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GEOLOGICAL SURVEY

E-Field Ratio Telluric traverses near Fortymile Wash, Nevada Test Site, Nevada

by

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Introduction

The U.S. Geological Survey working under Interagency Agreement DE-AI08-78ET44802, with the Department of Energy is engaged in a broad program to assess and identify potential repositories for high level nuclear waste on the Nevada Test Site (NTS), Figure 1. The U.S. Geological Survey's program consists of geologic, hydrologic, and geophysical studies that range in nature from regional to site specific. At present the Yucca Mountain area (fig. 1), is being intensively studied to determine its suitability as a waste disposal site. The Yucca Mountain site is located in the east-central part of Yucca Mountain. The proposed emplacement medium is one or more welded tuff members of Tertiary Age with emplacement to be in the depth range of 1000 to 5000 ft. Yucca Mountain is composed of inter-layered ash-flow and ash-fall tuffs dipping gently to the east.

Yucca Mountain is bounded on the east by Fortymile Wash, one of the principal surface drainage systems in the southwest part of NTS. The wash originates on the south side of Timber Mountain and runs south to the vicinity of Lathrop Wells where it runs into the Amargosa Desert. The wash is believed to be fault controlled occupying a narrow graben associated with Basin and Range normal faulting (Lipman and McKay, 1965). The location of the faults in alluvial covered areas along Fortymile Wash, however, are poorly constrained.

Ground water flow is believed to be south along Fortymile Wash to the Amargosa Desert system. A boundary between major ground water systems is believed to run along the eastern side of Fortymile Wash (Winograd and Thordarson, 1975) with ground water on the eastern side flowing in general southeast. South of Lathrop Wells in the vicinity of Ash Meadows the boundary of the ground water system is fault controlled. Faulting along Fortymile Wash north of Lathrop Wells might also control the boundary of the ground water system in that area.

Because of the importance of faulting in both controlling and understanding the hydrologic system in the Yucca Mountain area E-field ratio telluric traverses were run in four places across Fortymile Wash to attempt to better define the location of the principal Basin and Range faults.

Acknowledgements

Appreciation is expressed to the staff of the U.S. Geological Survey Core Library and Fennix and Scisson Inc., Mercury, Nevada, for invaluable support of the field operations; to R. W. Spengler for helpful discussions of the geological setting; and to R. K. Waddell for information on the ground water hydrology.

The Telluric Method

E-field ratio tellurics is a descriptive name applied to the electrical exploration technique used in this survey. The telluric method refers to the measurement of the earth's electric field generated by induction from natural electromagnetic waves arriving at the surface. The E-field ratio telluric method uses a receiving array of three electrodes spaced equidistant and in line. This array is, in effect, two colinear dipoles sharing a common electrode. The potential difference across each dipole is then proportional to the component of the telluric field in the direction of the array. This configuration permits the measurement of the ratio of the telluric field at each dipole in the direction of the dipole line, and hence the name. The traverse data is extended by moving the three-electrode array forward one dipole length so that the forward electrode becomes the center electrode for the next ratio measurement.

Electric-field data so obtained are proportional to the square root of the apparent resistivity of the earth at the location of the dipoles. However, because the apparent resistivity can be a function of the dipole direction, it is important to know the orientation of the dipoles with respect to major structures. Because the resistivity of fluid-saturated earth materials is largely dependent on the porosity of the rocks, the salinity of the pore fluid, and the presence of clays or similar material where surface conduction is high, alluvial fill, argillite and similar rocks tend to have low resistivities whereas igneous or high-grade metamorphic rocks have high resistivities. Variation in the electrical properties along a traverse may then be used to infer lithologic or structural changes.

Data Acquisition and Reduction

Telluric field observations were made with two 500-meter colinear dipoles moved along a straight line traverse incremented by 500 meters. By placing one dipole at the previous recording station as the array increments, all data along the traverse can be referenced to one dipole. The field equipment was manufactured by the USGS and is similar to that described by Beyer (1977). It consists of two matched narrow-bandwidth low-frequency amplifiers whose outputs are recorded on a portable X-Y recorder. The signals from the two colinear dipoles then appear as Lissajous figures (Sheriff, 1973), from which the ratio of the signal amplitudes may be determined. Figure two shows the Lissajous figures from a typical field record. For this survey the -6db points for the high- and low-pass filters were at 20- and 40-second periods (0.05 and 0.025 Hz). Normally a three-person field crew is used with the equipment being carried on a backpack frame.

At each field station, a minimum of three sets of Lissajous figures is recorded, each set comprising measurements of the natural electric fields for a time span typically of 2 to 5 minutes. In most cases the tangent of the angle of the Lissajous figure's major axis is the ratio of the magnitudes of the telluric field at each dipole (Beyer, 1977). The three sets of readings are then averaged to give a voltage ratio at each station. Typically the data accuracy is ±1 degree giving a 3 percent error in voltage ratio when the fields are equal (a 45-degree Lissajous figure). The traverse data are referenced to one of the dipoles on the line and the results are plotted as a variation in telluric voltage versus dipole position.

