of material from a wrecked ship occurring on reef or atoll: At Ujelang Atoll, F.R. Fosberg (personal communication) in 1952 found small and completely waterworn pieces of coal scattered at the top of the lagoon beach and inland on the west side of Ujelang Islet.

Of some material observed on Laysan Elschner (1915, p.35) writes:

> "... I wish to mention the occurrence [on Laysan] of smaller stones of volcanic material on the reef and beach. To prevent errors it may be remarked that they come out of the ballast of the phosphate ships formerly loading here; however the occurrence of pumice stone in the lagoon and on the shore of Laysan Island, as well as on the shores of Mecker, Pearl and Hermes Reef, Lisiansky and Midway Islands, is unusually interesting."

That natives of atolls valued foreign stones and were intrigued by them is shown further by the fact that in widely separated atolls, they made idols out of them. Gill's observation on the subject is mentioned earlier on p. 1. In addition, various missionaries and other residents have reported similar instances in the Marshalls (verbal communications).

## Imported soil

But the native people are not the only ones to have carted stones and soil around. On many atolls, the white residents, in an attempt to grow the vegetables to which they were accustomed, brought soil, often as ship ballast, from neighboring high islands: the Germans did so on Jaluit, the superintendent of the Cable Station did so on Midway (Bryan 1942, p. 202), and more recently small quantities have been brought to Kwajalein, and Johnston Island.

Wood-Jones (1910, p.180) says that 40 tons of soil were brought in 1902 from the Botanical Gardens of Singapore to Pulu Tikus, islet of Cocos-Keeling. He remarks that by 1905 "any trace of it was hard to find." Further information on soil imported into Cocos-Keeling is given by Gibson-Hill (1950, p.150).

## Conclusions

Floating pumice, drifting on the ocean, is deposited on the shores or inland on low islands scattered in most parts of the tropics. It is used by the natives for polishing, whetting, and above all, for fertilizing garden pits and coconut-trees; it must have some influence on plant-life; and it may indicate changes in shore lines in certain localities. It is to be regretted that so few records are available, that so few collections and analyses of the various materials observed were made, that so little is known of the ecological role of pumice, and that it is not easier to revisit some of the recognizable localities to find out what has become of the earlier recorded pumice. Has it become buried in humus? How fast is it "decomposing?" Has it left traces in the form of various minerals as assumed for Kita Daito Jima? There, the origin of the iron and aluminum in thick deposits of iron and aluminum phosphates is assumed to have been large masses of sea-borne pumice (Yamanari, 1935) some of which is still found on the island. Pumice might also be the source of the abnormally high content of aluminum found by Lipman and Shelley (1924, p.205) in the soil of Rose Island.

The widespread and, at times, extensive occurrence on coral atolls of extraneous volcanic materials so different from the normal calcareous substratum emphasizes the need for thoroughness in investigation and caution in drawing ecological conclusions. The fact that the natives of several groups of atolls have discovered the fertilizing effects of pumice applications brings out very strongly the ecological significance of this material. In any general investigation of atoll soils, attention should be devoted to discovering and assessing these effects and to isolating the properties of components of the pumice responsible for them.

## Addenda

After this review was completed, the work of Tayama on Micronesian coral reefs came to hand; it contains (Tayama 1952, pp. 152, 265) in a discussion of problems offered by coral reefs, an enumeration of occurrences of non-calcareous material on coral islands, which can be quoted here from the English text (p. 265):

> "Reef building corals, Foraminifera, calcareous algae, Mollusca, Echinodermata, sponges, Bryozoa, etc. are the construction materials of a coral island. Other and non-calcareous matter is extraneous. Pumice, however, is found in all coral islands, and will not be brought under discussion here.
>
> "a. Basalt gravel, in part intercalated in limestone, has been found on an isolated reef on Truk Almost Atoll and at a few localities on outer reefs.
>
> "b. Liparite gravels, scattered locally on the Jaluit Coast and Utwa Coast of Kusaie, are apparently from ballast washed ashore from wrecked vessels.
>
> "c. Boulders of crystalline schist are present on Pakin Atoll and granite, quartzite, and andesite boulders on Merir Table Reef.
>
> "d. One pebble of crystalline schist and two pebbles of basalt gravels are included in limestone (Younger Raised Coral Reef Limestone) on Etal Atoll.
>
> "e. The phosphatic reddish brown clay intercalated in the cay sandstone (Younger Raised Coral Reef Limestone) of Gaferut Island has already been mentioned. The analysis is as follows:

| $SiO_2$ | CaO | $Fe_2O_3$ | $Al_2O_3$ | $P_2O_5$ |
|---|---|---|---|---|
| 3.28 | 48.97 | 3.17 | 2.50 | 19.35% |

> "f. Beach sands on the lagoon shore of Marugai (coral islet) on Mille Atoll contain substantial amounts of magnetite and amphibole. Conditions of deposition rule out transportation by man or by wave action...."

