stations, the details have been worked out—the speed, the curves, etc. are all known. We know what the speeds of various kinds of waves are at every depth. Knowing that, therefore, it is possible to figure out what the normal modes of the earth are, because we know the speed of propagation of sound waves—in other words, the elastic properties of both kinds of waves at every depth. Suppose the earth were distorted into an ellipsoid and let go. It is just a matter of superposing waves travelling around in the ellipsoid to determine the period and shapes in a free mode. We have figured out that if there is a disturbance, there are a lot of modes, from the lowest, which is ellipsoidal, to higher modes with more structure.

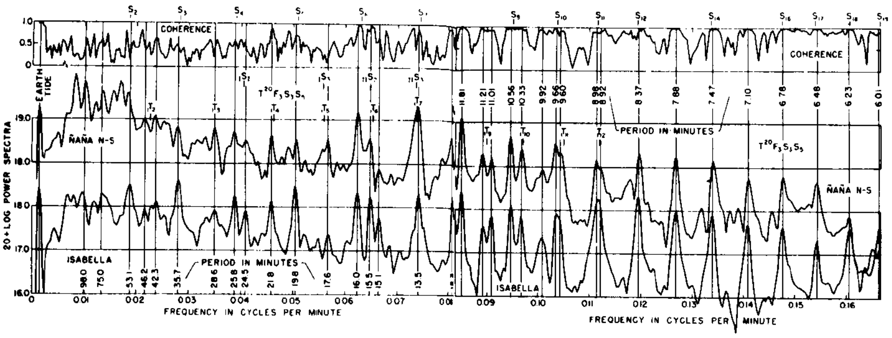

Fig. 51–7. Power versus frequency as detected at seismographs in Ñaña, Peru, and Isabella, California. The coherence is a measure of the coupling between the stations. [From Benioff, Press and Smith, *J. Geoph. Research* **66**, 605 (1961)].

This paragraph explains the calculated natural frequencies (from earlier earthquake data) and compares "the response" due to changed "initial conditions" resulting from Chilean earthquake with measurements.

The Chilean earthquake of May 1960 made a loud enough "noise" that the signals went around the earth many times, and new seismographs of great delicacy were made just in time to determine the frequencies of the fundamental modes of the earth and to compare them with the values that were calculated from the theory of sound with the known velocities, as measured from the independent earthquakes. The result of this experiment is illustrated in Fig. 51–7, which is a plot of the strength of the signal versus the frequency of its oscillation (a *Fourier analysis*). Note that at certain particular frequencies there is much more being received than at other frequencies; there are very definite maxima. These are the natural frequencies of the earth, because these are the main frequencies at which the earth can oscillate. In other words, if the entire motion of the earth is made up of many different modes, we would expect to obtain, for each station, irregular bumpings which indicate a superposition of many frequencies. If we analyze this in terms of frequencies, we should be able to find the characteristic frequencies of the earth. The vertical dark lines in the figure are the calculated frequencies, and we find a remarkable agreement, an agreement due to the fact that the theory of sound is right for the inside of the earth.

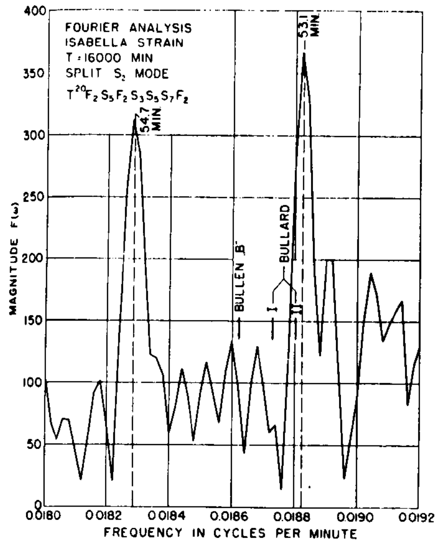

Fig. 51–8. High-resolution analysis of one of the seismograph records, showing spectral doublet.

A very curious point is revealed in Fig. 51–8, which shows a very careful measurement, with better resolution of the lowest mode, the ellipsoidal mode of the earth. Note that it is not a single maximum, but a double one, 54.7 minutes and 53.1 minutes—slightly different. The reason for the two different frequencies was not known at the time that it was measured, although it may have been found in the meantime. There are at least two possible explanations: One would be that there may be asymmetry in the earth's distribution, which would result in two similar modes. Another possibility, which is even more interesting, is this: Imagine the waves going around the earth in two directions from the source. The speeds will not be equal because of effects of the rotation of the earth in the equations of motion, which have not been taken into account in making the analysis. Motion in a rotating system is modified by Coriolis forces, and these may cause the observed splitting.

Regarding the method by which these quakes have been analyzed, what is obtained on the seismograph is not a curve of amplitude as a function of frequency, but displacement as a function of time, always a very irregular tracing. To find the amount of all the different sine waves for all different frequencies, we know that the trick is to multiply the data by a sine wave of a given frequency and integrate, i.e., average it, and in the average all other frequencies disappear. The figures were thus plots of the integrals found when the data were multiplied by sine waves of different cycles per minute, and integrated.

Source: Feynman Lectures on Physics Vol. 1, p.51-6, Addison-Wesley Publishing, 1963.