UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Audio-magnetotelluric and telluric profiling studies in the Shaw Warm Springs Region, Colorado

by

Karen R. Christopherson, Kevin H. Nervick, William D. Heran

and Laurel Pringle

Open-File Report 81-958

1981

Audio-magnetotelluric and telluric profiling studies in the Shaw Warm Springs Region, Colorado

by

Karen R. Christopherson, Kevin H. Nervick, William D. Heran and Laurel Pringle

During 1980, the U.S. Geological Survey conducted geophysical studies in the region of Shaw Warm Springs, Colorado. The work was done to help assess the geothermal potential of the region in a cooperative effort with the Colorado Geological Survey. The geophysical methods used were audio-magnetotellurics (AMT) and E-field ratio telluric profiles.

Shaw Warm Springs lies approximately 8 kilometers north-northeast of Del Norte, Colorado on the western edge of the San Luis Valley and at the eastern flank the San Juan Mountains. The thermal manifestations are one major spring which has a temperature of 30°C at the Shaw Springs Ranch. A few warm wells have been reported in the valley to the east.

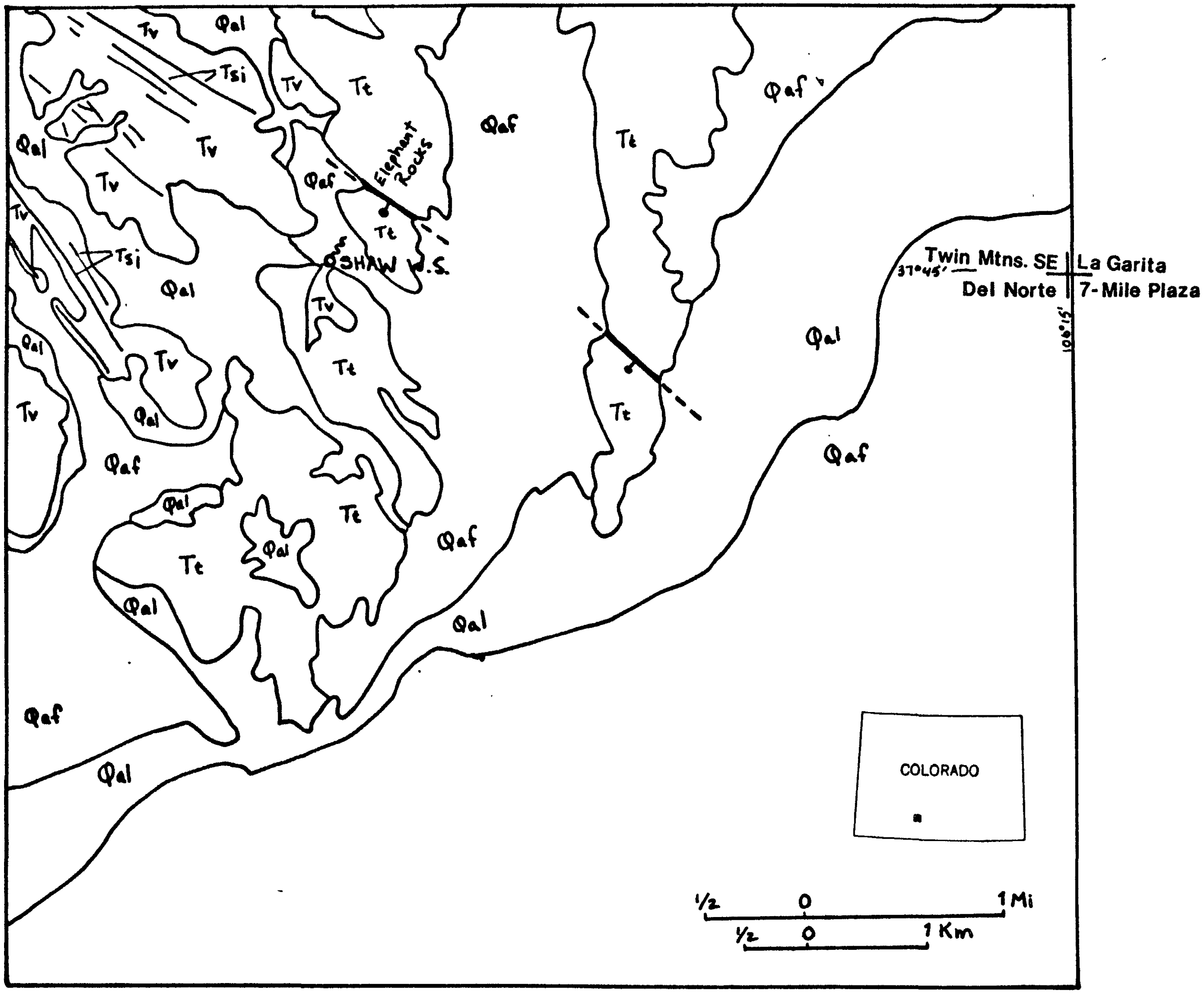
The geology of the eastern San Juans (including the Shaw Springs area) has been mapped and described by Lipman (1976). A generalized geologic map (adapted from Lipman, 1976) is shown in fig. 1. Shaw Springs lies 6 kilometers southeast of the Tertiary (Oligocene) Summer Coon Volcanic Center which was the source for most of the tuffs and rhyolites in the area. Shaw Springs is situated on exposures of Quaternary alluvial fan deposits at the edge of hills comprised of Tertiary tuffs. Numerous dikes of varying composition expand radially from the volcanic center. The only mapped fault in the immediate area lies approximately 1 kilometer northeast of the springs trending radially from the volcanic center in a southeast direction.

