SCIENTIFIC SEARCH FOR SHAFT-TOMBS

MAGDALENA LAKE BASIN, JALISCO, MEXICO

January 7 to February 5, 1971

(Report submitted by Betty Bell, Bruce Bevan
and Beth Ralph)

Introduction

Shaft tombs, which date from 100 B.C. to A.D. 200 (refs. 1-8) have been found at many sites around the perimeter of the present dry bed of Lake Magdalena. (The lake was drained for agricultural purposes about 60 years ago). The tombs contain large figurines that are readily salable, and have, therefore, been subjected to intensive clandestine digging. Not one, however, has ever been found by an archaeologist, nor excavated properly. For this reason Dr. Betty Bell asked members of the Museum Applied Science Center for Archaeology (MASCA) to come to the sites with geophysical prospecting instruments with the hope that the shaft-tombs could be found by scientific means. Three techniques were employed - namely, aerial photography, magnetic prospecting, and seismic detection.

Members of the expedition were:

Representing the Department of Antiquities, Mexico:

Dr. Betty Bell, Archaeologist, now resident in
Ajijic, Jalisco, Mexico.

Dr. William Winnie (Dr. Bell's husband),
Professor of Economics, University of Guadalajara

Representing the University Museum:

Dr. Froelich Rainey, Director, University Museum and of MASCA.

Mr. Hugh R. Sharp, Jr.

Mr. W. Sam Carpenter, III, Vice-Chairman, Board of Managers, University Museum

Mr. Harry Mayne, Vice President for Technical Services, Petty Geophysical Engineering Company, San Antonio, Texas.

Miss Elizabeth K. Ralph, Associate Director of MASCA

Mr. Bruce Bevan, Research Assistant in MASCA

Aerial Photography

On the first day of work, approximately 200 oblique aerial photographs were taken of the southwest section of Magdalena Basin. About 40 of these cover the primary site, El Arenal, and the area nearby; the rest are scattered over a larger area of the Basin.

These photos have been most useful in the geological analysis of the area, primarily in locating rock outcrops and cinder cones, which are difficult to detect on the ground. Several locations have been found which have about the same geology and geography as known tomb sites. The tombs are located in "tepetate", a volcanic ash-cinder layer near the former lake shore. Because of extensive digging by pothunters, photographs of known sites are too confused for any possible location of any remaining shaft tombs in the dry season.

These photographs were taken from a plane very kindly furnished and flown by Hugh Sharp. (Another plane kindly offered by Sam Carpenter was not used on this expedition.)

All aerial photographs were taken between the hours of 9:30 and 11:00 A.M. on 8 January 1971. Scattered clouds were present, but haze was low and ground illumination was bright and unshaded.

A Hasselblad 500C camera was used with 2-1/4 inch negatives. Other specifications are as follows:

80 mm focal length lens
1/250 second shutter speed
no filters
plus-x panchromatic film
10 rolls taken at 12 frames/roll

Additional photographs were taken by Bill Winnie with two Kodak Retina Reflex cameras, one with Kodochrome II color film and one with plus-x black and white, both 35 mm.

Because of the pressurization system of the airplane, all photos were oblique shots through the double plastic windows. Flight elevation above ground was about 400 meters and the slant range to the center of the photo scenes averages about one kilometer. Therefore the ground width of each photo, while quite variable, averages about 700 meters.

Ten prints of the Hasselblad photos are included with this report (Figs. 1-10). The locations of some of the sites and features seen in the photos are shown in Fig. 11.

Prospecting Instruments

Magnetometers

Experiments were conducted with three magnetometers - the Varian Associates Precision Portable Cesium Magnetometer Model 4920 and the more portable Cesium Magnetometer with Audio Readout Model V-4971. The third was the Schonstedt Portable Flux-Gate Gradiometer Model GMB-2. The Precision Model 4920 has been described previously (Rainey and Ralph, 1966; Ralph, Morrison, and O'Brien, 1968). When used with two sensors in the difference mode, it has the capability of 0.05 gamma (γ) sensitivity. At the sites, however, it was used with a single sensor for two reasons. The many rocks on and just under the surface of the ground were found to be highly magnetic. Therefore, the anomalies detected were much greater than the diurnal changes in magnetic intensity so that a second sensor for the cancellation of these was not needed. Also, El Arenal, the first site, is partially covered with scrub growth (see Fig. 8) so that it would have been extremely difficult to manipulate the 100-meter cable leading to the second sensor in a fixed position. The instrument in use is shown in Fig. 12. The Model 4920, set on a sensitivity range of one gamma, was used for making all of the grids.

The cesium magnetometer with audio readout, Model V-4971 (see Fig. 13) employs the same type of sensor, but the readout is very much smaller and gives an audio signal. One can walk along rapidly and listen for a change in frequency. If desired, a reading can be taken on an arbitrary scale calibrated roughly in units of two gammas by adjusting the frequency of a variable oscillator to that of the Larmor frequency from the sensor.

The GMB-2 has two flux-gate elements spaced 20 cm apart and in line with one another. These are mounted on a simple shaft with the circuit box at the other end. If there is a difference in the magnetic field at the two flux-gate elements, an electrical signal proportional to this difference is generated, amplified and converted to an audio signal and fed to a set of earphones or a single "squawker". The sensitivity of this instrument is about 10 gammas per 30 cm. Both the GMB-2 and the V-4971 were used for rapid exploration preliminary to and outside of the areas of the detailed grids.

Seismograph

The seismograph used was the Bison Instruments Signal Enhancement Seismograph Model 1570.* The signal enhancement feature of this portable instrument offers an improvement over other hammer seismographs including both the direct digital types and the cathode ray display types. The principle of

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*We are indebted to Axel M. Fritz, Jr., President, and to Bison Instruments, Inc. (Minneapolis, Minnesota) for the loan of this seismograph and to Harry Mayne from the Petty Geophysical Engineering Company, San Antonio, Texas for bringing it to Mexico and contributing his extensive experience in seismology during five days of field work.

operation rests on the fact that in-phase signals will add together to give a large total signal whereas signals which are randomly phased, such as those from seismic noise, will tend to cancel each other. The seismic signals from successive hammer impacts at any individual hammer station are added together and stored within the electronic memory of the instrument and are thus enhanced. As with other seismographs, all applications fall under two headings - namely, velocity and depth determinations. The instrument in use is shown in Fig. 14.

Surveys Completed

The sites investigated are shown on the map in Fig. 11 and in some of the aerial photographs (Figs. 1-10). The work at each is now described in more or less chronological sequence.

1) El Arenal (see Fig. 8 and for the location of grids, Fig. 15)

A 100-meter square grid (Grid No. 1, Fig. 16) was laid out roughly centered over the height of land of the particular area which is pockmarked with many diggers' pits and contains three shaft-tombs, the shafts of which are still open. (These are indicated in Fig. 16 by wavy radial lines). In this and other grids the baselines were laid out with tape measures, and starting with line 0, a rope calibrated at 2-meter intervals was followed from one baseline to the other. Readings were taken at 2-meter intervals. The rope was moved every 10 meters so that the man carrying the sensor was never more than 4 meters away from it, and was usually able to see the station markers on the rope easily.

It was soon apparent that most of the rocks in this area are extremely magnetic and that these were the cause of most of the anomalies detected. In Grid No. 1 (Fig. 16) we noted that a magnetic anomaly corresponded with only one of the empty shafts - the one centered on lines 86 and 88. Also, in the regions of many small pits and of many rocks, we had pronounced magnetic disturbances that indicated nothing. One of the most promising anomalies, in an area without pits and many stones, appeared to be the one between lines 60 and 62 in the northwestern edge of the grid. A magnetometer survey was repeated over this at 1/2 - meter intervals and with lower (1/2 meter) sensor height. This is shown in Fig. 17, which also illustrates the location of the test pit which intersects the horseshoe-shaped anomaly. A trench 1 x 3 meters (Pit 3) was laid out to test this anomaly, and a layer of very large magnetic stones was found at ca. 30-40 cm. over the entire surface of the trench. Inasmuch as stones of this kind sometimes are found over the mouth of a shaft, they were removed and the excavation continued. A hard clay was found at 50-60 cm., with tepetate (see pp. 22 ff. for explanation of tepetate) below it. At one end of the trench, however, there was an area of loose soil which was excavated further, but it was underlain by tepetate at about 80 cm. The opposite end of the trench was then extended about 0.5 meter and it was found that the stones appeared to continue for some distance, thus indicating that they formed part of what is known locally as the pedregal - a layer of large stones which is said to underlie the soil over much of the area. This test excavation and the stones (after removal) are shown in Fig. 18. Two projectile points, one of black obsidian and one of green, were found just under the surface, with a scattering of sherds down to the tepetate. (Before excavation, a seismic line run over the anomaly had indicated nothing unusual).

Grid No. 2, (see Figs. 15 and 19) was made in a lower region between two ridges as a control in an area where there are not pits and not likely to be tombs. We see that it is more quiet, but that it contains one pronounced magnetic anomaly (line 96) associated with a large surface rock about 0.6 meter in diameter.

Grid No. 3 (Fig. 20) was then laid out over the next high land to the west. The southern part of Grid No. 3 is also quiet, but we detected a significant disturbance in running line 0. Therefore, we extended Grid No. 3 to the north as far as the stone walls (see Figs. 8 and 15). Centered on line 10 of the extension, we did find a tremendous magnetic disturbance with a strong magnetic high to the north and an anti-magnetic low to the south - an anomaly typically due to materials which contain a large amount of remanent magnetization. Also other pronounced anomalies were detected nearby as well as fairly closely spaced long contours of changes in magnetic intensity. Over the large anomaly of line 10, the survey was repeated with a higher sensor height - namely, 3 meters (see Fig. 21). The significant decrease in maximum and minimum values indicated that the source of the anomaly was not very deep. Fortunately, Harry Mayne arrived with the seismograph at this time.

Seismic Tests

It was known from the clandestine digging and as told to us by our capable workmen, diggers themselves, that in this area, there is normally a layer of soil one to two meters thick and that this is underlain by tepetate to a depth of, at least, 17 meters, the depth of the deepest known shaft-tomb. This stratigraphy is shown more clearly in Fig. 22.

In order to find out about the velocities of these materials for sound waves, a long line was laid out away from pit areas, roughly along line 100 of Grid No. 1. Readings taken first at 1-meter, then at 2-meter, intervals are plotted in Fig. 23. It was found that in this line the velocity of the soil was 580 m/sec. and of the tepetate, 720 m/sec., and that underlying the latter was bedrock with a velocity of 2075 m/sec. Depth (D_1) of the transition from soil to tepetate is calculated with the formula:

$$D_1 = \frac{X_c}{2} \sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

where the slopes of the two lines give the velocities, V_1 and V_2 and X_c is found from the intersection distance of the two lines. It is assumed that both layers are horizontal. In this case, $D_1 = 3.6$ meters. The depth of the second change, from tepetate to bedrock can be estimated with the formula:

$$D_2 = 0.8\ D_1 + \frac{X_{c_2}}{2} \sqrt{\frac{V_3 - V_2}{V_3 + V_2}}$$

and it is found that $D_2 = 19.2$ meters. This value corresponds roughly with the maximum known depth of the shaft-tombs and probably explains why they were dug no deeper.

In subsequent tests, it was found that there were small variations in the tepetate. For example, a line run over an exposed outcrop indicated that the velocity ranged from 865 to 1020 m/sec. Unfortunately, in other areas, the velocity of the soil was found to be even lower and very close to that of air, approximately 330m/sec. This, plus the narrowness of the shafts and the comparatively low velocity of the tepetate, was extremely discouraging for the finding of shaft-tombs with a seismograph. Also, the seismograph was indicating the same situation that the magnetometer was finding - that the soil was extremely mixed and variable, and not appropriate for the use of these geophysical prospecting instruments.

Nevertheless, tests were made over the shaft-tomb that was completely hollow (located on line 70 of Grid No. 1, Fig. 16). These were made by moving the tape measure in arcs from the outside of the shaft, over it, and outside on the other side with a fixed distance between geophone and hammer just slightly greater than the diameter of the shaft, 2 meters for the first trial. The location of the lines and the data are shown in Fig. 24. No significant change in velocity was detected over the tomb. The test was then repeated with the geophone moved away from the tomb 1 meter and the plate, 0.5 meter, making the distance between them 3.5 meters as shown in Fig. 25. With this arrangement, a small decrease in velocity (higher millisecond travel time values), but hardly significant, was detected through the tomb (see data, Fig. 25). The next tests with 4.5 and 3.0 meter spacings were negative.

In spite of this and because our workmen insisted that there had to be a tomb in a direct line between this shaft and the open one of lines 86 and 88 (Grid No. 1), a line was laid out between the two and readings were taken forward and backward with a fixed 6-meter spacing between geophone and hammer. Exactly mid-way between the tombs, two readings were recorded that differed from the normal by about 1 ms. and were of higher velocity. This difference was not really significant, nor in the right direction, so that with faint hope, this little anomaly was tested by excavation. A pit 2 x 2 meters (Pit 1) was laid out with the stake which indicated the anomaly forming the southeast corner. A layer of large stones was found at 40-45 cm, but obviously these had been put down deliberately. The flattish side of each was uppermost, and one was stone of a kind which does not occur at El Arenal but is found at nearby Cerro Molcajete. In addition, roughly half of a stone <u>metate</u>

(grinding slab) was wedged on end among the stones. They were removed and the digging continued with some hope because of the obvious artificiality of the layer, but a reddish clay was reached at ca. 70 cm. and tepetate at about 80 cm. A small pocket of loose soil in the northwest corner of the pit was dug out, only to reach a hard white clay at roughly 1 meter. The north and east sides of the pit were extended by 20 cm., and an area 20 x 40 cm, centered on the stake, was also dug - all of these subsidiary excavations extending into the edges of adjoining, re-filled pot-holes. It was clear that the stone layer did not extend beyond the area of the pit, but no explanation for the anomaly could be found - except perhaps, as suggested by a perceptive workman, the "machine" might have recorded a small burrow-hole dug out to one side of the pot-hole to the south. A few sherds were found from about 10 cm. down to the tepetate.

Next, we tested the large magnetic anomaly of Grid No. 3 extension (Figs. 20 and 21) with the seismograph. It was found that there was indeed a high velocity layer within the soil. This is shown in Fig. 26 where

$V_1 = 360$ m/sec
$V_2 = 1800$ m/sec
$V_3 \sim 360$ m/sec
and $D_1 = 2.0$ meters

This information indicated quite definitely that our strong magnetic anomaly was caused by basaltic rock. The results of the seismic lines run and the depths found are shown in Fig. 27. Again, a test pit approximately centered over the magnetic high was dug and a natural outcrop of fine-black grained rock was found in the center at a depth of about 40 cm. The rocks exposed were not especially large and were mixed with some earth which probably accounts for the unusually low velocity (V_2) found for this type of dense rock. This pit (No. 2), was also 2 x 2 meters, and was dug in extremely hard soil which was difficult to break even with a pick. In the northwest part of the pit, the hard, brown topsoil was followed by a layer of reddish, sandy soil at about 20-25 cm., with hard rock below this. Over the rest of the pit, the topsoil was followed at depths of 20 to 30 cm. by a layer of very hard yellow-red clay which overlay the rock. The top of a cluster of large stones appeared approximately in the center of the pit at roughly 20 cm., and the size of the cluster was still increasing at 40 cm. No sherds were found; it was clear that none of the soil had ever been disturbed.

More work with the magnetometer was continued and Grids No. 4 and No. 7 (see Fig. 15) were completed. Grid No. 7 showed only a continuation of the magnetic and anti-magnetic anomaly of line 100 of Grid No. 1 (Fig. 16) plus two small-sized anomalies with steep gradients that were most likely caused by rocks. Grid No. 4, however, contained several small, but interesting anomalies. Part of this grid was repeated at

1-meter intervals as shown in Fig. 28. This region, adjacent to Grid No. 1, is also on high ground and is a more plausible area in which to find tombs. In order to make certain that we were not misinterpreting our anomalies, especially, the small ones, two weak but different types were selected for excavation. These are shown in Fig. 28. "A" is located between lines 49 and 50 and "B", between 44 and 45.

The pit labeled A (Pit 5) was 2 x 2 meters, and was dug to roughly 80 cm. The soil from top to bottom was reddish-brown; a layer of compact red clay, streaked with brown, was reached at 60 cm., and tepetate at 80 cm. There were a few sherds in the pit, extending down to the tepetate, and while no continuous layer of large stones was found, scattered stones of various sizes were found throughout the pit. Also, a 10-15 cm. layer of small stones was found at a depth of ca. 50 cm. over part of the surface of the pit (see Fig. 29). These were obviously put down artificially, but they are said to occur quite frequently at El Arenal, with no apparent purpose. Before the pit was closed at 80 cm., this layer was followed out for a distance of about 50 cm. in the west wall, but it was decided that the stones were not significant enough to warrant excavating an extensive area to trace them further.

