SEISMIC CAVE DETECTION MADE SIMPLE

PETER D. ROBERTSON*
Victorian Speleological Association

Abstract

Describes a practical method of cave detection using simple seismic methods and equipment. Investigations have proved that the equipment developed recently and used by the author will detect caves in various types of limestone. It has in many cases indicated passage widths and position accurately and with further investigation it may be possible to calculate depth as well.

Seismology is the study of sound or shock waves in the earth's surface and this paper looks at how these sound waves, when used in a systematic way, can be used to detect the presence of caves.

Several years ago a friend who has a property in South Australia found, after a day of ploughing, that he had picked up a number of geophones in the plough and so he tossed them into a shed for safe-keeping. Some time later while discussing caving with him, he mentioned the geophones and said I could have them to experiment with.

The first experiment was to connect them to my Hi Fi amplifier and then to listen to people walking down the street; amusing, but not the way to find caves.

The second experiment was more scientific. A storage cathode ray oscilloscope (C.R.O.) was connected this time, and recordings were made of a house brick hitting the ground (Fig. 1). This is all a bit meaningless to an untrained person and anyway what caver would want to carry a thing the size of a C.R.O. all over the countryside?

About two months ago I came across an article in a sales brochure on seismic equipment, titled *Seismic surveying made simple* and included was a sketch indicating that by timing shock waves through the ground from different points it was possible to determine the rock type and the depth of each stratum. This then gave me the clue on how caves might be able to be detected (Fig. 2).

The principle of operation is this. When a shock wave is "injected" into the ground from, say, a hammer blow it radiates out in all directions and three important waves are produced. They are:
(1) compression wave known as the P wave, whose motion is a push-pull one;
(2) shear wave known as the S wave, whose motion is a sideways shake; and
(3) Rayleigh or surface wave, whose motion is a combination of (1) and (2) (Fig. 3). It is the P wave that is most used in seismic work. As these waves radiate out from the point of impact they tend to take three different paths, being:
(1) direct path;
(2) reflected path; and
(3) refracted path (Fig. 4).

*134 Fordham Avenue, CAMBERWELL, Vic. 3124

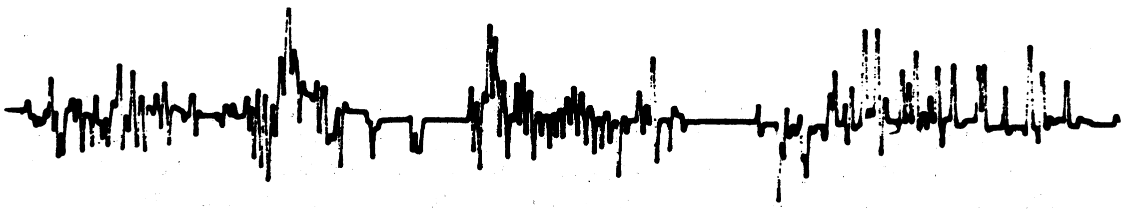


Fig. 1. Tracing taken from the output of a Geophone.

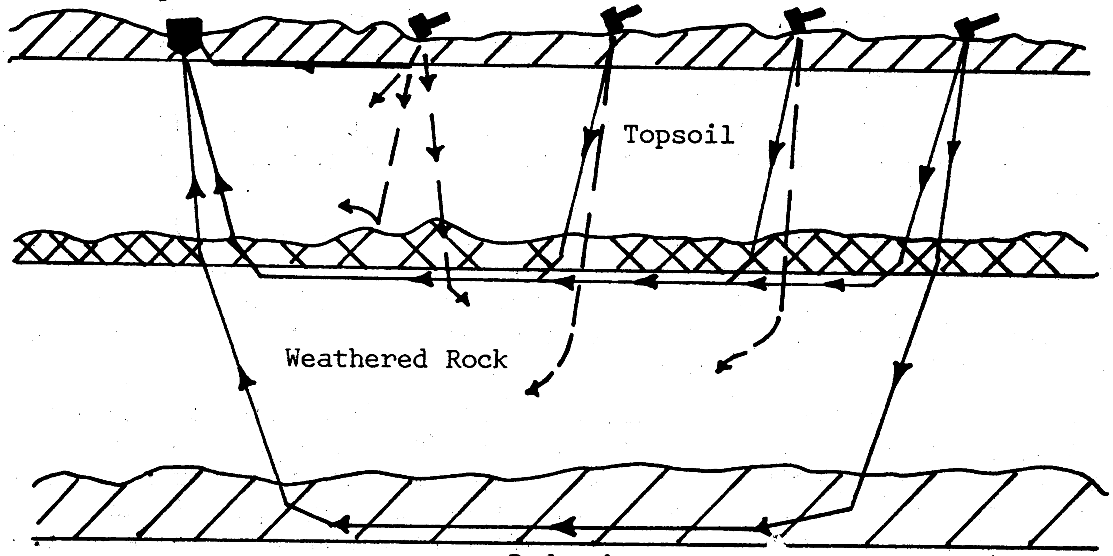
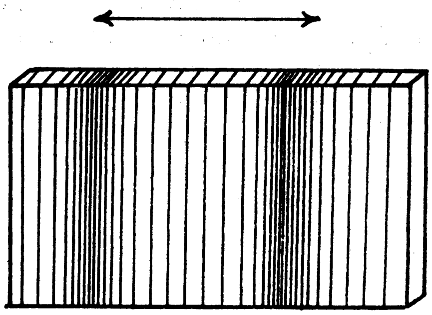


Fig. 2. Diagramatical cross-section of subsurface showing paths of seimic waves.