Traverses are run normal to the expected strike of geological structures and in as straight a line as practical. For two-dimensional structures this corresponds to measuring the electric field of natural electromagnetic signals in the transverse magnetic (TM) mode sometimes called the E-perpendicular case. For this condition the electric field is proportional to the TM mode apparent resistivity along the traverse. If the magnetic field in the same frequency band, .05 to .025 Hz, were known at one dipole position, then the TM mode apparent resistivities would be defined along the entire traverse. These resistivities are calculated when magnetotelluric data is available at some point on the traverse. The apparent resistivities are proportional to the square of the telluric voltage changes. Because telluric fields can be strongly polarized particularly in the vicinity of lateral resistivity boundaries, it is necessary to traverse in a straight line to maintain TM mode polarization. The discontinuity in the TM mode electric fields across vertical boundaries provides an effective means of defining lateral electrical boundaries in the earth. This is well illustrated by Beyer (1977) who shows TM mode responses over various theoretical geological models.

The maximum depth of exploration is determined by the electromagnetic skin depth in the earth. For a homogeneous half-space the skin depth δ in meters is given by,

$$\delta = 500 \sqrt{\rho / f} \text{ meters}$$

where ρ is the half-space resistivity in ohm-meters and f is the frequency in Hertz.

At the center frequency used in this survey (0.033 Hz) and in a typical 100 ohm-meter earth the skin depth is 27 km. As a rule of thumb, the detectability limit is about 1/2 a skin depth. However within the range of detectability, the spacial wavelength of variations in the telluric fields is proportional to the distance to the anomalous structure. Thus shallow structures may be distinguished from deeper ones.

Results of Telluric Surveys

Figure 3 and 4 show the locations where the four telluric lines were run. Figure 3 shows lines 1 and 2 which start in the Yucca Mountain site area on the west, cross Fortymile Wash, and run onto Jackass Flat. The lines are 16. and 15.5 km (9.6 and 10.0 miles) long. Line L-N runs about east-west, figure 4, 6.4 km (4 miles) north of Lathrop Wells. In this area Fortymile Wash has very little topographic expression. Line L-S, figure 4, runs east-west about 8 km (5 miles) south of Lathrop Wells. The line crosses a major gravity gradient which strikes north-south and in this area is inferred to mark the boundary of the Ash Meadows ground-water system. All the lines used 500 m (1,640 ft) dipoles.

The telluric data for lines 1 and 2 are shown in figure 5. The data show several prominent short wavelength anomalies in the vicinity of Fortymile Wash on both lines. Low relative telluric voltages correspond to areas where the earth resistivity is lower. Four north-south zones of low resistivity are clearly seen in the data, two on either side of Fortymile Wash. These are indicated by the dashed lines in figures 3 and 5.

The four zones of low resistivity are interpreted to be fault zones. The lower resistivity in these zones is probably due to increased porosity due to fracturing along and adjacent to the fault. These data give no information regarding permeability along the zones. The higher resistivity segments, between the lows reflect more competent and presumably lower porosity rock. Section BB′ of Lipman and McKay (1965) parallels line 1, 0.6 km to the south, and runs through well J-13. Well J-13 is due south of position 15.5 W on line 1. Lipman and McKay indicate that J-13 is within a graben. The two centered faults interpreted on the telluric profiles then would define the Fortymile Wash graben. If this graben had much alluvial fill then this would be expected to be expressed by relatively low telluric voltages and hence low resistivities across the graben. This is clearly not the case as shown by the highs at dipole 14 W - 15 W, line 1 and 13 E - 14 E on line 2, suggesting that the alluvial fill is shallow. This is in accord with drilling results at J13 (Lipman and McKay, 1965) which show only 132 m (435 ft) of fill.

The westernmost of the four interpreted faults is on the eastern boundary of the proposed site and gives the largest short-wavelength anomaly on line 2. The large amplitude may be due to very thin alluvial cover in that area. This fault has been mapped by Lipman and McKay (1965) although its location in some areas was not well constrained. It has been used as a "calibration fault" for a number of electrical methods employed at Yucca Mountain (Flanigan 1981, Fitterman, 1982) by which the response of this fault could be compared with like appearing anomalies. This "calibration fault" is clearly constrained in position by the data, and its telluric response supports the interpretation of the similar low zones as faults.

Two long-wavelength trends in the data can be seen in figure 5. On Line 2, a general decrease in telluric voltage is seen on the western half, which west of station 5E steepens significantly. This steep segment of the profile corresponds with a steep gravity gradient across the proposed disposal site due to a gravity low in the northwest part of Yucca Mountain (Snyder and Oliver, 1981). The gravity gradient and the telluric gradient are both believed due to a thickening of tuffs towards the west.

The east end of line one also shows low telluric voltages and hence a lower resistivity lithologic section. This is probably due, in part, to a thickening of alluvium on the eastern end of the line. It is not clear whether the decrease can be entirely attributed to this cause.

