detection of many resonant modes of a piezoelectric crystal. By simply pressing the crystal against his neck while sweeping the frequency spectrum with a variable frequency oscillator, the experimenter could locate weak resonances which the usual crystal resonance measuring circuit fails to indicate. Such weakly coupled modes were, of course, confirmed by more sensitive laboratory measurements.

A study of the mechanism by which ultrasonic vibrations over a wide frequency range are converted into an apparently constant band of audible sound suggests certain useful medical applications, such as in tests for certain types of deafness and, possibly, as a novel form of hearing aid. Also, in the field of communication, it is feasible by utilizing the ultrasound perception effect to devise signaling systems with unique performance characteristics for special purposes. Other possibilities will undoubtedly appear with further studies which will lead to a better understanding of the nature of the effect.

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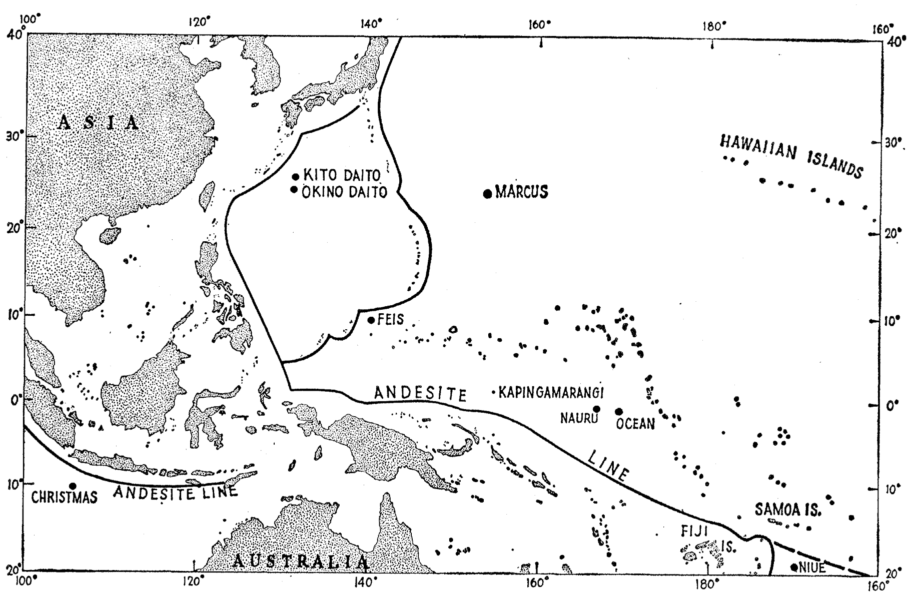

Fig. 1. Part of the western Pacific Ocean, showing eight uplifted islands. All lie close to the oceanic side of arcs or other parts of the andesite line.

Pattern of Uplifted Islands in the Main Ocean Basins

Abstract. *Most uplifted islands lie in one of three types of tectonic location: on mid-ocean ridges; between 200 and 750 km on the convex side of island arcs; and along a great circle across the southern Pacific, which may be a fault. Since the usual habit of islands is to subside, these islands may owe their uplift to their special tectonic positions. The regularity of this pattern of uplift supports the view that in the earth an elastic surface layer rests upon a plastic or viscous substratum.*

In 1842 Charles Darwin (*1*) suggested that the normal behavior of islands in the remote parts of the oceans is to subside and that during subsidence those lying in tropical waters pass through fringing reef, barrier reef, and atoll stages. After much debate, admirably reviewed in 1928 by Davis (*2*), Darwin's thesis seems to have been universally accepted. The results of drilling and recovering fossils from at least six islands, Funafuti, Bermuda, Bahamas, Daito, Bikini, and Eniwetok (*3–5*) support this view, as does the dredging and recovering of shallow-water fossils from the depths off at least Erben, Nazca, Hess, Cape Johnson, Sylvania, and Jimmu seamounts, and dredging off Providence and Tuamotu islands (*6*). Most of these data have been discussed by Kuenen (*7*) and Ladd *et al.* (*5*). No attempt is made here to consider the large literature on the possible structure of ocean basins, or the many ages determined on specimens dredged from the sea floor away from rises. All these ages are believed to be Cenozoic or Recent.