Two E-field ratio telluric profiles were made trending northeast using 250-meter dipoles. Their locations are shown in fig. 2. The changes in voltage (equivalent to the square root of resistivity) relative to station 0-1 are plotted along the traverses in figs. 3 and 4. These show the relative telluric voltage at an average period of 30 seconds referenced to dipole 0-1 on each line.

The telluric instrumentation and method has been described by Beyer (1977). For this survey the bandwidth of the recording system was 20-40 seconds (.025-.05 hertz), which results in a maximum depth of exploration of many kilometers in normal earth material. As a rule of thumb, changes in resistivity can be detected at about 1/2 a skin depth. In 20 ohm-meter material the skin depth is 13 kilometers at a period of 30 seconds. For the short traverses used, the results, of course, don't reflect changes at such great depths. The observed voltage variations can be thought of, approximately, as due to a constant d.c. current sheet flowing in the earth that gives rise to differences in voltage gradient as the current flows through regions of differing resistivities.

Profile 1 (fig. 3) trended northeast over fairly gentle topography on the western side of Elephant Rocks. The traverse crossed several geologic units of colluvium, tuff, andesite, and latite. The profile shows two major drops in voltage, the first between stations 3 and 5 and the second between stations 6 and 8. The second drop in voltage is almost a 40% decrease at the lowest point between stations 7 and 8. A fault mapped by Lipman crosses Elephant Rocks and if extended would cross profile 1 at station 8, and is co-linear with a major dike from the Summer Coon center.

Station 3 is also in line with the extension of another major dike running radially from the Summer Coon center. The telluric data is consistent with a small graben downdropped on faults located approximately at stations 3 and 8. The lower resistivity in the segment would then be due to a thickening



Qal	Qal, Qc	Quaternary alluvium and colluvium
Qaf	Qtf, Qo, Qc	Quaternary fan deposits
Tv	Tsq, Tsa, Tvs	Tertiary volcanic sandstone, andes and quartz latite
Tt	Tt, Tcr, Tfc, Tmp	Tertiary volcanic tuff
Tsi		Tertiary intrusive (dike)
		fault-dashed where inferred, ball on downthrown side
+		locations of corners of topographi quadrangles (7.5') covering area

2A

Fig. 1: Generalized geology of Shaw Warm Springs area, Colorado
(Geology after Lipman, 1976)

of alluvium or other low-resistivity fill. The slight increase in voltage at dipole 5-6 occurs when the line crosses a low ridge of andesite, which would produce the observed high because andesite is more resistive than alluvium. The lowest voltage dipoles (zones of lowest resistivity) at 3-4 and 7-8 reflect the edge of the graben and also increased porosity in and near the faults caused by fracturing and subsequent alteration.