An unpublished observation by F. R. Fosberg may also be added here: In October 1953, a worn boulder, over a foot long, seemingly of very light gray granite, was observed on Wake Islet, Wake Atoll. On inquiry of residents of the atoll, it turned out that this was brought by a Japanese party a year or so earlier, to mark a grave of Japanese soldiers killed there during the war.

During the U. S. Commercial Company's Economic Survey of Micronesia in 1946 the late Dr. Josiah Bridge found pumice on Nukuoro Atoll, south central Carolines. Details of this occurrence are not available.

In the summer of 1954, pumice was found on Kapingamarangi Atoll by members of the Pacific Science Board Expedition. Both light gray and black pumice are abundant on the back shore beaches of most islets, occasionally forming pure pumice layers. Details of occurrence and chemical analyses will appear in a later report by Edwin D. McKee who kindly provided the above information.

Of the specimens of pumice collected in the Marshall Islands by F. R. Fosberg in 1951-1952 (see p. 2 of this paper), some were submitted for quantitative spectrographic analysis for specified minor elements to the Geochemistry and Petrology Branch of the U. S. Geological Survey.

The specimens were as follows:

Field no. 242: A white pumice from Jemo Island
243: A dark fine pumice from Jemo
244: A black scoriaceous pumice from Jemo
245: A pale gray fine pumice from Ujae Atoll
246: A gray pumice from Ujelang Atoll
247: A gray pumice from Ujelang Atoll
248: A gray pumice from Wotho Atoll
249: A gray pumice from Pokak Atoll

| Field no. | Cu | Mn | Co | Fe | B | % Loss on ignition |
|---|---|---|---|---|---|---|
| 242 | .0009 | .1 | .0009 | 3.3 | 0 | 2.2 |
| 243 | .003 | .2 | .002 | 7.7 | 0 | 1.0 |
| 244 | .009 | .1 | .002 | 5.3 | .004 | .14 |
| 245 | .003 | .1 | 0 | 2.7 | 0 | 4.3 |
| 246 | .002 | .09 | .001 | 3.6 | 0 | 3.4 |
| 247 | .003 | .1 | .001 | 3.5 | 0 | 4.6 |
| 248 | .001 | .1 | 0 | 2.9 | .002 | 4.1 |
| 249 | .001 | .1 | 0 | 3.4 | .002 | 4.1 |

All samples were ignited at 900°C for 15 minutes. The following elements were not detected in any of the samples: Mo, Zn, P.

## Bibliography

Agassiz, A.
The coral reefs of the tropical Pacific.
Mem. Mus. Comp. Zool. Harvard 28: 1-410, 1903a; plus 3 volumes of plates and maps.

---

The coral reefs of the Maldives.
Mem. Mus. Comp. Zool. Harvard 29: 1-168, 1903b.

Alcock, A.
A naturalist in Indian Seas.
1-328, London, 1902.

Anon.
Sunda Strait.
Naut. Mag. 52: 849-852, 1883.

Bryan, E.H., Jr.
American Polynesia and the Hawaiian Chain.
1-253, Honolulu, 1942.

Burrows, E.G.
The people of Ifalik, a little disturbed atoll culture.
CIMA Rept. 16: 1-222, 1949 (unpublished, see next entry).

Burrows, E.G. and Spiro, M.E.
An atoll culture. Ethnography of Ifaluk in the Central Carolines.
1-353, New Haven, 1953 (offset by Human Relations Area Files).

Cameron, J. [Farrell, A., ed.]
John Cameron's Odyssey.
1-461, New York, 1923.

Chamisso, A. von
Remarks and opinions ... of the naturalist of the expedition: in, Kotzebue, A voyage of discovery .... 3: 1-318, 436-442, 1821.

Cloud, P.E., Jr.
Preliminary report on geology and marine environments of Onotoa Atoll, Gilbert Islands.
Atoll Res. Bull. 12: 1-73, 1952.

Cooksey, T.
Rock specimens.
Australian Mus. Mem. 3: 73-78, 1896.