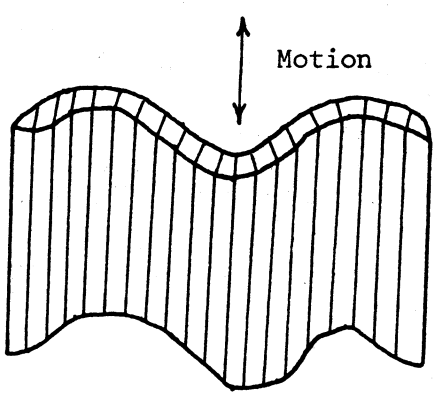


Fig. 3 Compression Wave (P) Shear Wave (S)

Another characteristic of the ground is that the more dense the soil or rock, the faster the shock wave will travel, for example:
(1) if the top soil is soft then the shock wave travels slowly;
(2) if in clay and sandstone the shock wave will be faster; and
(3) if in solid rock the shock wave will be very fast.
To measure the speed of sound through the ground, three pieces of equipment are required (Fig. 5):
(1) an electronic stop watch reading in milliseconds (ms).
(2) a hammer fitted with an "ON" impact switch.
(3) a geophone which is virtually a sensitive microphone connected to a high-gain amplifier driving an "OFF" switch.

The principle of operation is that when the hammer strikes the ground the impact switch closes, and starts the timer. The shock waves then travel through the ground and as they pass the geophone the signals are picked up, amplified and the timer is stopped. A digital readout indicates the time in milliseconds that has elapsed.

I will now describe how a seismic survey is conducted to obtain useful information suitable for interpreting what lies below (Fig. 6a).

The first thing to do is to lay out a tape measure over the line you want the survey to run. The geophone is then pushed into the ground at the zero end of the tape and connected to the timer. The lead to the hammer switch is also connected. Using at least two people, one using the hammer the other reading and plotting the results, the survey can commence. Using graph paper with the vertical scale indicating time, 1 cm = 5 ms and horizontal scale indicating distance 1 cm = 2 m, plot the times as they are indicated on the timer, for each station. At least three readings should be taken at each station and averaged before plotting, as false signals are recieved at times, for example, wind noise or someone moving. These errors are usually large and very random. True signals are always within 1 to 2 ms of each other.

Starting the survey at say, the 2 m point, record the time. Then move on to 4 m and record the time again. Continue this until the survey is completed over the whole line. On examination of the results, it will be seen that the line will be straight for a number of plots but then will tilt or level slightly (Fig. 6a). This indicates a change in the velocity as the shock wave gets out of the top soil and into a more dense subsurface stratum and increases velocity. Another tilt further on in the survey indicates an even deeper and denser stratum has been detected.

The plot in Fig. 6a is what may be obtained in most general surveys provided it is not cave country.

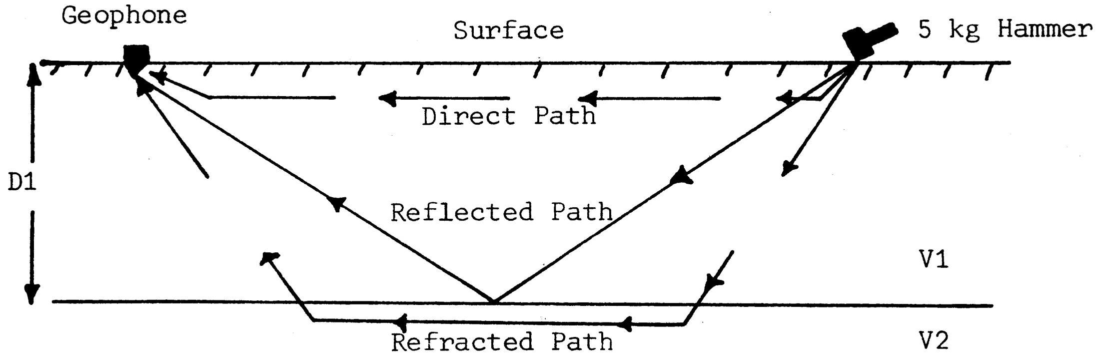


Fig. 4. Illustrates the direct, reflected, and refracted paths.

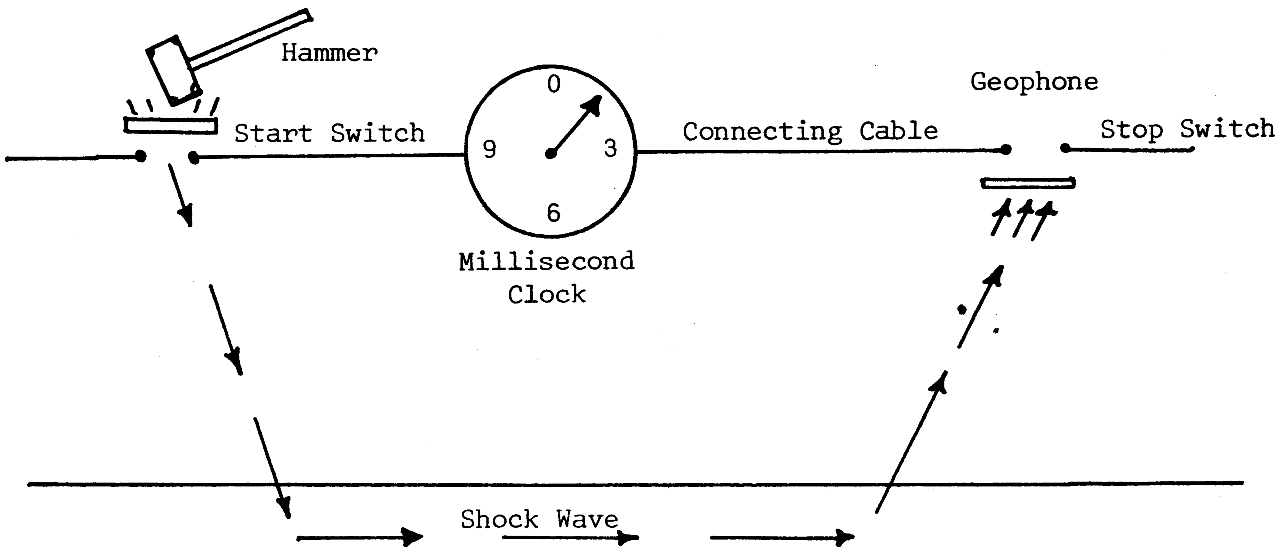


Fig. 5. Illustrates the three pieces of equipment required.