Excavation B (Pit 4, also 2 x 2 meters) was only 4-5 meters away, but it revealed a very different situation. Here the soil was a pale ashy-brown, and much lighter in consistency than the soil in A. There were sherds and a scattering of stones of various sizes, and pockets of loose soil were found starting at about 40 cm. By approximately 60 cm., the area of very fine, loose soil extended across the southern edge of the pit, leading to the transient hope that it might indicate the top of an undisturbed shaft. At 80 cm., however, the loose soil gave way to tepetate, which extended over the entire surface of the pit. The red-clay layer of A was visible only in one small portion of the wall of B, at about 60 cm. There was no readily apparent explanation for the marked difference in sub-surface conditions within such a small area. Much of the soil in B had apparently been disturbed, and a curious feature was the mixture of chunks of tepetate with the soil from *ca*. 40-80 cm., but no explanation for the anomaly could be detected. This last pit is shown in Fig. 30.

After these discouraging results, we moved to other sites, where either shaft tombs or graves had been found (see Fig. 11 for the locations of most of the sites).

Cerro Molcajete

At this site there was supposedly no tepetate, and we found immediately that the reddish top soil and the rocks were even more magnetic than those at El Arenal. This is shown in the small Grid No. 5 run in the normal way (Fig. 31). Note that the contours of this plot are drawn at 100-gamma intervals rather than at the usual 20-gamma increments. This grid was repeated with the sensor higher (Fig. 32), but still gave large changes in magnetic intensity. In desperation, a gradiometer arrangement was tried with one sensor 80 cm above the ground and the other 130 cm. above it, as shown in Fig. 33. The Model 4920 magnetometer was then operated in the difference mode. An even more confused picture was obtained as shown in Fig. 34.

The seismic data for a line in this same area are plotted in Fig. 35. From these we calculated that V_1 = 330 to 350 m/sec., V_2 = 550 to 660 m/sec. and that D_1 = 3.1 to 3.2 meters. Therefore, it is likely that there is some tepetate or, at least, more compacted soil, underlying about 3 meters of very magnetic and mixed top soil - not at all good for the instruments. As we left, we ran a long magnetometer line from this hill down to the lake bed where there is water today, we heard (on the audio V4971) very large magnetic variations all the way and even in the lake bed where the soil was dark brown.

Las Cuevas

This site was on an island when Magdalena was a lake and on high ground which can be seen in the aerial photograph, Fig. 6. It contains many pits, some of which were dug very recently. A grid was laid out starting in an undisturbed field of sorghum, but running into tall weeds where there were many pits. About all one can see in Grid No. 6, Fig. 36, plotted at intervals of 50 gammas, is that the soil here is also very magnetic.

There are certainly no significant anomalies that correspond with the pits.

From the seismic data plotted in Fig. 37, we suspect that there are three layers with the following ranges of velocities,

V_1 = 350 to 490 m/sec.
V_2 = 630 to 770 m/sec.
V_3 = 1420 to 11,100(?) m/sec.

Again, at this site, the instruments were defeated.

El Trigo

This site is not far from San Pedro in the direction of Magdalena. It, too, contains reddish soil and magnetic rocks. From the calculations for the NE to SW seismic lines, Fig. 38, we find V_1 = 340 m/sec., V_2 = 1480 m/sec., and D_1 = 2.8 meters.

Ahualulco

This site (about 15 Km. from Etzatlán in the direction of Guadalajara) with two large artificial mounds, was visited and it was apparent and detected with the audio V-4971 magnetometer that both the rocks and soil were magnetic and mixed.

Santa Gertrudis

This site is in the opposite direction from Las Cuevas and not far from San Marcos. Here, there are only 10 to 20 cm. or less of soil above the tepetate and many fewer rocks on the surface. In Grid No. 8 (Fig. 39) we see that it is quieter magnetically (contours are at intervals of only 10 gammas) except for a very strong magnetic anomaly centered on line 2. Since the soil is so thin, it can be probed with a crowbar down to the layer of compacted tepetate. With this technique the clandestine diggers locate tombs by the absence of hard tepetate when probed. The magnetic anomaly was investigated with a crowbar, and neither rocks nor absence of tepetate was found. Discouraging also is the fact that the two pits and one excavated tomb in the center of the grid caused no magnetic disturbance.

More encouraging indications were obtained at this site with the Bison seismograph. A 30-meter test line indicated that the mixed surface soil, if present, was much less than one meter thick, and that a homogeneous tepetate-like rock extended to some depth and had a velocity of 780 m/sec.

The first experiment over an open shaft, about 1 meter in diameter, was negative. However, parallel lines run with geophone and hammer 6 meters apart over a much larger shaft, about 2.5 meters in diameter and with two large visible chambers, did produce a lower velocity as we passed over the shaft. The lines and readings are shown in Fig. 40. Subsequently, another isolated shaft was investigated. This one had been almost completely filled, but it too gave a barely significant indication.

Therefore, a search for undetected tombs was made by proceeding in lines with geophone and hammer 6 meters apart, but progressing along the line in 3-meter jumps. Finally, a reading of 13.5 ms. was obtained in a region where normal readings were about 10 ms. We tested this area with parallel and perpendicular lines to pinpoint the anomaly more precisely. Unfortunately, the probers with pickaxe could find nothing - only compacted tepetate at depths less than 10 cm. After a few more days of searching and probing and finding no tombs, we decided to terminate the experiments, at least, for the rest of the dry season.

Suggestions for Finding Tombs

A. Wet Season

Return to the sites toward the end of the wet season, possibly mid-September to mid-October.

1. Aerial Photography

Repeat aerial shots, preferably at lower altitude when grass and other growth and crops are green. High resolution photography in the visible and infrared spectral bands which may indicate moisture content of plants and soil has possibilities in this area for the direct location of tomb shafts. This is because the loose soil in these shafts will act as a water sponge for the early part of the dry season and cause the overlying soil and vegetation to be wetter than normal. This ideal situation would be complicated by natural variations in soil moisture and the fact that the shafts are small, about one meter in diameter.

2. Resistivity Prospecting

Use resistivity apparatus (both Bison Model 2350 A and a Gossen Geohm) when ground is wet, but not saturated. It is reasonable to assume that the tomb shafts might retain more, or conversely, less, moisture than the undisturbed tepetate.

B. Bulldozer

At El Arenal, in the area of Grid No. 1, or part of it, bulldoze off the top meter of soil and rocks. Then, use any geophysical prospecting technique or one's eyes to detect or see the shaft-tombs. This land is owned by the Hacienta San Sebastian, and it is anticipated that this could be arranged with the present owner.

APPENDIX: Geology of Shaft-Tomb Sites in Magdalena Basin

The most characteristic geologic feature of shaft tomb sites is the rock locally known as tepetate. This soft but rigid rock was preferred for digging shaft tombs.

Tepetate is a layered volcanic rock which is the light weight, glassy fraction blasted from an erupting volcano. This tan-grey volcanic tuff is composed of a frothy ash with two size fractions: large, usually angular fragments between 2 mm and 800 mm; and a submillimeter groundmass which composes over 95% of the rock volume. Figure 41 shows a typical example. Obsidian is also present at some localities, but in quite variable quantities.

The weathering of tepetate is very dependent upon moisture. Outcrops of tepetate exposed to the air in this semi-arid climate develop a hard layer which is much more resistant to weathering than freshly exposed tepetate. This resistant layer also has a higher seismic velocity than the tepetate just below.

Tepetate which is buried beneath many centimeters of soil remains soft and moist, but tough. It slowly transforms to soil, with the fibrous ash decomposing first and the bubbly glass remaining as sand.

It is not known whether this tepetate was deposited in or from water, or if it was directly dropped from the air. Large, flat chunks of ash within the tepetate do not appear to have any preferred orientation. The Santa Gertrudis site has at least a half meter layer of tepetate overlaying clay of undetermined depth; this clay-tepetate interface possibly conforms approximately to the present surface topography (there are only a few centimeters of soil overlying the tepetate at this site). The evidence for this is shown by two tomb shafts with over a half meter difference in surface elevation. Both show the same depth to the tepetate-clay interface. The second part of the evidence is that much more change in elevation below these tombs still shows no clay on the surface.

Magdalena Basin is part of the large extrusive igneous zone which extends up West Mexico. The predominant rock types in this area are volcanic cinder, tuff, and basalt.

Former shorelines of the now dry Lake Magdalena are visible when the flat basin plain meets a steep rock outcrop. On a gently sloping surface it is difficult to locate shorelines except at Las Cuevas, where beach gravels are common.

Some summaries of the geology of the sites are given below:

El Arenal -- The tepetate from this site is shown in Figure 41. In the tomb area, this is overlain by about one meter of soil; the mixtures of rocks in this soil have probably drifted down from Cerro San Pedro, which overlooks the site. Over 80% of these drift rocks have significant remanent magnetism; the strongest and most common of these is a grey basaltic rock with many white, diffuse phenocrysts and fewer black phenocrysts with good cleavage. Since tepetate has negligible remanent magnetism, these basaltic rocks give pronounced anomalies at this site. While there were several surface outcrops of tepetate at this site, no surface outcrops of other rock types were found. Seismic testing in the tomb area indicated a stratum of high sound velocity rock (2000 meters per second) at a depth of about 19 meters. The magnetic anomaly in Grid Three North had a similar seismic velocity and could well be the same rock. When excavated, this anomaly proved to be basaltic rock at a depth of less than a meter; it was without phenocrysts and its color varied from grey to black. This jumble of rock, the bottom of which was not uncovered, is either an upward protrusion of similar basement rock or is "floating" just above it (as the seismic data seem to indicate). The geomagnetic map of the site, shown as Figure 42, further confirms this. The many dipole anomalies in Grid No. 3 indicate large near-surface rocks, while the magnetic contour slopes could indicate similar basement rock slopes. The geomagnetically quiet area around Grid One probably means a deep or uniform basement rock. (This "geomagnetic" map was prepared by roughly sketching, smoothing, and combining the magnetic grid data given in other figures.)

Santa Gertrudis -- A thin layer of tepetate covers a cream-colored, poorly lithified clay of unknown depth at this site. Because of the very thin soil layer and absence of sherds, this site has possibly been swept clean to the tepetate layer at some time since Indian occupation. No explanation was found for the half meter step in tepetate which passed through this site. (All four of the tombs which have been found here are above the step.)

An exploratory trip was taken into the hills north of this site. A stream cut revealed an 8-meter thick sedimentary sequence with 16 distinct layers.

These were primarily clay-like, but gravels were present too; none of these layers was tepetate (the elevation was probably above the tomb site). Further evidence of non-igneous rocks was seen in gently sloping rock strata visible across the valley to the south. One small flat-topped hill nearby had a horizontal stratum near its top composed of volcanic tuff with light-colored ash fragments and an unusually bright red ash groundmass. This tuff layer did not appear to intersect nearby hills. Amydaloidal basalt was found at an outcrop with white chalcedony on another slope. There was also some evidence for some steeply dipping non-sedimentary beds along the exploratory route.

Cerro Molcajete -- This site is a cinder cone whose upper slopes are entirely composed of spongy volcanic cinder weathered throughout to a uniform red. Cinder from the lower slopes still has a bluish grey interior. Basaltic rock is also found below the cone, but no ash or tepetate. An almost identical but smaller cone is immediately east of the cone with tombs. (At least 7 other suspected cinder cones were located in the basin.) The three known tombs at this site are located below the single, prominent notch which cuts the cone; possibly this was to take advantage of the easy digging in the finer grained material which could have washed down the resulting gully.

Las Cuevas -- The tepetate at this site encloses large chunks of an unidentified rock; this tepetate is also iron stained. Cisterns and water collecting troughs have been cut into tepetate at one location on this former island. The northern part of the island is primarily volcanic cinder and one pot hunters' pit was found there. The magnetic contours at this site indicate a constant magnetic slope upwards away from the former shoreline; this possibly indicates a highly magnetic bedrock overlain by alluvium which is thicker toward the beach. It is possible that a gradiometer arrangement of the magnetometer here would minimize the effect of subsurface, large-scale geology.

Thin section microscopic analysis of rock specimens collected in the field will be used to identify some surface float rocks from the sites; preliminary inspection indicates primarily basalts and tuffs. It may be possible to estimate the age of volcanic activity in this area by fission track analysis of the obsidian.

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4) Berger, Rainer, C. J. Fergusson, and W. F. Libby
1965 UCLA Radiocarbon dates IV. Radiocarbon 7: 336-371.

5) Berger, Rainer, and W. F. Libby
1966 UCLA Radiocarbon dates V. Radiocarbon 8: 467-497.

6) 1967 UCLA Radiocarbon dates VI. Radiocarbon 9: 481 - 485.

7) Berger, Rainer, R. E. Taylor, and W. F. Libby
1966 Radiocarbon content of marine shells from the California and Mexican West coast. Science 153, 3738:864-866.

8) Fergusson, G. J., and W. F. Libby
1963 UCLA Radiocarbon dates II. Radiocarbon 5: 1-22.

9) Rainey, Froelich and E. K. Ralph
1966 Archaeology and its New Technology, Science 153, 1481-1491.

10) Ralph, Elizabeth K., F. Morrison, and D. P. O'Brien
1968 Archaeological Surveying Utilizing a High-Sensitivity Difference Magnetometer. Geoexploration 6: 109-122.

FIGURE CAPTIONS

Fig. 1. The Center of the town of Etzatlán. Figs. 1-10 are photos taken January 8th, 1971, of the Southwest area of Magdalena Basin, Jalisco, Mexico, with a Hasselblad 500 c camera, and plus-x pan black and white film was used for these prints.

Fig. 2. Part of the town of San Pedro, several miles across Magdalena Basin from Etzatlán. Cerro San Pedro is in the near background.

Fig. 3. Cerro Molcajete is the small cinder cone in the foreground. About three shaft tombs have been found near the base of this volcanic cone just below the notch which cuts into it.

Fig. 4. The small foothill, El Arenal, is the scrub-covered area in the center of this photo. The crescent-shaped outcrop of Tepetate, the volcanic rock in which shaft tombs are often dug, at the left of center marks a former boundary of lake Magdalena.

Fig. 5. This flat-topped hill is of interest because, like Cerro Molcajete, it may be a burial site. Furthermore, it has some light marks on its flanks, similar to the tomb robber's excavation marks in the El Arenal photos. While the location of this photo is not known, it can probably be determined from the hacienda to the left and the shape of the mountain in the background.

Fig. 6. The site, Las Cuevas, at the right hand side of this former island is still being dug by pot hunters. Caves are visible at the foot of the cliffs which are facing the camera; these are at least 6 meters high and are locally said to have been inhabited by Indians. Many fields of corn shocks surround the island and were to be harvested by hand shortly.

Fig. 7. This cloud-crested mountain is probably Vulcan Tequila.

Fig. 8. This closer view of El Arenal shows some evidence of the digging of tomb robbers in the white area to the left of center. The white circular areas scattered around the photo are sterile spots caused by ant colonies. Fields of corn are on the flat former lake bed at the bottom of the photograph. The ground width of this photo is about 700 meters.

Fig. 9. El Arenal is in the foreground and the hacienda San Sebastian is in the background.

Fig. 10. Photo of the hacienda San Sebastian shows what may be four cinder cones in the background.

Fig. 11. Map of Magdalena Lake Basin showing sites.

Fig. 12. Photo of CS Model 4920 in use at El Arenal.

Fig. 13. Photo of CS Model V-4971 in use.

Fig. 14. Seismograph in use.

Fig. 15. Map of grid locations, El Arenal.

Fig. 16. Grid #1.

Fig. 17. Detail of lines 60 and 62 anomaly, Grid #1, at 1/2 m spacing.

Fig. 18. Test pit 3.

Fig. 19. Grid #2.

Fig. 20. Grid #3.

Fig. 21. Part of Grid #3 Extended N made with higher sensor height. Region of pronounced anomaly.

Fig. 22. Plot of shaft tomb showing soil and tepetate layers.

Fig. 23. Seismic Line - edge of Grid #1.

Fig. 24. Seismic measurements made over Hollow Tomb located on line 70 of G #1.