The topography strongly suggests a fault trending parallel to the aforementioned faults and crossing profile 1 at approximately station 5. This fault would also trend near Shaw Springs. Traverse 1 shows little evidence of this fault. The slight increase in voltage at dipole 5-6 could be due in part to this fault with the upthrown side to the north. More likely though there was little vertical movement on the fault and hence no expression of it in the telluric data.

Profile 2 (fig. 4) was done on flat terrain entirely in a valley of Quaternary alluvial fan deposits. The profile shows little expression of lateral resistivity change. There is a slight decrease in voltage at dipoles 2-3 and 5-6 (both about 10% changes). The Elephant Rocks fault most probably crosses the profile near station 5 as it is mapped farther to the southeast. The decrease at dipole 5-6 is probably a weak expression of this fault. The low magnitude of voltage change could be caused either by damping of the electric currents in the low-resistivity tuff and alluvium above the fault or by a small resistivity contrast across the fault. If the slight decrease at dipole 2-3 is also a fault expression then extension of it to the northwest parallel to the Elephant Rocks fault would come near Warm Springs and connect with the other fault inferred by the topography to lie near station 5 on traverse 1. The decided difference in expression of the Elephant Rock fault on the two traverses could be due to a change in resistivity contrasts across the fault on the two traverses.

Key

- **Qf** Quaternary alluvial fan deposits
- **Qal** Quaternary alluvium
- **Qc** Quaternary colluvium
- **Tvs** Tertiary volcanic sandstone and conglomerate
- **Tcr**, **Tfc**, **Tmp** } Tertiary tuff
- **Tsd** Tertiary rhyodactite
- **Tsq** Tertiary quartz latite
- **Tsa** Tertiary andesite
- **Tsi** Tertiary dikes
- ■ AMT stations
- fault-dashed where inferred, ball on downthrown side