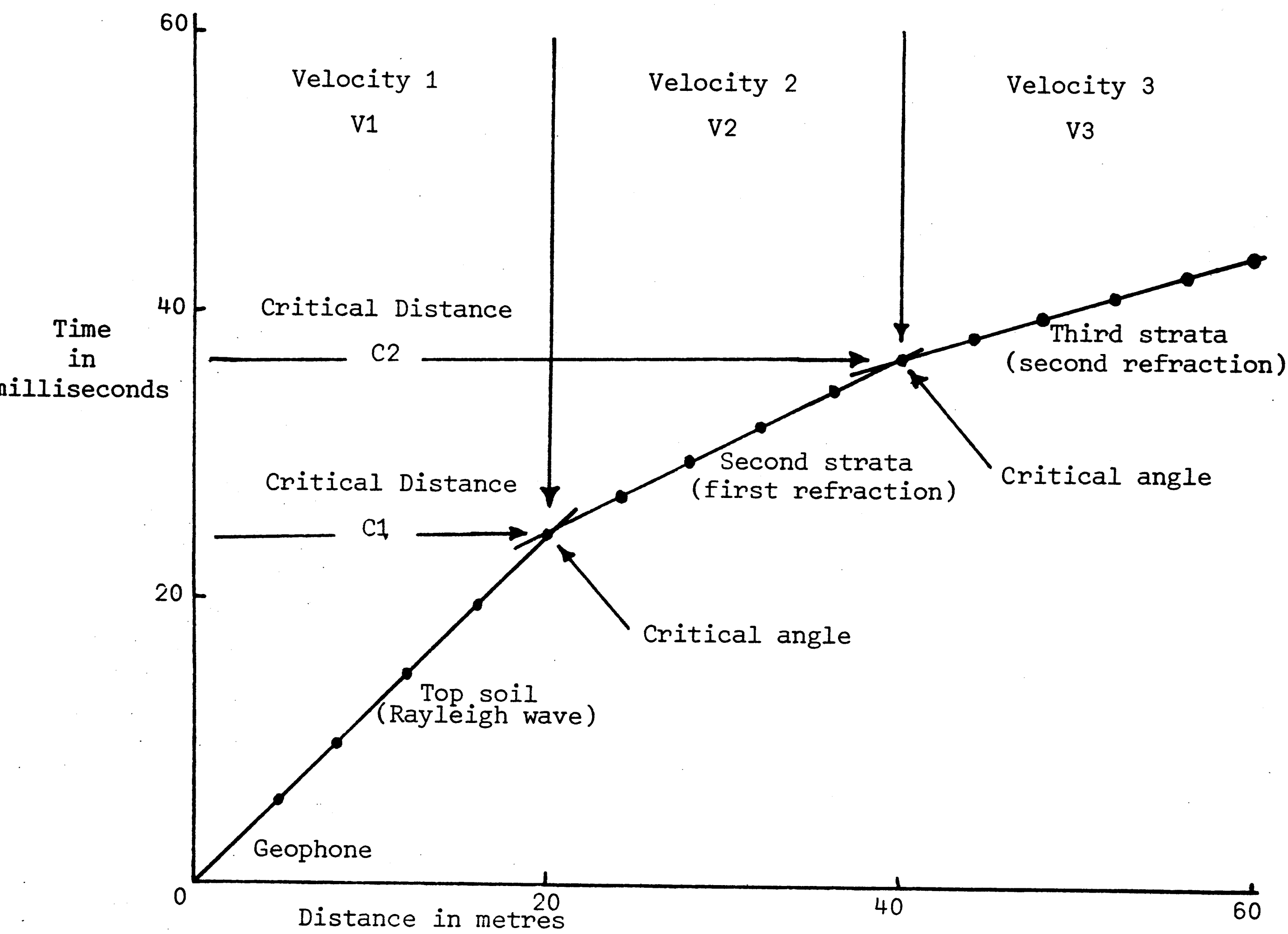


Fig. 6a. Illustrates a survey done over perfect strata and shows the meaning of each point.

If we know the rock strata to be generally level then by using the following formulae it is possible to determine the depth to each stratum (Fig. 6a & 6b).

(1) $$D_1 = \frac{C_1}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

(2) $$D_2 = 0.8\ D_1 + \frac{C_2}{2}\sqrt{\frac{V_3 - V_2}{V_3 + V_2}}$$

where D_1 = thickness of first layer

D_2 = thickness of layer 2 plus preceding layer

V_1 = true velocity in metres per second ($m\,s^{-1}$) of first layer

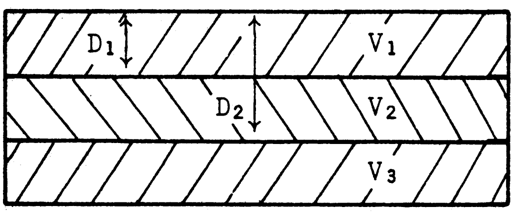
V_2 = true velocity in $m\ s^{-1}$ of second layer

V_3 = true velocity in $m\ s^{-1}$ of third layer

C_1 = critical distance from geophone to first change in slope of time-distance graph

C_2 = critical distance from geophone to second change in slope of time-distance graph.

Figure 6b. Numbering of layers for depth and velocity.



Now consider Figure 7. Suppose we insert a cave in our traverse line and carry out the same experiment. Everything will be normal until we start passing over the cave, and what will happen then? Confusion? That's right! Three things may happen:
(1) no signal will get back as it is absorbed by the cave;
(2) the signal will have to travel around the cave therefore giving a longer delay;
(3) only the surface wave will return, also giving a longer delay.
In all cases an anomaly will show. If we continue on past the cave, our original curve will follow on again but with some modification - usually a loss of range.

This was the theory on which I decided to design and build the seismic cave detector. Some of the results that have been obtained in practice over known caves in different types of limestone are given below with some annotation.