The telluric data for line L-N, figure 6, shows a fairly simple pattern. West of dipole 6E - 7E the telluric voltage is low and to the east it is high. This is a typical response in the Basin and Range province (for example, Hoover and others, 1981) where normal faulting juxtaposes a thick alluvial section next to basement rock of the ranges. A similar situation is interpreted along this line. At Station 8, and 1 km north of station 7, Devonian carbonate rocks (Nevada Formation) crop out (Sargent and others, 1970). The resistivity contrast between these basement rocks on the east and alluvium and possibly some volcanic units on the west are inferred to be responsible for the sharp observed resistivity contrast. The small variations of resistivity seen along the traverse within the down-dropped block could be attributed to lateral variations in the alluvium or volcanic section, or in part to variations within the Paleozoic basement rocks. Faulting may be present near stations 1W and 3E based on inflection points of the traverse data.

The high resistivity eastern end of the line shows a monotonic trend of lower resistivity towards the east. This is interpreted to reflect the presence of a thickening section of Tertiary volcanics on the Paleozoic rocks towards the east.

Line L-S, figure 7, shows a much more complex picture with the short-wavelength changes implying corresponding changes in the near surface. A major resistivity change occurs at station 12E with lower values to the west. Paleozoic rocks crop out adjacent to the line near stations 13E and 14E. The resistivity change is interpreted to be due to faulting which has down-dropped units on the west. This inferred fault and the similar one on line L-N to the north occur on a regional gravity gradient (Healy and Miller, 1971) believed due to faulting and which is believed to define the boundary of the Ash Meadows ground-water system. If the fault does define this boundary, the telluric data has provided better definition of that boundary.

As on line L-N the variations of the telluric data west of station 12E, may be due to variations within Paleozoic basement rock combined with changes in the Tertiary and younger section.

The eastern end of line L-S shows a very large decrease in resistivity east of dipole 18E-19E. This is interpreted as due to a thickening of alluvium and probably Tertiary volcanic units in the Amargosa Flat basin. The large change in telluric voltage implies that the basin on the east end of the line is deep or that the material overlying basement rock has very low resistivities. These data support the cross-section shown by Winograd and Doty (1980, fig. 2) across Amargosa Flat.

Conclusions

E-Field ratio telluric traverses have identified abrupt changes in resistivity at several places along the Fortymile Wash drainage. These resistivity changes have been interpreted to result from Basin and Range normal faulting along the wash. East of the Yucca Mountain site four north-south trending faults have been identified. The central block between these faults comprises the graben through which Fortymile Wash flows. Further south the graben appears to be much broader and only the eastern boundary has been defined by telluric data near Lathrop Wells. Extrapolation of trends from either the northern two lines or the southern set does not give any correspondence. This suggests that cross structures may offset the Basin and Range faults between line 1 and line L-N. These lines are separated by 12 km (7.5 miles). In order to define the electrical structure in the intervening region additional work would be required.

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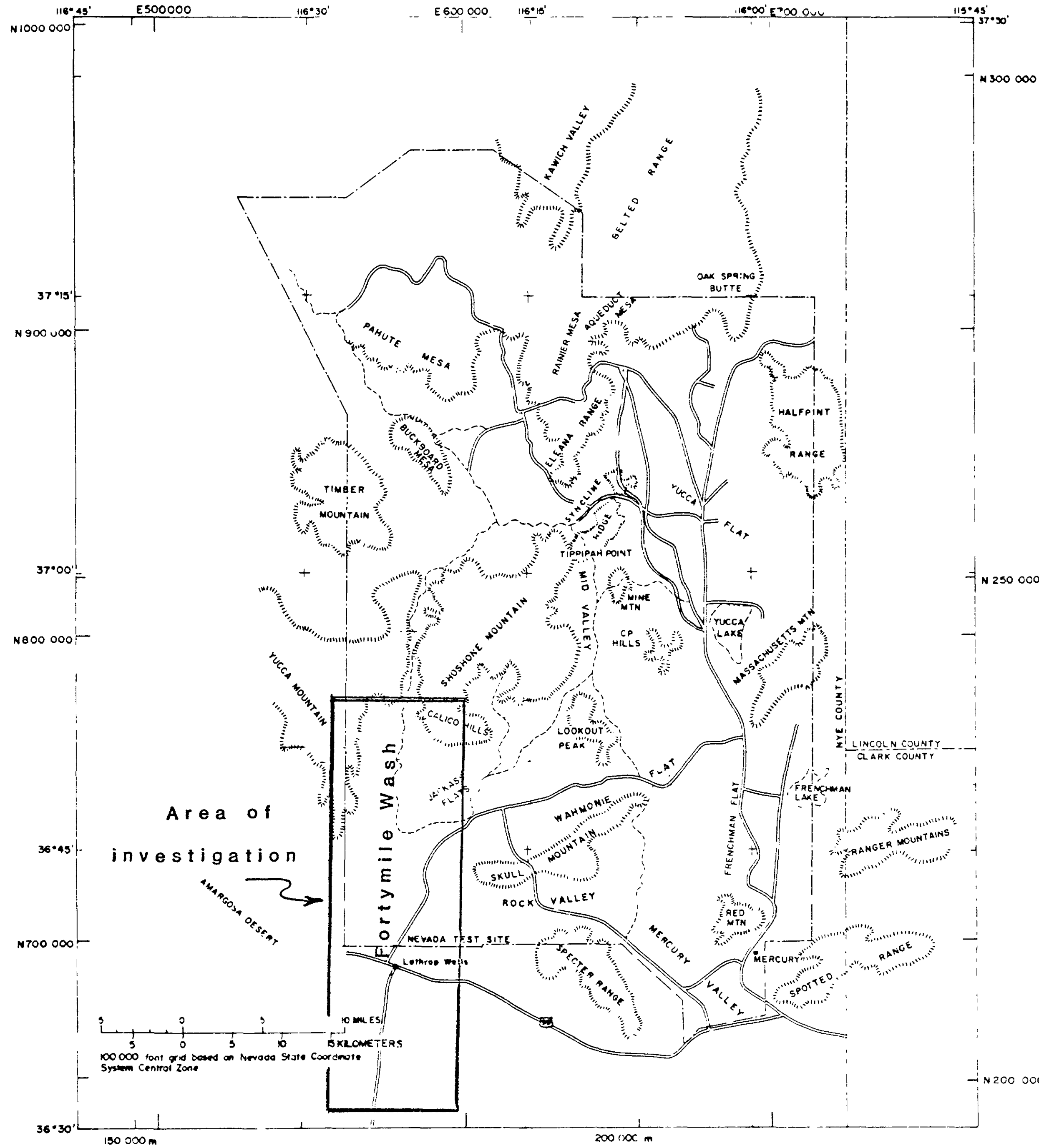

