COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1963/135

VISIT TO THE TENTH PACIFIC SCIENCE CONGRESS, HAWAII, AND TO CALIFORNIA, 1961

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SUMMARY

Aspects of the Solid Earth Sciences symposia convened at the Tenth Pacific Science Congress are discussed with some reference to individual papers. Recent research into the tsunami problem, and the use of earthquake surface-waves are considered of special interest.

An outline of the Congress geological and geophysical field excursion is given including a brief note on work at the Hawaiian Volcano Observatory.

Seismological projects at the Berkeley and Pasadena laboratories in California are reviewed and reference is made to the extensive seismic-outstation networks in northern and southern California. Recent methods developed by the California Institute of Technology Division of Engineering to measure earthquake-response spectra have provided a realistic basis on which aseismic design data can be derived. Recourse to these methods in Papua and New Guinea could have important implications for building programmes in that Territory.

Recommendations relate to the undertaking of earthquake engineering research in New Guinea and means are suggested whereby data could be processed, in part, with existing Bureau equipment.

The need for a network of single-component vertical seismographs in the New Guinea area is regarded to be of paramount importance if the Bureau of Mineral Resources is to undertake more than a superficial earthquake seismology programme in the region.

Reference is made to the desirability of creating means for closer collaboration between various Australian seismological research and data-recording institutions.

1. INTRODUCTION

This Record describes an overseas visit to the Tenth Pacific Science Congress in Hawaii in August and September 1961, and to seismological laboratories of the University of California and the California Institute of Technology at San Francisco and Los Angeles in September 1961.

At the Science Congress I presented a paper entitled 'Seismic wave velocities in the New Guinea-Solomon Islands Region' in the symposium 'The Earth's Crust in the Pacific Basin' in the Section of Solid Earth Sciences, Division of Geophysical Sciences (Brooks, 1962).

The Congress was followed by a geological and geophysical field excursion to three of the other islands in the Hawaiian group. Vulcanological research work at Hawaii I. was of particular interest.

The visit was extended to California so that I could inspect the seismological laboratories at Berkeley in San Francisco and at Pasadena in Los Angeles and also discuss with prominent seismologists the question of New Guinea seismicity. My specific aims were:

(a) to secure information on the latest methods of assessing earthquake risk as it applies to construction, and to determine the best means of providing quantitative aseismic-design data to construction authorities,

(b) to examine current practices relating to the operation of a network of seismograph stations with particular reference to how these might best be adapted in New Guinea, and

(c) to examine methods currently used to interpret seismic network data.

Timetable

Science Congress Formal Sessions	- 19th August to 2nd September
Geological and geophysical field excursion	- 3rd to 10th September
University of California (Berkeley)	- 13th September
California Institute of Technology (Los Angeles)	- 14th to 21st September

2. TENTH PACIFIC SCIENCE CONGRESS - FORMAL SESSIONS

General

Congresses of the Pacific Science Association are convened every four years. They are held under the auspices of the Pacific Science Association formed to promote scientific study of the Pacific Region. Therefore, Congresses are extremely broad in scope as distinct from smaller and more specialised international meetings e.g. The International Meeting on Cosmic Rays and Earth Storms held in Japan (September 1961), The Symposium on Rapid Magnetic Variations held at Utrecht, Holland (September 1959), or such meetings as IUGG.

The Tenth Pacific Science Congress included sections devoted to most major fields of scientific study, i.e. Agricultural Sciences, Anthropology and Social Sciences, Biological Sciences, Geophysical Sciences, Public Health and Medical Sciences. The Congress attracted between 2000 and 3000 visitors.

The section on geophysical sciences consisted of three principal divisions:

(a) Meteorology,

(b) Oceanography, and

(c) Solid Earth Sciences

A number of symposia on various topics were organised in each division.

The symposia organised within the Division of Solid Earth Sciences were:

Antarctic research,

Pacific island terraces : Eustatic?,

Volcanism and plutonism in relation to types of crustal deformation,

Topography and sediments of the Pacific,

The Earth's Crust in the Pacific Basin .

In addition there were various sessions of contributed papers.

As well as the above, the symposium on tsunamis in the Division of Oceanography was of particular interest.

It will be seen that while there was a considerable number of symposia and individual papers of great general interest the proportion of these having specific relevance to work in which I am engaged within the Bureau was relatively small. Even though attendance at sessions was restricted to those of the above type, clashes in the timetable were unavoidable. A timetable of sessions attended is listed in Appendix 1.

The formal scientific sessions were supplemented by half-day visits to areas and institutions of interest and by three public lectures. One of these included a visit to the Halawa pumping station where the Ghyben-Herzberg lens principle, which explains the formation of Hawaiian groundwater resources, was illustrated (Plate 16).

In the following subsections I have endeavoured to present an outline of the chief features, as they appeared to me, of the symposia that I attended. It is clearly impossible and unnecessary to review (or even mention) all papers heard. The form of presentation, which sometimes precluded adequate note-taking, is one reason, quite apart from the amount of material involved.

Antarctic research

This symposium brought together summaries of recent research work carried out in the Antarctic, particularly during the IGY. The geology and glaciology of Antarctica were especially well reviewed from the regional aspect; in addition, more-detailed descriptions were given of the geology in certain areas.

The evolution of two distinct Antarctic geological provinces was discussed by Adie following general comments on the broad geological features and history of Antarctica as a whole. The suggested nomenclature of the Andean and Gondwana Provinces for the western and eastern sections respectively was put forward. This was followed by a summarised description of the topographical features of the Antarctic ice cover as well as the subglacial topography inferred by Bentley from seismic and gravity traverses made by many nations during, and since, the IGY. Data were presented in the form of slides of contour maps and cross-section diagrams. Thiel completed the general description of the Antarctic ice sheet with estimates of the volume of ice covering the Antarctic continent and comparisons of this with the total world ice cover. A figure of 23.8×10^6 km^3 was given for the quantity of Antarctic ice.

During a discussion on Antarctic-region crustal thickness, the subglacial topography, and the thickness of the Antarctic ice sheet, Woollard gave the impression that results derived from seismic and gravity observations made by the British Trans-Antarctica Expedition were at variance with data from surveys made by USSR field parties. He implied that the latter were more reliable in some respects.

The general picture of geology of Antarctica was supplemented by two or three papers covering aspects of glaciation and geology in the McMurdo Sound area, presented by members of US Antarctic Research teams.

The disciplines of geomagnetism and ionospheric physics were represented by papers from Nagata and Shapley.

The magnetic charts of East Antarctica are characterised by two isoporic foci which were interpreted by Nagata as 'breaking out of a fairly intense filament in the electric-current vortex near the surface of the Earth's core'.

An analysis of the SD field in the Antarctic regions, from IGY data, has confirmed its similarity to the northern SD field. Nagata suggested that the correlation between conjugate points in the two auroral zones may be evidence for simultaneous impinging of corpuscular streams on northern and southern zones. He discussed the interrelation between magnetic, auroral, and ionospheric effects.

Shapley reviewed some results of IGY observations of F, E, and D-region phenomena.

Contributions to the symposium by USSR authors were in many cases read in their absence.

Tsunamis (Division of Oceanography)

This symposium attracted a great deal of interest as well as a number of very significant contributions. In some cases the latter dealt with the 1960 Chilean earthquakes and resultant tsunami. The wide interest reflected the current awareness of governments and countries generally of the need for more knowledge of the tsunami problem, and the symposium concentrated principally on the following three aspects of the question :

(a) knowledge of precise cause of tsunamis,

(b) need for a more effective and integrated tsunami warning system, and

(c) means of effecting dissipation of tsunami energy.

The chief contributions came from United States and Japanese investigators.

Cause of tsunamis The most widely-held belief of the general cause of tsunamis attributes them to some form of sea-floor deformation, and although alternative suggestions have been made, e.g. wave coupling, resonance, slumping, these have not received much support, although an isolated instance where slumping has been responsible for small tsunamis (at least) was given by Houtz (Fiji).

Significant advances made by the Caltech Seismological Laboratory research group in the analysis of major-earthquake source conditions were discussed by Press whilst describing methods of deducing fault length, fault-rupture velocity, and direction for the great Chilean earthquake of 22nd May 1960. Three methods were used to determine a fault length of the order of 1000 km and a rupture velocity of 3.5 to 4.0 km/sec, the fault breaking from north to south. The methods used were :

(a) comparison of phase difference between horizontal and vertical components of free-earth oscillations (standing-wave pattern of interfering trains of mantle Rayleigh Waves) for a range of harmonics,

(b) observation of amplitudes of mantle 'surface' waves reaching an observing station from opposite directions, from which fault length and rupture velocity are computed,

(c) measurement of differential phase of mantle 'surface' waves of successive order (from the same direction) provide data from which the fault length and direction can be computed.

Press believes that although these methods can only be applied crudely at the present time, they may be useful in determining the nature of the source of many of the large earthquakes which produced tsunamis in the past. Work is currently proceeding in this direction at Pasadena.

Verification of the Pasadena (Caltech) group's calculations of the order of dimensions of the fault were given by St Armand who carried out extensive field work in the area. St Armand further suggested a possible cause of the tsunami as due to a coupling between seismic surface waves and the ocean surface.

Many of the conclusions reached by Japanese investigators are dependent on extensive correlation of earthquake and tsunami statistics. Iida (Japan) attempted to define the 'tsunami-producing potential' of earthquakes in terms of their magnitude, depth of focus, depth of water at the epicentre, and distance of epicentre from the shoreline from a statistical analysis of 60 earthquakes which produced tsunamis near the coasts of Japan since 1900. A number of empirical results of this study were presented and may form a more realistic basis for tsunami warnings in Japan. Examination of aftershock areas enabled Iida to conclude that tsunamis were caused by crustal deformation in the aftershock area. This was followed by an assessment of the efficiency of energy transfer from stored potential energy, computed for the aftershock volume, to seismic wave energy and to tsunami energy according to earthquake magnitude. It was suggested that for the greater shocks about half the stored potential energy is converted to seismic wave energy, of which about one-tenth is again converted to tsunami energy.

Conclusions of further work on the mechanism of tsunami generation were presented by Takahasi (Japan) in connexion with studies of spectral analyses of tsunamis. Relative amplitudes of spectral components were found to depend on tsunami magnitude and therefore may be related to the so-called aftershock area or area of crustal deformation discussed by Iida.

Van Dorn (USA) presented the results of an analysis of dispersion of long-period ocean (tsunami) waves recorded at Wake Island on a long-wave recorder, and he inferred a line source for the tsunami of 9th March 1957 generated in the Aleutian Islands.

Tsunami warning system. The present warning service is operated by the Coast and Geodetic Survey Observatory at Honolulu and depends on:

(a) visual recording of large shocks,

(b) radio reports of seismological data from a few key stations around the northern Pacific, and

(c) radio reports of tide fluctuations, where obtainable, in the vicinity of the epicentre.

It is recognised that this system is extremely inadequate and suggestions to reorganise the basis of future warnings were shown to depend on two main aspects of tsunami research:

(a) seismological data, and

(b) behaviour of tsunamis in mid-ocean, *e.g.* energy transfer and wave heights.

At present the following information can be deduced by seismological methods:

(a) rapid epicentre location,

(b) magnitude,

(c) focal depth, and

(d) fault-plane solutions of motion and evaluation of source motion.

The first three parameters are now routinely determined and rapid evaluation of fault-plane data by using computers is now envisaged.

Times of arrival of tsunamis, being dependent on the intervening depth of water, can be determined with relative ease. On the other hand, wave-height forecasts are dependent on dispersion, energy transfer in mid-ocean, and source motion. It has been shown that earthquake energy and focal depth probably also affect wave heights.

Wave-height forecasts therefore depend on more data being obtained from mid-ocean, and the installation of deep-sea pressure gauges.

Effective dissipation of tsunami energy. Some work has been done on the use of small-scale models to determine the effect of tsunamis in harbours, but these apparently have a limited application because of the difficulties of employing very unusual fluids and the requirements of exact geometrical similitude of models.

Theoretical research into the wave response of harbours of simple geometrical shape (rectangular) indicate that the more-enclosed harbours have higher resonance factors than open harbours and thus are prone to stronger build up of seiches (i.e. standing waves). It has been concluded that the entrance width of harbours prone to tsunami damage should be made as large as is consistent with protection from incoming swell.

Internal damping or energy dissipation devices may be very effective in reducing damage in harbours with high resonance characteristics.

The Earth's Crust in the Pacific Basin (Division of Solid Earth Sciences).

This symposium summarised the present state of knowledge of the crustal structure of the Pacific, deduced principally from seismological and gravity studies in recent years. None of the important contributors presented any unpublished work; they briefly summarised the main conclusions of the principal investigators in their fields.

Prominent contributors were Press and Ewing (seismic, particularly earthquake surface-wave studies) and Woollard and Worzel (gravity studies).

The increased utilisation of earthquake surface-waves for crustal and upper-mantle structure studies was emphasised by both Press and Ewing. According to Press, surface-wave results are in better agreement with gravity data in revealing isostatic unbalance than seismic refraction results, possibly owing to the effect of local irregularities on the shorter wavelengths. A profile across the USA showing a comparison between surface-wave phase velocity, Bouguer anomaly, and surface topography illustrated the application of phase velocities to crustal thickness determinations. Techniques for interpreting group-velocity dispersion data have been refined in recent years through the ability of computers to provide theoretical dispersion curves for a great number of complex Earth models with which observed data can be compared.

Using such techniques evidence has been presented suggesting, for the first time, that the Earth's mantle is not a symmetrical shell. Two conclusions support this:

(a) velocities in the low-velocity layer of the mantle may be lower under continents than under the oceans,

(b) the top of the mantle may be hotter (resulting in lower shear-wave velocities) under the Atlantic and Indian oceans than under the Pacific.

The extent and nature of the Conrad discontinuity separating the crust into two layers have not yet been fully determined.

Ewing's paper summarised surface-wave dispersion data obtained from the Pacific area during the IGY by long-period seismometers installed at Honolulu, Fiji, and Japan. A normal oceanic crust is indicated for the Pacific, except for the Melanesia-New Zealand region where the crust is thicker.