It is apparent that all the islands investigated have sunk at average rates varying for different islands from 4 to over 50 m per million years. It is here assumed that sinking is the normal behavior of islands, that the cause is isostatic adjustment, and that the variation in rates is real.

An investigation of the literature reveals that a few exceptional islands, listed in Table 1, have been uplifted. This study has been limited to islands lying in the main ocean basins beyond continental shelves, island arcs, and the andesite line, for other factors enter into the behavior of islands within the border zones in young mountains and arcs. The very numerous references to islands that appear to have been uplifted by 6 m or less have been omitted, because a small lowering of sea level is known to have been universal since the climatic optimum 4000 years ago (*8*) and this is the cause of most of these cases.

Marine fossils found above sea level on some islands show that uplift has sometimes followed subsidence and terraces show that uplift has sometimes been intermittent. There is little point, therefore, in attempting to calculate average rates of uplift. It is more important to note that the amounts of uplift are in general much less than the amounts of subsidence. It is therefore easy to believe that uplift may be only a temporary and unusual state for islands. Tectonic disturbance seems to be the most likely cause of uplift.

The pattern of distribution of uplifted islands is of greater interest. It will be noticed that the first four islands in Table 1 lie on prominent ridges which are tectonically active. The next three groups of islands lie off the coast of Africa; I do not know either the amount or cause of their uplift. The next eight islands all lie immediately in front of active island arcs or close to active linear chains of Melanesia (Fig. 1). It is believed that the uplift of these islands is due to tectonic activity at the borders of the ocean basins. The depression of an ocean trench is considered to cause uplift of the ocean floor adjacent to it on the convex side. As a matter of interest the approximate distance of these islands to the nearest trench or border is given in Table 1.

The fact that Kapingamarangi and a few other atolls in the Caroline Islands equally close to the margin of the ocean do not appear to have been uplifted is not regarded as a valid argument against this hypothesis, because islands are known to sink at different rates and subsidence usually exceeds uplift. Thus if Kapingamarangi Atoll had been uplifted by tectonic forces as much as Feis and Nauru Islands have been, but was subsiding faster for isostatic causes than they are, the uplift might not be evident.

It can be seen in Fig. 2 that, except Makatea and Rapa, all the remaining islands of Table 1 lie along a great circle which extends from the point of sharp deflection of the andesite line near Samoa to a point a short distance north of Easter Island. The extension of this great circle east of Easter Island to San Felix Island, an active volcano off the coast of Chile, is already known to be a ridge. This part has been shown by Menard (*9*) as a great fracture. Eighty miles north of Easter Island, Dietz (*10*) has described a scarp 2 miles high, facing north, which is presumably part of the same fracture. Fisher (*11*), on the other hand, has described the ridge as a chain of seamounts.

I tentatively suggest that this great feature is a fault extending across the Pacific Ocean, which has uplifted the islands along with it. The pattern of uplifted islands in the main ocean basins is thus remarkably simple. With few exceptions all uplifted islands are in one of three locations: (i) on active mid-ocean ridges, (ii) immediately on the convex side of active island arcs and trenches, or (iii) close to a great circle across the Pacific which perhaps forms one of the great fracture lines of the earth.

The pattern is made even more symmetrical and simple when it is realized that the only ocean islands existing in a vast area of the eastern Pacific Ocean lie at a uniform distance of about 200 to 600 km in front of the trenches off South and Central America. I suggest that many of these islands (except Clipperton) have also been uplifted; this has been previously suggested, at least in the case of Juan Fernandez and Galapagos Islands, but, unfortunately, all except Clipperton are volcanic and without limestone rocks which could provide sure evidence of uplift. Others of these islands are San Felix, San Ambrosia, Cocos, Malepo, Clarion, and others off Mexico.