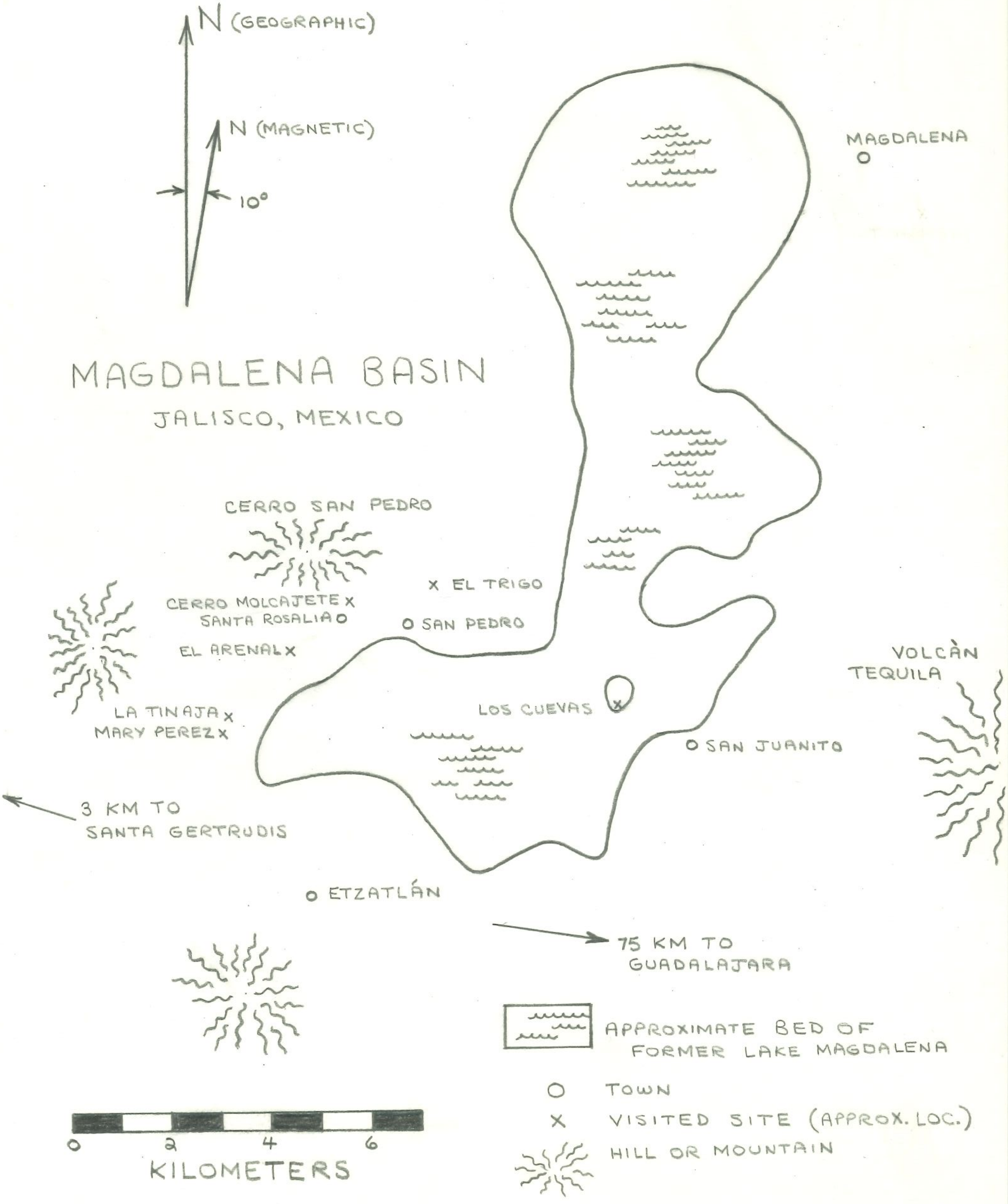
Fig. 25. Repeat of Fig. 24 with greater distance between geophone and hammer.

Fig. 26. Seismic velocities over large anomaly of G #3 extended N.

Fig. 27. Depths of large anomaly of G #3 extended N as determined by seismic measurements.

Fig. 28. Detail of part of Grid #4 at 1-meter intervals.

FIG 11



N (GEOGRAPHIC)
N (MAGNETIC)
10°
MAGDALENA BASIN
JALISCO, MEXICO
MAGDALENA
CERRO SAN PEDRO
X EL TRIGO
CERRO MOLCAJETE X
SANTA ROSALIA O
O SAN PEDRO
EL ARENAL X
VOLCÀN TEQUILA
LA TINAJA X
MARY PEREZ X
LOS CUEVAS
O SAN JUANITO
3 KM TO SANTA GERTRUDIS
O ETZATLÁN
75 KM TO GUADALAJARA
APPROXIMATE BED OF FORMER LAKE MAGDALENA
O TOWN
X VISITED SITE (APPROX. LOC.)
HILL OR MOUNTAIN
0
2
4
6
KILOMETERS

FIGURE 15

EL ARENAL
GRID PLAN

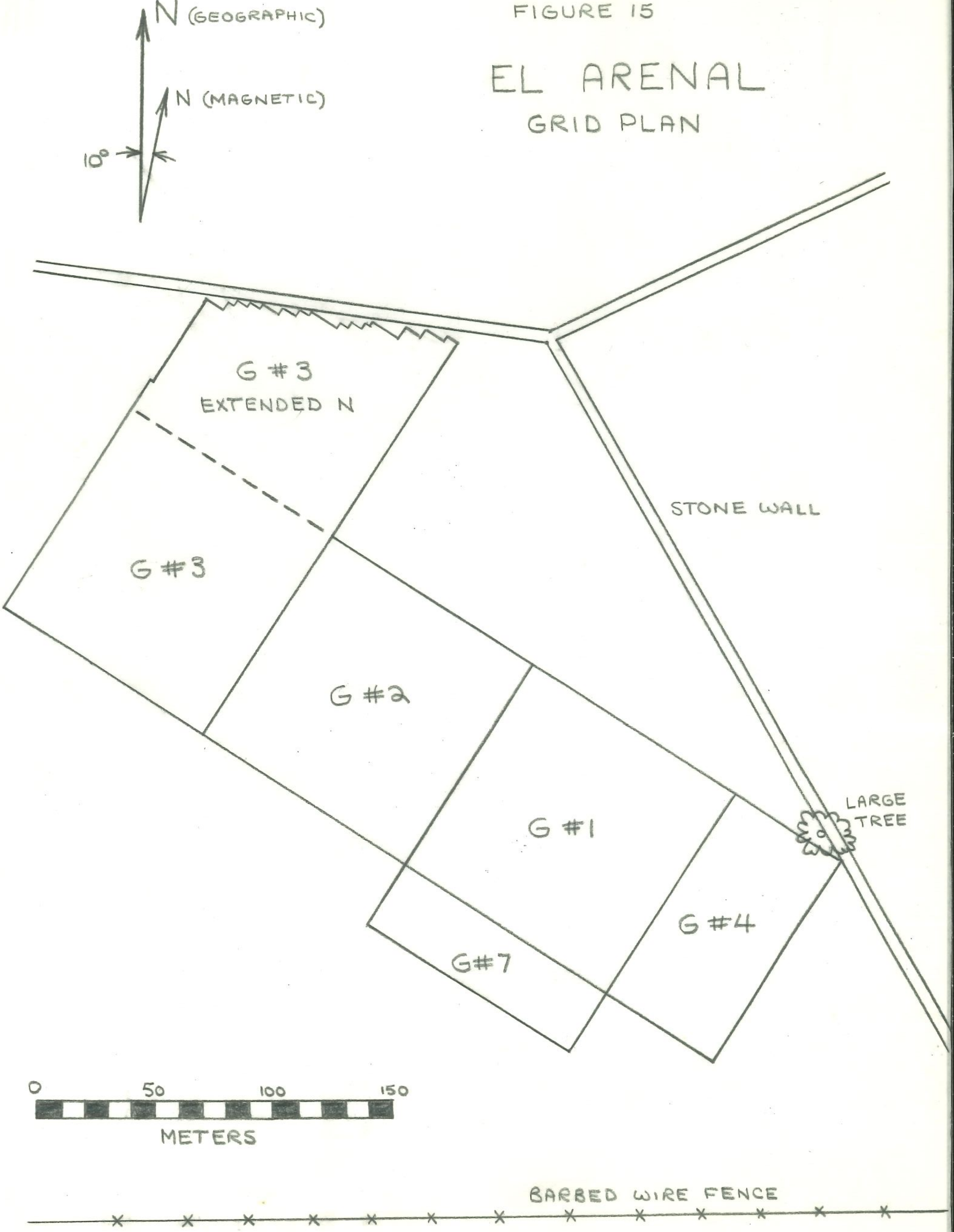
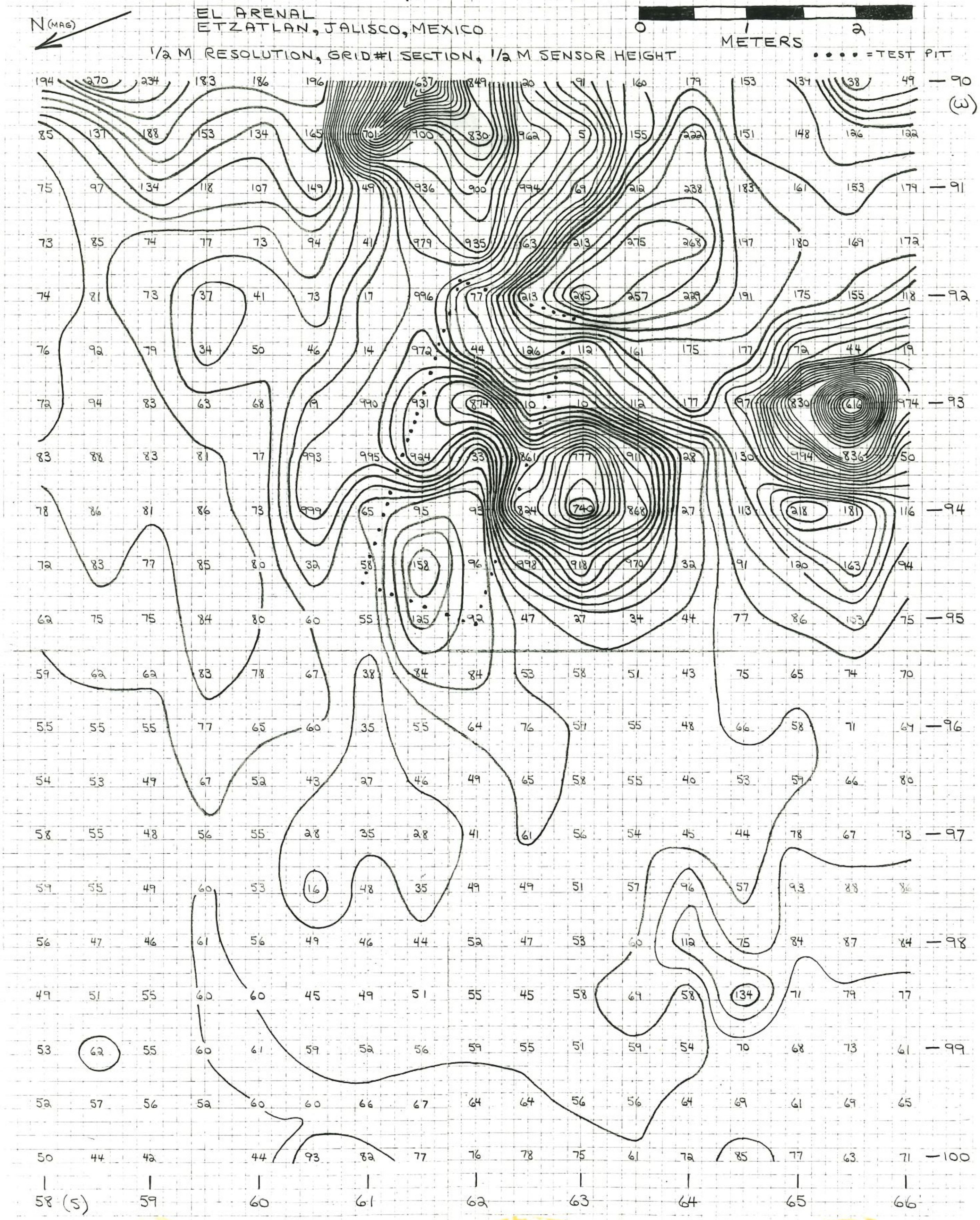


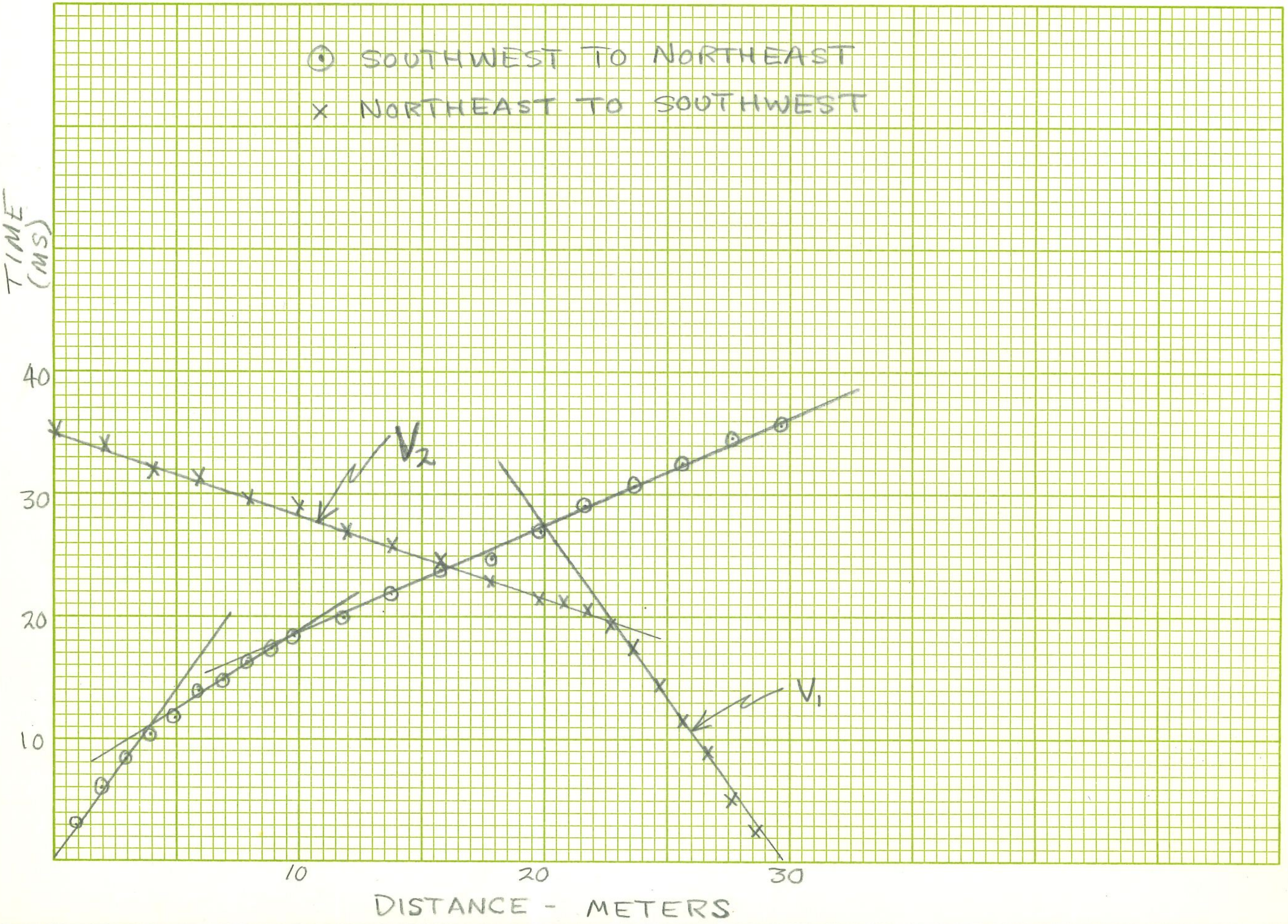
Fig. 16. Grid A1

FIG 17



EL ARENAL
ETZATLAN, JALISCO, MEXICO
1/2 M RESOLUTION, GRID #1 SECTION, 1/2 M SENSOR HEIGHT

FIG 17


⊙ SOUTHWEST TO NORTHEAST
x NORTHEAST TO SOUTHWEST
TIME (MS)
40
30
20
10
V2
V1
10
20
30
DISTANCE - METERS

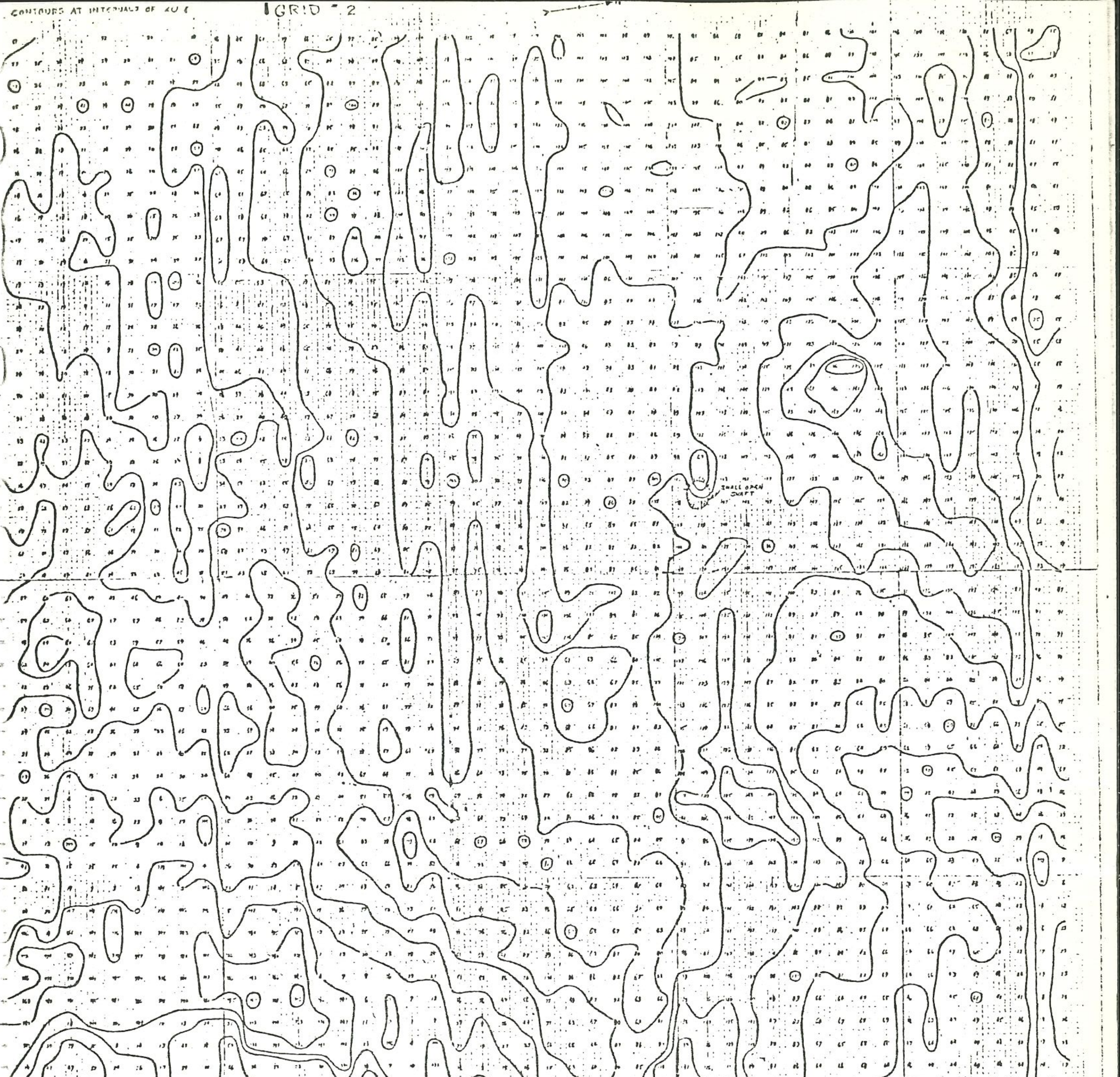


Fig. 19. Grid #2.