Figure 1. Index map of the Nevada Test Site, showing the area studied.

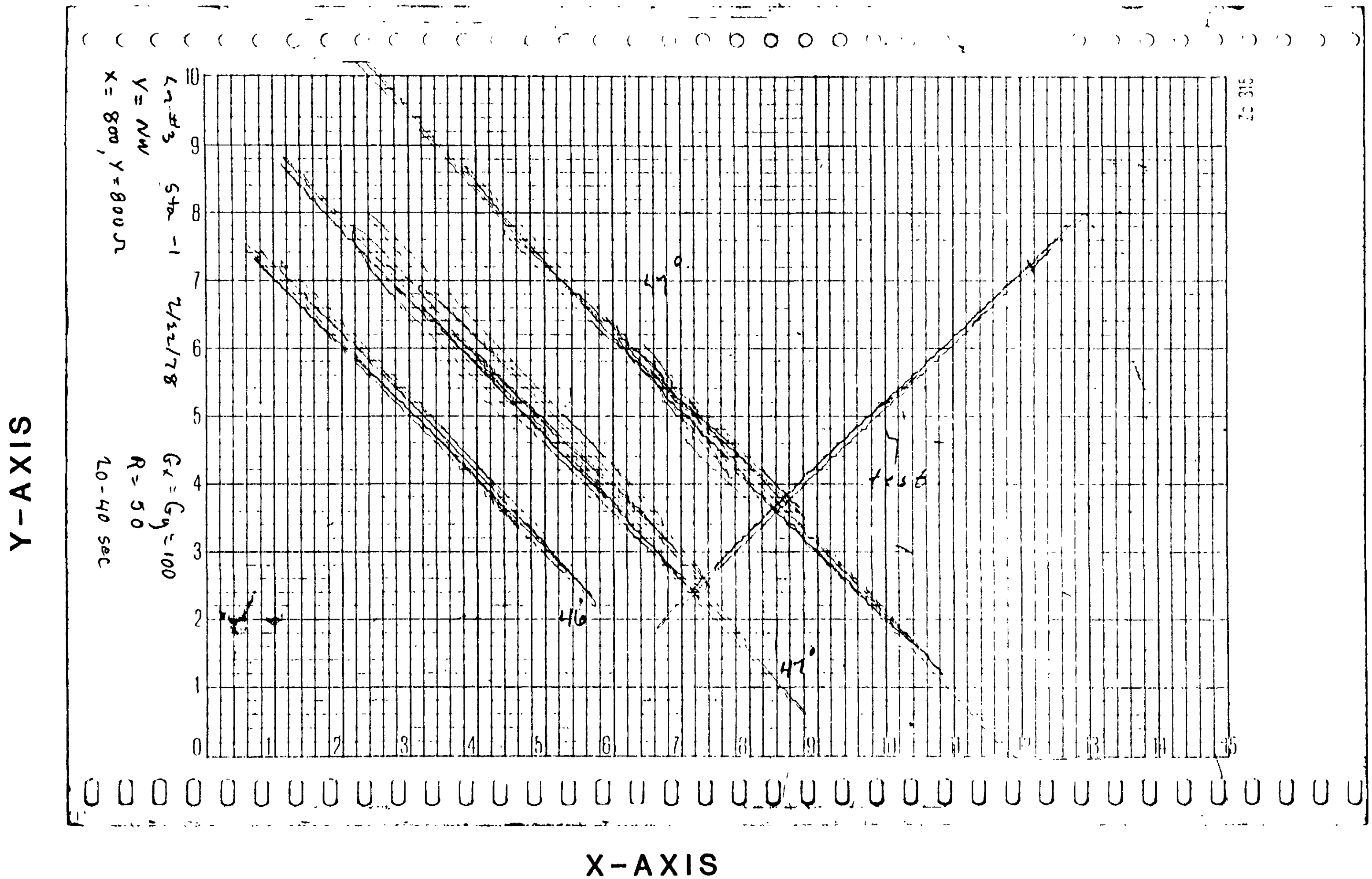

Figure 2. Illustration of a typical E-Field ratio telluric record showing the Lissajous figures, in this case very elongate ellipses. The tangent of the angle of the major axis of the ellipse