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On Reducing the Amplitude of Surface Waves by Source Arrays

G. C. Werth

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Lawrence Livermore National Laboratory

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November 23, 1959

TO: Distribution

FROM: G. C. Werth

SUBJECT: Report "On Reducing the Amplitude of Surface Waves by Source Arrays".

The Geneva conference of experts stated that surface waves help define the nature of a seismic perturbation. A "phase equalization" method has been proposed by several seismologists to determine the polarity of the source using crustal surface waves. In this report a horizontal source array is designed which will reduce the amplitude if the crustal surface waves by a factor of five. Experimental data from Geophysical Prospecting is cited to support the effectiveness of such arrays. It is thought that phase shifts will accompany this amplitude reduction. It is concluded that these amplitude and phase changes will make the phase equalization method unreliable. The significance of the report is that the Geneva negotiations must take into account the possibility of horizontal as well as vertical arrays. The work is in an early stage of developement; criticism will be appreciated.

Glenn C. Werth

Glenn C. Werth

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sources would have to be known. Such information can not be obtained from present interpretational techniques for epicenter location. We are forced to conclude that man can confuse the surface wave interpretation as easily as the longitudinal wave interpretation. These factors should be borne in mind in writing a treaty.

Oil Company Experience in The Design of Source Arrays

In "good" record areas surface waves are not a problem because either they are highly attenuated by the particular geologic formation or their frequencies are below the frequencies of interest and can be eliminated through filtering. In "poor" record areas, if surface waves are observed, it is routine for the prospecting crew to take steps to eliminate them. The velocity (phase) and dominent frequency is measured from the record. Standard charts are consulted to design either a receiver array or source array or both. If the area is such that topographic irregularities reflect the surface waves back to the geophone line, a pattern or two dimensional source array is required. Otherwise a simple line array is sufficient.

The theoretical results of arrays with two through six units are summarized in Figs.1 and 2. These graphs are taken from Parr and Mayne (1955) but they were first described for seismic work in a patent by Taylor (1931). These curves give the steady state response. Transient analyses have also been made but it is found that the transient results are not very different from an "eyeball" average through the loops and nodes of the reject region. Since crustal surface waves at Geneva Network distances should be fairly well dispersed, the steady state response is the one that should be used when working with amplitude discrimination.

As expected, the curves show that as the number of elements is increased, the band width of the rejected waves becomes larger and there is more rejection. Various authors claim that an addition rejection, by a factor of two or so can be obtained by departing from the uniform strength of individual units to particular variable strengths.

Experimental work has proven that these design criteria are effective. Figure 3 is reproduced from Parr. The lower panel clearly shows a surface wave

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of high amplitude generated by a single charge extending from 4.5 seconds on the bottom trace to 8 seconds on the top trace. The upper panel using an array shows no evidence of this surface wave. Instead the automatic gain control has raised the gain sufficiently to see good reflections at the surface wave time. The fifteen element array in Fig. 3 is equivalent to a 6 or 7 element line array in any particular direction.

Figure 4 gives a second experimental verification of the effectiveness of arrays in discriminating against surface waves. The illustration is from an article by Domenico (1958). In this instance the seismic energy is generated by dropping a three ton weight nine feet onto the ground. The receiver set up is maintained constant and the drop truck has proceeded from 2,000 feet to 4,000 feet dropping the weight at 20.8 foot intervals.

The upper panel clearly shows a well developed surface wave. A four element line source array is simulated by summing four adjacent traces. The surface wave has been almost eliminated. We maintain that this four trace summation is essentially identical to the record that would have been obtained if four weight dropping trucks were used simultaneously.

Although these experiments were not designed to obtain a precise quantitative measure, a prospecting seismologist readily accepts them as proof that the factors of reduction of five or so predicted by theory are found in practice.

<u>Design of a Test Facility To Reduce Surface Waves</u>

The array will be designed to discriminate against crustal surface waves. The highest amplitude part of the wave, the Airy phase, occurs at the group velocity minimum. Experimentally the minimum occurs at a period 18 seconds. A representative phase velocity for this period is 3.4 km./sec. (see Fig. 5) (Ewing and Press (1959)). We choose a 4 element array with dimensions such that $\lambda/D = 2.4$ with $\lambda = (3.4)(18) = 61$ km. Hence D = 25.4 km. in the direction of a particular network station. Two layouts of a clandestine test facility designed to discriminate against surface waves are shown in Fig. 6. By geometry successive elements for the line array are 34.2 km. apart.

