They further suggested that this attenuation is due to local pockets of molten or partially molten material in the mantle. This may reflect a high-temperature zone in the outer mantle at a depth of 100 to 300 km and may be related [*Press*, 1959] to the low-velocity layer for which evidence has been accumulating. There is some evidence that regional differences exist for this effect.

This attenuation can be investigated in detail by long refraction profiles using nuclear and large chemical explosions in the appropriate regions, provided adequate shear waves are generated.

(*c*) A search is in order for seismic differences in the outer mantle related to the large differences in surface heat flow observed in the oceans. Heat flow through the Pacific floor varies by more than a factor of 50 from one place to another. Such variation can hardly be due to conditions in the crust, but must come from different temperature gradients in the mantle. Seismic studies from explosions have not yet penetrated any appreciable distance below the Mohorovicic discontinuity anywhere and may not have penetrated it at all in the region of the highest observed heat flow—the Albatross plateau off the west coast of South America.

Large chemical explosives probably will suffice to plumb the depths sufficiently to resolve this question.

(*d*) A similar search should be made for the mechanism of isostatic compensation of oceanic regions of different elevation that are in isostatic balance. For example, on opposite sides of the Mendocino escarpment, the elevation is different by more than a kilometer, yet the acceleration of gravity at sea level is the same on both sides. The difference in density necessary to maintain this balance should be detectable seismically, but it has not been found in the shallow refraction studies to date.

Determination of the nature of earthquakes. Since explosions are implusive sources of short duration, the seismometer output is the response of the earth for transmission of the known source impulse. Hence it is possible, in principle, once this response is known, to work backward from earthquake records to determine the true nature of earthquake sources. This would have great value for tectonic studies. It is also pertinent to the problem of discriminating between earthquakes and explosions in the event of a test moratorium.

Specific Proposals

Many possible experiments will occur to geophysicists. We outline below one possible program to illustrate the magnitude of the effort we have in mind. The final program must be decided by an international group of scientists.

Exploitation of Plowshare detonations. Each explosion planned in the Plowshare program constitutes a unique source of seismic waves. It is to be hoped that appropriate steps will be taken to insure that the maximum seismological benefit will be derived from these explosions. To this end, it is necessary that the detonation time and position be published long enough in advance to allow the various seismological organizations to plan and deploy their instruments. It would be desirable if, in each Plowshare project, a series of chemical explosions could be detonated before the nuclear explosion, to provide calibration of seismometers.

Plowshare explosions such as the shot in salt (Gnome), the proposed test shot in the Athabaska tar sands, and the proposed harbor excavation project (Chariot) would constitute seismic sources of unusual interest, since they are all in regions of interesting geology where there have been no large explosions for seismic purposes. All the other proposed Plowshare projects would also be very valuable seismic sources.

In particular, each Plowshare explosion should be used as a source for several refraction profiles radiating from it. We propose that several hundred automatic or remote-controlled seismic recorders be deployed for this purpose at each Plowshare explosion. An effective refraction line to probe the outer few hundred kilometers of the mantle should be composed of about a hundred sensitive seismometer arrays on a line 2500 to 3000 km long. When several such lines are established, radiating from the position of the nuclear explosion, a series of large chemical explosions should be conducted along each line to determine local structure and thus reap the maximum benefit frcm this extensive seismic array. The unmanned seismic stations proposed by the *Panel on Seismic Improvement* [1959] would be admirably suited for deployment on the Plowshare lines. Such a use, prior to installing them in the Geneva network for seismic detection of A-bomb tests, would constitute an excellent field test for the equipment and would provide much-needed information on the nature of seismic signals from a nuclear explosion in addition to the purely scientific rewards.

A series of such profiles associated with Plowshare projects like Gnome, Chariot, and the Athabaska tar sand test shot would provide seismology with far more detailed and accurate information than has been obtained from earthquakes and chance quarry blasts in fifty years. We would begin to know in detail what the underpinnings of continents are like.

These profiles should be augmented by other seismic detectors—notably a coarser net of long-period instruments to utilize the surface waves emanating from the Plowshare shots.

Oceanic seismometer lines. In many respects the ocean floor is the best site for seismological stations. The multitude of short (100–150 km) refraction profiles that have been made by Ewing, Press, Officer, Raitt, Shor, and others have shown that the crust beneath the deep ocean floor is thin and remarkably uniform. The evidence at hand indicates that seismic background noise is low. Hence, high-sensitivity seismometers with precision timing can provide far more accurate information on the characteristics of the mantle than may ever be possible from typical continental sites. The 'station error' which plagues ordinary seismological observations results from local variations in velocity. In continental stations, seismic waves coming from different directions will have travel times in the last hundred kilometers different by as much as several seconds, averaging about ½ second for 'good' observatories.

The deep oceanic crust is about one-eighth as thick as the continental crust, and its variation in velocity is about one-third that in the continental crust. Hence the inherent error for an uncalibrated station should be about 0.02 seconds, and this may be reduced by calibrating the stations with local refraction profiles. Whereas conventional seismological stations report arrival times to the nearest second, deep ocean stations should report to the nearest tenth or possibly hundredth of a second.

We propose that several lines of seismometers be established on the floor of the ocean. Each line should be 2500 km long and should be composed of 100 evenly spaced stations. Ninety of these could be arrays of ordinary hydrophones. Every tenth station should also contain three-component short- and long-period seismometers placed on the bottom. There are various ways in which this can be done—all expensive. Perhaps the best way, considering all aspects of the problem, is to lay a single long cable with the seismometers attached to it, terminating on an island or continental shore. The seismometers would receive power through the cable, and would transmit their signals to the land station for recording and processing. Alternative methods of establishing such a line are to use telemetering buoys or recoverable ocean-bottom instruments.[4]

The position of each seismometer must be known to a high degree of accuracy if the full potential of these seismometer lines is to be realized. Long-range travel times were determined to an accuracy of about 0.2 per cent by earthquake seismology. We are striving to make a substantial improvement in this accuracy. The most promising method of location seems to be to determine the travel times of the direct waterborne shock wave from explosive sources to the seismometers. Deep water velocity is now known to about 0.1 per cent. This accuracy must and can be improved. Two methods are obvious: (1) Collect samples of bottom water and measure the velocity in the laboratory at the appropriate pressures and temperatures. Such velocity measurements can be made to accuracies of better than 0.01 per cent. (2) Determine the distance between the stations by radio ranging methods and thus calibrate the average water velocity, correcting locally for changes due to temperature, pressure, and salinity.

Figure 3 shows a schematic layout of an oceanic seismometer line together with a suggested schedule of 10-, 100-, and 1000-ton chemical explosive shots. The 10-ton shots can be recorded to distances of about 300 km and will penetrate the mantle to a depth of about 80 km. The 100-ton shots can be recorded to 1000 km or

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[4] A recent experiment by the Lamont Geological Observatory, with a self-contained bottom seismometer, demonstrated that seismic noise on the sea floor is exceedingly small—so much so that bottom seismometers seem much the best technique for conducting this experiment. This remarkable advance might make possible a significant decrease in shot size over those given below.