is equal to the ratio of the telluric voltage on each dipole.

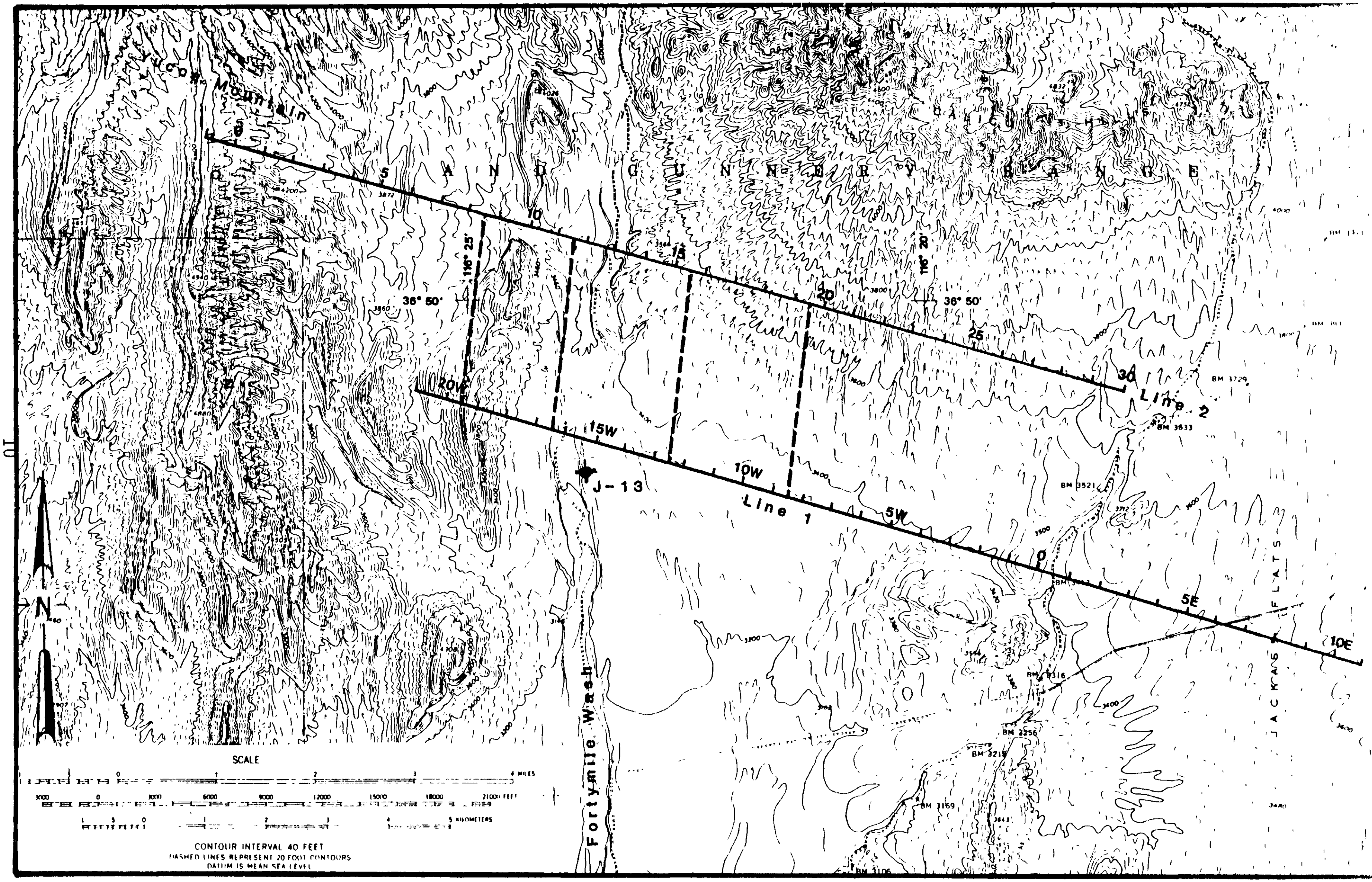

Figure 3. Map of part of the Topopah Spring, Nevada, 15′ Quadrangle showing the location of telluric lines 1. and 2. The dashed lines show the location of faults inferred from the telluric data.