We now calculate the reject band width. According to Fig. 1, the band width runs from $\lambda/D = 1.3$ to 5.1 or $\lambda = 33$ to 130. The periods are $T = 33/3.25 = 10.1$ sec. to $T = 130/3.8 = 35.8$ sec. The phase velocities have

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been taken from Fig. 5. Most of the crustal wave energy is contained within this frequency band.

The reduction in this band averages .2 or a facor of 5. Details can be examined in Fig. 1. Although no experimental data on surface waves from nuclear detonations are available at LRL, we conjecture that more energy is put into the wave by the source at periods below the Airy frequency than above. If this is true then the higher amplitude parts of the surface wave would be reduced by a factor approaching ten. Further reductions are possible (factor of 2 or so) by having different strengths in the individual members of the array. Of course with more elements in the array, more reduction over a wider band can be obtained.

Although detailed calculations have not been made it would appear that, because of the rarefaction first motions, and the large epicenter location uncertainty by S-P methods, a seismologist might prefer an earthquake-in-the-mantle interpretation. (See the report by Werth (1959)).

Theoretical calculations on the waveforms of surface waves are not far enough along at LRL to show what would happen if the Brune Oliver-Aki source function technique were used. We make the following speculation. First of all the amplitude would be down by a factor of 5. However, careful filtering may still reveal a remnant surface wave. The Brune Oliver-Aki technique assumes a single impulse type source (no phase shifts at the source) at a known distance. There is too much uncertainty in the distance to apply it here. If a particular distance were chosen, and even if it were correct for one of the sources, it is expected that the effect of the multisources is to introduce drastic phase shifts in an assumed equivelent single source function. It might be possible to design this array to give earthquake type polarities for surface waves. In order to be sure of these statements, we will have to wait until theoretical waveforms from multisources are derived for various configurations. The amplitude reduction can be depended upon because of the oil company experience.

The discussion so far has been based on the first ring of network stations. Oil company work shows that three to four additional elements are necessary to obtain the same reduction independent of direction.

There is no intent to minimize the contribution of the Brune Oliver-Aki technique to the general scientific literature, only to point out that complications arise in applying the technique to the Geneva system if arrays are used.

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Significance

While crustal surface waves may be of some help in the detection and identification of underground nuclear detonations, it should be borne in mind that they can be materially changed in amplitude and probably phase as well by using an array. Any rules for on-site inspection must recognize the possibility of horizontal as well as vertical arrays. Extreme care must be taken not to over simplify the technical situation in the wording of a treaty.

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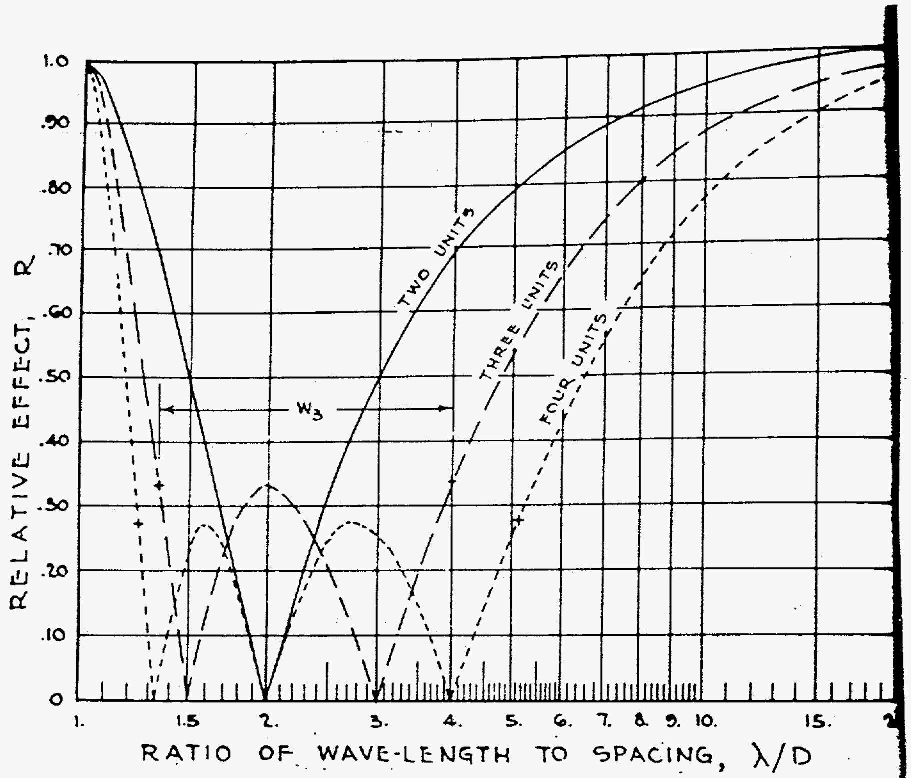

The relative effect, R, of uniformly effective units with a uniform spacing in line as a function of λ/D. λ is the wavelength of the received energy. D is the spacing between the units, and R is the ratio of the relative effect of the spaced units to what it would be if all units were bunched at the center of the group. The solid line shows the relative effect of two units (detectors or charges). The dashed line shows the relative effect of three uniformly effective units. The dotted line shows the relative effect of four uniformly effective units.