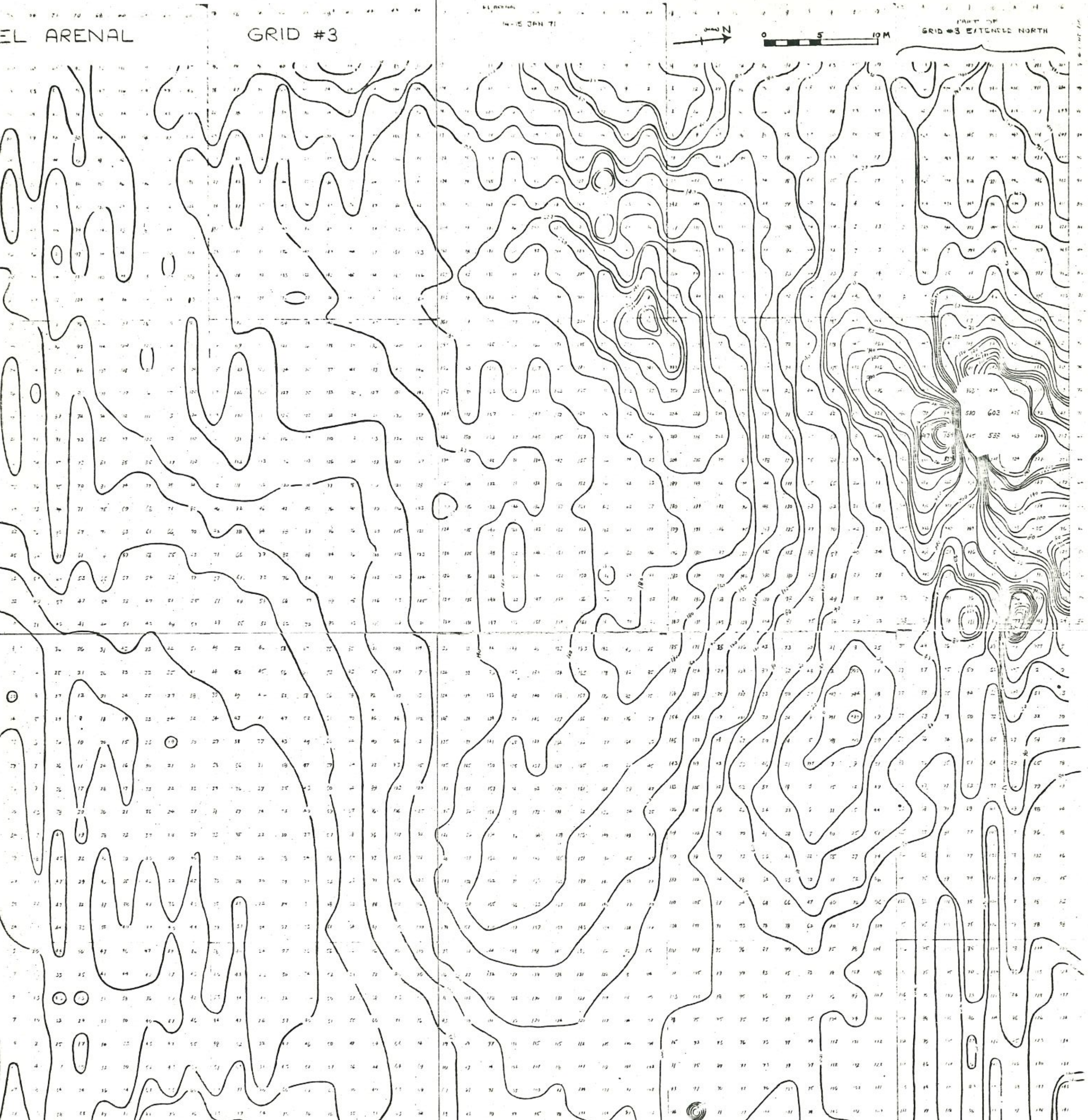
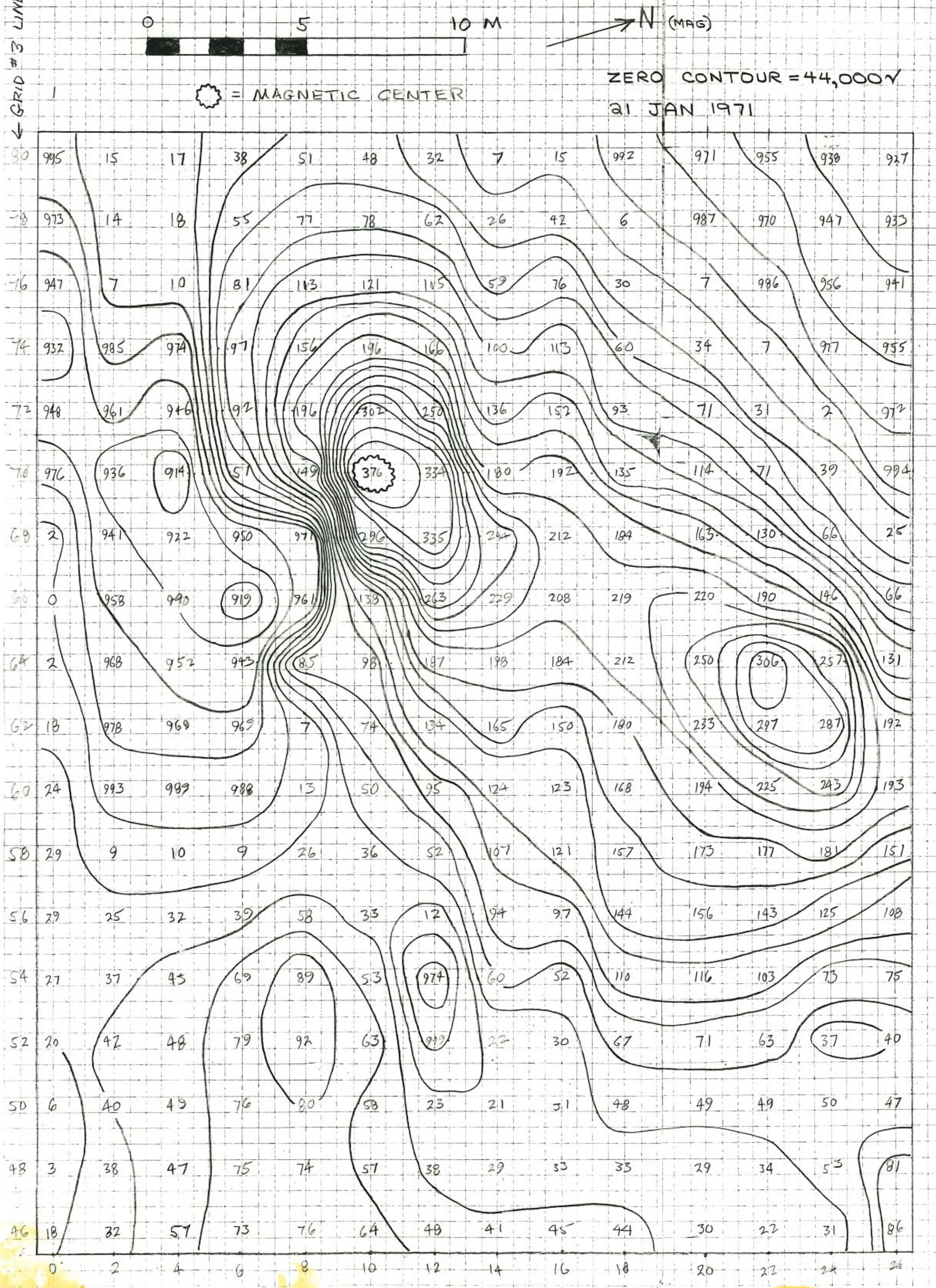

EL ARENAL
GRID #3
EL ARENAL
14-15 JAN 71
N
0
5
10M
PART OF
GRID #3 EXTENDED NORTH

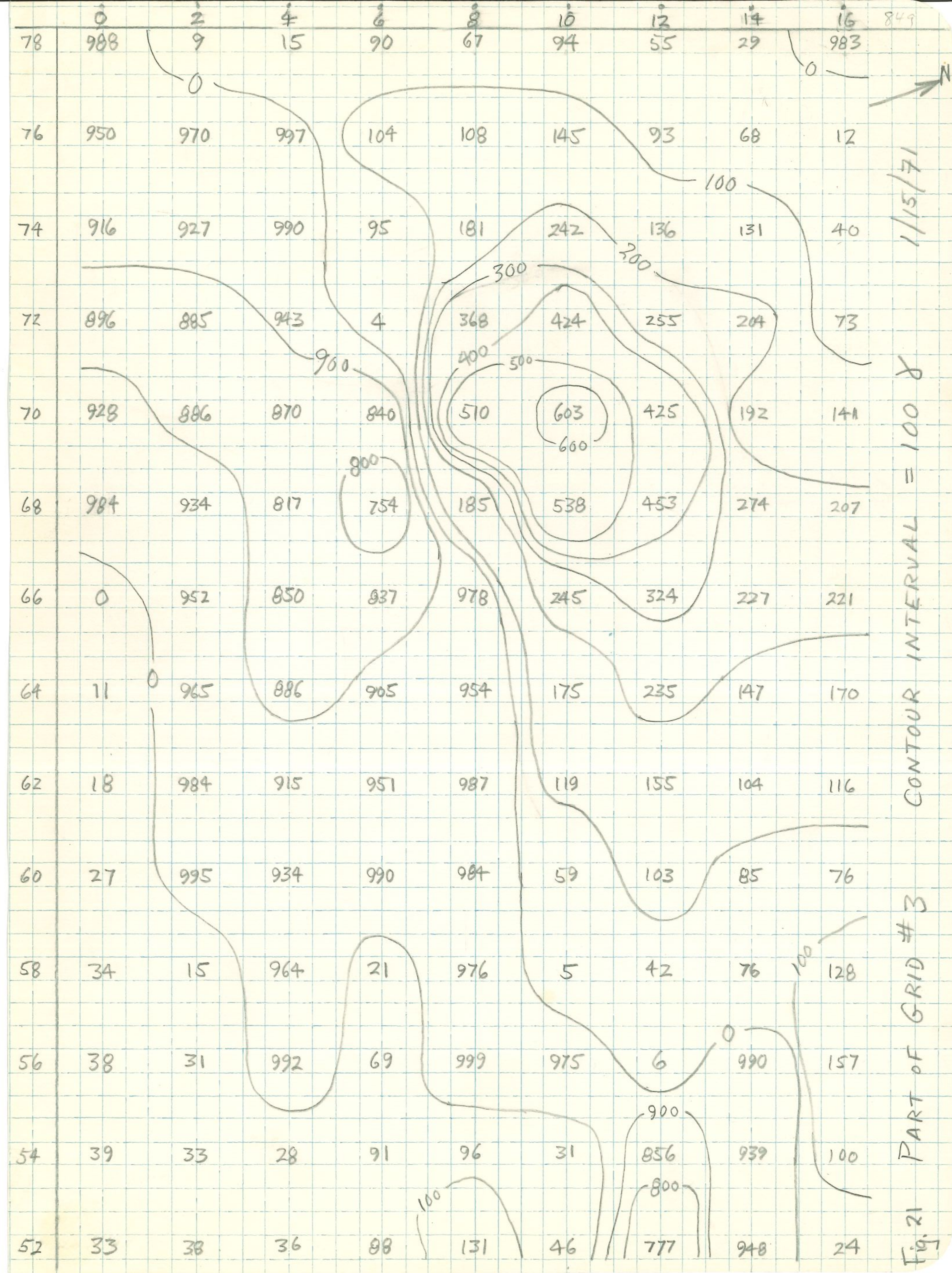
Fig. 20. Grid #3.

FIG 21

GRID #3 EXTENDED N

SENSOR HEIGHT = 3 METERS





	0	2	4	6	8	10	12	14	16
78	988	9	15	90	67	94	55	29	983
76	950	970	997	104	108	145	93	68	12
74	916	927	990	95	181	242	136	131	40
72	896	885	943	4	368	424	255	204	73
70	928	886	870	840	510	603	425	192	141
68	984	934	817	754	185	538	453	274	207
66	0	952	850	837	978	245	324	227	221
64	11	965	886	905	954	175	235	147	170
62	18	984	915	951	987	119	155	104	116
60	27	995	934	990	984	59	103	85	76
58	34	15	964	21	976	5	42	76	128
56	38	31	992	69	999	975	6	990	157
54	39	33	28	91	96	31	856	939	100
52	33	38	36	88	131	46	777	948	24