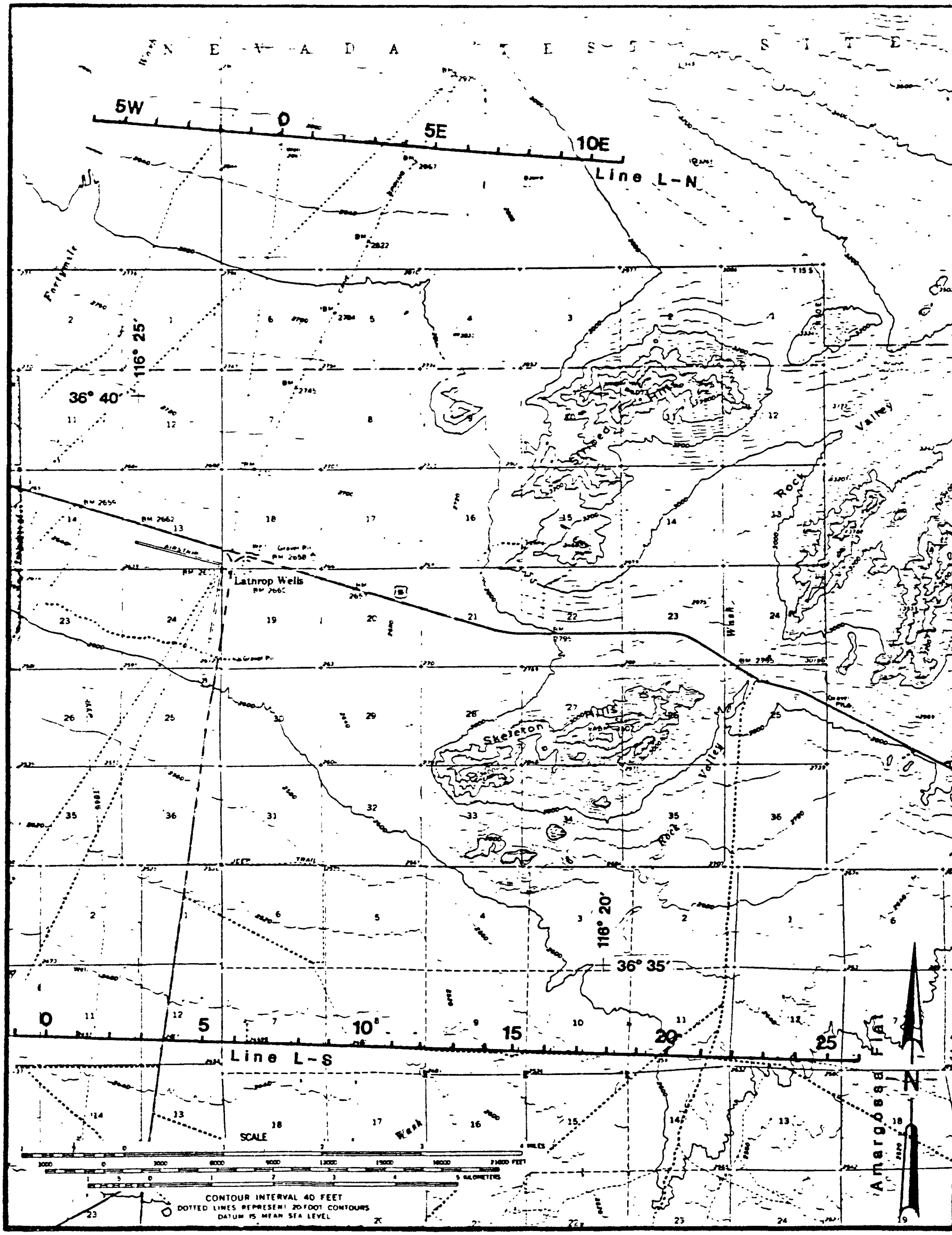

Figure 4. Map of part of the Lathrop Wells 15' Quadrangle showing the location of telluric lines L-N and L-S.