Fig. 1

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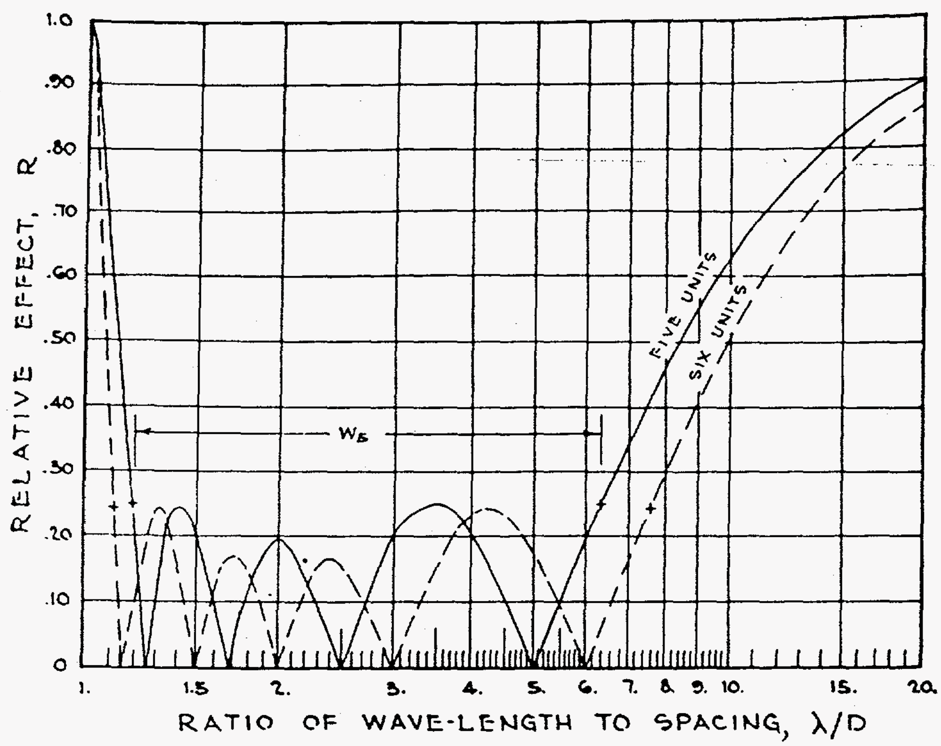

Same as Figure 1 except that the solid line represents the relative effect of five uniformly effective units and the dashed line shows the relative effect of six uniformly effective units.