Figure 8. This was the very first plot done over a cave passage. The cave was in Buchan limestone (mid-Devonian; Exponential Cave) and the passage was accurately known as an R.D.F. survey point had been installed on the surface. The cave anomaly stands out very well. The depth to the cave would be about 6-7 m.

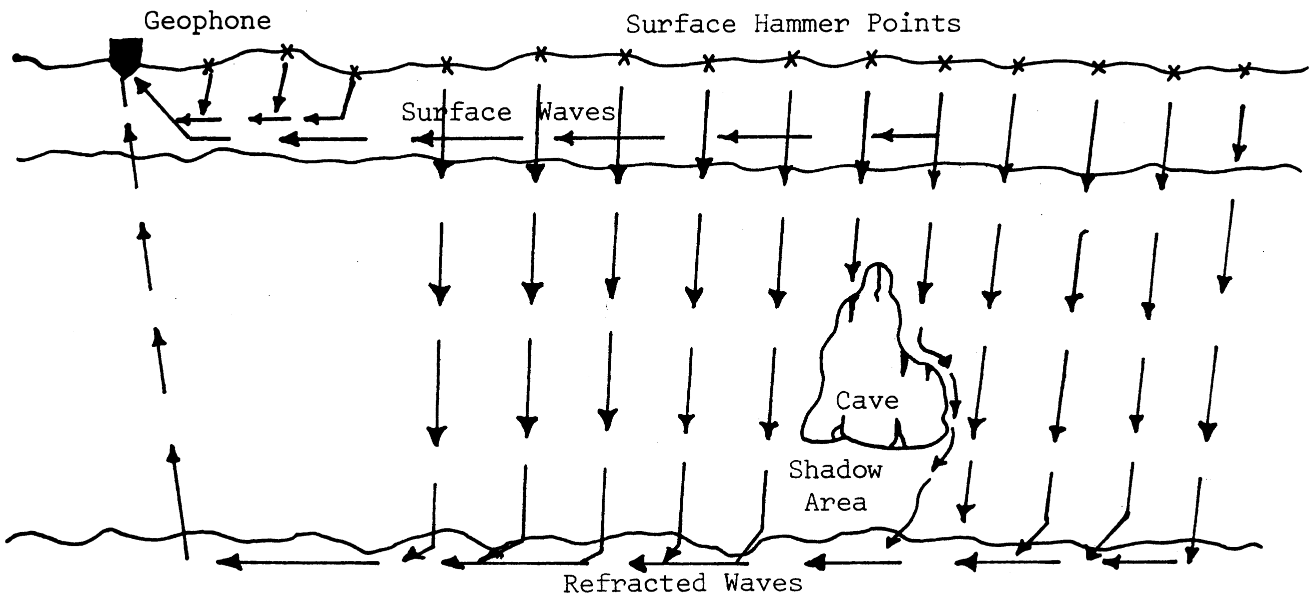


Fig. 7. If we insert a cave in our seismic survey, three things could happen; (1) No signal return, (2) Signals go round the cave, (3) Surface wave only returns.

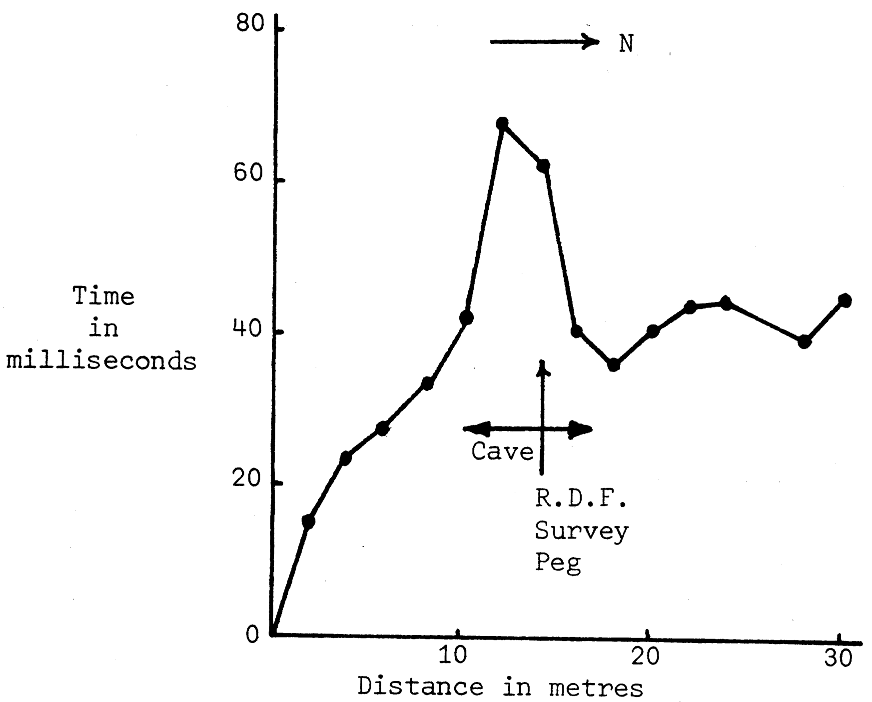


Fig. 8. The first seismic survey results.

Figure 9. This plot was over a much deeper passage of a cave in the same area (Honeycomb Cave). Again the passage stands out clearly.

This seemed to prove the system would work. The next thing to do was to collect as many results over known caves in different limestones as possible and see what could be interpreted from them.

Figure 10. This plot indicates the results obtained when a survey was done across a 60 m shaft (Jam Pot, Buchan).

Figure 11. This is the plot on a hillside containing no known caves (Buchan).

Figure 12a. This is the plot taken between two sinkholes. A portion of the graph is missing, indicating that no signals could be received.

Figure 12b. This is a closer look at the missing section by moving the geophone up to the 28 m point and doing the survey again. Note the extra detail.