Couthouy, J.P.
Remarks upon coral formations in the Pacific.
Boston Jour. Nat. Hist. 4: 66-105, 137-162, 1842.

Damm, H., Hambruch, P., and Sarfert, E.
Inseln um Truk (Polowat, Hok, und Satowal) :in, G. Thilenius, Ergebnisse der Südsee Expedition II B 6, 2: 1-288, 1935.

Dana, J.D.
Geology: in, U.S.Exploring Expedition 10: 1-756, Philadelphia, 1849.

Darwin, C.
Journal of researches ....
1-519, London, 1852.

Dixon, W.A.
Notes on the meteorology and natural history of a guano island, and, The guano and other phosphatic deposits occurring cn Malden Island.
Jour. Proc. R. Soc. N.S.W. 11: 165-175, 176-181, 1877.

Eilers, A.
Inseln um Ponape (Kapingamarangi, Nukuo, Ngatik, Mokil, Pingelap): in, G. Thilenius, Ergebnisse der Südsee Expedition II B 8: 1-464, 1934.

---
Westkarolinen: in, G. Thilenius, Ergebnisse der Südsee Expedition II B 9, 1: (Songosor, Pur, Merir): 1-405, 1935.

Ellis, R.H.
A short account of the Laccadive Islands and Minicoy.
1-123, Madras, 1924.

Elschner, C.
The Leeward Islands of the Hawaiian group.
1-68, Honolulu, 1915 (reprinted from Honolulu Advertiser, 1915).

Finsch, O.
Ein Besuch auf Diego Garcia im Indischen Ozean.
D. Geogr. Bl. 10: 30-42, 1887.

---
Ethnologische Erfahrungen und Belegstücke aus der Südsee.
Dritte Abtheilung: Micronesien (West-Oceanien).
Ann. Naturhist. Mus. Wien 8: 1-106; 119-275, 295-437, 1893.

---
Südseearbeiten.
1-605, Hamburg, 1914 (published as vol. 14 of Abhandlungen des Hamburgischen Kolonialinstituts).

Foote, R.B.
Notes on Rameswaram Island.
Madras Christian College Magazine 7(5): 828-840, 1889.
Seen only as typed quotations by courtesy of Mr. T.W. Ballard.

Fosberg, F.R.
Northern Marshall Islands Expedition 1951-1952. I. Narrative.
Atoll Res. Bull. 38: 1-36, 1955.

Gardiner, J.S.
The fauna and geography of the Maldive and Laccadive Archipelagoes.
2: 473-1078, 1906.

Gibson-Hill, C.A.
Notes on the insects taken on the Cocos-Keeling Islands.
Bull. Raffles Mus. 22: 149-165, 1950.

Gill, W.W.
Myths and songs from the South Pacific.
1-328, London, 1876.

Girschner, M.
Die Karolininsel Namoluk und ihr Bewohner.
Baessler-Archiv 2: 123-215, 1912.

Grundemann, D.
Unser kleinstes Schutzgebiet, die Marshallinseln.
D. Kolon. Zeit. 4: 441-444, 1887.

Gulick, L.H.
Micronesia.
Naut. Mag. Nav. Chron. 31: 169-182, 237-245, 298-308, 358-363, 408-417, 1862.

Guppy, H.B.
The Solomon Islands: their geology, general features, and suitability for colonization.
1-152, London, 1887.

---
The Cocos-Keeling Islands.
Scott. Geogr. Mag. 5: 281-297, 457-474, 569-588, 1889.

---
Plants, seeds and currents in the West Indies and Azores.
1-531, London, 1917.

Hartzer, F.
Les Iles Blanches des Mers du Sud.
1-345, Paris, 1900.

Hedley, C.
General account of the atoll of Funafuti.
Australian Mus. Mem. 3: 1-71, 1896.

Hochstetter, F. von
Das Stewart-Atoll im Stillen Ocean: in, Reise der Oesterreichischen Fregatte Novara ....
Geologischer Theil II, 1: 153-161, 1866.

Jukes, J.B.
Narrative of the surveying voyage of H.M.S. Fly ...
2 vols., London, 1847.

Keating, A. S.
[Account of Cocoas or Keeling's island]: in, J. Holman, Travels in China, New Zealand .... Ed. 2.
4: 374-385, 1840.

Kubary, J.
Beitrag zur Kenntnis der Nukuoro- oder Monte Verde Inseln (Karolinen-Archipel).
Mitt. Geogr. Ges. Hamburg 16: 71-138, 1900.