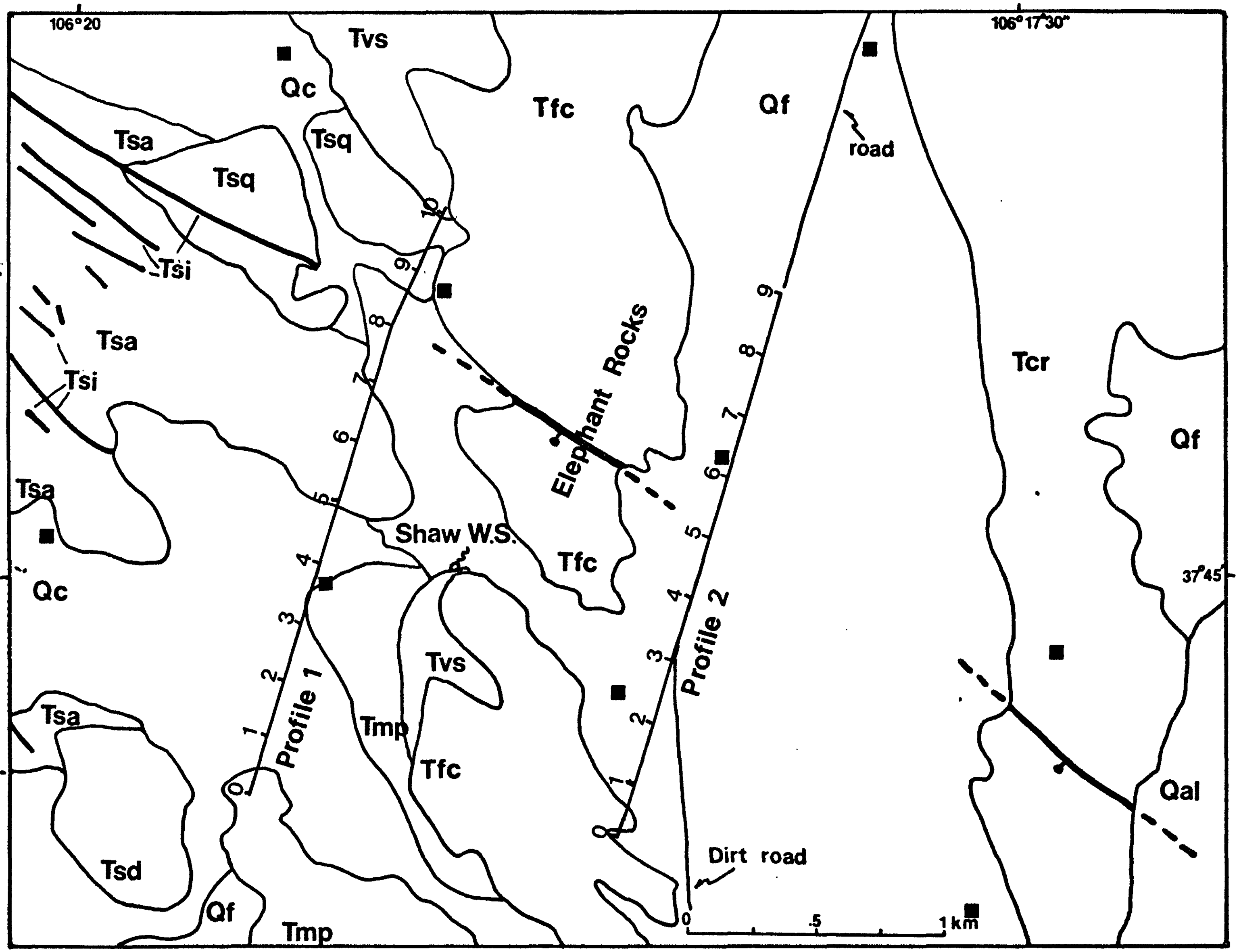


Fig. 2: Telluric profile location map and generalized geology - Shaw Warm Springs, Colorado (Geology after Lipman, 1976)