Fig. 21 PART OF GRID #3 CONTOUR INTERVAL = 100 γ 1/15/71

FIG 22

EL ARENAL STRATIGRAPHY

HYPOTHETICAL, BUT TYPICAL, SHAFT TOMB

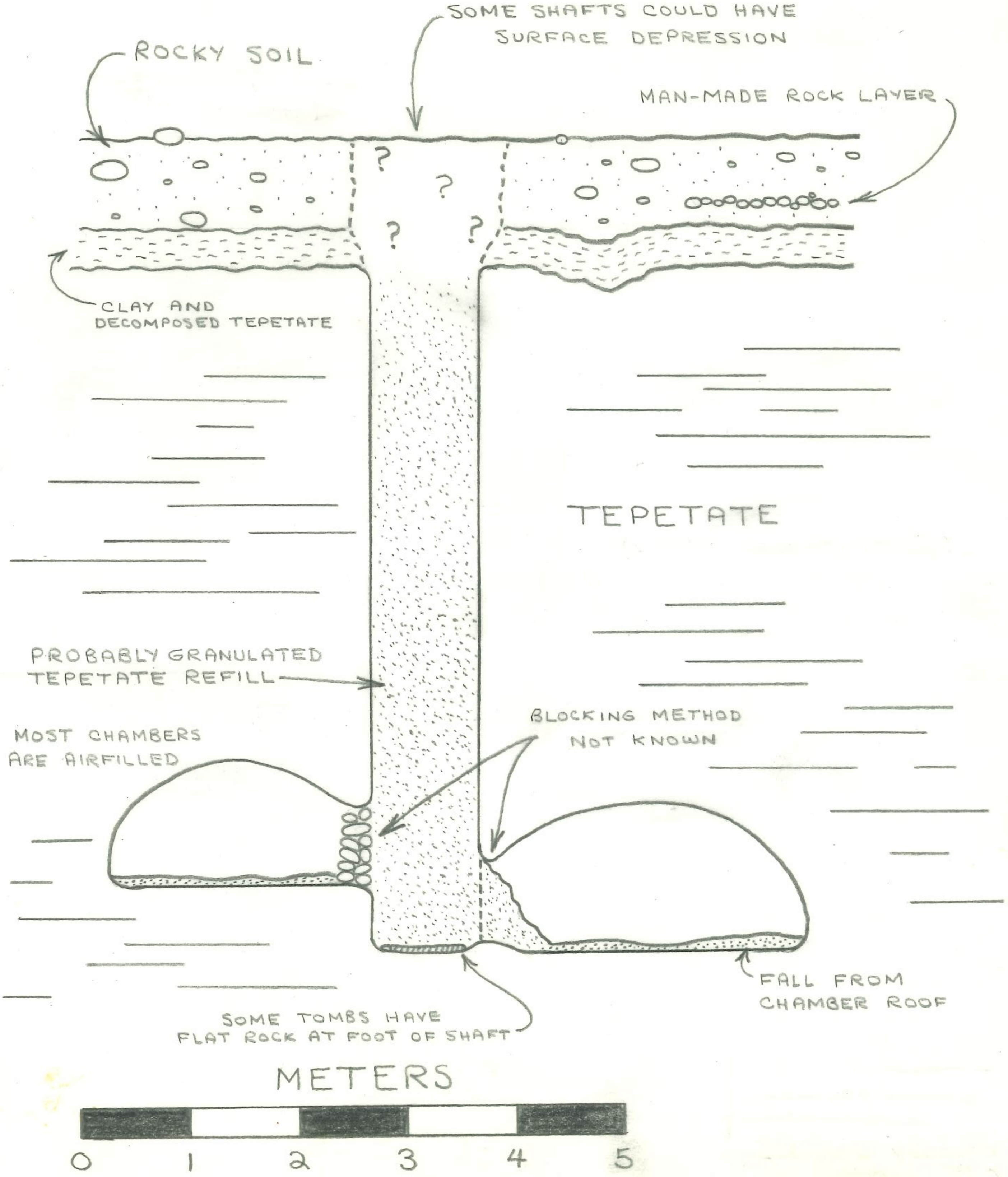
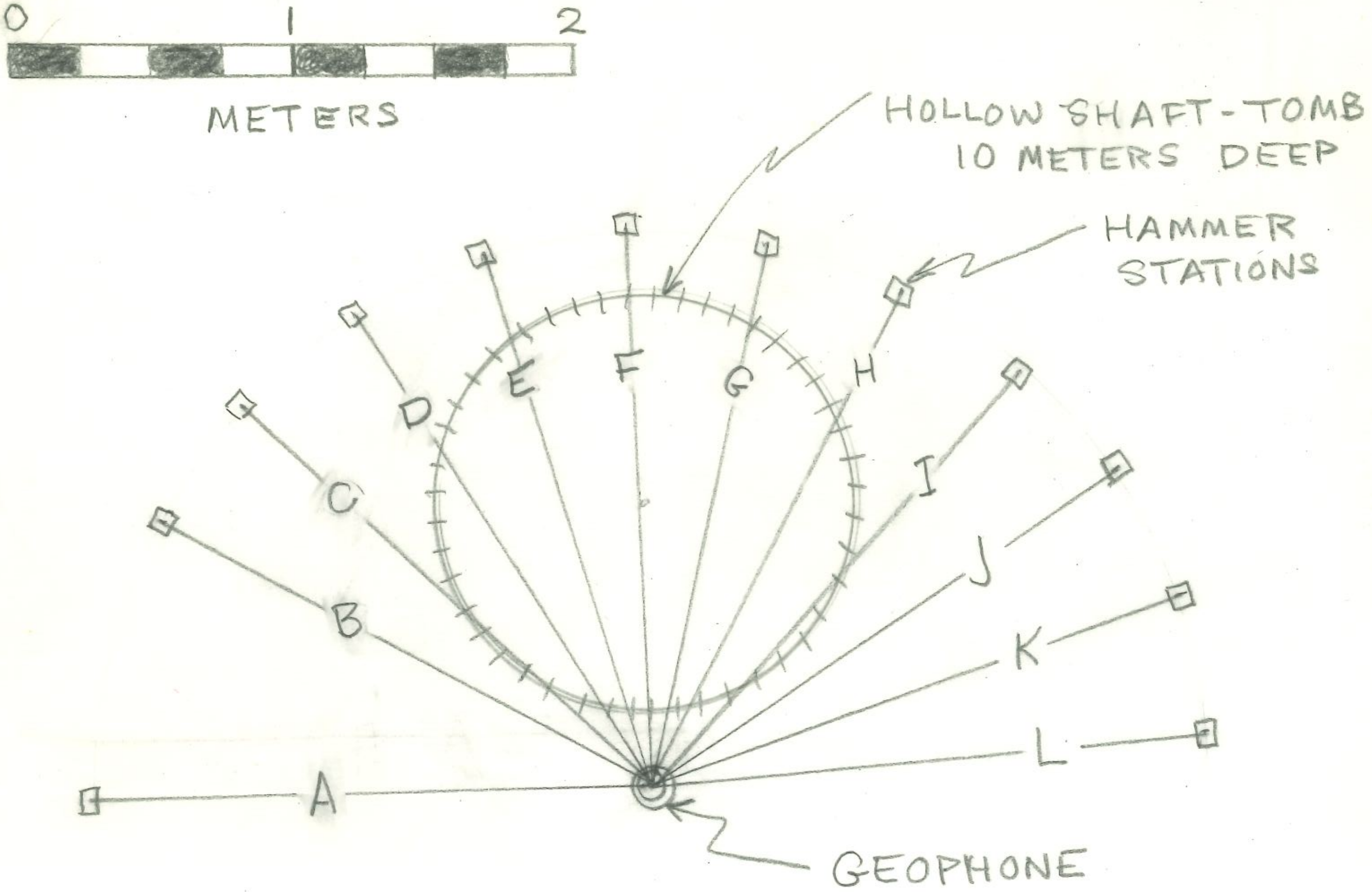


FIG. 23


MS
120
100
80
60
40
20
TIME
0
10
20
30
40
50
60
70
80
90
100
DISTANCE - METERS
V1
V2
V3

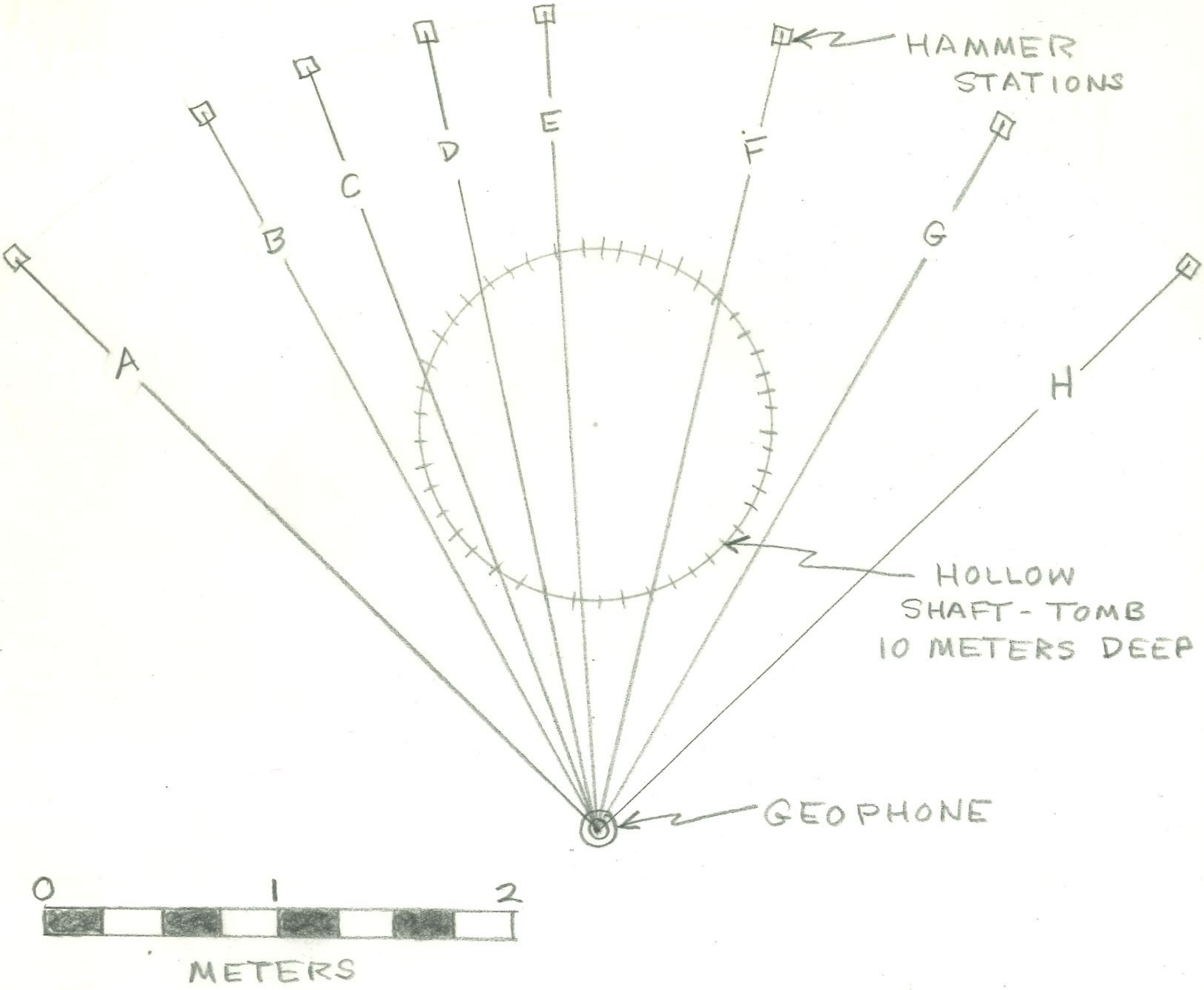


LINES

READINGS IN MILLISECONDS (MS)

METERS BETWEEN HAMMER STATION AND GEOPHONE	A	B	C	D	E	F	G	H	I	J	K	L
1	2.7											
2	5.7	5.5	5.5	5.7	5.5	5.1	5.1	5.1	4.6	4.7	4.7	4.3
3	7.3											
4	8.7											
5	10.1											

FIG 24



METERS BETWEEN HAMMER STATION AND GEOPHONE	LINES READINGS IN MILLISECONDS (MS)							
	A	B	C	D	E	F	G	H
2.5	6.7							
3.5	7.5	8.1	8.1	8.5	7.9	7.3	7.3	6.5

FIG 25

Fig. 26

FIG 26

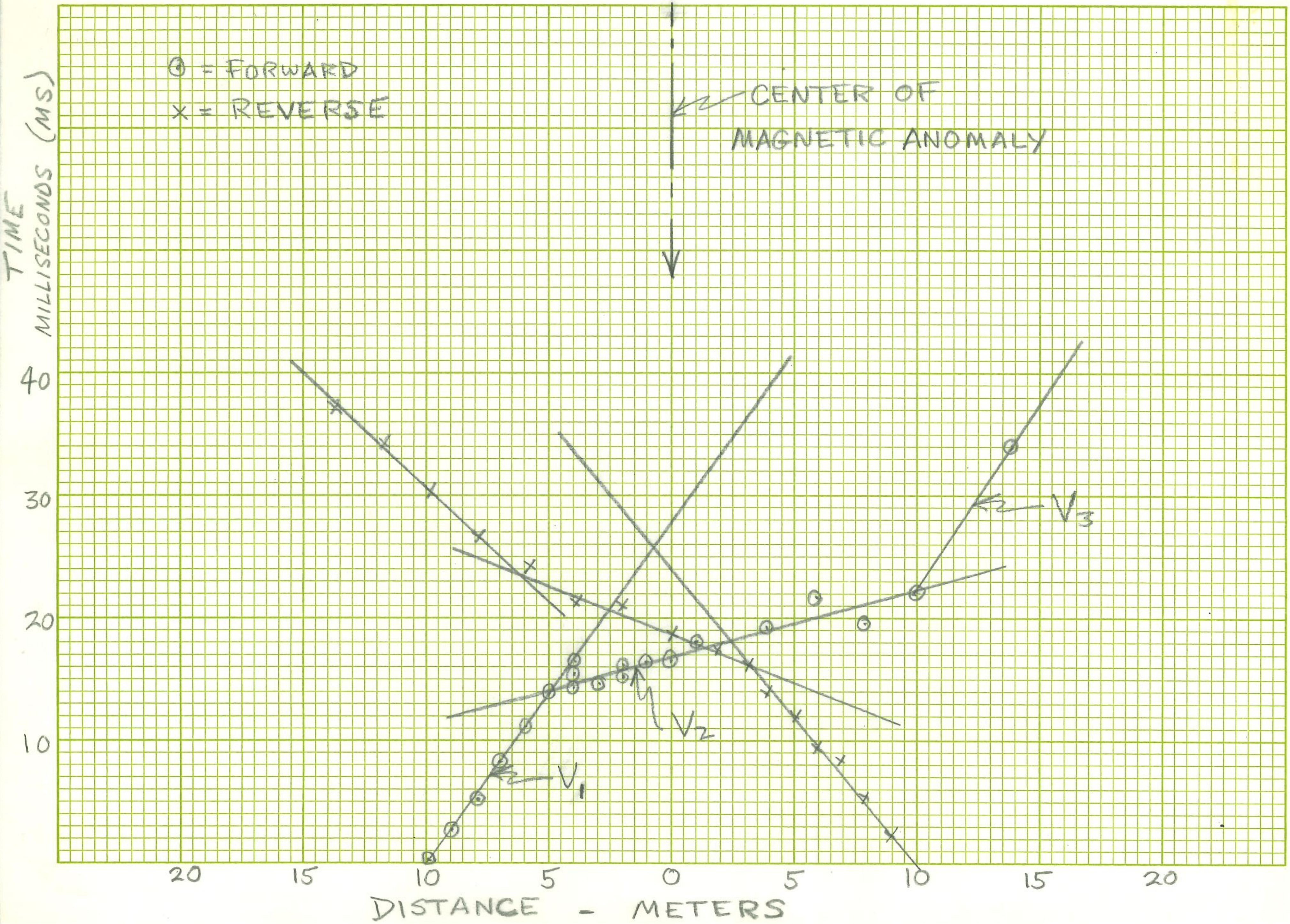

⊙ = FORWARD
× = REVERSE
CENTER OF
MAGNETIC ANOMALY
TIME
MILLISECONDS (MS)
40
30
20
10
V1
V2
V3
20
15
10
5
0
5
10
15
20
DISTANCE - METERS