Figure 13. This is a survey done over a cave in South Australia (Robertson Cave, Tertiary limestone). A plot was done in two directions using the same hammer points but moving the geophone to the other end. As can be seen, the cave anomaly can only be seen in one direction. This was probably caused by the fact that a new hammerman took over and was not hitting as hard as the first more experienced person. This only seems to be a problem with the Naracoorte limestone as the caves there have a hard capping over them.

Figure 14. This plot is a two-directional plot (over Blackberry Cave, Naracoorte) and this time a mean is plotted of the two curves thus producing a straight line plot with only the anomaly standing out.

Figure 15. This plot was done in dune limestone at Bat Ridges, Portland, Victoria. The cave was located 13 m down and on the plot is a cross-section of the cave accurately positioned using an R.D.F. point.

Figure 16. This plot was done over Nannup Cave, Witchcliffe, Western Australia in eolian calcarenite. The cave was located 20 m below and accurately positioned using R.D.F. equipment. Notice the dip in the plot over the cave. It was found on entering the cave that a column about 2.5 m in diameter had been resolved in the seismic survey.

I think I have given enough illustrations to prove that the method and equipment works. In the next few months, I intend to conduct many more tests in an effort to build up a library of reference graphs.

From what has been done so far, it seems clear that the anomaly is in fact the surface (Rayleigh) wave taking over control of the equipment as the hammer blows pass over the cave, and the deeper faster shock waves are attenuated by the cave to the point where they are no longer received. This is also borne out by the fact that quite often as the survey passes over the actual interface between solid rock and a cave it is very hard to get three consistent readings, but the next point on will be satisfactory.

It has also been found that the distance between hammer points is important, particularly if narrow passages may be present. Using, say, a 6 m spacing between hammer stations, it is possible to completely miss a 2 m passage. It seems the signals are very directional. Refer back to Figure 16: seeing the column proves this.

On several surveys, points have been reached where all return signals have been lost and only by moving the hammer station about, have returns been possible. This feature has been used to determine the size of chambers.

Another feature that stands out is that whenever a cave passage cross-section has been plotted in below the seismic survey results (Fig. 15) an offset to the right occurs. It might be possible to use this error as a means of determining depth.

By taking two or more plots over a passage but spacing them, say, 30 m apart, it is possible to determine the direction the passage runs. Taking this further as we have already done, a full grid was done over an area and the results fed into a computer which in turn produced a three dimensional contour-type plot of the cave.

Finally, the main functions I can see the seismic cave detector performing could be determining the extent of a known cave system from the surface, and being able to evaluate the resources of caves in an area where as yet no entrances have been exposed.

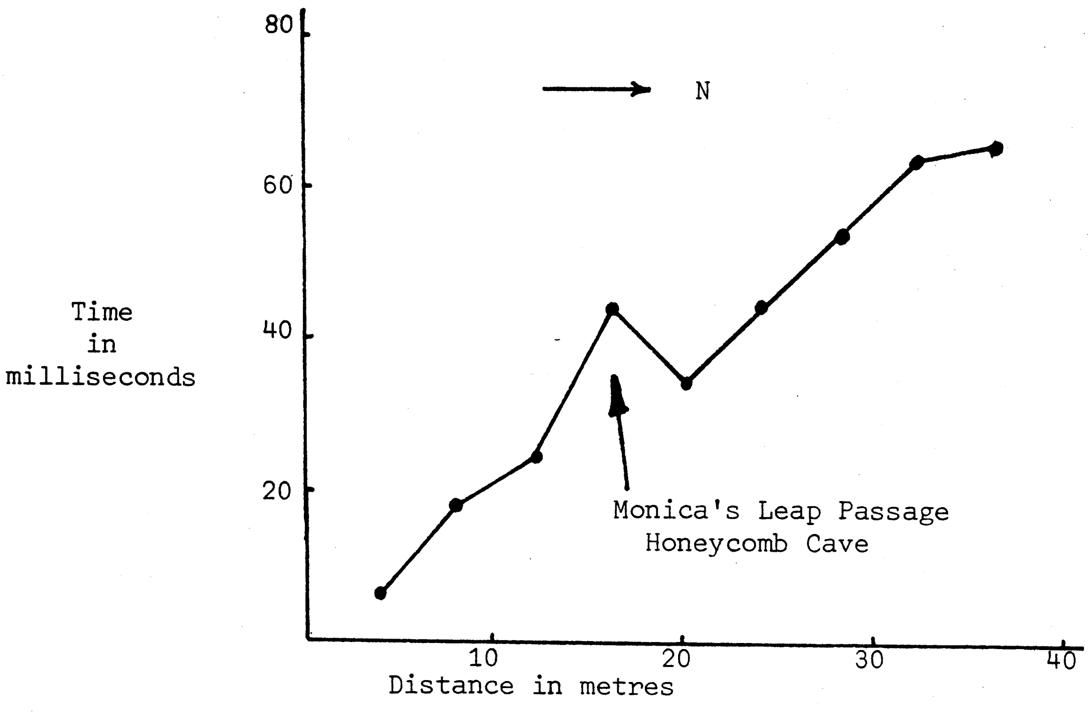


Fig. 9. This shows a deep pasage.