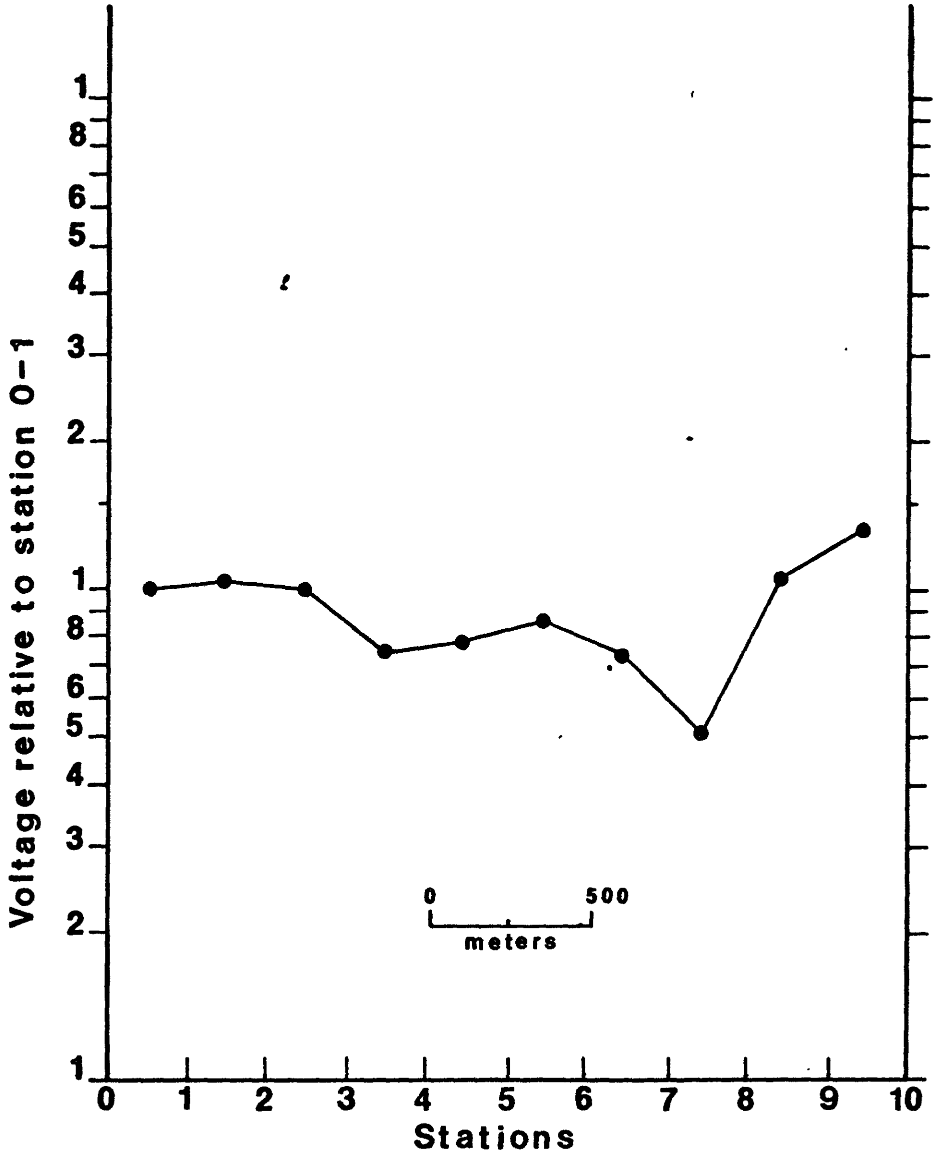


Fig. 3: Shaw Warm Springs, telluric traverse 1

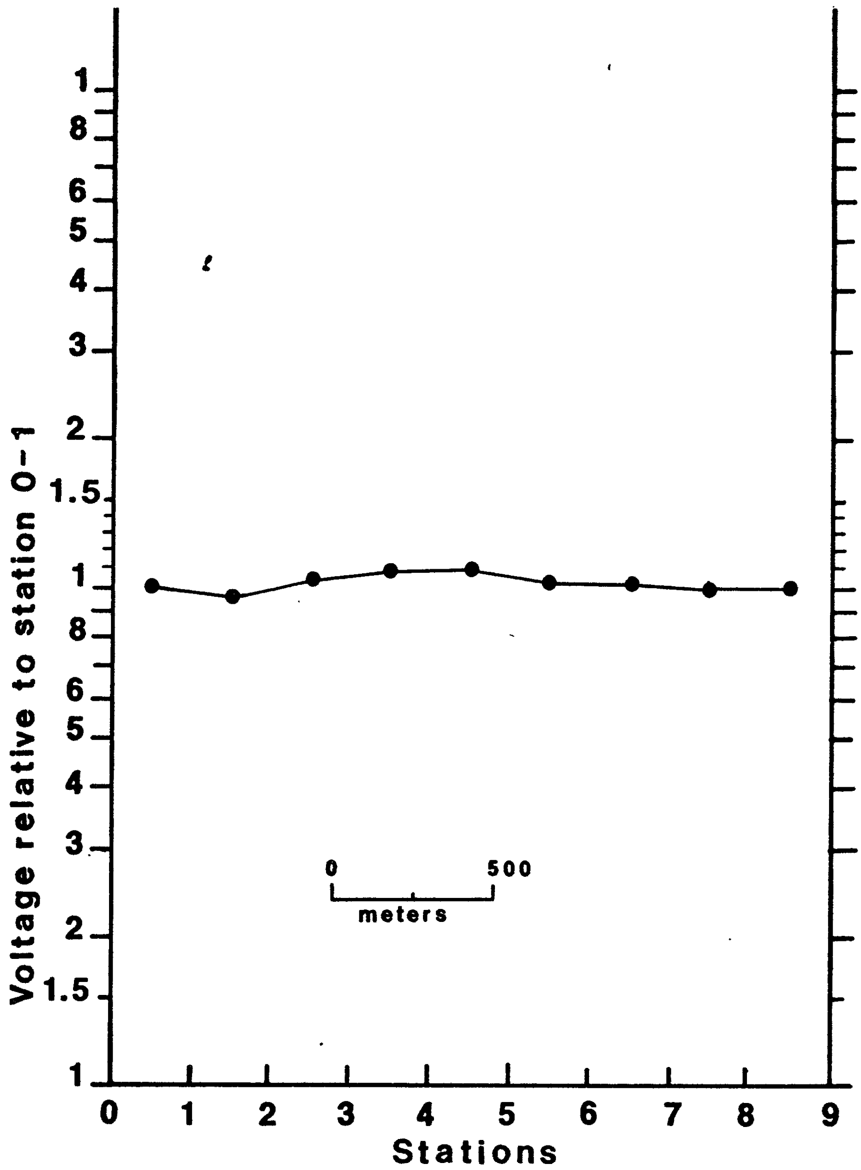


Fig. 4: Shaw Warm Springs, telluric traverse 2

Also, the topography and AMT data imply that a northeast-trending fault lies on the eastern side of Elephant Rocks, creating a graben in the valley in which traverse 2 is located. If this fault does exist, traverse 2 is close to parallel with its trend. Thus changes in voltage on traverse 2 are probably reflecting faulting in both northwesterly and northeasterly directions which can explain the difference in signature of the Elephant Rocks fault on the two telluric profiles.

Twenty-three audio-magnetotelluric soundings were made in the vicinity of Shaw Warm Springs. Station locations were separated by about 1 mile in most cases.

The USGS scalar AMT system (Hoover & Long, 1975) measures earth response to natural and artificial electromagnetic waves at 16 frequencies between 4.5 and 23000 hertz. The electric and magnetic fields are measured in orthogonal directions at each frequency by 50-meter electric-field lines (E-lines) and an orthogonal ferrite-cored coil. Two simultaneous soundings were made with E-lines and coil oriented north-south and east-west. Apparent resistivities are calculated from a ratio between the measured electric- and magnetic-field responses in orthogonal directions. (See Hoover and Long, 1975, for details.)

In this survey, maps were prepared of the measured apparent resistivities at two frequencies, 7.5 and 27 hertz, for the two E-line orientations. At 7.5 hertz, the skin depth or approximate depth of penetration by electromagnetic waves is 821 meters in 20 ohm-meter ground. At 27 hertz the skin depth is 433 meters in 20 ohm-meter material. Detectability of resistivity changes would be no better than one-half of the skin depth. The resistivity values were contoured in logarithmic intervals and are shown in figures 5 through 8.