Ewing remarked on the difficulties of using Love-wave dispersion for oceanic crustal structure studies, owing to the effect on the dispersion of oceanic sedimentary layers of varying thickness. Observations of Love-wave dispersion in the North Pacific were cited to illustrate the masking effect of varying thicknesses (including very thin) of sedimentary layers.

Gravity data relating to Pacific crustal structure were presented by Worzel in a summary of submarine observations made during the IGY. Special reference was made to crustal thicknesses in the Tonga-Thermadec Trench, and cross-sections of this area were illustrated in which gravity and seismic refraction results were compared and shown to be in some disagreement.

Woollard's paper dealt with the general study of gravity anomalies, topographical association, and derivation of crustal structure.

Eaton, director of the Hawaiian Volcano Observatory, discussed the interpretation of the dimensions of a volcano magma chamber, and its depth below the surface from measurements of tilt made near the volcano crater. Eaton has estimated the depth and size of the Kilauea magma chamber from tilt measurements and shown this to correspond with the depth of volcanic earthquake swarms, derived using local P-wave travel-time curves determined initially from a single earthquake of moderate magnitude.

<u>Volcanism and plutonism in relation to types of crustal deformation</u>

Brief comment only will be made on this symposium as the subject matter was generally unfamiliar to me.

The most significant contribution seemed to come from Kuno (Japan) in discussing the frequency distribution of rock types associated with different classes of volcanic eruption. He suggested a quantitative measure of the fractionation stages reached in basalt magmas and presented an analysis of rocks from each of three major provinces of volcanoes in the circum-Pacific belt. He used the quantity

$$MgO \times 100/(FeO+Fe_2O_3+MgO+Na_2O+K_2O)$$

as an index ('solidification index') of the source of the volcanic magma from which the basalt originates. On this basis the primary basalt magmas were found to be not the most predominant in any province. This apparently contradicts previously-held concepts based on the volume of erupted basalt and andesite.

The most frequent type of magma corresponded to a fractionation stage reached after separation of about 50 percent crystalline material.

Gorai (Japan) discussed the origin of calc-alkaline magmas and suggested they are generated deep in the mantle under high pressure conditions. His hypothesis explaining the release of these magmas involves triggering by 'favourable tectonic disturbances'.

Other papers dealt with a variety of petrological features of parts of Sumatra, Japan, Thailand, and a hypothesis by Coats on the origin of volcanic rocks in the Aleutian arc.

Contributed papers

Comment will be made on the following small selection from the great variety of such papers heard :

(a) progress report on the Mohole Project,

(b) mapping of the structure of the Pacific Ocean floor by geomagnetic measurements,

(c) on the relation of electric and magnetic fluctuations in the ocean to the depth of conducting material in the mantle,

(d) depth to sources of magnetic anomalies (a project 'Magnet' report).

(e) sub-Pacific structure as inferred from seismic waves generated by nuclear explosions in the central Pacific.

Report of progress, Project Mohole - Lill. A test hole of 600-ft depth in approximately 12,000 ft of water has already been drilled from the experimental drill ship 'Cuss I' off the Californian Coast near Guadalupe Island. On the basis of experience gained in drilling in great depths of water, a more advanced vessel, 'Cuss II', is now being built, and the objective of a drill hole through the Earth's crust may be attempted with this vessel.

The ocean-basin cores to 600-ft depth have provided samples of dolomite from below the sea floor and have shown the existence of a basalt/dolomite contact zone. Sedimentation was found to be about ten times greater than expected and to be of late Miocene or mid-Miocene origin.

The technique of drilling in great depths of water has been successfully established. Illustrations were shown of the vessel and of the method of positioning using automatically-controlled servo-motors driving positioning propellers and actuated by radar control from fixed buoys.

The site for the attempt to drill through the crust has not yet been chosen.

Mapping of the structure of the Pacific Ocean floor by magnetic methods - Vacquier The mobility of the oceanic crust has been inferred from the evidence of geomagnetic measurements of total force(F) using a proton-precession magnetometer at sea.

Positive and negative magnetic anomalies were depicted on a map of the surveyed area as a series of corresponding black and white bands. The magnetic anomaly profiles were taken several degrees apart off the California coast and south of New Zealand and Australia. The anomalies appear to be aligned in the same general direction as oceanic rises. Fault lines are inferred from the horizontal shift in the banded anomaly pattern, and the comparison of profiles on both sides of an inferred fault seems to be fairly simple and enables the amount of movement along the fault to be determined.

On the relation of electric and magnetic fluctuations in the ocean, to the depth of conducting material in the mantle - Cox. Cox believes that a relation exists between the magnetic field fluctuations of periods ranging between 10 minutes and 10 hours and the depth of conducting regions in the mantle. He thinks it may be possible to estimate the latter by measuring a phase shift between the 'applied' magnetic field associated with currents in the ionosphere and the resulting electric field in the ocean.

Depth to sources of magnetic anomalies - Alldredge. Several very long and fairly straight magnetic total-field intensity profiles were examined to determine the 'spectral' distribution of magnetic anomalies. The profiles used were all more than 2000 miles long and most were recorded during Project Magnet. The theoretical dipole-field values were first subtracted from the observed measurements of $|F|$.

The method permitted examination of the frequency of occurrence of short-wavelength anomalies (usually determined in normal aeromagnetic survey work), long -wavelength anomalies (seen in world magnetic charts) and intermediate wavelengths (between a few tens of miles and a few thousand miles). The latter would not be revealed by normal regional magnetic surveys, which aim at mapping the long wavelengths or by mineral exploration surveys, which are concerned with the short wavelengths.

Evidence from these profiles supports a suggestion that magnetic anomalies occur in two wavelength regions - short and long - and that no intermediate-wavelength anomalies exist. The short-wavelength anomalies are attributed to crustal effects, and the long-wavelength anomalies to sources near the core-mantle boundary.

Sub-Pacific structure as inferred from seismic waves generated by nuclear explosions in the central Pacific - Carder. Carder's paper was read in his absence. It presented P-wave velocities determined from the 1958 series of nuclear explosions to epicentral distances of 65 degrees. The velocity of P-waves just below the crust/mantle boundary was found to be 8.2 km/sec, and a crustal thickness of 15 km was found for the Bikini and Eniwetok Atolls. Carder suggests that the outer half of the mantle may consist of a number of concentric shells, and cites the form of the P-wave travel-time graph, which he divides into three fairly definite straight-line sections as evidence of this.

3. VISIT TO USCGS OBSERVATORY (BARBERS POINT, HONOLULU)

During the Congress, I visited this establishment with Dr E.I. Robertson of the New Zealand DSIR.

The observatory is operated along similar lines to the Bureau of Mineral Resources observatories and fulfils three functions:

(a) those of a standard seismological observatory,

(b) those of a standard geomagnetic observatory,

(c) the operation of a tsunami warning service for coastal areas around the Pacific

The observatory is situated at Barbers Point west of Honolulu and Pearl Harbour. It has only recently been moved from an original site a few miles distant, which became unsuitable owing to the proximity of armed-service installations. Photographs showing various parts of the observatory are to be seen on Plates 4 and 5.

The seismological equipment consists of two Milne-Shaw seismographs of 12-sec free period (the north-south component recording visually as well as photographically), a Wilson-Lamison short-period vertical seismograph, a HTL short-period vertical seismograph, and a three-component set of Press-Ewing long-period instruments operated for the Lamont Geological Observatory (seismometers 15-sec period; galvos 75-sec period). In addition, an outpost station is operated at Kipapa (single-component vertical seismograph).

Recording and absolute magnetic equipment is entirely of Ruska manufacture. Normal-sensitivity and rapid-run variometers are in use.

Variometer magnet alignment and calibration tests are carried out with auxiliary magnets and not with Helmholtz coils.

Absolute equipment consists of a Ruska magnetometer and earth inductor. The absolute house features large box-like electric-light housings using ground-glass screens about 2-ft square immediately above each instrument pier (Plate 5).

The tsunami warning service is operated by observatory staff, who maintain contact with four or five well-spaced seismograph stations in Japan and North America, as well as some tidal stations, through armed-forces communication facilities. The Milne-Shaw N/S recording pen actuates an alarm signal at a pre-set amplitude, thus ensuring that records of all earthquakes of significantly-large magnitude are inspected as they occur. Warnings are issued on the basis of location and magnitude of shock together with tidal station reports when these can be obtained. Warnings can usually be issued within one hour of the occurrence of a large earthquake.

4. CONGRESS GEOLOGICAL AND GEOPHYSICAL FIELD EXCURSION

General

The field excursion occupied the period from 3rd to 10th September at the conclusion of the formal congress sessions.

It fulfilled two main purposes:

(a) to illustrate the principal geological features of the island chain represented on the islands of Hawaii, Maui, and Kauai, and

(b) to facilitate a brief inspection of the currently-active volcano of Kilauea and the US Geological Survey Hawaiian Volcano Observatory.

Brief visits (ranging in duration from a few minutes to an hour or more) were made to :

(a) tsunami-inundated areas of Hilo, Hawaii,

(b) geothermal steam drilling project, Hawaii,

(c) Mauna Loa weather research station, Hawaii,

(d) Smithsonian Institute satellite tracking station, Maui,

(e) University of Hawaii airglow station, Maui, and

(f) water-resources pumping station, Maui.

Visits to the CRPL ionospheric sounding station and the NBS radio time-signal station WWVH at Kehei on the island of Maui were not included on the programme, and no opportunity arose to arrange a visit.

The Hawaiian Islands consist entirely of volcanic islands extending for 1500 miles south-east from Kure Island (see Plate 1). The larger and the only inhabited islands at the south-eastern end are also the youngest, these being (in order of age) Kauai (oldest), Oahu, Molokai, Maui and Hawaii (youngest). High rainfall and dense tropical vegetation are characteristic of all the islands, although local microclimatic variations can be extreme and are an interesting geographic feature.

The oldest rocks found on the major islands are believed to be late Tertiary. Radioactive dating processes have found no application as yet. With the sequence of formation being north-west to south-east, striking evidence of deep weathering and erosion which followed the cessation of active volcanism are features of Kaui, the north-westernmost island, these features becoming progressively less pronounced on the islands of Oahu, Molokai, and Maui. Active volcanism has been known in historic times only on the island of Hawaii, the largest and the most southerly of the group.

The topography of the islands is striking, particularly the two southernmost islands of Maui and Hawaii. The main peaks rise to 10,000 ft on Maui (Mt Haleakala) and 13,000 ft on Hawaii (Mauna Kea and Mauna Loa), and the slope of Mauna Loa is only of the order of 1:20.

Hawaii Island

This is the only volcanically-active island in the group. It consists of five major peaks (Plate 2) of which Mauna Loa was most recently active in 1949 and Kilauea is currently active.

Hawaii was visited from 3rd to 7th September 1961. It is barren of vegetation above 4000 to 5000-ft altitude, where the exposed surface consists entirely of lava flows (Plate 9). Some sugar and coffee is grown on the lower slopes where climatic conditions are suitable.

The evidence of weathering and deep erosion seen from the air on the northern part (Kohala mountains) is characteristic of the older and volcanically-extinct part of the island.

Hawaiian volcanoes are typical shield volcanoes, the lavas being very basic in composition and having a very low viscosity, which accounts for the gentle topographic slopes (Plate 6). The basalts of Hawaii are broadly classified into two groups, the tholeiitic basalts of Mauna Loa and Kilauea and the alkalic (andesite) basalts of Mauna Kea, Kohala, and Hualalai, representing the later stages of volcanic activity (Plate 7).

There are two principal types of lava flows found on Hawaii (see Plate 9) viz: pahoehoe (having a solid, ropy-like surface) and aa (a flow with fractured surface but solid and massive interior).

The excursion to Hawaii began with a visit to the lower slopes of the east rift zone of Kilauea, observing the January-and-February-1960 flank-eruption of Kilauea. This flank outpouring characteristically followed a summit eruption two months previously. Illustrations of the main cinder cone, principal lava flows, and remains of the destroyed town of Kapoho are shown on Plates 9, 10 and 12.

A novel geothermal steam drilling project is being attempted near, but not in, the rift zone at the base of the cinder cone, on fresh lava (Plate 12). Temperatures measured a few feet below the surface in the rift zone were 260°C, which was considered too high. The intention is to use steam, produced at a depth of the order of 100 to 200 ft from continuously percolating rain water, and to try to retain the pressure, in the absence of a cap rock, by using 12-in. drill casing. A second, but less-successful, attempt was seen a few miles away. In the latter case, temperatures of 180° to 225°C were found at a depth of 580 ft, but trouble was being experienced in preventing drill bits from becoming jammed.

One of the typical geological features is the black-sand beaches formed by the disintegration of lava flows meeting the sea. These were seen at Kalapana.

The excursion followed the route around the island (Plate 2), in the course of which several historic lava flows, of both the pahoehoe and aa types, were examined. Brief stops were also made to examine local petrology. The external features of the structure of Mauna Loa being built up by successive layers of lava flows can be clearly seen from the north and west sides of the mountain.

The major feature of the excursion was the currently-active volcano of Kilauea (Plate 3). The summit of Kilauea is 4000 ft above sea level. It has been built largely by eruptions from two rift zones extending eastward and south-westward from the summit. Its principal features are a summit caldera, about two miles by three miles. Near its south-western edge the caldera floor is indented by a collapse crater Halemaumau, see Plate 10) over 500 ft deep, which is thought to mark the point where the principal lava conduit of Kilauea reaches the surface.

A second feature is a smaller active crater of Kilauea Iki immediately north-east of the main caldera (Plates 3, and 10). Summit eruptions of Kilauea are confined to the Halemaumau collapse crater and Kilauea Iki.

The third prominent feature is the line of collapse craters north-east of the summit caldera.

A brief inspection was made to the worst-affected section of Hilo inundated by the 22nd-May-1960 tsunami generated by the Chilean earthquake. Photographs of some of the damaged buildings are reproduced in Plate 13. A comprehensive description of this was given by Eaton, Richter, and Ault (1961).