Fig. 2

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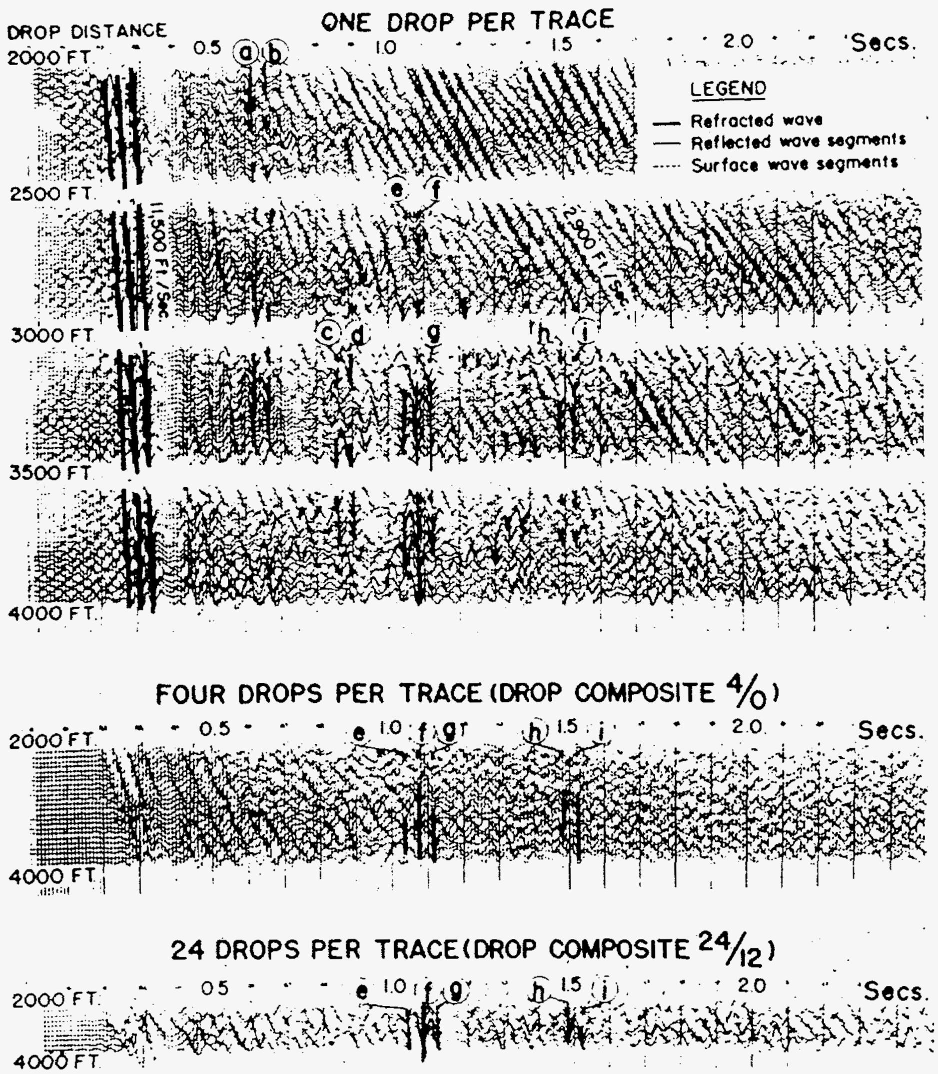

Records from Test Site II. Traces on the upper four records represent single drops at 20.8-ft intervals along a line extending 2,000 to 4,000 ft from the recording seismometer station containing 36 seismometers. The bottom two records were obtained by compositing these drops four to a trace and 24 to a trace, respectively.

Fig. 4

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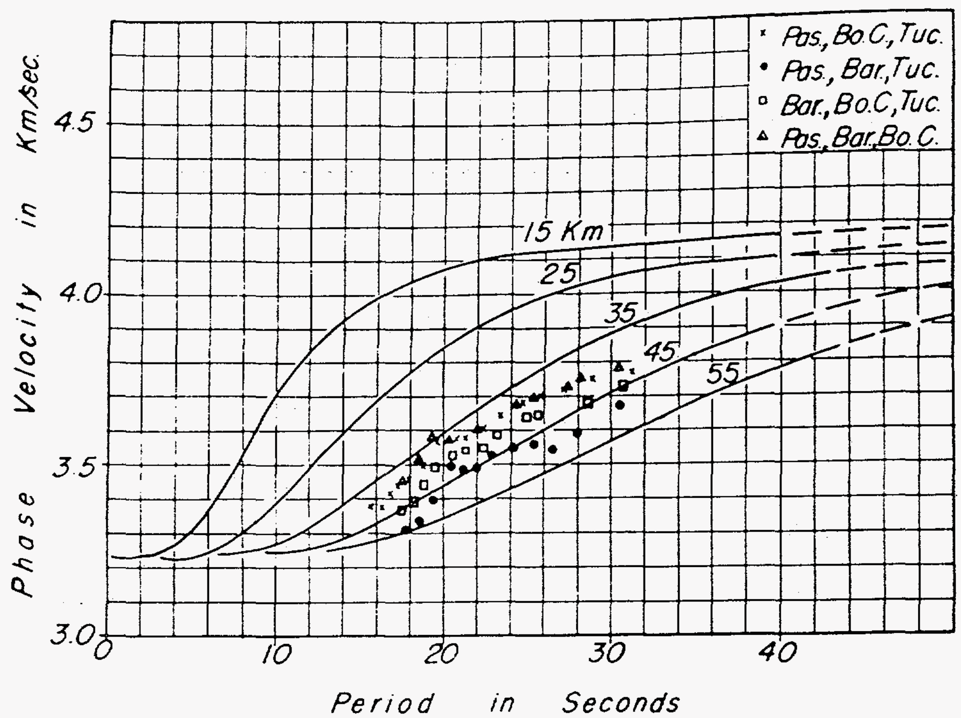