The general conclusion that ocean islands sink except where recently uplifted by tectonic forces supports the view that the earth is not infinitely rigid, but capable of creep or flow. The pattern in the Pacific is like that of a thin plate with a tear in it which rests upon a viscous fluid. The plate represents the Pacific Ocean floor. Its extreme edges have been forced down and flow has caused the plate from 200 to 700 km inside those edges to rise. Disturbance along a tear across the plate has caused some uplift along that tear also.

This plate is not to be confused with the crust; it is rather to be regarded as the cooler and hence more rigid and viscous upper layer of mantle and crust resting upon the main portion of the mantle, which, being white-hot, is more fluid than its upper surface.

Before I wrote this report I tried to discover something about the geology of every island in the main ocean basins. Much of the literature is obscure and a few general works have been of great help in elucidating the geology and obtaining references (*2*, *4*, *12*).

There is one reference to a very small island, Stewart or Sikaiana, only 1.2 miles long, in the northern Cook group, which is said to be 80 feet high, but whether this height is due to dunes or uplift is uncertain, and the island has not been included in Table 1.

The Marquesas are also volcanic islands said to have been much uplifted, but they are without limestone and the geology is not well known. They have been volcanically active in the recent past and still have at least two hot springs.

In view of the common opinion that linear chains of islands in the Pacific are due to faults or anticlines, it may

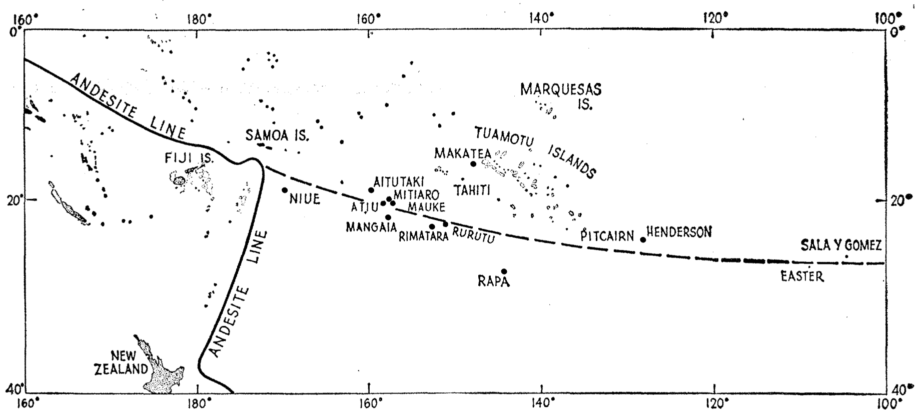

Fig. 2. Part of the central Pacific Ocean, showing eleven uplifted islands, of which nine lie very close to a great circle which extends from the channel between Samoa and Fiji to Easter Island.

Table 1. Some uplifted islands of the main ocean basins.

Name	Oldest uplifted rock	Highest uplifted sediments (m)	Distance to arc (km)	Reference
Azores	Miocene	?		*15*
Rodriguez	?	160		*16*
Heard	Paleocene	?		*17*
Kerguelen	Miocene	?		*18*
Madeira	Miocene	?		*19*
Canary	Middle Tertiary	?		*20*
Cape Verde	Lower Cretaceous	?		*21*
Christmas (Indian O.)	Eocene	360	200	*22*
Marcus	?	23	750	*23*
Feis (Carolines)	?	20	230	*2, 24*
Ocean	Upper Tertiary	82	750	*25*
Nauru	?	66	600	*26*
Niue	?	91	300	*27*
Borodino (Daito Is.)	?	60	300	*2*
Rasa (Daito Is.)	?	30	200	*2*
Mangaia (Cook Is.)	Miocene-Oligocene	69		*28, 29*
Atiu (Cook Is.)	Pliocene	21		*30*
Mauke (Cook Is.)	?	30		*30*
Mitiaro (Cook Is.)	?	27		*30*
Aitutaki (Cook Is.)	?	30		*30, 31*
Rimatara (Austral Is.)	?	6 to 9		*32*
Rurutu (Austral Is.)	?	60 to 90		*29, 32, 33*
Rapa (Austral Is.)	?	30		*32*
Henderson (Pitcairn Is.)	?	15		*2*
Makatea (Tuamotu Is.)	Eocene	69		*2, 34*

seem strange that I here propose that a great fracture crosses one of these chains (the Austral Islands) at a small angle and that islands along the fracture are uplifted, whereas the other Austral Islands are not. I discuss this problem elsewhere (*13*), as well as the evidence for horizontal motion of ocean islands (*14*).