A half-hour visit was made to the US Weather Bureau Research Station (Plate 14). This station was established at an altitude of 11,000 ft prior to the IGY to facilitate high-altitude meteorological studies. The following aspects are studied:

(a) ice nucleii counts,

(b) measurement of surface ozone,

(c) measurement of atmospheric ozone,

(d) solar radiation measurement (four wavebands),

(e) CO_2 measurements,

(f) regular wind, temperature, cloud, and rainfall observations

(g) photographs with an all-sky camera at 5-min. intervals,

(h) dust particle counts, and

(i) infra-red hygrometer measurements

<u>The Hawaiian Volcano Observatory</u>

This observatory is situated on the western rim of the Kilauea Caldera at Uwekahuna (Plate 11) and overlooking the Halemaumau crater (Plate 10). It is operated by the US Geological Survey, and its activities may be subdivided into vulcanological, seismological, geological, and geochemical.

The observatory was established in 1912 to permit continuous observation of the Kilauea lava lake. Since then the scope of observatory activities has been widened to include the operation of a network of 11 seismological stations on the island of Hawaii and one on the island of Maui. These, together with the instruments at the USCGS observatory at Barber's Point, Oahu, constitute the entire network of seismographs in the State of Hawaii.

The observatory staff averages about 12 in number, half of whom are professional geologists and who have either completed, or partially completed, post-graduate degrees. The operation of the seismograph network and periodic measurement of tilt at 12 fixed stations around Kilauea form the routine basis of the more general research work of analysing the behaviour of the island volcanoes, and the practical work of predicting eruptions, the course of lava flows, and the danger from these to populated areas.

<u>Seismic work</u>. The disposition of seismic stations on Hawaii is shown in Plate 2. Instrumentation is diverse and consists of high-magnification short-period (HTL) vertical electromagnetic seismographs similar in appearance to the Benioff type, or Wood-Anderson seismographs. Some stations are also equipped with Willmore seismographs. Generally speaking, only one instrument, or at the most two instruments, operates at any one station, the exception being at Uwekahuna (the main observatory vault), where Sprengnether short-period vertical and horizontal instruments, Wood-Andersons, and a long-period Press-Ewing vertical seismograph operate. Seismometers at the four satellite stations of Mauna Loa, Desert, North Pit (Halemaumau) and Whitney are connected to the observatory by land-line; these seismometers record on smoked paper (Plate 11). Analysis of local seismic events is carried out by the use of local travel-time curves deduced from a single earthquake in 1955 which was large enough to be well recorded by the whole network. The crustal structure interpreted by Eaton and Murata (1960) from these curves is shown in Plate 8.

Observations of ground tilting are normally carried out at two-monthly intervals at each of a series of 12 tilt stations using a special water-tube tiltmeter. These have begun to demonstrate the swelling and collapse of the magma chamber with a high degree of precision. Recent theoretical work by Eaton has demonstrated the possibility of calculating the depth and position of the Kilauea magma chamber from the tilt observations (Eaton, 1962).

Maui Island

The main feature of the excursion to Maui Island, which occupied little more than a day (7th-8th September) was the visit to the Mt Haleakala summit (10,000 ft).

The summit 'caldera' is illustrated in Plate 16. It is the largest caldera in the Hawaiian island chain, being seven miles long and three miles wide. Some doubt exists as to its exact nature, there being a suggestion that it may be an erosion feature rather than a volcanic feature. The 'caldera' wall has been breached in two places by immense lava flows and the floor is dotted with innumerable cinder cones, the largest of which is 2000 ft high.

Mt Haleakala forms part of East Maui which is geologically younger than West Maui and is characterised by deeply-eroded river valleys and coastlines.

On the north flank of Haleakala, gibbsite deposits containing up to 60 percent Al, present in some of the ash flows, were pointed out in several road cuttings. Similr occurrences are also to be found in the Pahala ash deposits north-west of Hilo on Hawaii Island.

Very brief visits only were paid to the University of Hawaii airglow laboratory and the satellite-tracking station on the summit of Mt Haleakala. The equipment used is an automatic rotating camera fitted with a birefringent filter. Two wavelengths are observed, the camera being programmed to rotate through 360 degrees at successively increasing altitudes of five degrees.

The tracking station operated by the Smithsonian Institute operates purely optical equipment, a Schmidt 12-in. telescope. Photographs are taken of all satellites and their positions are approximately determined from star charts. The information is forwarded to the Institute and used to compute and predict future orbits.

Kauai Island

The visit to Kauai Island, the northernmost inhabited island of the group, was of minor significance only. Its chief topographic features are deeply-weathered and eroded canyons and valleys to depths of 4000 ft (Plate 15).

Rainfall is very heavy in the interior and microclimatic variations (west side dry, east side wet) are also characteristic geographical features of this island.

5. SEISMOLOGICAL LABORATORY, BERKELEY, CALIFORNIA

The Berkeley laboratory is located in the Earth Sciences Building on the main campus of the University of California. The laboratory is under the direction of Professor P. Byerly and the seismological programme is under the immediate supervision of Dr Don Tocher.

Routine seismic programme

The routine seismological programme involves the operation of 15 to 20 outstations in northern California, together with the main Berkeley station, to record local earthquakes. Outstations are serviced by local inhabitants who change records which are mailed in for interpretation by computing staff at Berkeley.

Epicentres are still determined manually by successive approximation to determine least residuals, using local travel-times compiled by Byerly for northern California in 1939. It is recognised that these need modification in some areas.

Magnitude determinations are made using Wood Andersons (M_L), or in the case of teleseisms, from body waves (m scale converted to M) or surface waves (M scale). Periods ranging from 17 to 23 sec are considered suitable for the surface waves.

All data pertaining to each earthquake are filed on a separate card.

The instrument composition of the Berkeley station is as follows:

2 standard Wood-Andersons

2 low-magnification (V=200) Wood-Andersons

3 long-period Press-Ewings

2 Galitzin horizontals of magnification 1200

3 short-period Sprengnethers

2 short-period vertical Benioffs - one for visual recording and one for photographic recording

Research programme

The laboratory has recently acquired new recording equipment for aftershock studies under a Vela Uniform grant. The equipment is of two kinds :

(a) a central-laboratory visual monitoring and recording system,

(b) portable field units mounted in trucks

All equipment is manufactured by Geotech Corporation. The eventual aim is to record automatically all data from the northern-California outstations by using rented telephone lines. Up to seven seismometer signals can be transmitted simultaneously on one line.

Each seismometer signal is amplified and used to frequency-modulate an audio carrier signal. The signals are separately filtered and discriminated at the central recording station. Recording is simultaneous on 16-mm film which is automatically developed and displayed 11 min after recording. The equipment is capable of handling five channels, each carrying seven individual signals.

Provision is made also for four hot-wire helicorder drums. Three of these are used for a three-component instrument in the Berkeley vaults and the fourth drum can monitor any of the outstations.

The portable field equipment, which is mounted in three trucks, consists of portable Benioff short-period vertical seismometers, tuning-fork time-mark generator, and WWV receiver and amplifier. The seismometers are provided with 200 yd of cable and the trucks have an independent power supply.

This equipment will be used to determine the focal positions of aftershocks and the pattern of energy release. The portable equipment will be moved to the epicentral region of a large shock as soon as possible after occurrence.

The extent of the whole northern California seismograph network (Plate 17) illustrates clearly the need for additional stations in the Territory of Papua and New Guinea, which has a much higher seismicity, if some aspects of this seismicity are to be studied in any detail. The remote-recording equipment described above may be adaptable for recording in the Territory.

6. CALIFORNIA INSTITUTE OF TECHNOLOGY

Seismological Laboratory, Pasadena

The Laboratory, a division of the School of Geological Sciences, is directed by Dr Frank Press. It is primarily a seismological research laboratory and is engaged in a large number of theoretical and experimental research projects, including instrument development and use of exploration seismology techniques for measurement of crustal velocities.

In addition, the Laboratory operates a network of outstations in southern California for a variety of research purposes in addition to routine recording. Instrumentation at these stations ranges from single-component instruments to complex arrangements of nine or twelve seismographs of various types. The location of the outstations is shown in Plate 17. Approximately two-thirds of these are permanently recording, the remainder being for special projects or for occupation during periods of local activity. Two of these outstations, at Mt Palomar and Riverside, were visited.

The office and main laboratory are located at 295 North San Raphael Avenue, Pasadena, and the laboratory workshop is sited directly opposite.

The chief personnel and their current special fields of study are :

Dr F. Press	-	Crustal and upper-mantle structure
Dr C.F. Richter	-	Seismicity and near earthquakes
Dr H. Benioff	-	Seismic instruments and magnetic micro-pulsations
Dr S. Smith	-	Free oscillations of the Earth
Dr Ari Ben Menahem	-	Theory of faulting and radiation from faults
Dr Phinney	-	Theoretical seismology
Mr A. Cisternas	-	Machine epicentres
Mr J.M. Nordquist	-	Machine epicentres
Mr F. Lehner	-	Development of seismic instruments, especially the lunar seismograph. Responsible for instrumentation of southern Californian network.
Mr Toksez	-	Model seismology
Mr Kovach	-	Geophysical basins
Mr W. Miller	-	Digital seismograph

Instrumentation at the laboratory is very comprehensive and extremely varied, consisting chiefly of sets of long-period Press-Ewing seismometers, short and long-period Benioff seismometers, standard and strong-motion Wood-Andersons, and a two-component Benioff linear-strain seismometer.

Most recording is standard photographic, but at least two three-component visual recorders (short-period Benioff and long-period Press-Ewing) were in operation at the time of my visit. The operation of different instruments is frequently varied according to changing experimental requirements, e.g. at the time of visiting the laboratory a three-component visual recorder was temporarily monitoring a set of Press-Ewings through a filter which eliminated all ground motion of periods less than 15 sec. It was being found that a continuous background noise of 15 to 20-sec period was present, and the most favoured hypothesis at the time attributed this to surface waves from the incessant low-magnitude earthquakes occurring somewhere in the world.

A rather novel aspect of my visit was an inspection of a prototype of the lunar seismometer. This is illustrated in Plate 18.

The development of a digital seismograph is being undertaken under a grant from the Vela Uniform project. An early model has already been operated at the Isabella outstation. This was not visited. However the Vela unit was seen under construction and will be more advanced. It will produce a visual seismic record in addition to a digitised output at very closely spaced time intervals (order of 0.01 sec), facilitating automatic spectral analyses of the output of the seismometer.

Out-station network. This network of 17 permanent stations (in addition to a number of semi-permanent stations) was initially set up to monitor southern California seismicity, but the stations are also used for research projects.

Two stations, Riverside and Mt Palomar, were inspected. The instrumentation is diverse and in some cases, such as Riverside and Isabella, quite comprehensive. The Riverside instrument layout is shown in Plate 19). The Mt Palomar station has a single-component Benioff short-period vertical. This instrument will soon be replaced by USCGS standard instruments.

All record changes are made by local personnel, records being sent to Pasadena for developing. Control circuits are all arranged so that time control is automatic (refer to circuit diagrams on Plates 20 and 21).

Stations are serviced by Laboratory personnel at irregular intervals, usually one to three months, depending on station location and other requirements.

Discussions with Dr C.F. Richter - Local earthquakes, seismicity, New Guinea problems. Dr Richter supervises the interpretation of near-earthquake data recorded by the southern California network. Interpretations are made by a small staff of female assistants. The network of stations apparently operates fairly satisfactorily. The number of stations is sufficient to ensure adequate coverage of most events in the case of occasional station breakdown. Owing to distance, these breakdowns often cannot be rectified for days, or at times for one or two weeks.

Wood-Anderson records are the basis of local and near-earthquake magnitude determinations on the M_L scale. Magnitudes of teleseisms are computed in the standard way from surface waves of about 20-sec period (M) or body waves (m), the latter being transposed on to the M scale.

Dr Richter is of the opinion that much work remains to be done to define magnitude scales more closely and to relate the various methods of determination of magnitude. He expressed a strong conviction that we should try to keep the Port Moresby Wood-Anderson instruments operating as long as possible to facilitate such studies in the New Guinea region. This is a particularly favourable area owing to the range in depth of occurrence of earthquakes.

Regarding New Guinea seismicity, Dr Richter pointed out that the value and detail of seismic studies depend in the first instance on quality and quantity of instrumentation and that obviously we must install more stations before we can expect to obtain quantitative results of real significance as far as local earthquake studies are concerned. The New Guinea area is most interesting seismically and not a great deal is known about it. The method I have used to describe the seismicity of New Guinea (Brooks, in press) involving assessment of relative strain release and relative frequency is, in Dr Richter's view, the only possible method of handling such limited earthquake statistics as are available.

There are no proposals as yet to record southern California outstation routine data by remote means as is being done in northern California. Direct photographic recording is desirable to preserve amplitude and phase parameters.

Beyond establishing that routine epicentre determinations are still made using manual methods (by female computing staff), little information was gained concerning computer programmes currently being developed at Pasadena by Mr Nordquist. These are still in the experimental stage and are too unreliable for the production of routine data to the high degree of accuracy envisaged.

However, I did establish that before a computer programme for the determination of epicentres of the frequent low-magnitude earthquakes in New Guinea would be warranted, a greater number of reporting stations would be required together with more-detailed information on local crustal velocities.

Several sets of oustation records were examined, chiefly from Wood-Anderson and Benioff instruments.

Studies relating earthquake intensities, acceleration, and magnitude have not clearly related these parameters as yet. Dr Richter expressed some personal dissatisfaction with the findings of the latest paper (Gutenberg and Richter, 1956) on this subject and he suggested much more work is required in this direction.

The application of such data from standard-type seismic recorders to aseismic design problems was not practicable and much more success had been achieved in this field by Drs Hudson and Housner of the Institute Division of Engineering, to whom Dr Richter referred me for discussions concerning engineering problems of New Guinea seismicity.