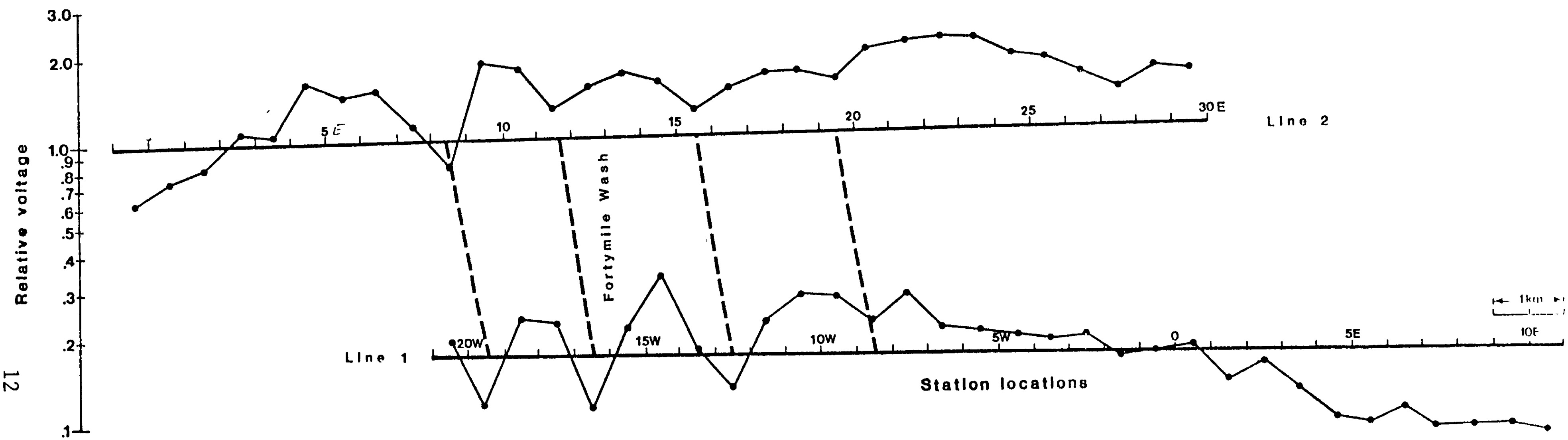

Figure 5. E-field ratio telluric data at a 30 sec. period for lines 1 and 2. Yucca Mountain, Nevada Test Site, Nevada. The dashed lines connect areas of low resistivity on each line which are inferred to be caused by Basin and Range faults.