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Zirconium and Hafnium in Stone Meteorites

Abstract. *The abundances of zirconium and hafnium in stone meteorites, were determined by neutron activation analysis. Specific radiochemical separations were used to obtain individual zirconium and hafnium samples of high radiochemical purity. The average abundance of zirconium in chondrites for six analyses was 35 parts per million; of hafnium, 0.19 ppm. The hafnium abundances are in good general agreement with the predictions of current theories of nucleosynthesis.*

The abundances of zirconium and hafnium have been determined for five stone meteorites by neutron activation analysis. Radiochemical separation procedures have been developed which separate zirconium and hafnium simultaneously from a 1-g sample (*1*). The abundance of hafnium in our samples is significantly lower than the abundances reported by others.

After irradiation with thermal neutrons, the meteorite samples were dissolved in mixtures of concentrated acids, and aliquots of standard zirconium and hafnium carriers were added to permit determination of the individual chemical yields. The fluoride complexes of zirconium and hafnium were then adsorbed from 10*M* HF on a Dowex 1, X–8, anion-exchange column. The bulk of the major contaminating radionuclides are not adsorbed (*2*). Zirconium and hafnium were simultaneously eluted from the column with 4*M* HCl. Zirconium was separated from hafnium by means of solvent extraction (*3*) from a 2*M* $HClO_4$ solution into 0.025*M* thenoyltrifluoroacetone in benzene. Hafnium remains in the aqueous phase. After back-extraction of zirconium into 10*M* HF, zirconium and hafnium were each precipitated by use of an aqueous solution of mandelic acid (*4*). The zirconium and hafnium tetramandelates were ignited to oxides at 800°C. The chemical yields, calculated on the basis of the carrier added for each element, were variable and ranged from 5 to 50 percent for each element.

The zirconium activity was determined by measuring the area under the 0.76-Mev gamma-ray photopeak of Zr^{95}. The hafnium activity was determined by measuring the area under the 0.48-Mev gamma-ray photopeak of Hf^{181}. No evidence of the Zr^{95} photopeak was observed in the Hf^{181} sample spectra, and no evidence of the Hf^{181} photopeak was observed in the Zr^{95} sample spectra. Tracer experiments demonstrated that the radiochemical purities of the zirconium and hafnium samples with respect to each other were greater than 96 percent. A 512-channel pulse-height analyzer coupled to a 3-by-3-inch NaI crystal scintillation detector was used throughout.

The data obtained to date for the abundances of zirconium and hafnium are given in Table 1. The average abundance of zirconium for the four chondrites is 35 ppm by weight; the average abundance of hafnium is 0.19 ppm. Duplicate analyses on the same batch of powdered meteorite, as indi-

Table 1. Abundances of zirconium and hafnium in meteorites.

Meteorite	Abundance (ppm)		Zr/Hf
	Zr	Hf	
Elenovka chondrite	40	0.19	210
Plainview chondrite (*a*)	31	0.23	135
Plainview chondrite (*b*)	32	0.21	150
Forest City chondrite	37	0.21	180
Pultusk chondrite (*a*)	38	0.16	240
Pultusk chondrite (*b*)	35	0.15	230
Av.	35	0.19	190
Johnstown achondrite	26		

Table 2. Comparison of zirconium and hafnium abundance data as determined by different workers in four meteorite samples.

Meteorite	Zr (ppm)			Hf (ppm)		Zr/Hf	
	Ref. (*6*)*	Ref. (*5*)	This work	Ref. (*5*)	This work	Ref. (*5*)	This work
Plainview		33	30	1.7	0.23	19	130
Pultusk	32	30	38	1.2	0.16	25	240
Forest City	39		37		0.21		180
Johnstown	30		26				

* Spectrographic analyses.