Discussions with Dr Frank Press. One of Dr Press' major interests in seismology at present is the application of surface-wave data to problems of crustal and upper-mantle structure, and he is of the opinion that these methods, e.g. phase velocity, could be usefully employed in the Territory.

Much useful data has been obtained on local crustal velocities in southern California using seismic refraction techniques. This work has led to more accurate determination of local earthquake foci (within 3 km). Such methods could be applied in the Territory to advantage.

Dr Press commented that, from my remarks, he was under the impression that the few groups actively engaged in seismological work in Australia were operating quite independently. A more closely co-ordinated research programme utilising both government and university facilities may, therefore, be worth investigating.

He considers that the Territory is a most interesting area from a seismologist's point of view. He would be willing to advise on any research projects if this is ever needed.

School of Geology - Discussions with Dr C.R. Allen

Dr Allen is Associate Professor of Geology at the California Institute of Technology. He has been engaged for some time in studying the application of strain accumulation to fault displacement. Owing to the much greater accuracy with which shocks can be located (nominally to 1 min) in southern California, he has been able to compute strain release for discrete squares of 5-min side length. (I have applied this method in assessing Territory seismicity, using squares of one degree). Dr Allen has been able to contour his diagrams of strain release and relate the pattern to the known geological faults. It is hoped to use the change in the contour pattern with time to identify faults along which no strain release has occurred and use these data as a possible aid to prediction. For example, Dr Allen has noted that no strain release has taken place across the San Andreas Fault in the vicinity north-east of Los Angeles and that geodimeter measurements indicate the accumulation of some strain. It is expected therefore that this will be released by a future earthquake.

Division of Engineering - Discussions with Drs Hudson and Housner

Drs G.W. Housner and D.E. Hudson are the professors of Mechanical Engineering and Civil Engineering respectively at the California Institute of Technology. In addition Dr Housner is President of the Earthquake Engineering Research Institute.

The Earthquake Engineering laboratory in the Division of Engineering is engaged in studying structural response to actual earthquake ground motion and the development therefrom of aseismic design principles for application in seismic areas. It was explained that the principal factor governing the structural response of buildings to ground motion, such as those produced by an earthquake, is ground acceleration. Hence in order to determine structural strains, ground acceleration is required as a function of time. Normal seismograph records are of little or no use for providing acceleration data as :

(a) they respond directly to displacement or velocity,

(b) instrument periods are usually too long,

(c) time scales are too short, and

(d) it is not possible to derive accelerations from velocity and displacement records to the required limits of accuracy. Nevertheless, epicentre and depth of focus must be accurately determined by the usual methods.

Earthquake resistant design in the USA is now based on a dynamic approach rather than the outdated static approach (Appendix 2(b) - 3). Structural response of single and multiple-degree-of-freedom structures is inferred from the response of the electric analogues of mass-spring-dashpot mechanical systems, to input-voltage functions corresponding to actual ground-acceleration records made during earthquakes.

Use is made of an electric analogue computer to determine response spectrum curves for typical structural types, the curves being computed for a range of free periods of the 'building' and a range of damping. Investigations are also beihg made into the use of digital computers for this work. It has been found that the concept of a single 'resonance' period at which excessive vibration of a building was thought to occur, is not valid in most practical cases (Appendix 2(b) - 20).

Acceleration records are produced by specially designed accelerometers (Appendix 2(b) - 3) and are supplemented by seismoscope recordings from a simple device consisting of an inverted pendulum of prescribed period and damping (Appendix 2(b) - 4, 5). The latter are distributed at sites to determine the seismic effects attributed to local variations of geological foundations by providing a check on the amplitude of the response curve (determined by the accelerometer) at chosen values of period and damping.

The response spectrum technique has led to realistic lateral force requirements being laid down for California. Methods have been developed to compute structural strains in complex buildings having a variety of modes of vibration.

Drs Hudson and Housner feel that the installation of a network of accelerometers and seismoscopes in the Territory of Papua and New Guinea is the only sound approach on which realistic aseismic design practices could be based. It is necessary to obtain actual accelerations under the specific geological conditions of a particular location. Work in the USA has been restricted by the limited amount of data from destructive earthquakes that have been recorded so far. They are anxious to obtain records from other countries that experience more-frequent large earthquakes, particularly at varying depths. Any records from the Territory would therefore be of great interest to see if response spectra are different from those made in the USA.

The Institute would be willing to assist the planning of any such project in the Territory.

Dr Hudson referred to the two world conferences which have been held in San Francisco (1956) and Tokyo (1960), mentioning that there had been no representation from Australia. He suggested that such representation would be welcomed at the next conference to be held in New Zealand.

During a brief inspection of the Laboratory, the Analogue Spectrum Analyser and the type of seismoscope used for field recording were shown to me (Appendix 2(b) - 4). An electric analogue random-motion generator also used for earthquake-excitation studies was seen.

7. SCHOOL OF GEOPHYSICS (UNIVERSITY OF CALIFORNIA AT LOS ANGELES)

A visit to this institution was arranged through Dr Milton Dobrin of the United Geophysical Corporation.

Seismological work is entirely theoretical and a small research group is directed by Dr Leon Knopoff. The research group consists of Drs Knopoff, Gilbert, and Pilant.

Analyses of phase velocity of Rayleigh waves are being attempted from a network of single-component vertical Press-Ewing seismometers in Europe and the Middle East, to determine crustal structure. Spectral analyses are obtained of individual records through a Bendix G15 computer. Records are first scaled using a telereader, the amplitudes and times being scaled every second on to punched cards. The latter are transferred to punched paper tape. The effects of higher frequencies are eliminated by an arbitrary smoothing process which obtains a weighted running-mean and then selects every fourth point. The project had only just begun at the time of my visit and there was some doubt about the effect of the smoothing process on the Fourier analyses. No results had been obtained at that time.

Other equipment seen in the geophysics school included a La Coste-Romberg submarine gravity meter converted for use in surface ships. The instrument had been used in the Argo ('Monsoon' Expedition) and had an accuracy of 3 mgal.

An earthtide tiltmeter using a 6 ft long pendulum and having a resolution of 10^{-6} in. was also seen. The instrument had a recording system similar to the La Coste and Romberg instruments, featuring a phase comparator using a rotating perforated disc to permit registration of a DC signal representation of the pendulum shift.

A Blum Quartz tiltmeter having 10^5 mechanical magnification was also seen.

The La Coste and Romberg tidal gravity meter recorded on a digital readout system to 0.1 microgal accuracy and 0.0025 microgal definition (repeatability of the digital readout to a recorded curve). The recording system consisted of a counter coupled to the output of a servo motor, the former being photographed.

8. RECOMMENDATIONS

Aseismic design

A survey of the precise requirements of various authorities for aseismic design information is warranted. Subsequently, consideration could be given to the purchase and installation by the Bureau, of accelerometers and seismoscopes in selected areas of the Territory of New Guinea, to provide the required data.

The Earthquake Engineering Research Laboratory at the California Institute of Technology would be willing to act in an advisory capacity and would be interested in receiving copies of records.

Reduction of acceleration data to response spectra requires the use of either analogue or digital computer methods. The Telereader already possessed by the Bureau could probably be used to convert accelerogram records to a suitable form for a digital computer programme.

Alternatively, construction of an electric analogue computer may be considered. This would not be a major undertaking and could perhaps be investigated jointly by the Bureau of Mineral Resources and other interested organisations, e.g. the Snowy Mountains Hydro-Electric Authority, the Commonwealth Department of Works, the Administration of Papua and New Guinea, the Australian National University, and the Sydney Metropolitan Water Board.

World Conference on Earthquake Engineering

In view of the apparent lack of contact between Australian authorities interested in earthquake engineering problems and overseas organisations conducting research in this field, I suggest that the attendance of Australian representatives at the next World Conference on Earthquake Engineering (to be held in New Zealand in 1964) be sponsored. Representation to appropriate organisations could be made by the Bureau to initiate steps necessary to examine this possibility.

New Guinea seismological work

The operation of even a small network of short-period vertical-component seismographs in New Guinea is essential if :

(a) any earthquake engineering data is ever to be provided. Determination of the epicentres and focal depths of shocks used in response-spectra calculations is a prior requirement before significance can be attached to the spectra,

(b) more-precise investigations into any aspect of local seismicity is to be undertaken.

Therefore, departmental policy with respect to seismological work in New Guinea should be re-examined and clarified in the light of possible future requirements.

Equipment for such stations need not be prohibitively costly to purchase or operate. To this end much could be achieved by re-allocating existing vertical seismometers of all types already possessed by the Bureau. Conversion to electromagnetic detection and visual recording would be relatively straightforward. Recent developments of visual-recording seismograph systems combined with solid-state amplifiers have increased reliability of remote recording stations, and eliminated the need for expensive vaults to house such instruments.

Earthquake surface-wave study

The increasing use of earthquake surface waves as a research tool for studying crustal and upper-mantle structure was very clear from discussions with Professor Press and others.

Some of the methods developed, such as the measurement of group-velocity dispersion or the measurement of Rayleigh-wave phase velocities across simple networks of stations are easy to apply and interpret. Their application to areas in the immediate vicinity of BMR seismic observatories should be feasible.

In addition to revealing new and valuable regional structural data, the use of long-period instruments and the development of recording systems should help raise the standard of our seismological work and generally enhance the scientific stature of the Bureau.

Formation of an Australian seismological association

There is a gradually increasing interest in earthquake seismology and the application of seismological methods to Earth structure problems in Australia. At present there is not a permanently-established scientific organisation primarily interested in seismology in this country, through which such work could be more effectively promoted and coordinated.

Particularly as Australia has a relatively small community of seismologists, at present without organisation, the formation of an Australian seismological Association might serve a practical purpose and be feasible.

I suggest that the Bureau consider seeking the views of prominent Australian seismologists on this matter. In making such a recommendation I have two objects in mind :

(a) to promote a greater degree of coordination of the various institutions engaged in seismological research and measurement in Australia,

(b) to secure visits to this country by prominent overseas seismologists.

Regional seismology

BMR seismological observatories installed in the last decade have been primarily designed and equipped to fulfill the needs of world programmes requiring chiefly routine data. Less consideration appears to have been given to the suitability (geographically) of the various stations for investigating regional or local geological environment.

I have gained a very strong impression from my visit to California that at least as much attention is paid to the latter function of observatories, many of which are, of course, established in the first place as part of a seismological project.

An extreme view of this matter is taken by Professor Knopoff of UCLA who expressed the opinion that routine observatories would gradually lose their utility in favour of specialist stations equipped for specific project investigations that were local, regional, or global in character.

Reporting of severe earthquakes

During my conversations with Dr Richter, he stressed the importance, to seismology generally, of early and accurate field observations of macroseismic effects of severe earthquakes.

At the present time geophysical staff in Port Moresby would be delayed, for administrative reasons, in carrying out such work if suddenly called upon to do so. The scientific value of any observations might therefore be reduced.

I recommend that steps be taken to examine the possibility of securing emergency travel arrangements through a local authority for specific purposes such as outlined above.

9. REFERENCES

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APPENDIX 1

SELECTED LIST OF CONGRESS PAPERS DELIVERED AT SYMPOSIA ATTENDED

DATE (1961)	SYMPOSIUM	SIGNIFICANT PAPERS
22nd August	Antarctic research	Glacial and sub-glacial geology of Antarctica - Bentley. Geology of Antarctica - Adie. Gravity and crust dynamics - Woollard. Morphology and some interpretations of geomagnetic variations in Antarctica - Nagata. The ionosphere over Antarctica - Shapley.
23rd August	Antarctic research	Mean-westerly jet streams in the Southern Hemisphere - Philpott. The amount of ice on Planet Earth - Thiel.
	Oceanography - contributed papers	Report of progress, Project Mohole - Lill.
24th August		No papers of special interest.
25th August	Volcanism and plutonism	Magma type and crustal structure in the Aleutian Arc - Coats. On the age of granitic rocks in relation to the structural features of Sumatra - Katili. Frequency distribution of rock types in kratogenic, orogenic, and oceanic volcanic associations - Kuno.
26th August	Tsunamis	The seismic source - Press. Wave response of harbours to tsunamis - Miles and Munk. Magnitude, energy, and generation mechanism of tsunamis and catalogue of earthquakes associated with tsunamis - Iida. The source of motion of the tsunami of March 9, 1957 as deduced from wave measurements at Wake Island - Van Dorn.
26th August		Interpretation and prediction of tsunami waves approaching a variable coastline - Yoshida. The 1953 Suva earthquake and tsunami - Houtz. The Chilean tsunami of May 22, 1960, probably caused by seismic surface waves - St Armand.

DATE (1961)	SYMPOSIUM	SIGNIFICANT PAPERS
28th August		No papers of special interest.
29th August		No papers of special interest
30th August	Earth's crust in the Pacific Basin.	Crustal and upper-mantle structure of the eastern Pacific Ocean and adjacent continent - Press. Seismic wave velocities in the New Guinea-Solomon Is. region - Brooks. Crustal structure in the Pacific Ocean and adjacent continental areas from gravity observations - Woollard. Surface wave studies of the Pacific crust and mantle - Ewing. Crustal structure and volcanism in the Hawaiian Islands - Eaton. Gravity measurements in the Pacific Ocean - Worzel
31st August		Programme cancelled
1st September	Solid Earth Sciences - contributed papers	Geodetic positioning of Hawaii - Thomas. Magnetometer survey of total magnetic intensity in the Bering Sea - Fabiano. Depth to sources of magnetic anomalies - Alldredge. On the relation of electric and magnetic fluctuations in the ocean to the depth of conducting material in the mantle - Cox. Mapping the structure of the Pacific Ocean floor by geomagnetic measurements - Vacquier and others. On the relationship between the S and ScS waves - Furumoto. Tectonic features of the Pacific Basin as deduced from nuclear test results - Carder. Propagation of T waves in the Pacific Ocean - Wadati.

APPENDIX 2

LIST OF PAPERS OBTAINED

(a) Papers presented at the Tenth Pacific Science Congress.

Tsunamis.