Fig. 27

SEISMIC ANOMALY OF LINE 10
OF GRID #3 EXTENDED N
VALUES = DEPTH OF ANOMALY
IN METERS

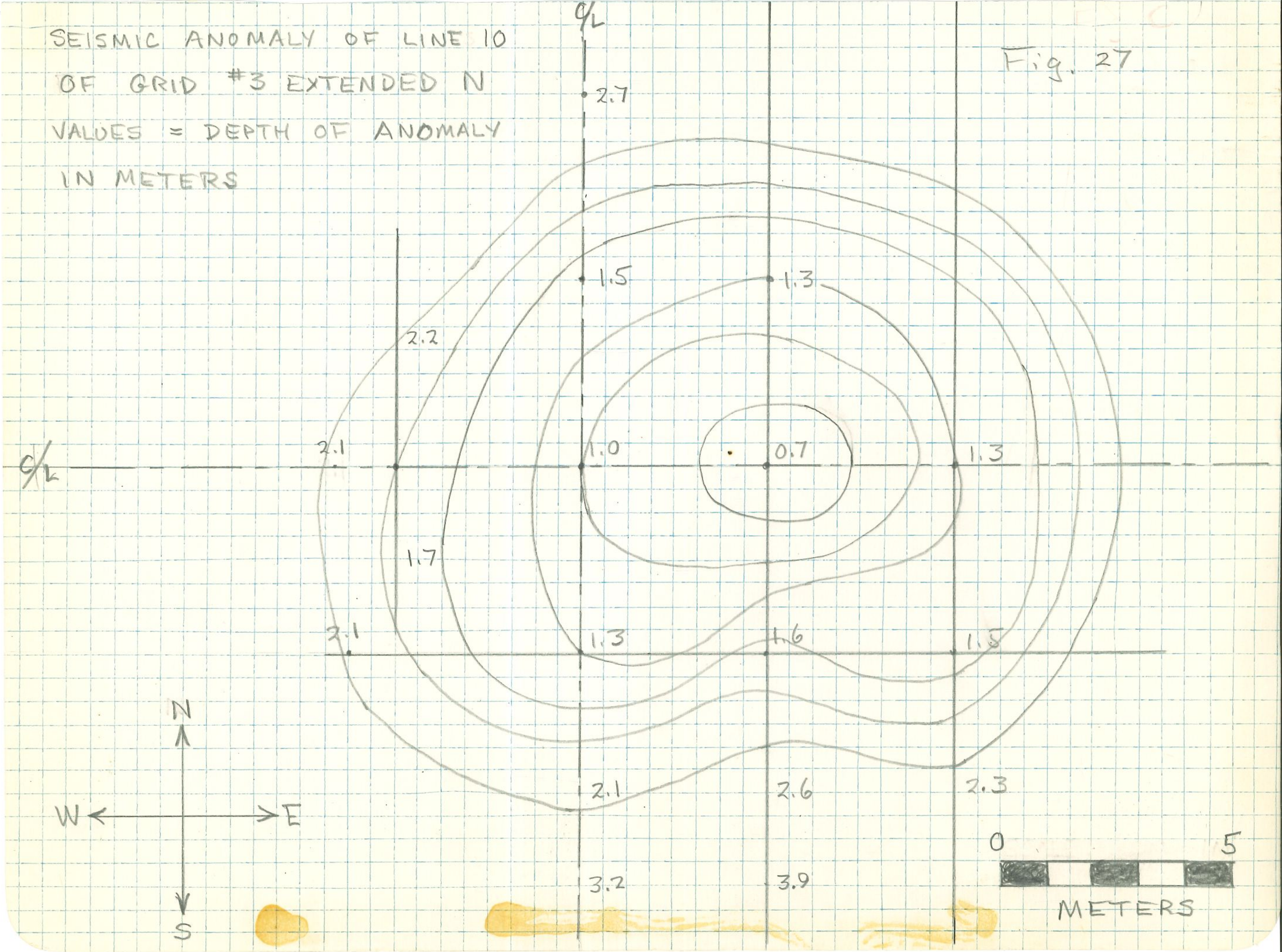
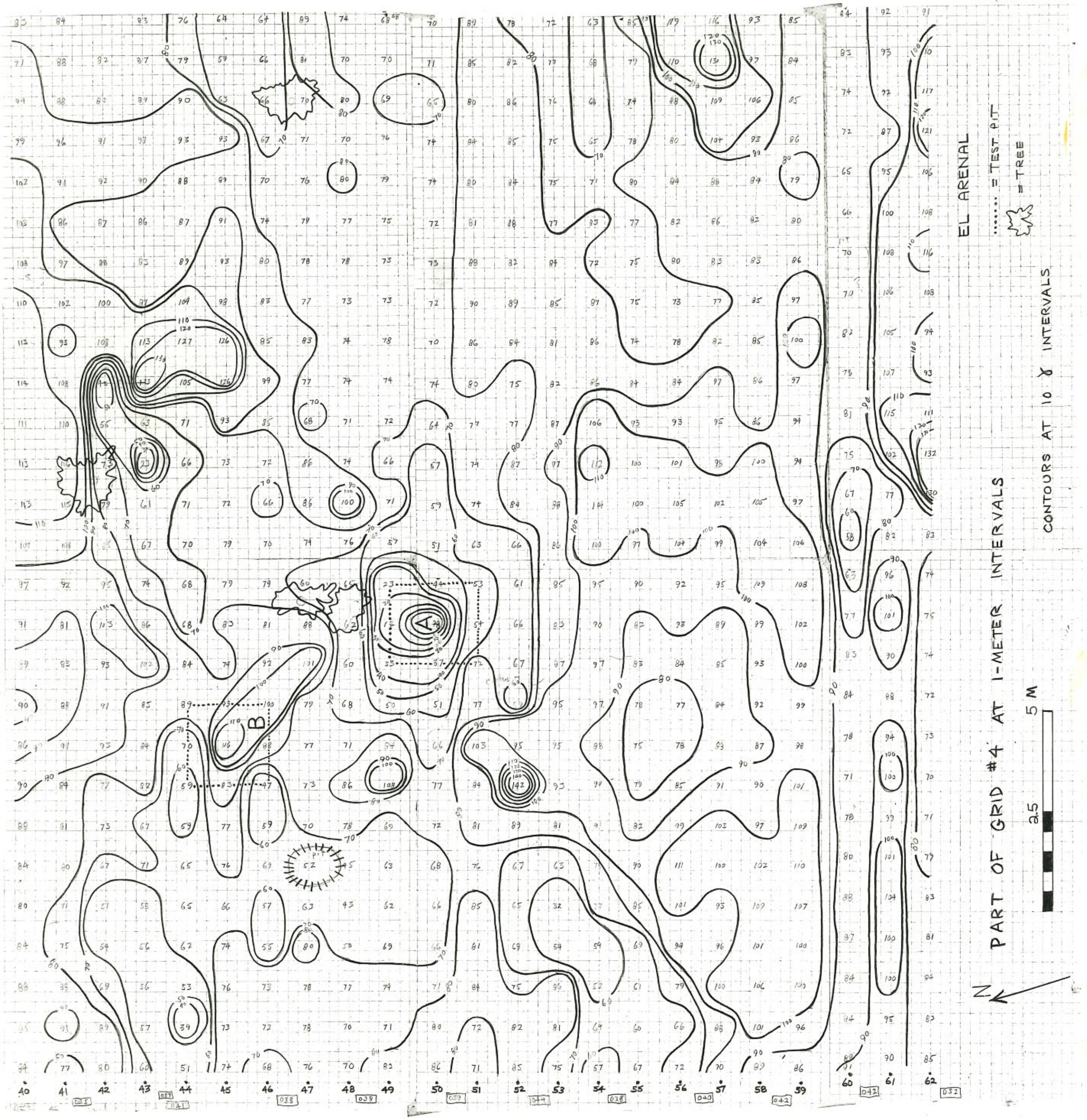
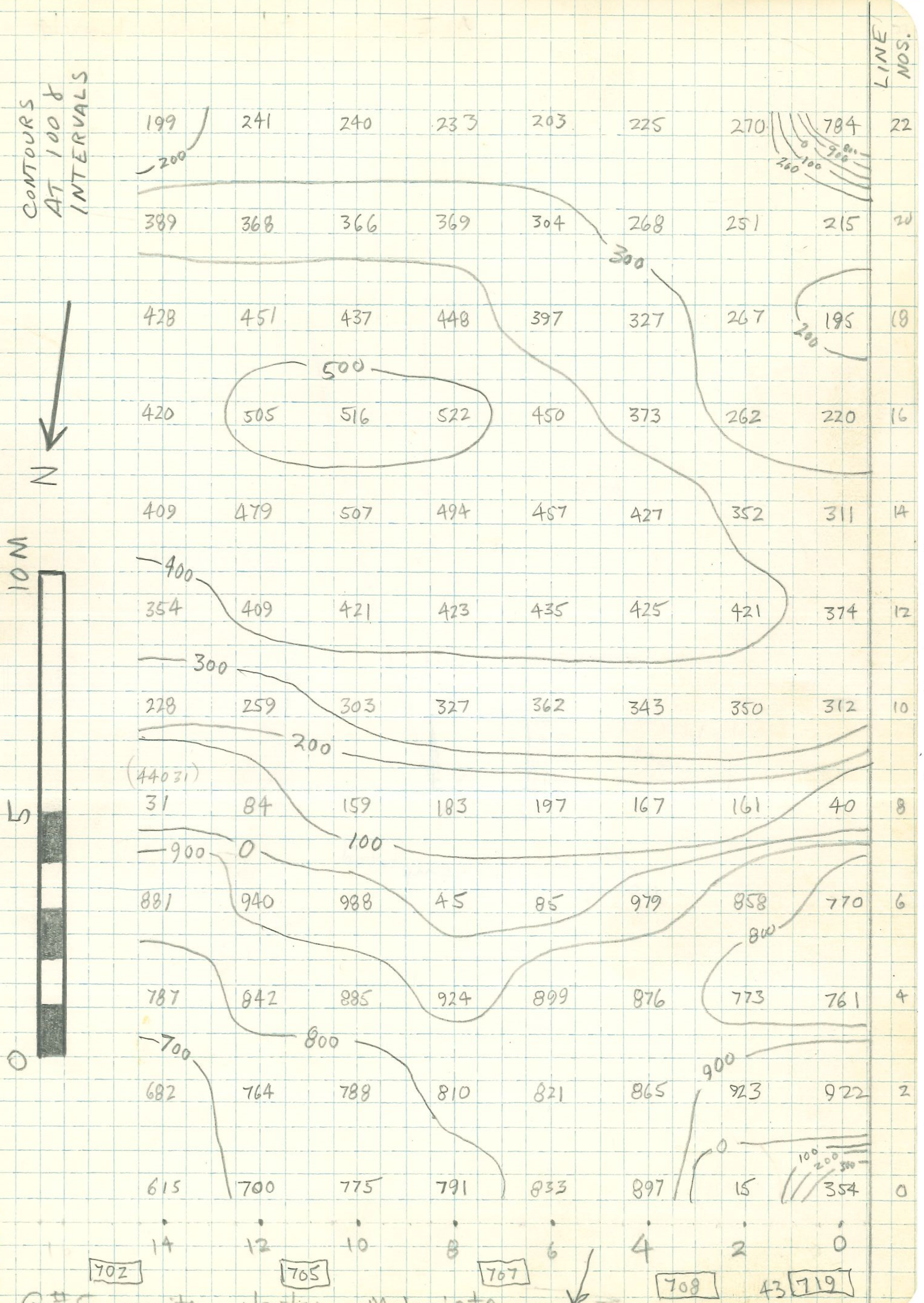


FIG. 28


EL ARENAL
...... = TEST PIT
= TREE
CONTOURS AT 10 γ INTERVALS
PART OF GRID #4 AT 1-METER INTERVALS
5 M
2.5
N
A
B
PIT
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62

CERRO MOLCAJETE GRID # 5

NORMAL SENSOR HEIGHT 1.4 M

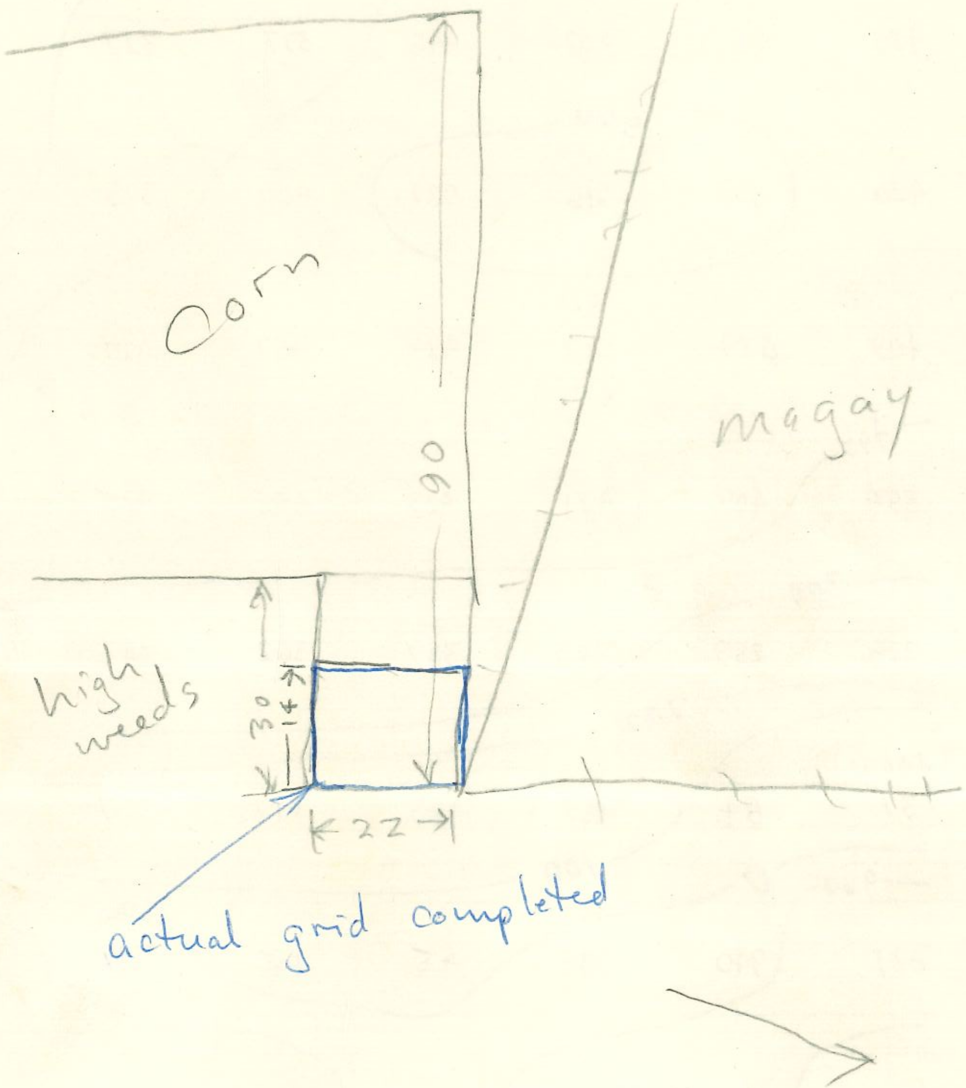


199	241	240	233	203	225	270	784	22
389	368	366	369	304	268	251	215	20
428	451	437	448	397	327	267	195	18
420	505	516	522	450	373	262	220	16
409	479	507	494	457	427	352	311	14
354	409	421	423	435	425	421	374	12
228	259	303	327	362	343	350	312	10
31	84	159	183	197	167	161	40	8
881	940	988	45	85	979	858	770	6
787	842	885	924	899	876	773	761	4
682	764	788	810	821	865	923	922	2
615	700	775	791	833	897	15	354	0
14	12	10	8	6	4	2	0	