Kurze, G.
Mikronesien und die Mission daselbst.
Allg. Missions-Zeitschr. 14: 64-80, 123-128, 1887.

Lacroix, A.
La constitution lithologique des îles volcaniques de la Polynésie australe.
Mém. Acad. Sci. Paris 59(2): 1-82, 1928.

---
Remarques sur les volcans sous-marins, à propos de ponces rhyolitiques recueillies sur l'atoll Marutea du Sud (Archipel des Tuamotu).
C.R. Acad. Sci. Paris 208: 609-611, 1939a.

---
Les ponces dacitiques flottant sur l'océan, entre les Fiji, les Nouvelles-Hébrides et la Nouvelle-Calédonie.
C.R. Acad. Sci. Paris 208: 853-857, 1939b.

Lipman, C.B. and Shelley, P.E.
Studies on the origin and composition of the soil of Rose Islet.
Carnegie Inst. Pub. 340: 201-208, 1924.

Mayor, A.G.
Rose Atoll, American Samoa.
Carnegie Inst. Pub. 340: 73-79, 1924.

Meinicke, C.E.
Die Gilbert- und Marshall-Inseln.
Zeitschr. f. Allg.Erdk. Berlin n.s. 15: 369-417, 1863.

Moresby, [R.]
[The Chagos Archipelago].
Trans. Bombay Geogr. Soc. 1: 307-310, 1844.

Munro, G.C.
Notes on Midway Island birds.
Elepaio 6: 43-46, 1946.

Oldham, C.F.
The topography of the Arabian Sea in the neighbourhood of the Laccadives, and the physical features of some of the Laccadive Islands.
Jour. Asiat. Soc. Bengal 64(2): 1-14, 1895.

Pickering, C.
Geographical distribution of animals and plants [Part II]: in, [U.S. Exploring Expedition 19 (2)]: 1-524, [Philadelphia, 1876].

Sachet, M.-H.
A summary of information on Rose Atoll.
Atoll Res. Bull. 29: 1-25, 1954.

Schauinsland, H.H.
Drei Monate auf einer Korallen-Insel (Laysan).
1-104, Bremen, 1899.

Scherzer, K.
Narrative of the circumnavigation of the globe by the Austrian Frigate Novara ....
Vol. 2: 1-627, London, 1862.

Schultz, L.P.
The Navy surveying expedition to the Phoenix and Samoa Islands, 1939.
Smiths. Explor. 1939: 45-50, 1940.

Seurat, L.G.
Observations sur la structure, la faune et la flore de l'île Marutea du Sud (archipel des Tuamotu).
1-18, Papeete, 1903.

Sewell, R.B.S.
An account of Addu Atoll.
J. Murray Exp. Rept. 1: 63-93, 1936a.

---
An account of Horsburgh or Gorfurfehender Atoll.
J. Murray Exp. Rept. 1: 109-125, 1936b.

Stone, E.L., Jr.
The soils of Arno Atoll, Marshall Islands.
Atoll Res. Bull. 5: 1-56, 1951.

Tayama, R.
Coral reefs in the South Seas.
Bull. Hydrogr. Office Japan 11: 1-292, 1952.

Thilenius, G. and Hellwig, F. E.
Allgemeines: in, G. Thilenius, Ergebnisse Südsee Expedition ....
I: 1-489, Hamburg, 1927.

Van Zwaluwenburg, R. H.
Canton Island.
Hawaiian Pl. Rec. 45: 15-24, 1941.

Whitmee, S.J.
[Note on pumice in Ellice Islands].
Nature 19: 108, 1878.

Wilkes, C.
Narrative of the United States Exploring Expedition during the years 1838, 1839, 1840, 1841, 1842.
5 vols., Philadelphia, 1845 ( unofficial octavo edition used for convenience).

Willis, J.C. and Gardiner, J.S.
The botany of the Maldive Islands.
Ann. R. Bot. Gard. Peradeniya 1: 45-164, 1901.

Wilson, R.F.M.
An hour on a coral island-- by a student of lichenology.
Vict. Nat. 5: 141-145, 1889.

Wood-Jones, F.
Coral and atolls.
1-392, London, 1910.

Yamanari,
Aluminum phosphate deposit in Kita Daito-Jima.
Contr. Inst. Geol. Pal. Tohoku Univ. no. 15: 1935.
Seen only as translation, by T. Hirasawa, pp. 1-73, filed in U.S.Geological Survey Library, Washington, D.C.