Criteria for tsunami evaluation.	:	Zetler, Schuldt, and Bailey.
Potential tsunami inundation areas in Hawaii.	:	Cox.
A summary report on the Chilean tsunami of May 24, 1960 as observed along the coast of Japan.	:	Takahasi.
A theory of growth of tsunamis in a bay	:	Nakano.
A proposed central seismic system for tsunami warning purposes.	:	Lomnitz.
The Hilo tsunami gage system	:	Johnson.
Study on the tsunamis of the Sanriku coast.	:	Watanebe.
On the spectra and the mechanism of generation of tsunamis	:	Takahasi.
On the use of small-scale hydraulic models in tsunami research	:	Perry.
Magnitude, energy, and generation mechanism of tsunamis and catalogue of earthquakes associated with tsunamis	:	Iida.
On the estimation of tsunami energy	:	Iida.
On the partial reflection of water waves passing over a bottom of variable depth	:	Kajiura.
Tidal variations due to subsidence of a continental shelf	:	Lomnitz.
Propagation of T waves in the Pacific Ocean	:	Sato.
Los Terremotos de Mayo - Chile 1960 (An eyewitness account of the greatest natural catastrophe in recent history)	:	St Armand

Miscellaneous

Depth to sources of magnetic anomalies	:	Alldredge and Van Voorhis
Correlation of gravity and geologic data	:	Durbin.
Geodetic positioning of the Hawaiian Islands	:	Thomas.
The Earth's crust and upper mantle	:	Press.
A short outline of the geology of Malaya	:	Alexander.

APPENDIX 2

Reports issued in conjunction with the Congress.

Geophysics in Japan since 1921.	:	Rikitake.
Status of geophysical investigations in Indonesia.	:	Decker.
Progress in geology and geophysics in the Philippines since the first Pacific Science Congress in 1920.	:	Alcoraz.
Hawaii	:	MacDonald.
Progress in geophysics in New Zealand since 1920.	:	Robertson.
Status of geological and geophysical study of the islands of the western North Pacific	:	Johnson.
The progress of geological science in Indonesia 1921-1961.	:	Katili.
Marine geology of the Pacific Basin.	:	Hamilton.
Summary of studies of thermal waters and volcanic emanations of the Pacific region, 1920-1961.	:	White.
Progress reports of meteorological services in the Pacific area, 1957-1961.	:	Report of the Standing Committee on Meteorology.

APPENDIX 2

(b) Earthquake engineering papers

No.	Title		Author	Date of Publication
1.	The Earthquake Engineering Research Institute.	:		1960
2.	Bibliography of Engineering Seismology. (Note: This book contains complete references to all publications in the field. It is most comprehensive.)	:	P. Hollis.	1958 - second edition
3.	The measurement of ground motion of destructive earthquakes.	:	D.E. Hudson.	July 1961
4.	The Wilmot survey type strong-motion earthquake recorder.	:	D.E. Hudson.	1st September 1958
5.	The Wilmot survey type strong-motion earthquake recorder. (The USCGS Seismoscope). Part 2.	:	D.E. Hudson and W.D. Iwan	25th November 1960
6.	The CIT Mark II electric analog type response spectrum analyser for earthquake excitation studies.	:	T.K. Caughey, D.E. Hudson and R.V. Powell.	March 1960
7.	Earthquake resistant design based on dynamic properties of earthquakes.	:	G.W. Housner.	July 1956
8.	Earthquakes - construction inspection.	:	Committee on building inspection- H.J. Degenkolb, C.M. Herd, G.E. Morris, H.W. Bolin, Chairman.	1959
9.	Behavior of structures during earthquakes.	:	G.W. Housner.	October 1959
10.	Behavior of structures during earthquakes, vibration of structures by earthquakes.	:	G.W. Housner.	
11.	Recommended lateral-force requirements.	:	Seismology committee Structural Engineers Assoc. of California.	July 1959
12.	Geotechnical problems of destructive earthquakes.	:	G.W. Housner.	1954
13.	Dynamic effects of earthquakes.	:	R.W.Clough. (From Proc. Amer. Soc. civ. Engrs (J. Struct. Div.)	April 1960

APPENDIX 2

	Title		Author(s) / Source	Date of Publication
14.	Interaction of building and ground during an earthquake.	:	G.W. Housner. (Reprinted from Bull. seism. Soc. Amer. 47 (No.3)	July 1957
15.	A comparison of theoretical and experimental determinations of building response to earthquakes.	:	D.E. Hudson.	
16.	Effect of foundation compliance on earthquake stresses in multi-storey buildings.	:	R.G. Merritt and G.W. Housner (Reprinted from Bull. seism.Soc. Amer., 44 No.4)	October 1954
17.	Structural vibrations produced by ground motion.	:	D.E. Hudson and G.W. Housner, A.M.ASCE (Paper No.2880 Reprinted from Transactions, Vol.122, p.705)	1957
18.	A dynamic test of a four-storey reinforced-concrete building.	:	J.L. Alford and G.W. Housner. (Reprinted from Bull. seism. Soc. Amer., 43 No. 1)	January 1953
19.	Response spectrum technique in engineering seismology.	:	D.E. Hudson. (Reprint from the Proceedings of the World Conference on Earthquake Engineering).	June 1956
20.	Spectrum analyses of strong-motion earthquakes.	:	J.L. Alford, G.W. Housner, and R.R. Martel.	August 1951
21.	Limit design of structures to resist earthquakes.	:	G.W. Housner. (Reprinted from the Proceedings of the World Conference on Earthquake Engineering.)	June 1956
22.	Integrated velocity and displacement of strong earthquake ground motion.	:	G.V. Berg and G.W. Housner. (Reprinted from Bull. seism. Soc. Amer. 51 (2), 175-189).	April 1961
23.	A simplified instrument for recording strong-motion earthquakes.	:	W.K. Cloud and D.E. Hudson. (Reprinted from Bull. seism. Soc. Amer. 51 (2), 159-174).	April 1961

APPENDIX 2

	Title		Author(s)	Date of Publication
24.	An analysis of strong- motion accelerometer data from the San Francisco earthquake of March 22, 1957.	:	D.E. Hudson and G.W. Housner. (Reprinted from Bull. seis. Soc. Amer. 48, No. 3)	July 1958
25.	Measured response of a structure to an explosive-generated ground shock.	:	D.E. Hudson, J.L. Alford, and G.W. Housner. (Reprinted from Bull. seis. Soc. Amer., 44, No.3)	July 1954
26.	The plastic failure of frames during earthquakes.	:	G.W. Housner.	
27.	Design of nuclear power reactors against earthquakes.	:	G.W. Housner.	
28.	The effect of torsional oscillations on earthquake stresses.	:	G.W. Housner and Hannu Outinen (Reprinted from Bull. seism. Soc. Amer. 48 (3), 221-229)	July 1958
29.	Earthquake Engineering - Seminar held at the University of Roorkee, India.			February 1959
30.	An earthquake strain gauge for multi-storey buildings.	:	C.J. Dencich, C.M. Duke, and G.W. Housner.	1959
31.	San Francisco earthquakes of 1957.	:	G.B. Oakeshott.	1959
32.	Vibration tests of a steel-frame building.	:	D.E. Hudson and G.W. Housner.	July 1954
33.	Mode superposition methods applied to linear mechanical systems under earthquake type excitation.	:	H.C. Merchant.	March 1961
34.	The dynamic response of bilinear hysteretic systems.	:	W. D. Iwan.	July 1961
35.	Vibration tests of the Encino Dam intake tower.	:	W.O. Keightley, G.W. Housner, and D.E. Hudson.	July 1961
36.	Ground accelerations caused by large quarry blasts.	:	D.E. Hudson, J.L. Alford, and W.D. Iwan. (Reprinted from Bull. seism. Soc. Amer. 51(2) 191-202)	April 1961

APPENDIX 2

			Date of Publication
37.	The Port Hueneme earthquake of March 18,1957.	: G.W. Housner and D.E. Hudson (Reprinted from Bull. seism. Soc. Amer., 48 (2), 163-168)	April 1958
38.	Earthquake - Fire.	: Prepared by the Committee on Fire Protection : C.J. Derrick, H.M. Engle, A.V. Saph, and D.F. Moran, Chairman.	1958

APPENDIX 2

(c) Reprints of seismological (chiefly) papers

Earthquake surface-waves

Classification of surface waves and related topics	: Sato.
Upper-mantle structure under oceans and continents from Rayleigh waves	: Aki and Press.
Interpretation of source functions of circum-Pacific earthquakes obtained from long-period Rayleigh waves	: Aki.
Further study of the mechanism of circum-Pacific earthquakes from Rayleigh waves	: Aki.
Extent of the Antarctic continent	: Press and Dewart.
A comment on the flattening of the group velocity curve of mantle Rayleigh waves with periods about 500 sec	: Takeuchi.
Study of earthquake mechanism by a method of phase equalisation applied to Rayleigh and Love waves	: Aki.
Some implications on mantle and crustal structure from G waves and Love waves	: Press.
Long waves observed in the Kamchatka earthquake of November 4 1952	: Benioff.
Rayleigh-wave evidence for the low-velocity zone in the mantle	: Takeuchi, Press, and Kobayashi.
The use of Love Waves for the study of earthquake mechanism	: Aki.
Determination of crustal structure from phase velocity of Rayleigh waves - Part 1 - Southern California Part 2 - San Francisco Bay region Part 3 - The United States	: Press.

Californian seismicity and geology

Crustal structure in the California-Nevada region	: Press.
San Andreas Fault Zone in San Gorgonio Pass, Southern California	: Allen.
The San Andreas Fault	: Allen.
Earthquakes in Kern County during 1952	: Various authors.
Seismicity of southern California	: Richter and Gutenberg.
Earthquakes and earthquake damage in southern California	: Richter.

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Californian seismicity and geology (cont'd)

Seismic evidence for crustal structure and tectonic activity	: Benioff.
Crustal structure in northern and middle California from gravity pendulum data	: Tsuboi.
Note on the tectonics of Kern County, California as evidenced by the 1952 earthquakes	: Scheidegger.

Free oscillations of the Earth

Excitation of the free oscillations of the Earth by earthquakes	: Benioff, Press, and Smith.
Free oscillations of the Earth : 1, Toroidal oscillations	: Gilbert and MacDonald
Observations of the free oscillations of the Earth	: Ness, Harrison, and Slichter.
The fundamental free mode of the Earth's inner core	: Slichter.
Fused-quartz extensometer for secular, tidal, and seismic strains	: Benioff
Torsional oscillations of the Earth and some related problems	: Takeuchi.
Searching for the Earth's free oscillations	: Benioff, Harrison, La Coste, Munk, and Slichter.
Experimental determination of earthquake fault length and rupture velocity	: Press, Ben-Menahem Toksoz

General seismology

Long-period seismographs	: Benioff.
Earthquake energy released at various depths	: Gutenberg.
Low-velocity layers in the Earth, ocean and atmosphere	: Gutenberg.
The magnitude scale - its use and misuse	: Richter.
Probing the Earth with nuclear explosions	: Griggs and Press.
Energy release in earthquakes	: Kropoff.
The tsunami of May 23, 1960, on the Island of Hawaii	: Eaton, Richter and Ault.
Rigidity of the Earth's core	: Press.
Earthquake energy, earthquake volume, after-shock area, and strength of the Earth's crust	: Tsuboi.
Mount Wilson and at the Seismological Laboratory, Pasadena	: Gutenberg.

APPENDIX 2

General seismology (cont'd)

Low-velocity lithosphere channel	: Gutenberg.
Earthquake waves reflected at the inside of the core boundary	: Gutenberg.
An ultra-long-period seismograph galvanometer	: Lehner.
Seismic regionalisation	: Richter.
Magnitude and energy of earthquakes	: Gutenberg and Richter
Calibrating seismometers by means of earthquake data	: Forester.
Channel P Waves IIg in the Earth's crust	: Press, Gutenberg.
Channel waves	: Bath.
The energy of earthquakes	: Gutenberg.
The asthenosphere low-velocity layer	: Gutenberg.
A lunar seismic experiment	: Press.
The orogenic significance of a soft layer at 140-km depth	: Scheidegger.
The shadow of the Earth's core	: Gutenberg.
Waves reflected at the "Surface" of the Earth: P'P'P'P'	: Gutenberg.
Waves velocities below the Mohorovicic Discontinuity	: Gutenberg.
Statistical analysis of recent fault plane solutions of earthquakes	: Scheidegger.
Seismological research	: Benioff.

Theoretical seismology

A seismic model study of the phase-velocity method of exploration	: Press.
Two-dimensional seismic models with continuously variable velocity, depth, and density functions	: Healy and Press.
Leaking modes in the crustal waveguide	: Phinney.
General solutions of equations of some geophysical importance	: Takeuchi.
Note on the variational and homogeneous-layer approximations for the computation of Rayleigh-wave dispersion	: Press and Takeuchi.
A fast, convenient program for computation of surface-wave dispersion curves in multilayered media	: Press, Harkrider, and Scafeldt.

APPENDIX 2

Theoretical seismology (cont'd)

Absorption of Rayleigh waves in low-loss media	: Press and Healy.
Radiation of seismic body waves from a finite moving source in the Earth	: Ben-Menahem.
Elastic wave propagation in layered anisotropic media	: Anderson.
Automatic computation of impulse response seismograms of Rayleigh waves for mixed paths	: Aki, Nordquist.
First-motions from seismic sources	: Knopoff and Gilbert.
Diffraction of elastic waves by the core of the Earth	: Knopoff and Gilbert.
Radiation from a strike-slip fault	: Knopoff and Gilbert.
First-motion methods in theoretical seismology	: Knopoff and Gilbert.
Elastic wave radiation from faults in ultra-sonic models	: Press.
Further model study of the radiation of elastic waves from a dipole source.	: Healy and Press.
Exact transient solution of some elementary problems of elastic-wave propagation	: Flinn.
Radiation of seismic surface waves from simple models of fault planes Part 1: Rayleigh waves	: Ben-Menahem.
Part 2 : SH Waves (With application to the G Wave)	: Ben-Menahem.

Structural geology.