702 705 767 708 43 719

G#5 new site 1/25/71 Molcajete

Fig. 31



actual grid completed

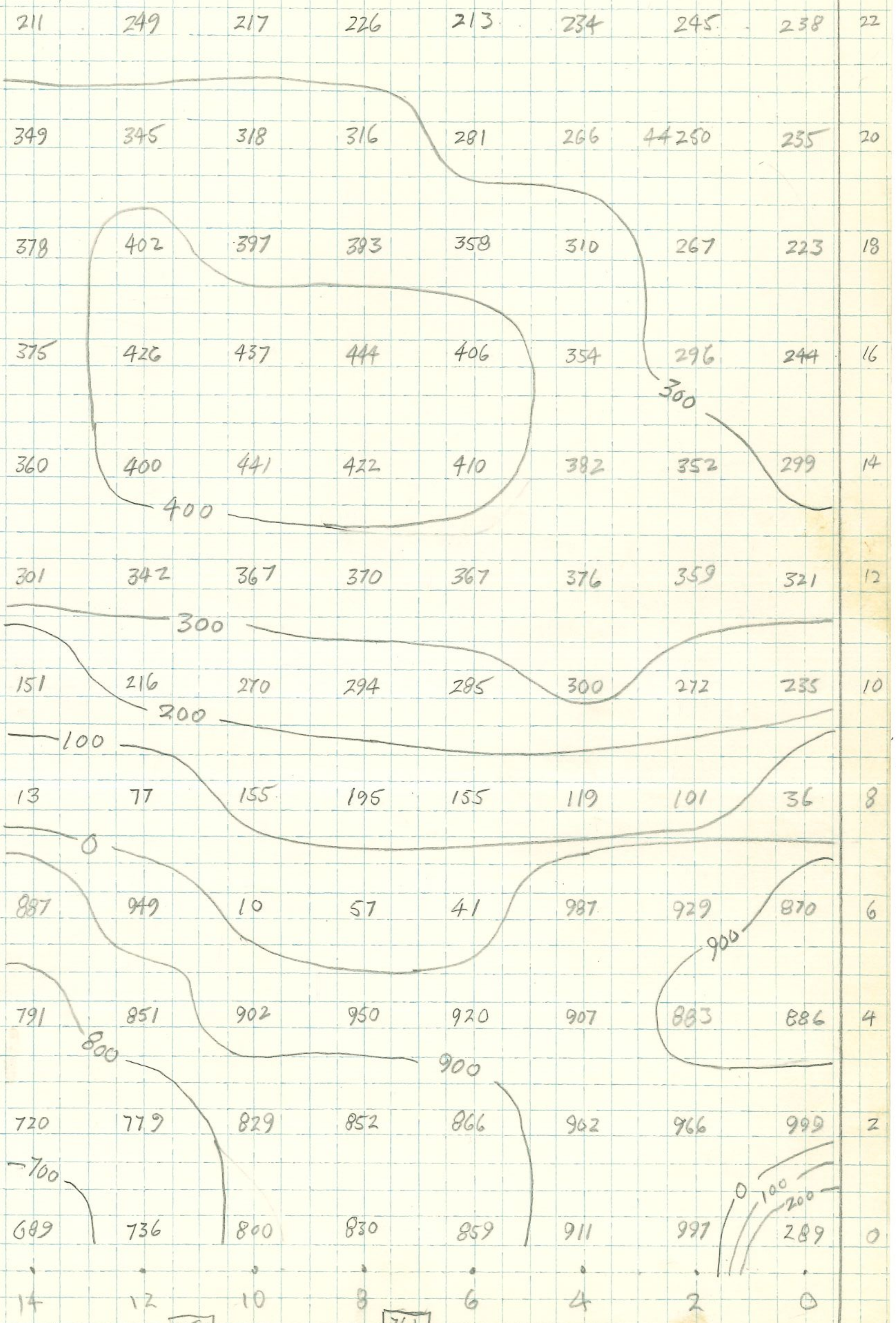
FIG 32

Fig. 32

GRID #5 CERRO MOLCAJETE REPEATED

WITH SENSOR HEIGHT = 2.2 M

CONTOURS AT 100 δ INTERVALS



752 761

11/25/71 G#5 repeated with single sensor 2.2M high

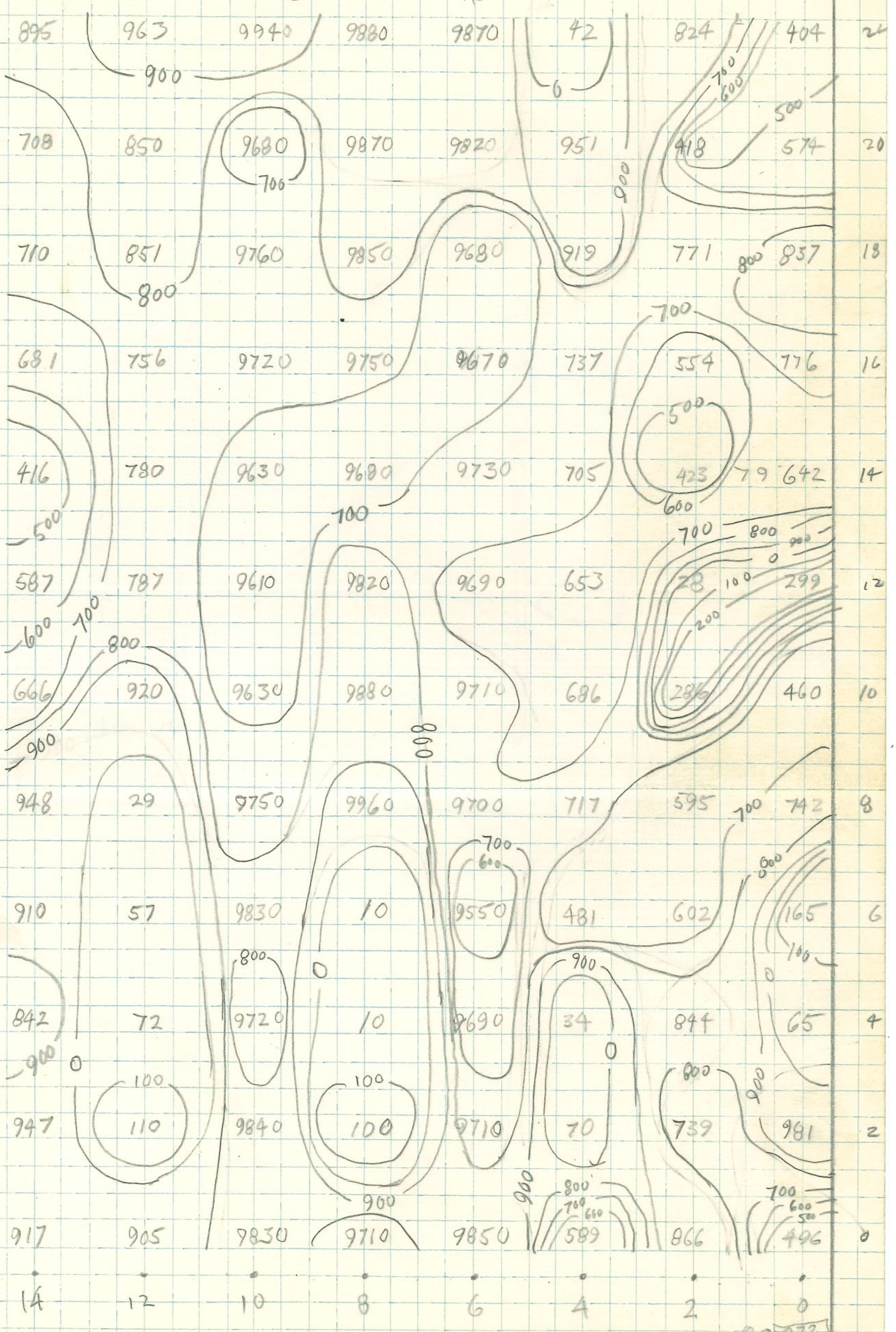
762 43 757

FIG 34

CERRO MOLCAJETE GRID #5 REPEATED IN DIFFERENCE MODE WITH UPPER SENSOR AT 2.1 M AND LOWER AT 0.8 M. (SEE PHOTO)

CONTOURS AT 100 UNIT INTERVALS ~ 50 γ

MAGNETOMETER SCALE = x 1	MAGNETOMETER SCALE = x 10 (0's added)	MAGNETOMETER SCALE = x 1



	14	12	10	8	6	4	2	0
2	895	963	9940	9880	9870	42	824	404
20	708	850	9680	9870	9820	951	418	574
18	710	851	9760	9850	9680	919	771	837
16	681	756	9720	9750	9670	737	554	776
14	416	780	9630	9680	9730	705	423	79 642
12	587	787	9610	9820	9690	653	28	299
10	666	920	9630	9880	9710	686	286	460
8	948	29	9750	9960	9700	717	595	742
6	910	57	9830	10	9550	481	602	165
4	842	72	9720	10	9690	34	844	65
2	947	110	9840	100	9710	70	739	981
0	917	905	9830	9710	9850	589	866	496

80|072

N↙ 1/25/71 G#5 repeated in difference mode, sensors 1.3 m apart Molcajete

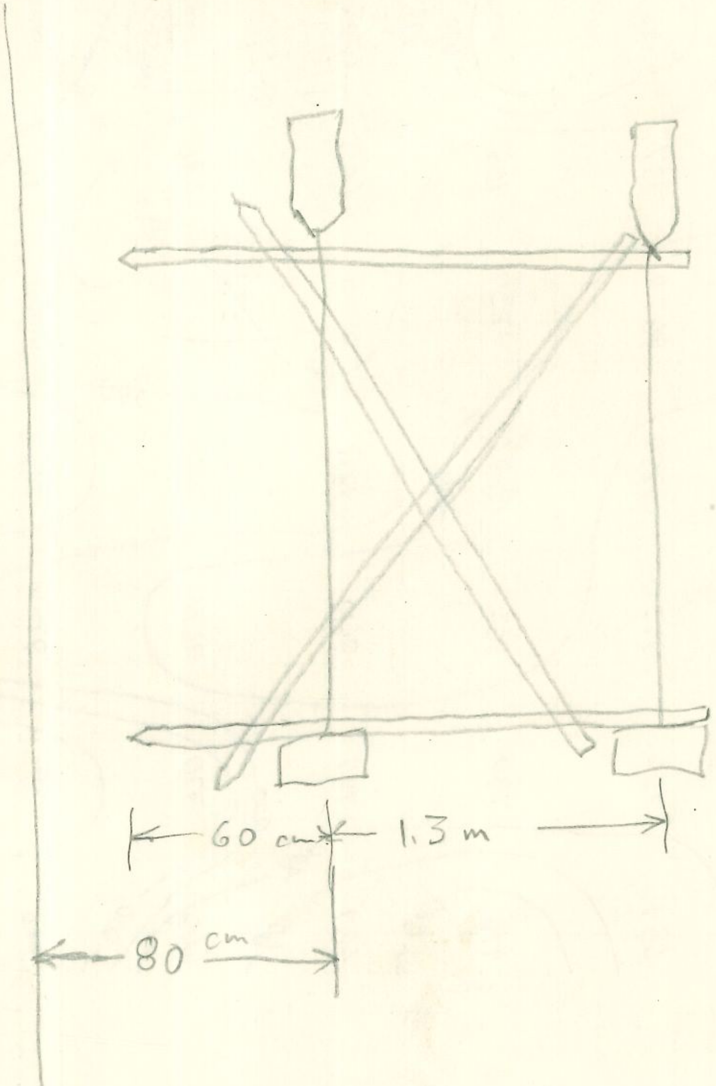

60 cm
1.3 m
80 cm

Fig. 35

FIG 35

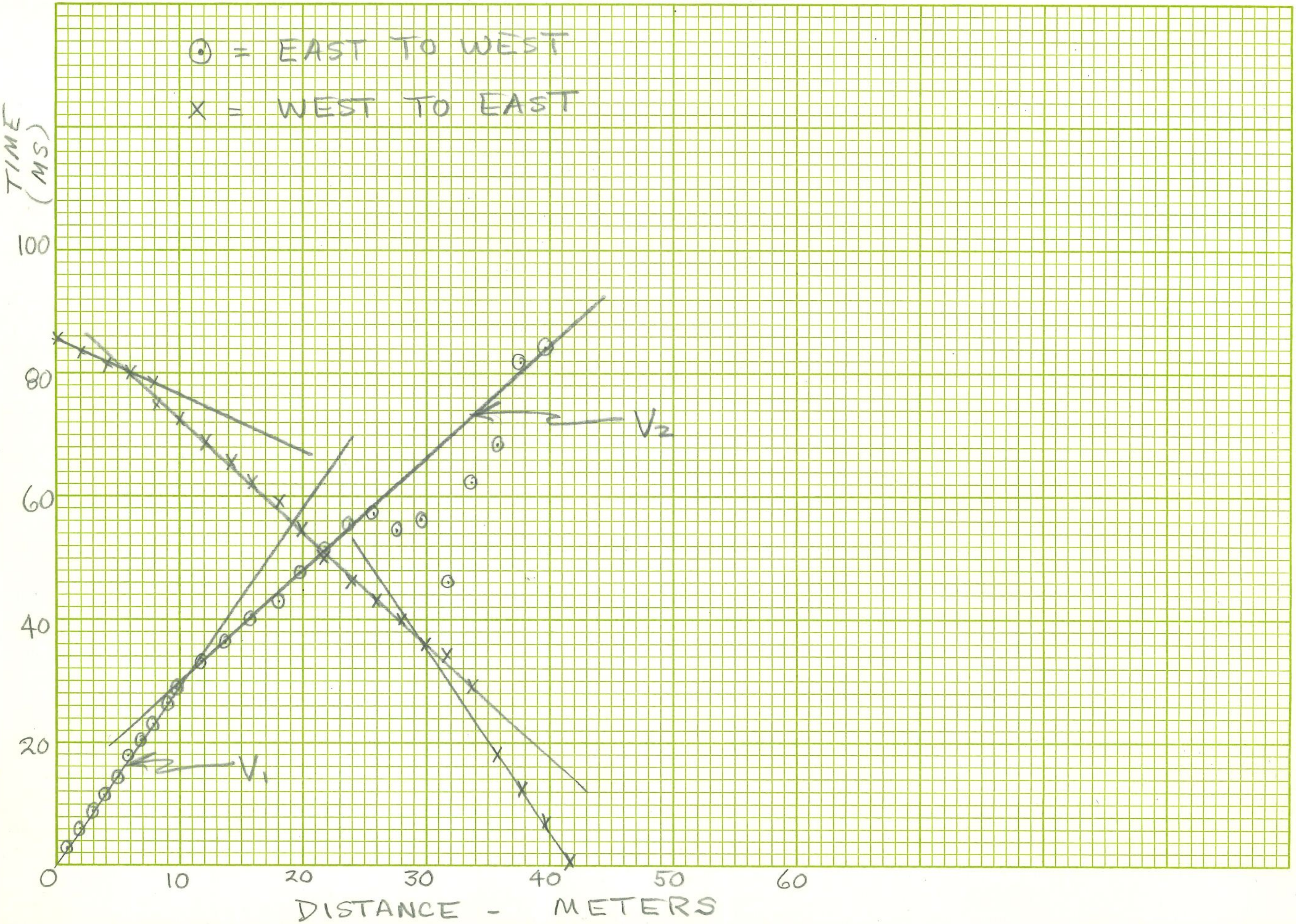

⊙ = EAST TO WEST
X = WEST TO EAST
TIME (MS)
100
80
60
40
20
0
10
20
30
40
50
60
DISTANCE - METERS
V2
V1

FIG 36

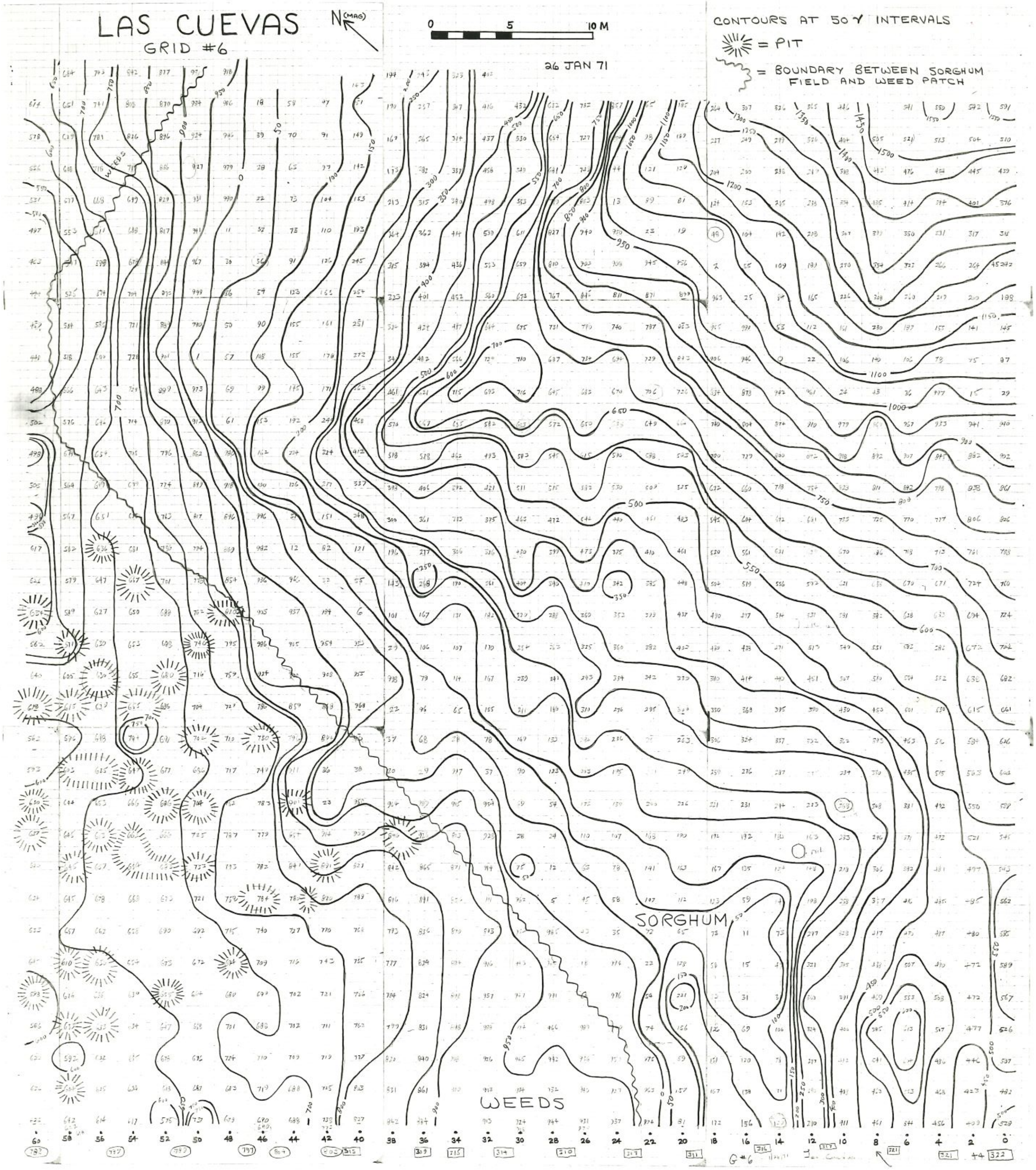

LAS CUEVAS
GRID #6
N(MAG)
0 5 10 M
26 JAN 71
CONTOURS AT 50 γ INTERVALS
= PIT
= BOUNDARY BETWEEN SORGHUM FIELD AND WEED PATCH
WEEDS
SORGHUM
WEEDS
60 58 56 54 52 50 48 46 44 42 40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0

FIG 37

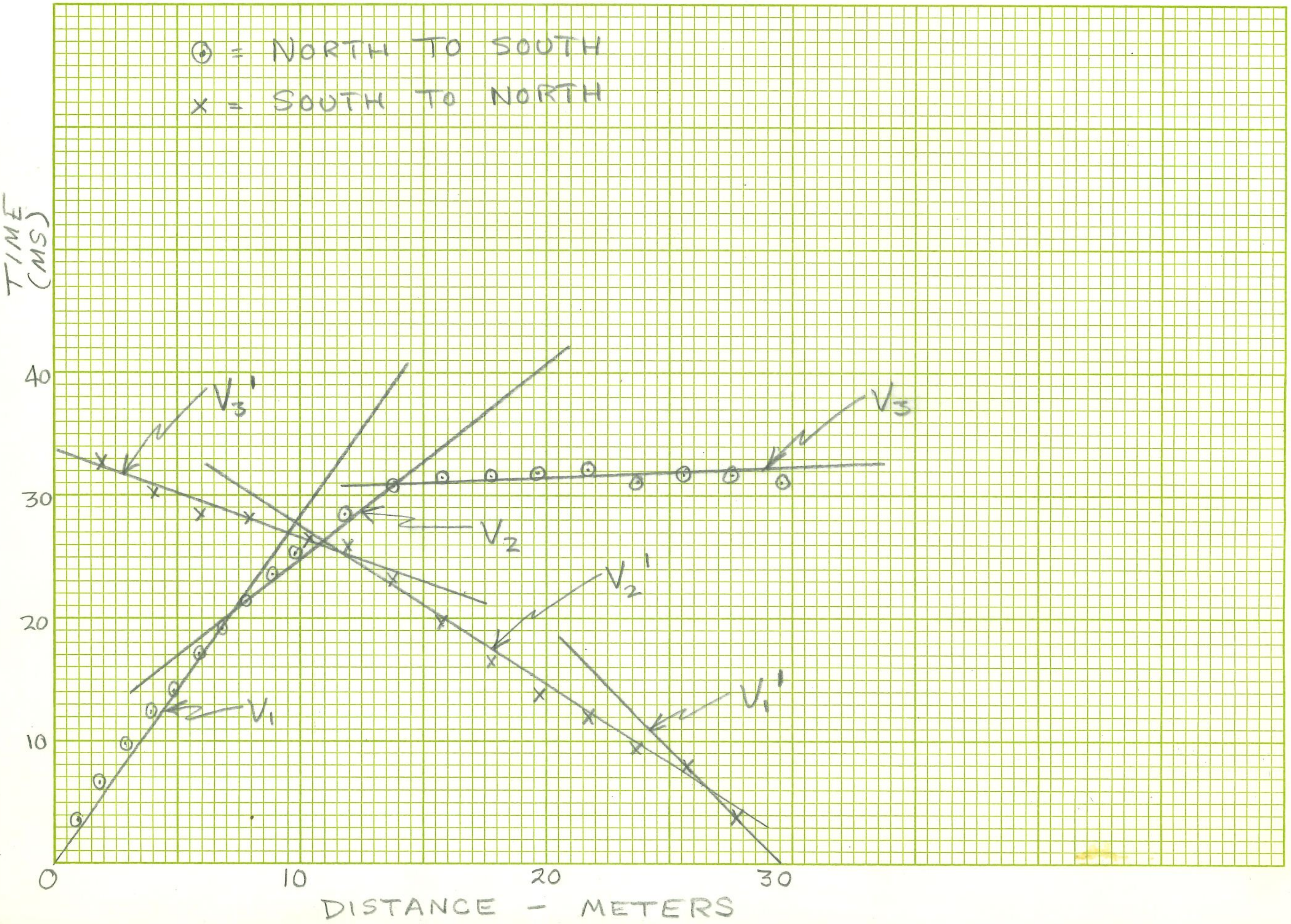

⊙ = NORTH TO SOUTH
x = SOUTH TO NORTH
TIME (MS)
40
30
20
10
0
10
20
30
DISTANCE - METERS
V_3'
V_3
V_2
V_2'
V_1
V_1'

Fig. 38. Seismic line at El Trigo.