—Phase-Velocity Determinations for Peninsular Ranges-Southwest Desert Region

Fig. 5

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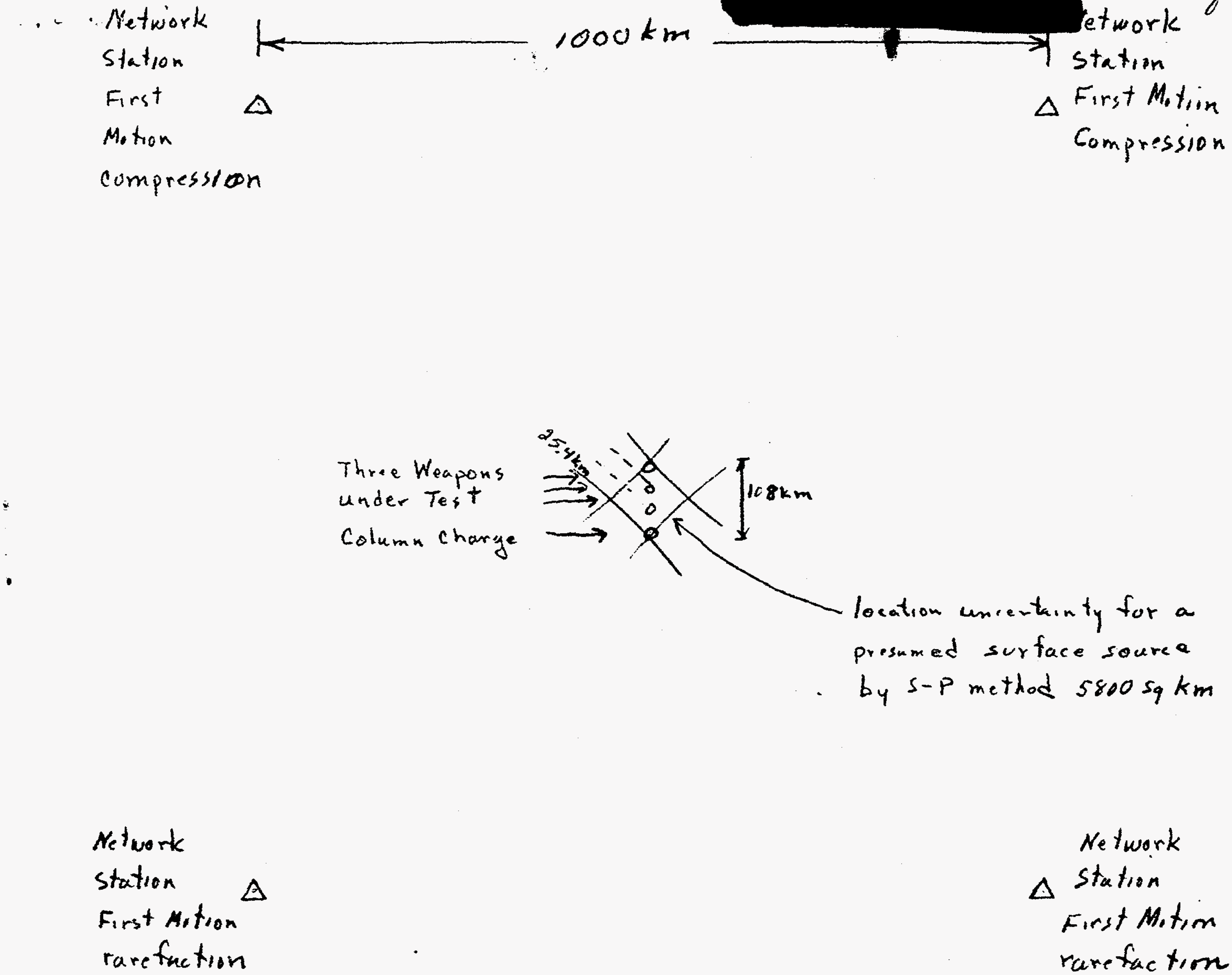
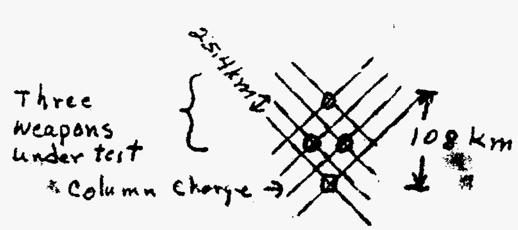


Linear Array To Reduce The Amplitude
of Crustal Surface Waves



Alternate Source Arrangement
equally effective

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Figure 6

Werth 11/23/59