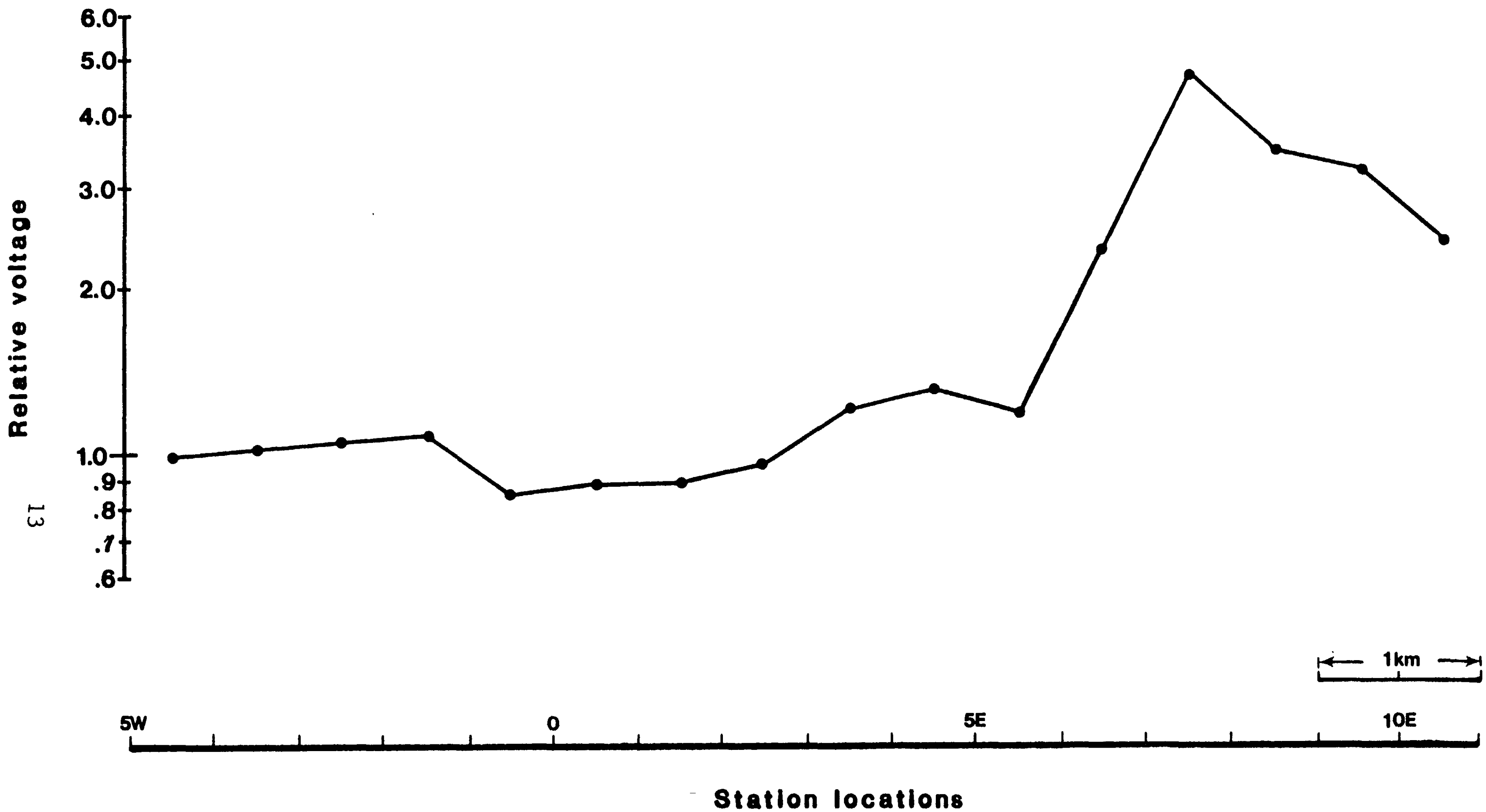

Figure 6. E-Field ratio telluric data at a 30 sec. period for line L-N near Lathrop Wells, Nevada.

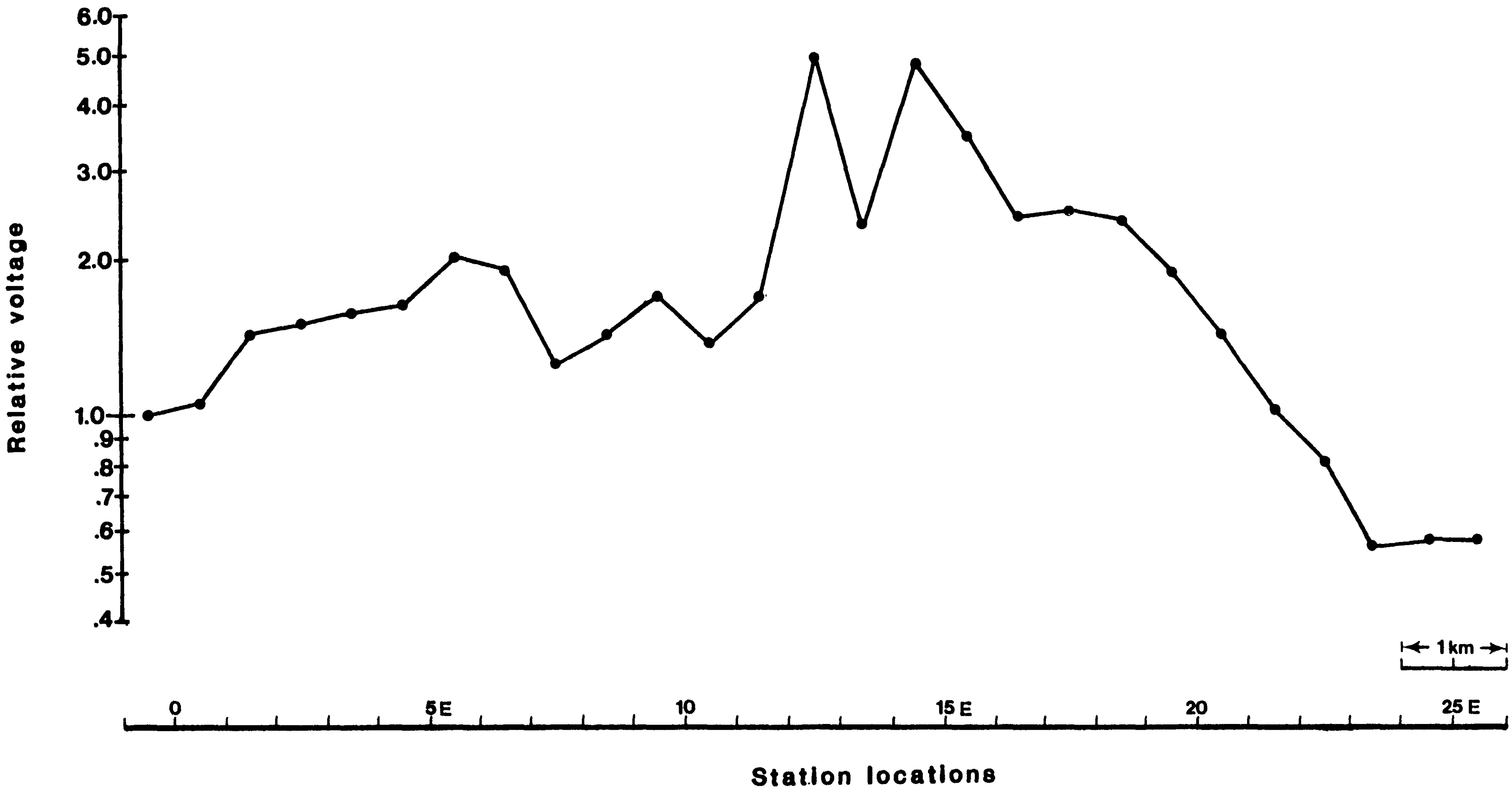

Figure 7. E-Field ratio telluric data at a 30 sec. period for line L-S near Lathrop Wells, Nevada.

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