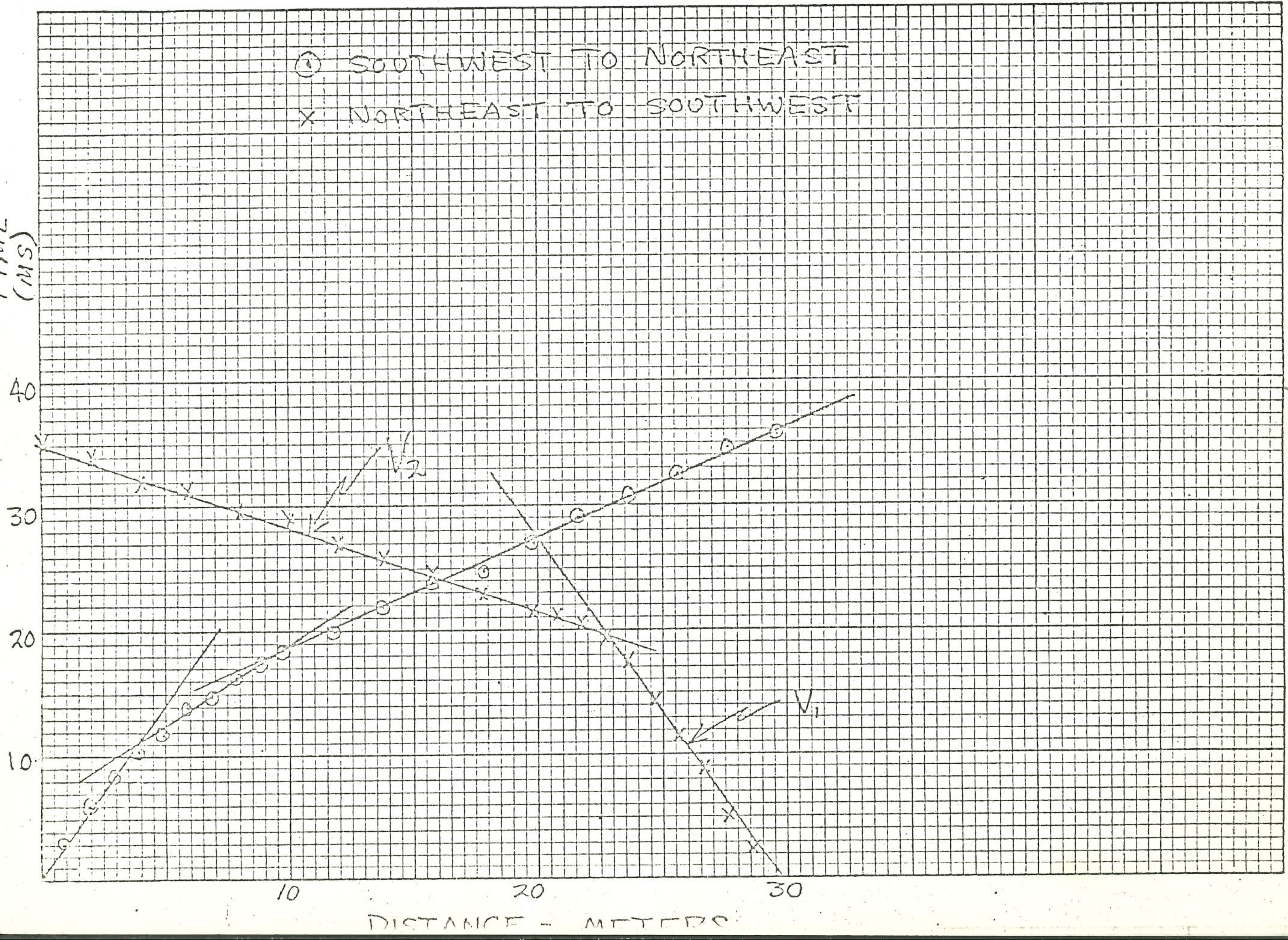


FIG 38

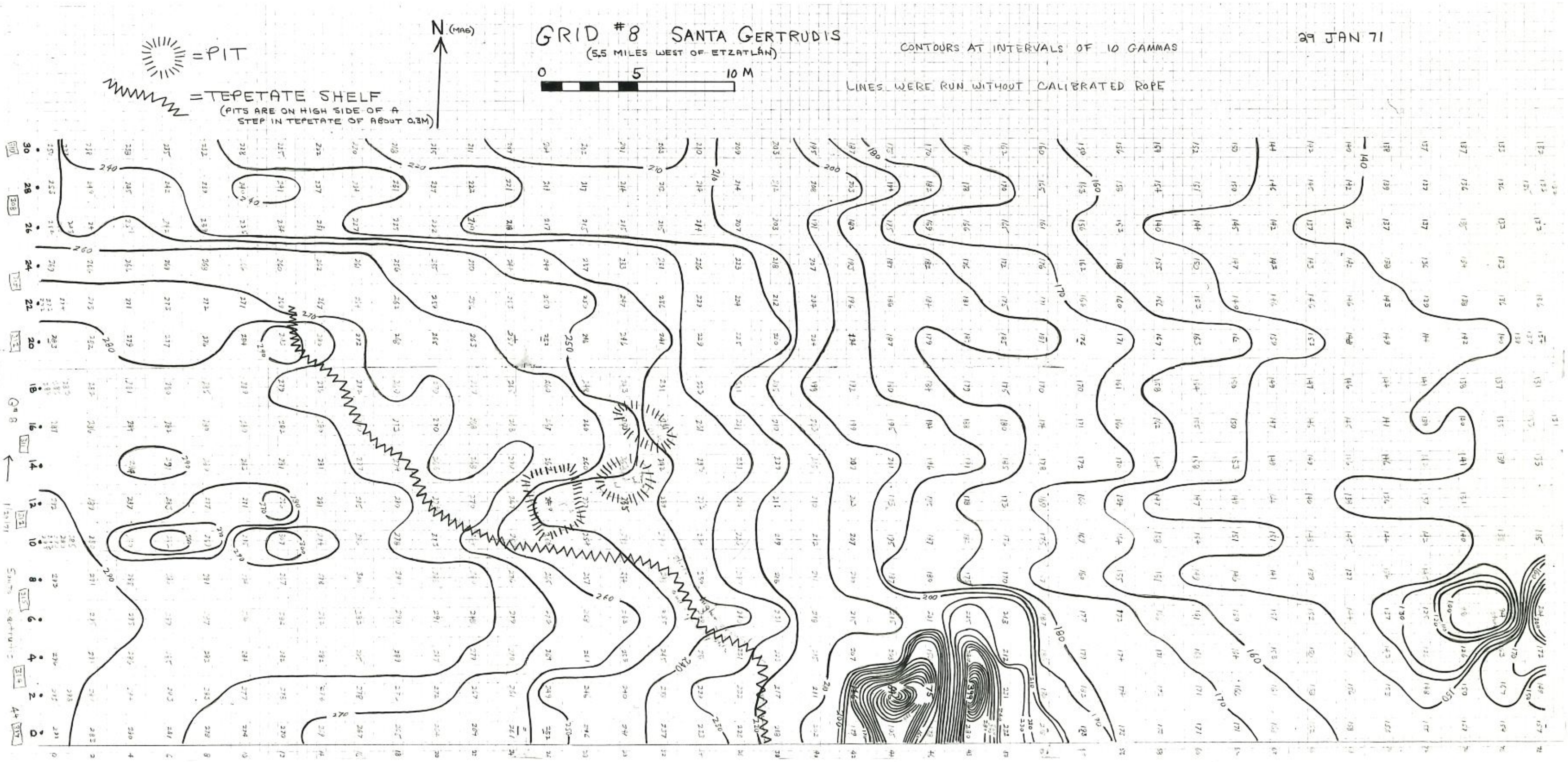
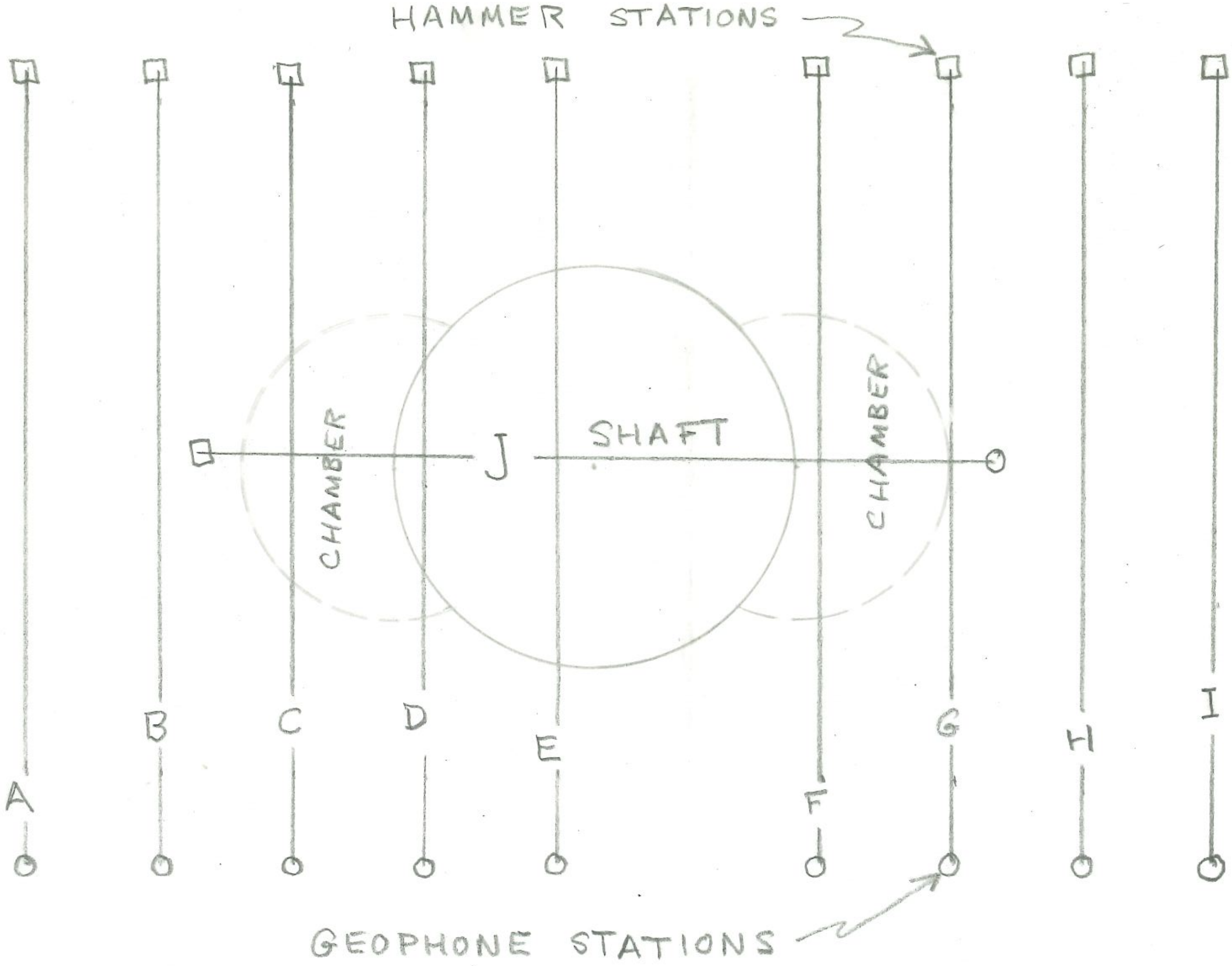


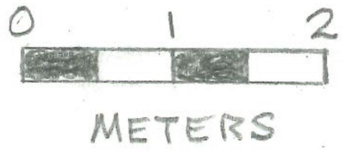
Fig. 39. Grid #8 at Santa Gertrudis.

FIG 39

FIG - 40



LINE NO.	TRAVEL TIME (MS)
A	10.4
B	9.8
C	11.4
D	12.4
E	13.8
F	11.0
G	9.6
H	10.4
I	10.6
J	14.2



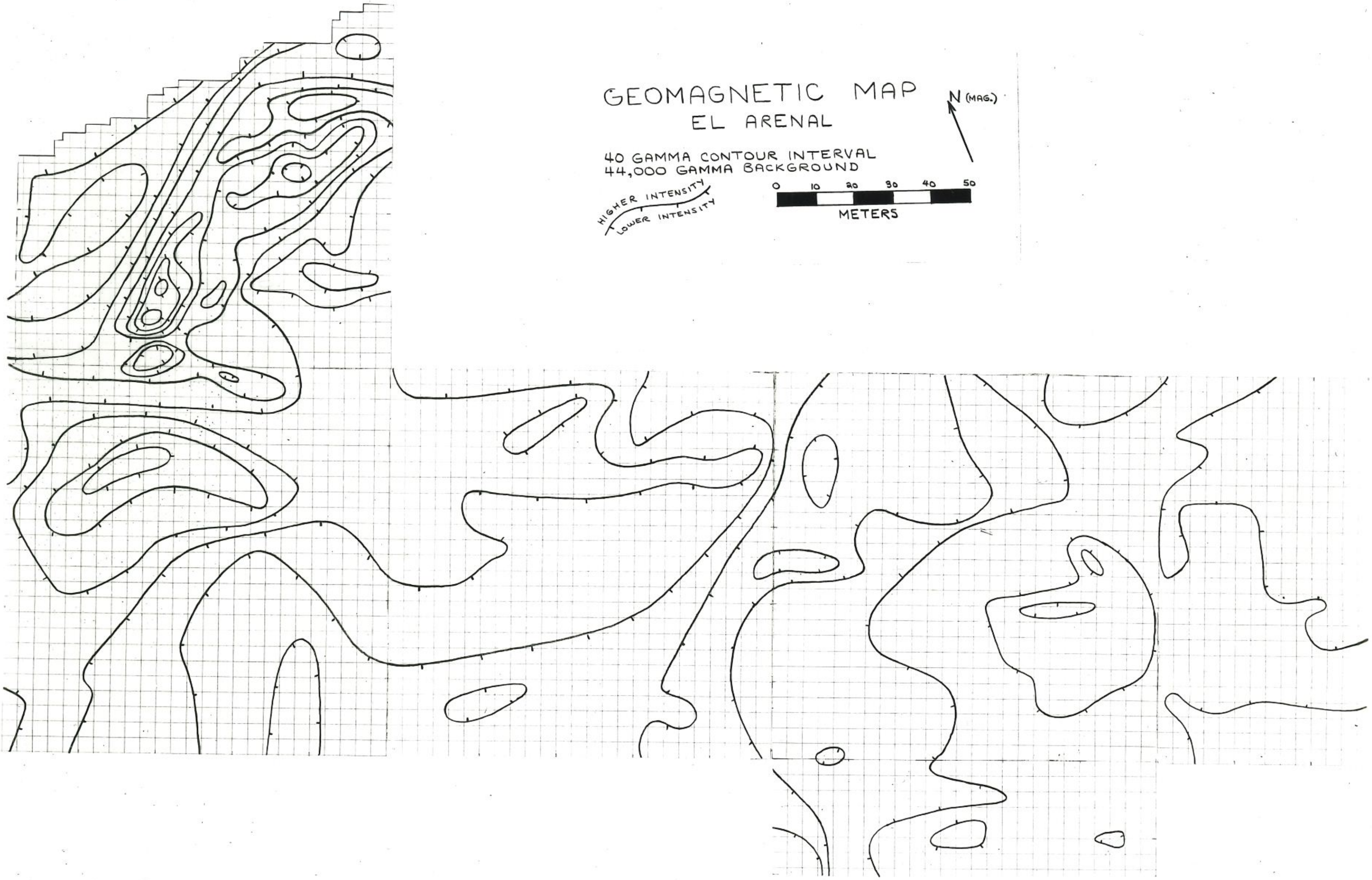

GEOMAGNETIC MAP
EL ARENAL
N (MAG.)
40 GAMMA CONTOUR INTERVAL
44,000 GAMMA BACKGROUND
0 10 20 30 40 50
METERS
HIGHER INTENSITY
LOWER INTENSITY

FIG 42