Geological and geophysical synthesis of the tectonics of portions of British Columbia, the Yukon Territory, and Alaska	: St Amand
Comparison of block and arc tectonics in Japan with those of some other regions	: Richter
Crustal structure along a certain profile across the East Indies as deduced by a new calculation method	: Tsuboi
Circum-Pacific tectonics	: Benioff

APPENDIX 2

General

The magnetic field and the central core of the Earth	:	Knopoff and MacDonald
On the chemical composition of the outer core	:	MacDonald, Knopoff
Polar wandering, displacements of continents, and subcrustal currents	:	Gutenberg
Geophysical research and progress in exploration	:	White and Press
Geophysical data implied in isostatic calculations	:	Gutenberg
Upper limit for interstellar millicycle gravitational radiation	:	Forward, Zipoy, Weber, Smith, and Benioff
A seismologist in Japan	:	Richter
Radio-wave reflections from the mesosphere	:	Gregory
Properties of the atmosphere between 90 and 300 km	:	Kallmann
Observations of geomagnetic fluctuations in the period range 0.3 to 120 sec	:	Benioff
The interpolation of Earth-tide records	:	Longman
Volcanoes, ice, and destructive waves	:	Press
How volcanoes grow	:	Eaton and Murata
Feasibility of a lava-diverting barrier at Hilo, Hawaii	:	Wentworth, Powers, Eaton
Electronic packaging for 5000-g survival	:	Miller
Scientific aspects of the nuclear test ban	:	Press

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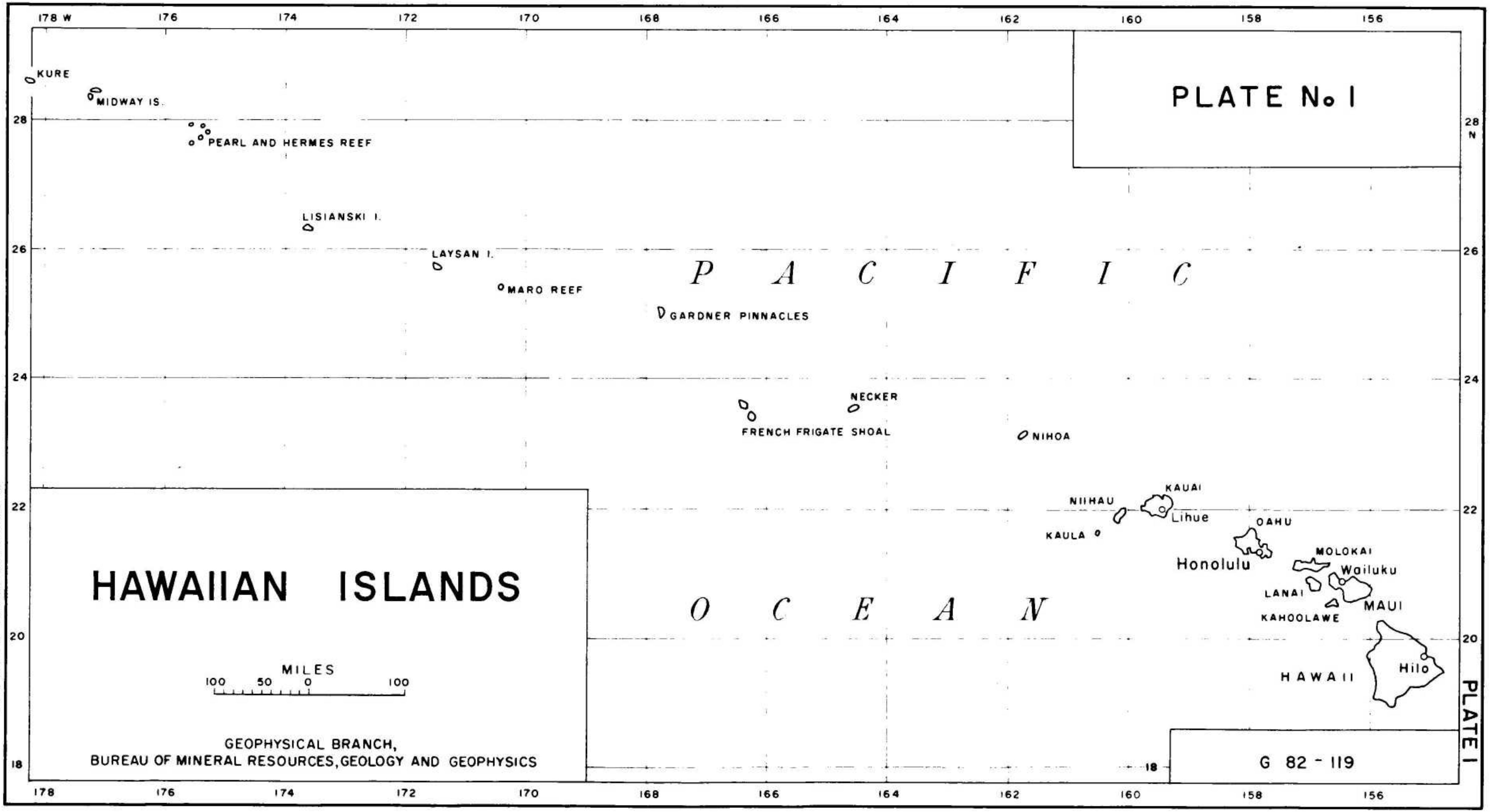
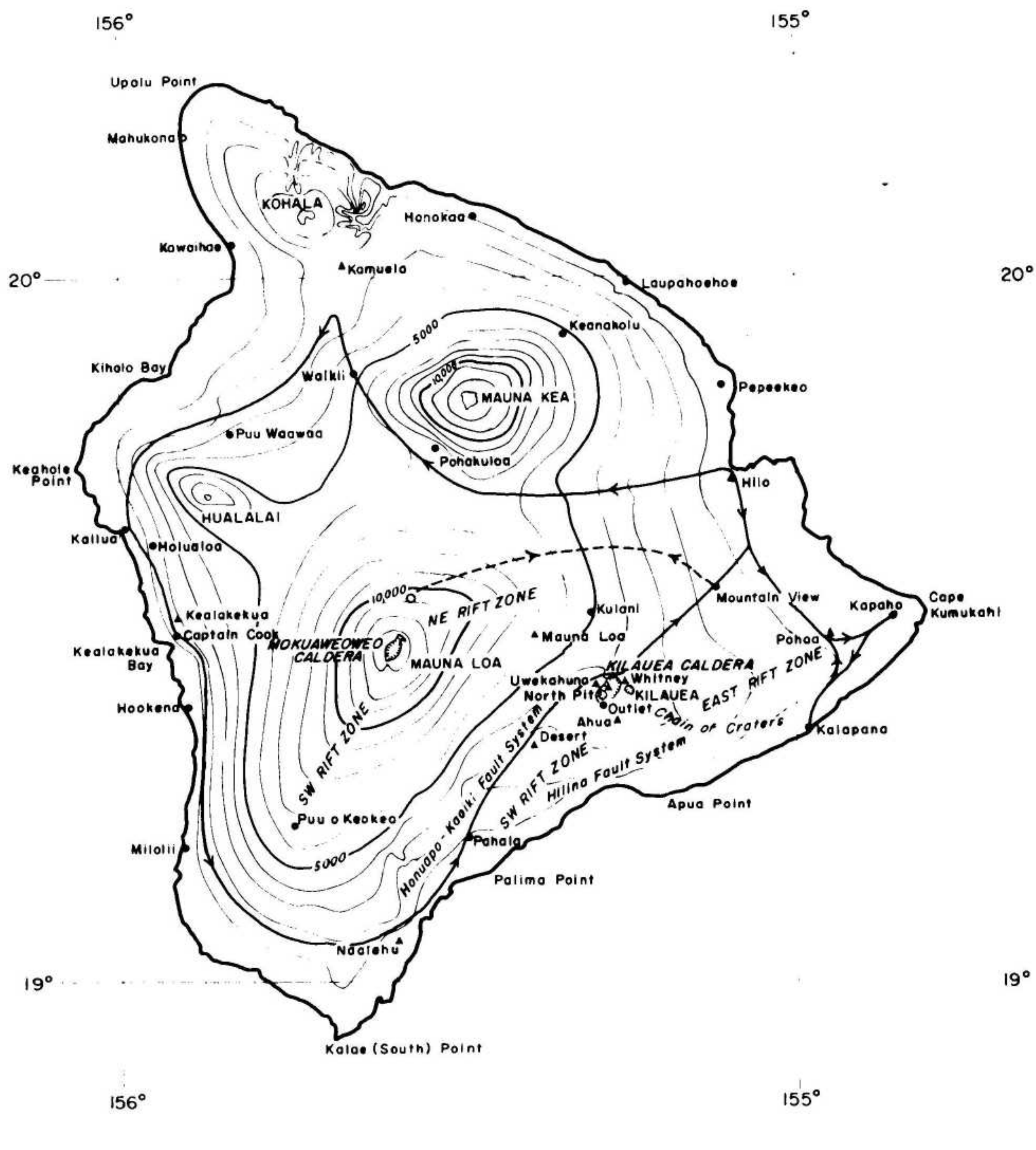


PLATE I

PLATE 2



▲ Seismograph Station

● Town or locality

○ Mauna Loa Met station

Topography by US Geological Survey

→ Route of Field Excursion

MAP OF HAWAII ISLAND

MILES

10 0 10 20 30

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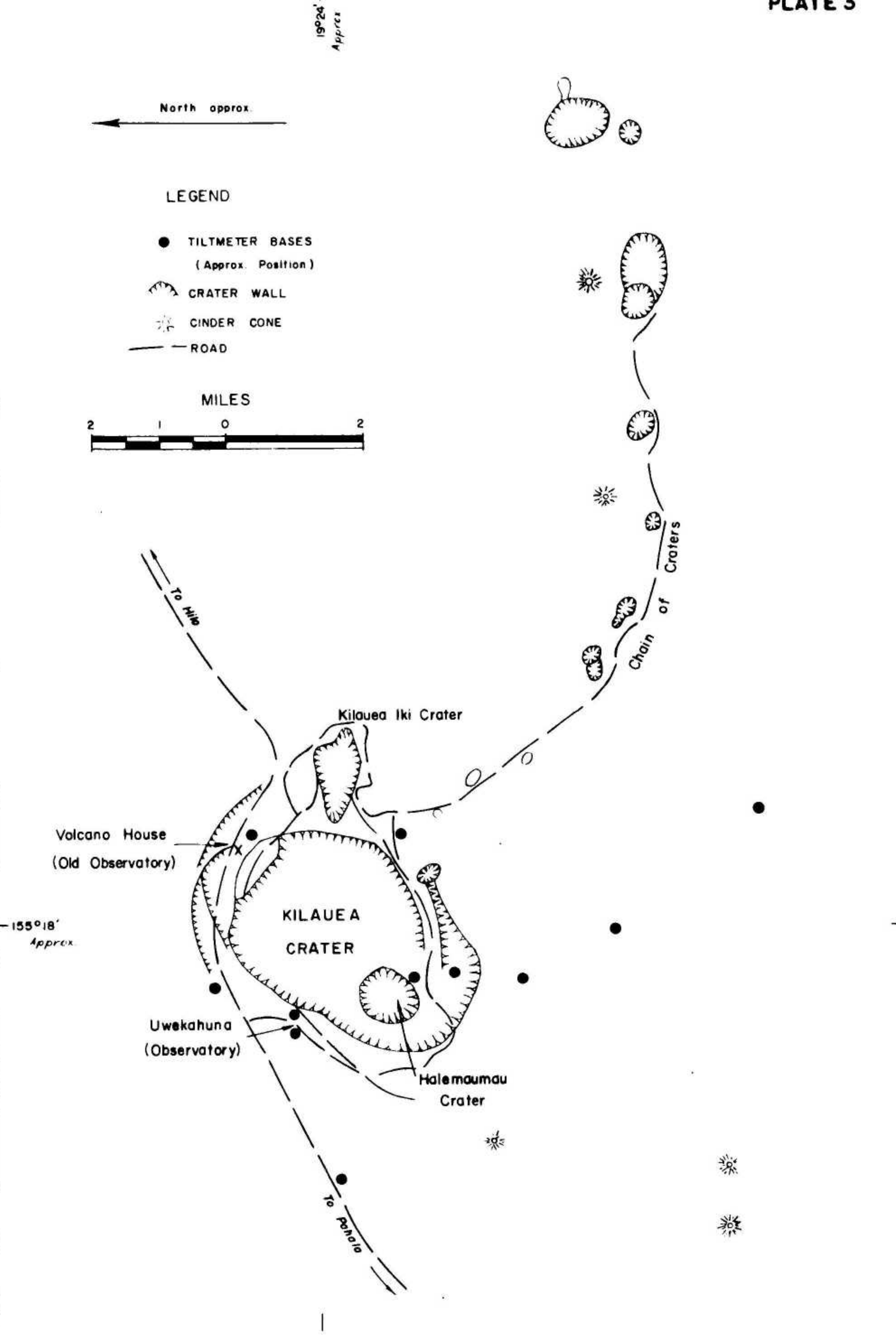
PLATE 3



HAWAII NATIONAL PARK

(KILAUEA CALDERA)

(FROM BULLETON 9, HAWAII DIVISION OF HYDROGRAPHY)