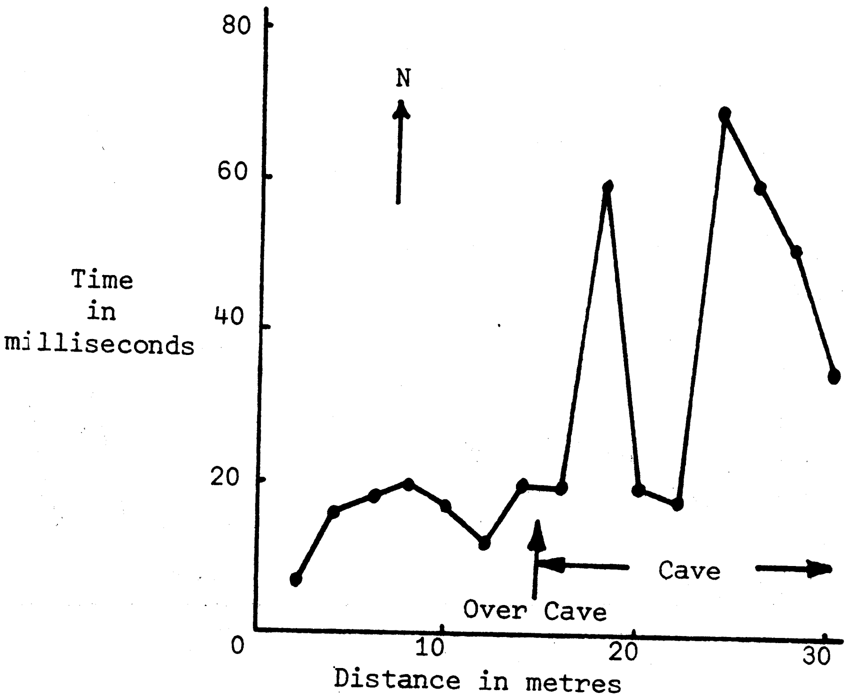


Fig. 10. Plot over a 60 metre shaft.

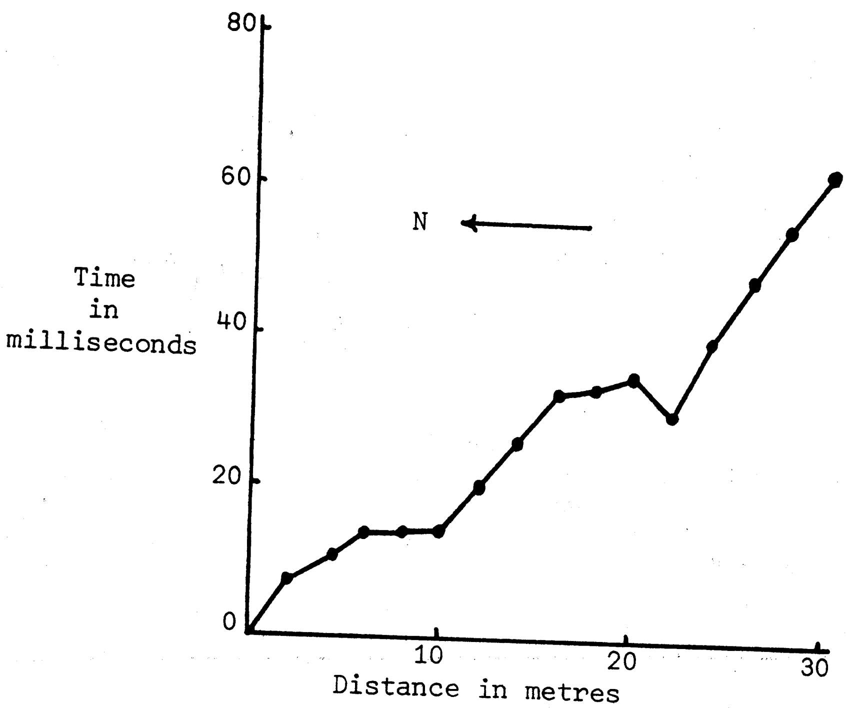


Fig. 11. This plot was on a hillside containing no known caves.

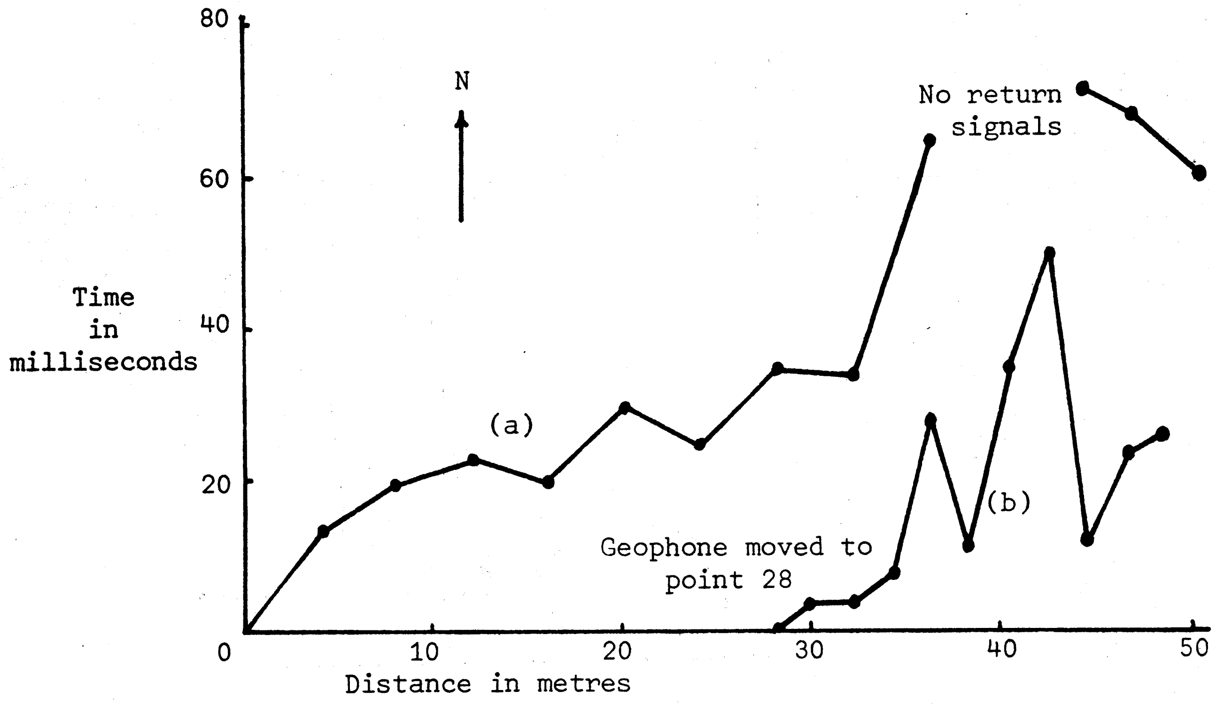


Fig. 12. (a) This plot was between two sinkholes.
(b) This is a closer look at the missing section.