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HAWAII NATIONAL PARK

PLATE 4

Observatory Site
Office in foreground

Seismic Vault

Absolute and
Variation Buildings

USCGS OBSERVATORY
BARBERS POINT, OAHU

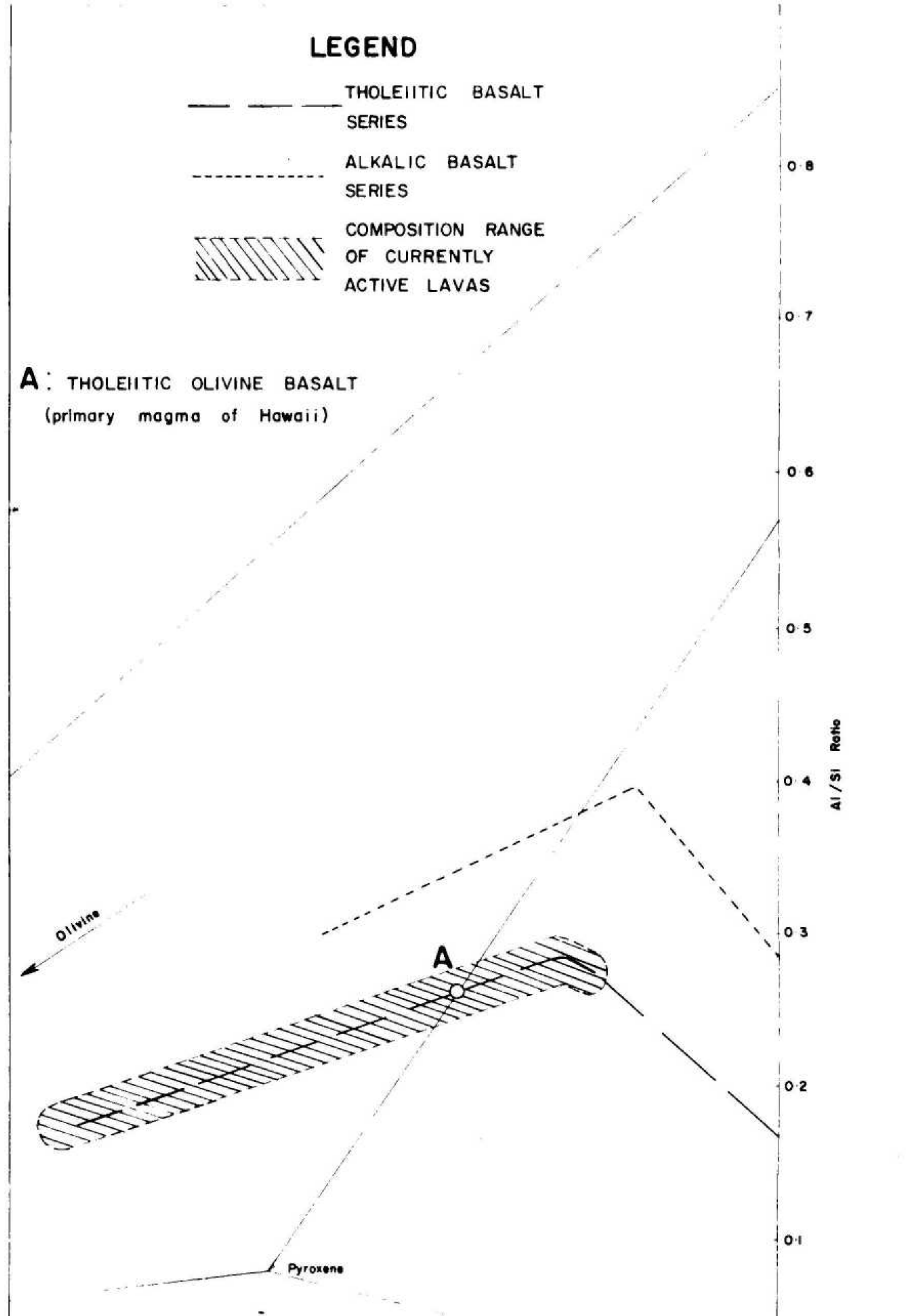
Absolute Magnetic House
(Ruska Earth Inductor)

Ruska Magnetometer
(note method of illumination)

USCGS OBSERVATORY
BARBERS POINT, OAHU

Mauna Loa from Volcano House, Kilauea

Mauna Kea 13,000 ft.
(from aircraft at 11,000 ft)



HAWAIIAN VOLCANIC ROCKS

COMPOSITION WITH RESPECT TO Mg and Al:Si RATIO
(from Eaton & Murata, 1960)

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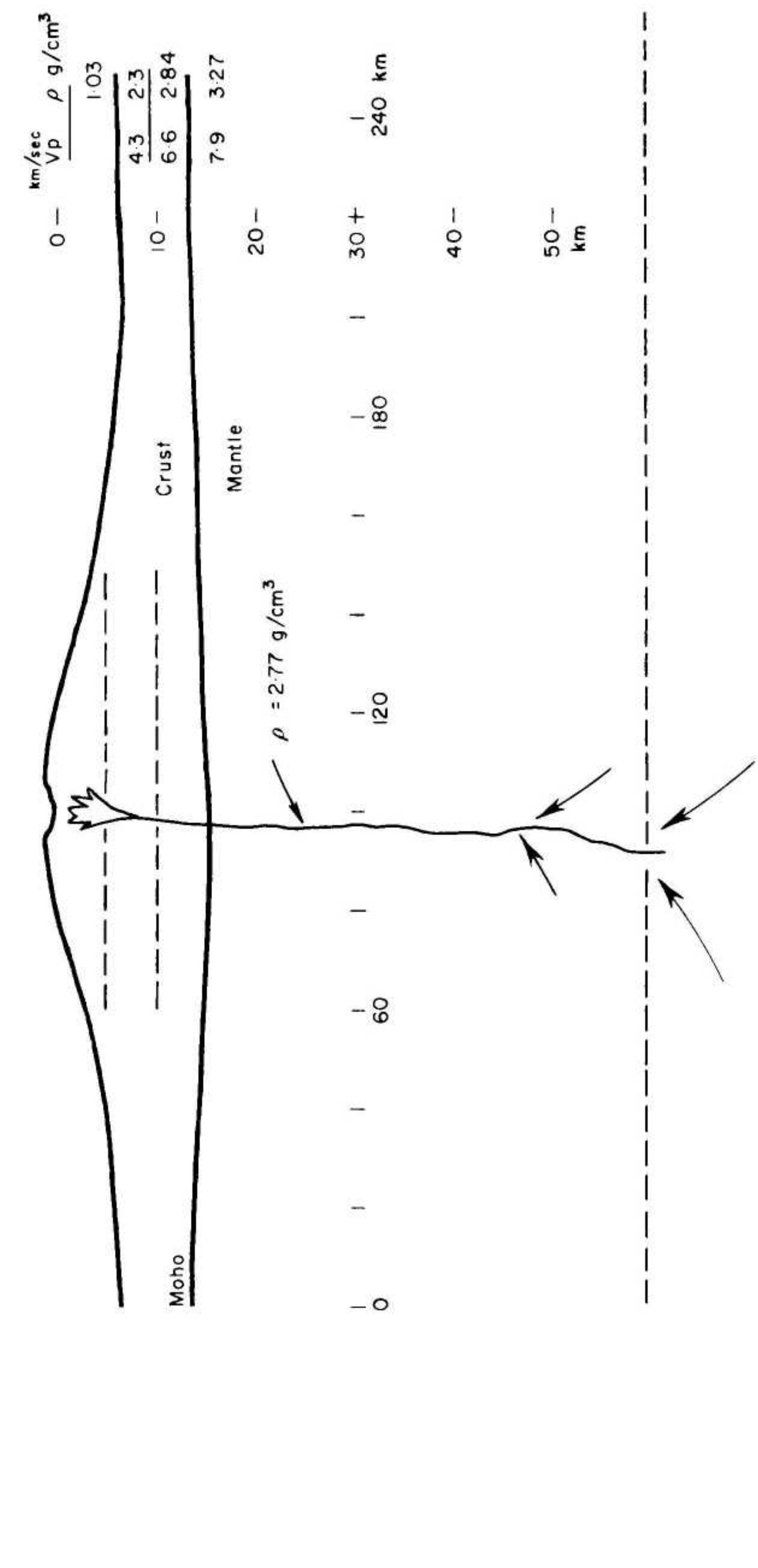
HAWAIIN VOLCANIC ROCKS

PLATE 8



INFERRED CRUSTAL STRUCTURE — HAWAII

REPRINTED FROM "HOW VOLCANOES GROW" (EATON AND MURATA, 1960)

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Pahoehoe lava flows, 1935

Pahoehoe lava flows 1935

Aa lava fields, Mauna Loa (elevation approx 9,500 ft)

Typical lava fields, Mauna Loa (elevation 11,000 ft)

LAVA FLOW TYPES, HAWAIIAN ISLANDS

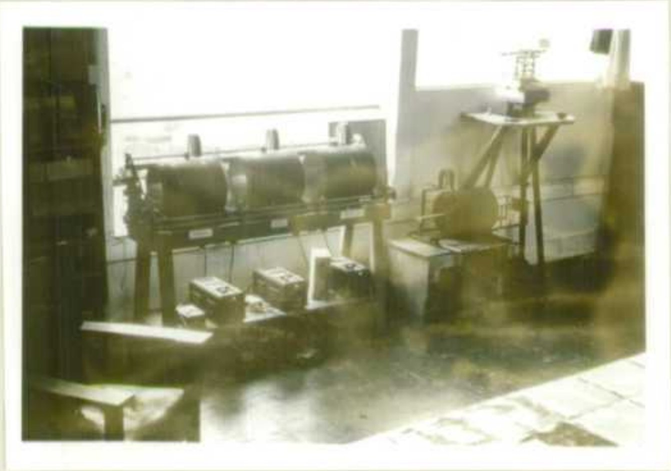
Kilauea Caldera and
Halemaumau (background)

Halemaumau crater,
Kilauea volcano

Kilauea Iki Cinder Cone
and Crater

(Halemaumau in background)

Volcano Observatory,
Kilauea



Visual Seismographs,
Uwekahuna

Uwekahuna Seismic vault

HAWAIIAN VOLCANO OBSERVATORY

Geothermal Steam Drilling Project, Kapoho
(Puna Area)

Remains of Kapoho following rift
Eruption (early 1960)

PUNA AREA — HAWAII ISLAND

Tsunami Damage, Hilo (Taken Sept. 1961)

Tsunami Damage, Hilo Foreshore
(Taken Sept. 1961)

(For Map of inundated area see Bull. Seis. Soc. Amer. Vol.51 No.2 P.146)

TSUNAMI DAMAGE — HILO

Research Station

Research Station

U.S. WEATHER BUREAU RESEARCH STATION,
MAUNA LOA. ESTABLISHED IN IGY 1957
(elev. 11,000')

PLATE 15

Eroded floor of
ancient Caldera,
Waimea Canyon

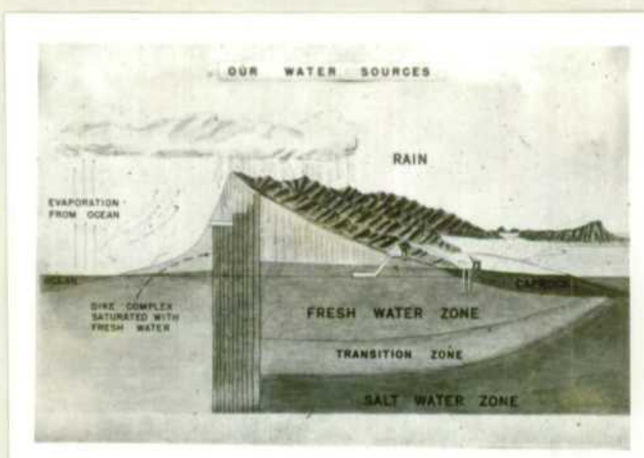
Eroded floor of ancient
Caldera, Waimea Canyon
3,000 ft deep

Kauho Valley
(elev. 4,000 feet)

WAIMEA CANYON AND KAUHAO VALLEY, KAUAI I.

PLATE 16

Haleakala Summit Crater, Maui (elev. 10,000')



Diagrammatic illustration of Oahu I. water resources

HALEAKALA SUMMIT CRATER, MAUI I. AND DIAGRAM OF WATER RESOURCES, OAHU I.

SEISMIC STATIONS
CALIFORNIA

STATIONS 1-20, NORTHERN CALIFORNIA (HEADQUARTERS-BERKELEY).
STATIONS 21-49, SOUTHERN CALIFORNIA (HEADQUARTERS-PASADENA)

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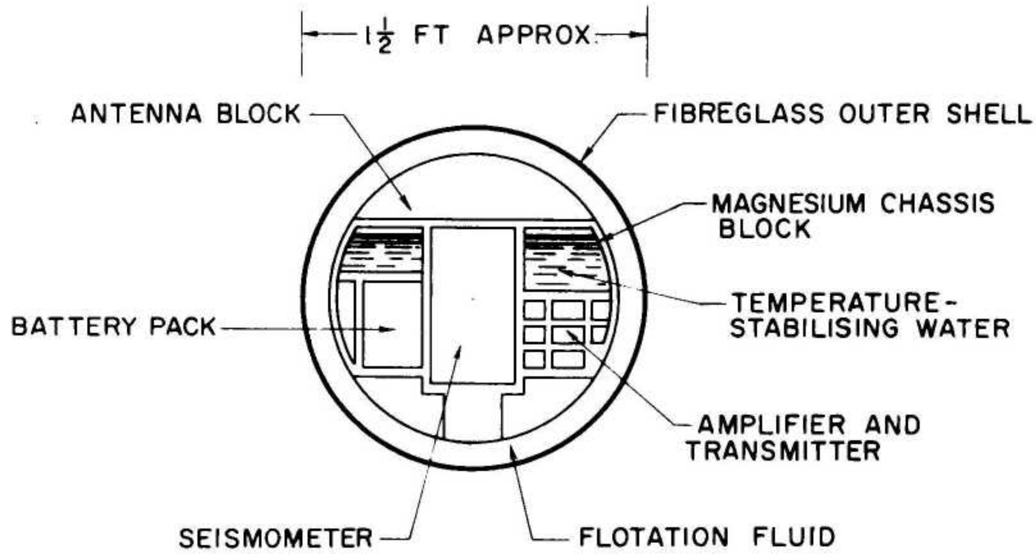
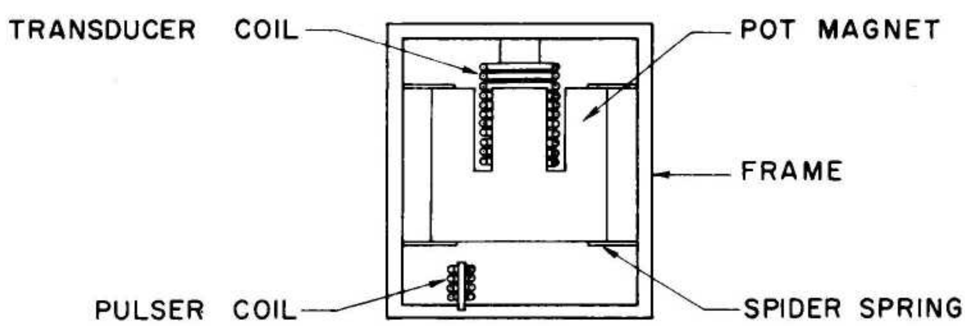
LUNAR SEISMOMETER



LUNAR CAPSULE SURVIVAL SPHERE



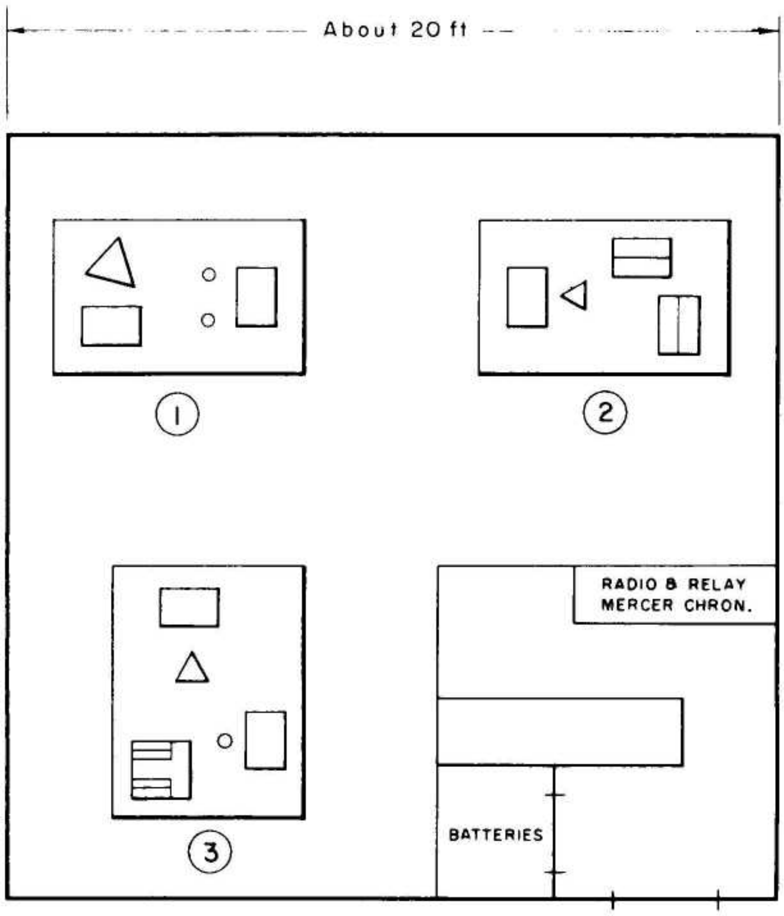
SCHEMATIC - SEISMOMETER CONSTRUCTION

REPRINTED FROM
" PACKAGING FOR 5000g SURVIVAL "
BY W.F. MILLER (1962)

PLATE 19

RIVERSIDE CALIFORNIA
SEISMIC STATION LAYOUT

(STATION IS IN A CONVERTED FORMERLY DISUSED BUILDING)



PIER 1 : BENIOFF S.P. Z + RECORDER

LP RECORDER E,N + 90 sec galvos.

PIER 2 : W.A. TORSION + RECORDER

2 BENIOFF S.P. HORIZONTALS

PIER 3 : W.A. TORSION

STRONG-MOTION TORSION 4 RECORDINGS ON FILM 3:100x, 1 4x

LP RECORDER, Z + 90-sec galvos

PORCH : ELECTRICALLY-WOUND MERCER CHRONOMETER

N.C. 88 RADIO + RELAY for AUTOMATIC TIME MARKING

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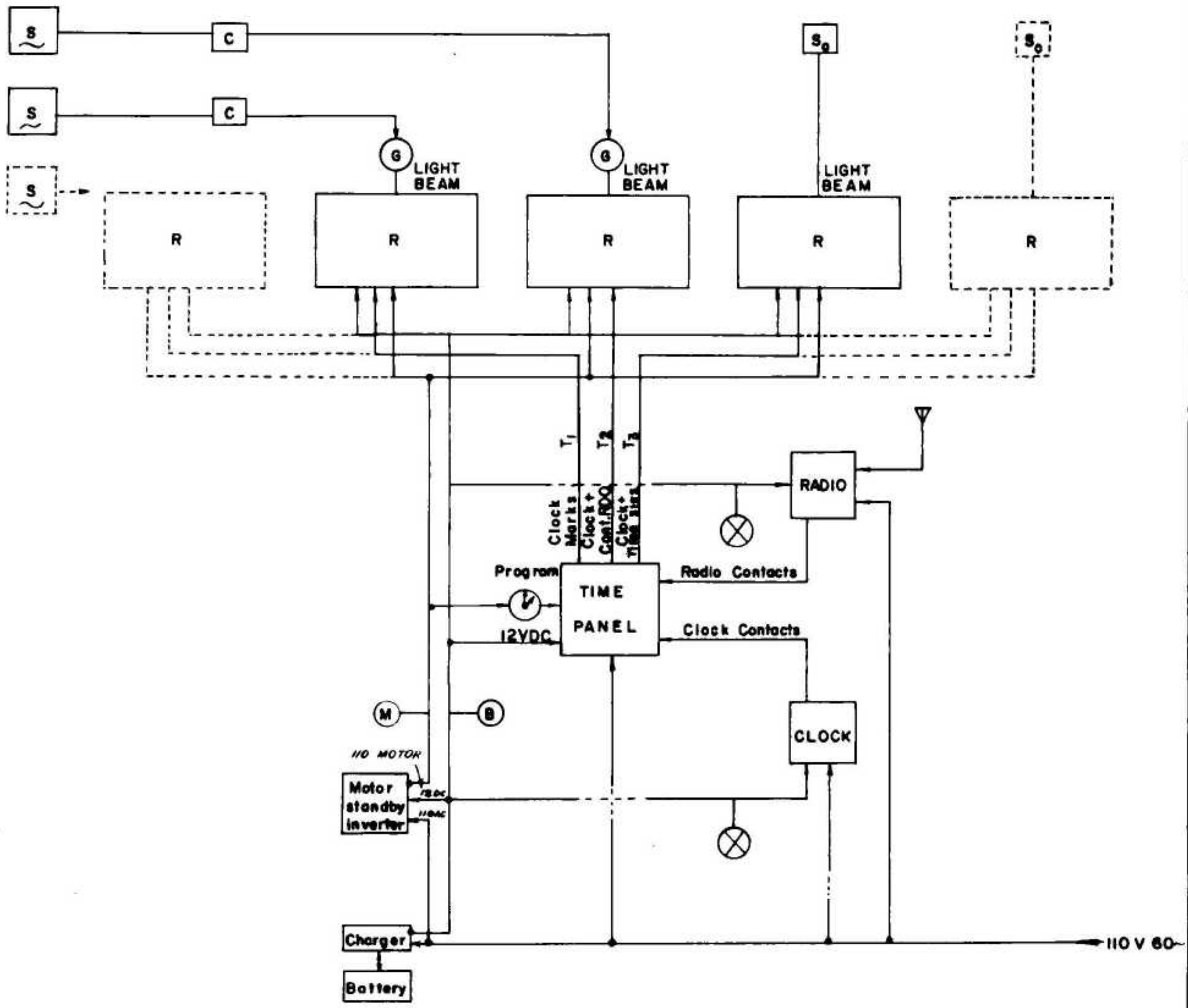
G 82-120

LEGEND

B = 12-V BATTERY LINE
C = GALVO CONTROLS
G = GALVANOMETER (OR OTHER ELECTRIC RECORDING METHOD)
M = MOTOR LINE - 115V60 ~
R = RECORDERS OR RECORDER CHANNELS
S = SEISMOMETERS - ELECTRIC (OPTICAL, INK, OR HOT STYLUS)

S_o = SEISMOMETERS - DIRECT OPTICAL RECORDING
T_1 = TIME LINE #1 CLOCK MARKS
T_2 = TIME LINE #2 T_1 + CONTINUOUS RADIO
T_3 = TIME LINE #3 T_1 or T_2 AS SELECTED
⊗ = CONNECTED ONLY IF REQUIRED BY PARTICULAR EQUIPMENT

NOTE: SEVERAL RECORDER CHANNELS MAY BE INCORPORATED INTO ONE UNIT-AS IN THE 4-CHANNEL FILM RECORDERS



BLOCK DIAGRAM OF TYPICAL SEISMOGRAPH STATION INSTRUMENTATION

as used in

CALIFORNIA INSTITUTE OF TECHNOLOGY SEISMIC OUTSTATIONS 1961

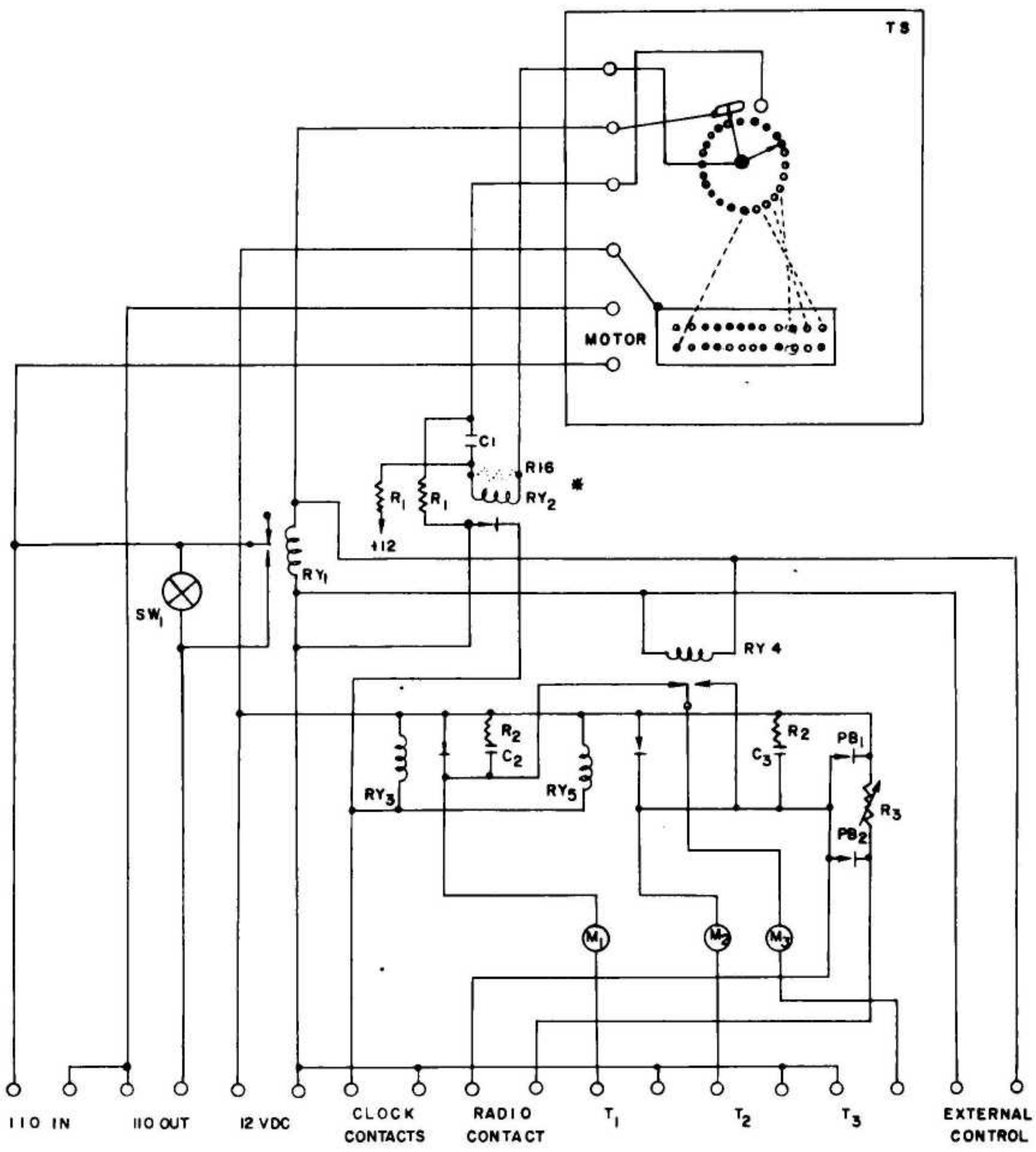
(see Plate 21 for details of Time Panel)

PLATE 21

LEGEND

C_1 = 1000 MFD 25V ELECTROLYTIC CAPACITOR
C_2 = 2 MFD 100V PAPER CAPACITOR
C_3 = 2 MFD 100V PAPER CAPACITOR
M_1 M_2 M_3 = D.C. MILLIAMMETER
PB_1 PB_2 = PUSH-TO-MAKE PUSH BUTTON SWITCHES
R_1 = 50 K, 1/4 W RESISTOR
R_2 = 1000 OHM 1/4 W RESISTOR
R_3 = 2000 OHM 4 W WIREWOUND POTENTIOMETER

$R_1R_2R_3R_4R_5$ = ADVANCE # RELAY
TS = L and G RADIO PROGRAMMING TIME SWITCH
T_1 = TIME LINE # 1 CLOCK ONLY
T_2 = TIME LINE # 2 CLOCK PLUS CONTINUOUS RADIO
T_3 = CONTINUOUS # 3 CLOCK PLUS RADIO AS PROGRAMMED BY TS



TIME PANEL CIRCUIT

as used in

CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMIC OUTSTATIONS 1961

* R16 MAY BE ADJUSTED FOR CORRECT HOUR MK LENGTH

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