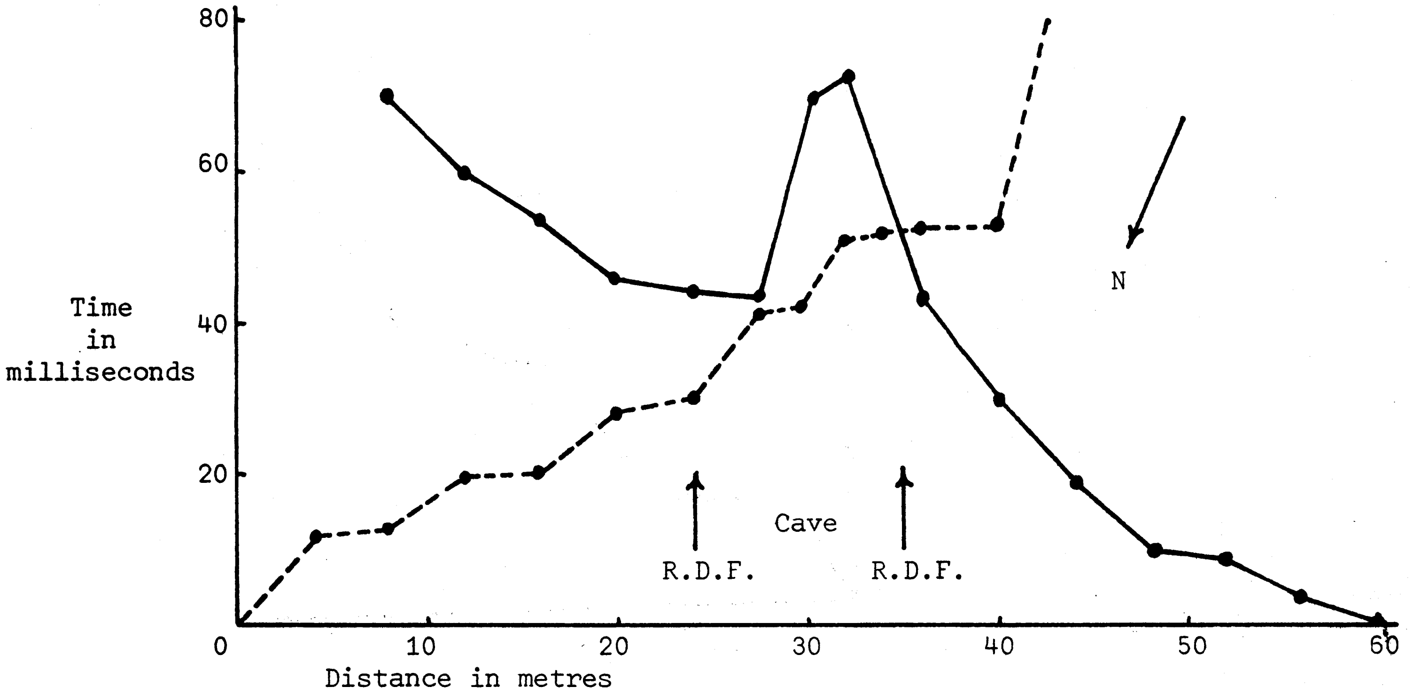


Fig. 13. This is a two direction plot showing the position of the cave relative to the plot.

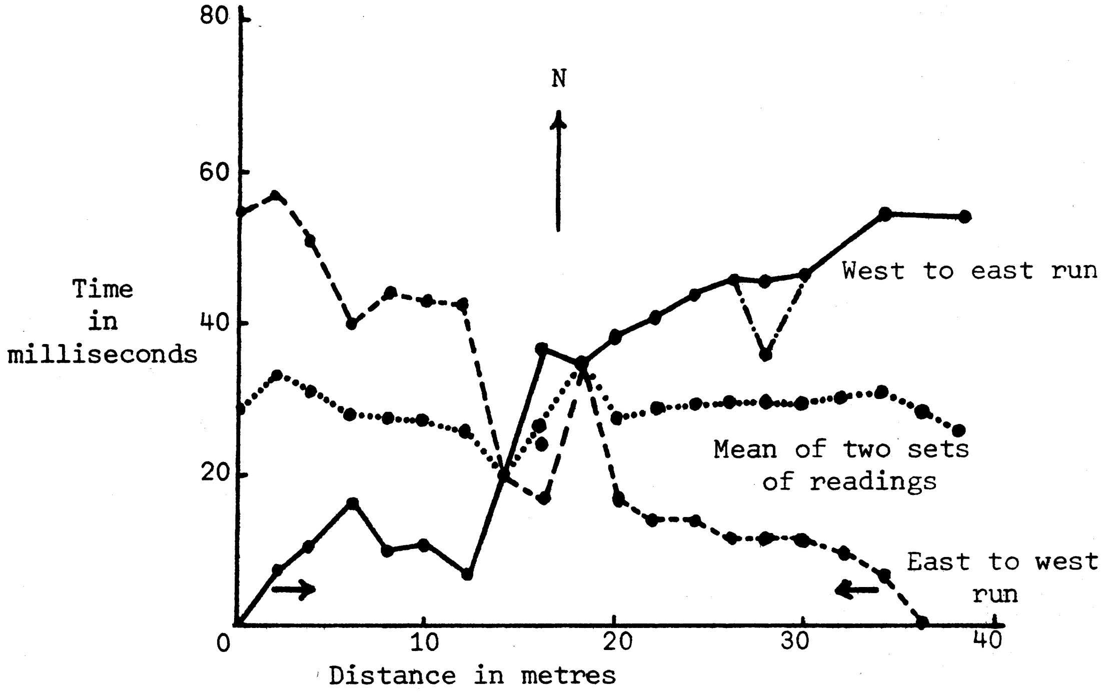


Fig. 14. A two direction plot to obtain more detail.

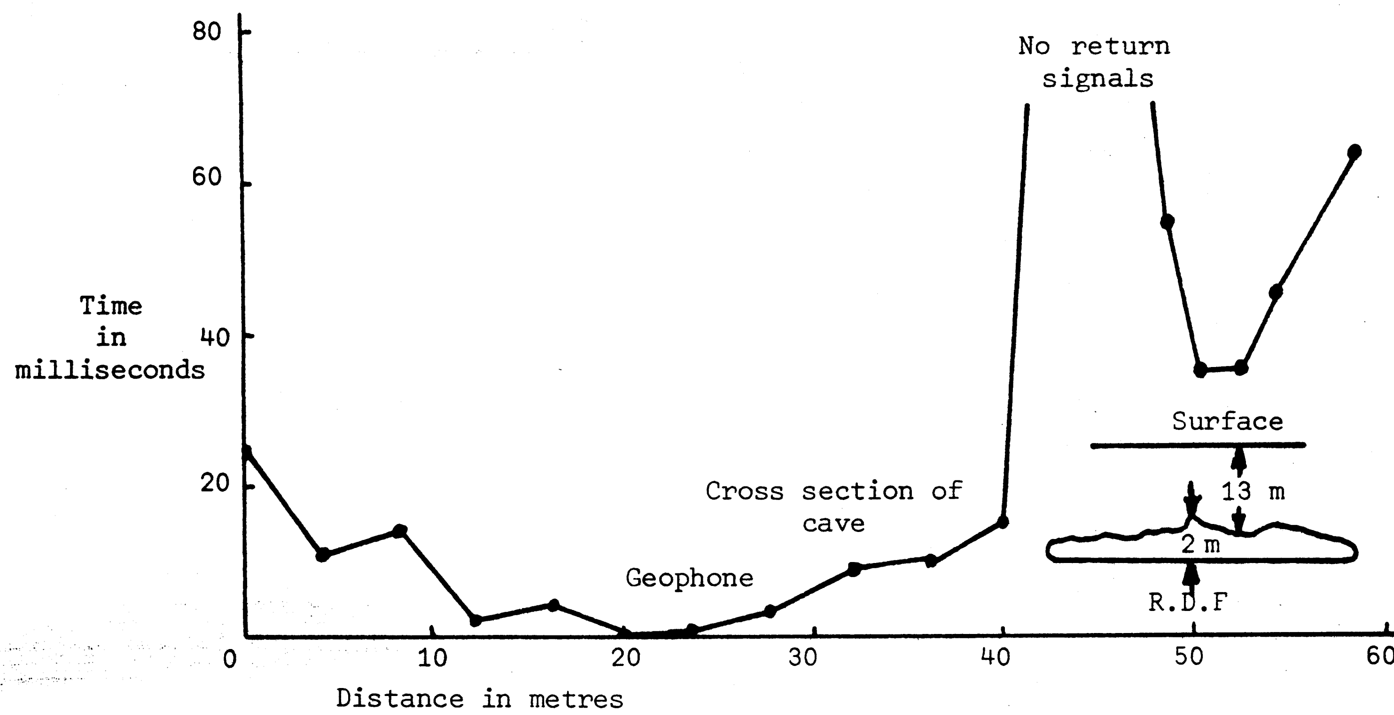


Fig. 15. Bat Ridges limestone gives clear indication of caves.

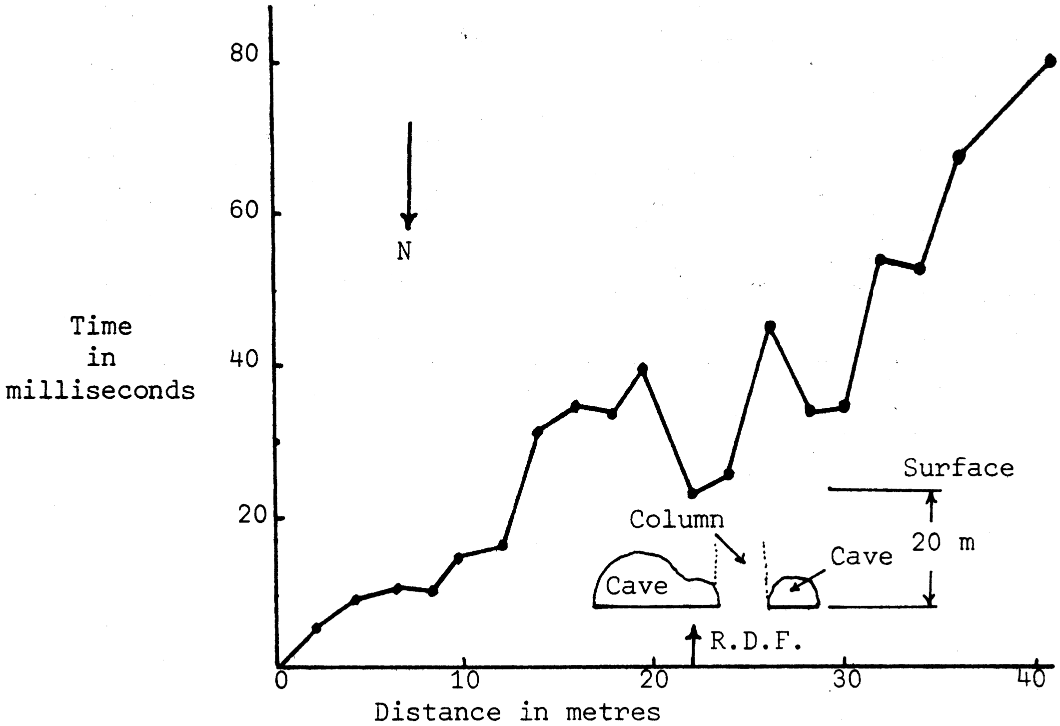


Fig. 16. Nannup Cave, W.A., plot has resolved 2.5 m column in cave.

Proceedings of 12th Conference of the ASF 1979