At 7.5 hertz (figs. 5 and 6) the lowest apparent resistivity values (less than 25 ohm-meters) lie in the middle of the area in surficial exposures of fan and outwash materials. The increasing highs to the northwest and west denote the thickening of fresh volcanic rock with a higher resistivity than the valley fill. The higher values to the east probably denote the detection of Precambrian bedrock beneath the alluvium of the San Luis Valley.

The higher values near Shaw Springs of 33 and 45 ohm-meters probably show that pervasive alteration by geothermal waters has occurred and that there is a present lack of much warm water near the surface (or within the first 500 meters).

At 27 hertz, which samples at about one-half the depth of 7.5 hertz, the apparent resistivity maps (figs. 7 and 8) are more homogeneous than the 7.5 hertz maps with most values between 10 and 100 ohm-meters. The decrease in resistivity for stations to the northwest and west when compared to 7.5 hertz data is probably the result of sampling low resistivity surficial material (alluvium or altered volcanics). The decrease in values to the east probably results from the signals penetrating only into the valley alluvium and not into the bedrock.

The resistivity values for the station near Shaw Springs at 27 hertz (20 and 22 ohm-meters) are slightly less than at 7.5 hertz signifying more alteration closer to the surface or a sampling of a larger fraction of alluvium. Still, the resistivities are not low enough to denote a large geothermal system but could denote the presence of ground water. The lowest values, occurring southeast of Shaw Springs, could result from leakage and alteration by warm waters along southeast-trending faults into a thick porous alluvial section.

All four AMT maps show lowest resistivity values lying to the southeast of Shaw Springs. These, along with topography and geology, suggest a north-trending graben filled with fan deposits (Qaf) lying east of Elephant Rocks

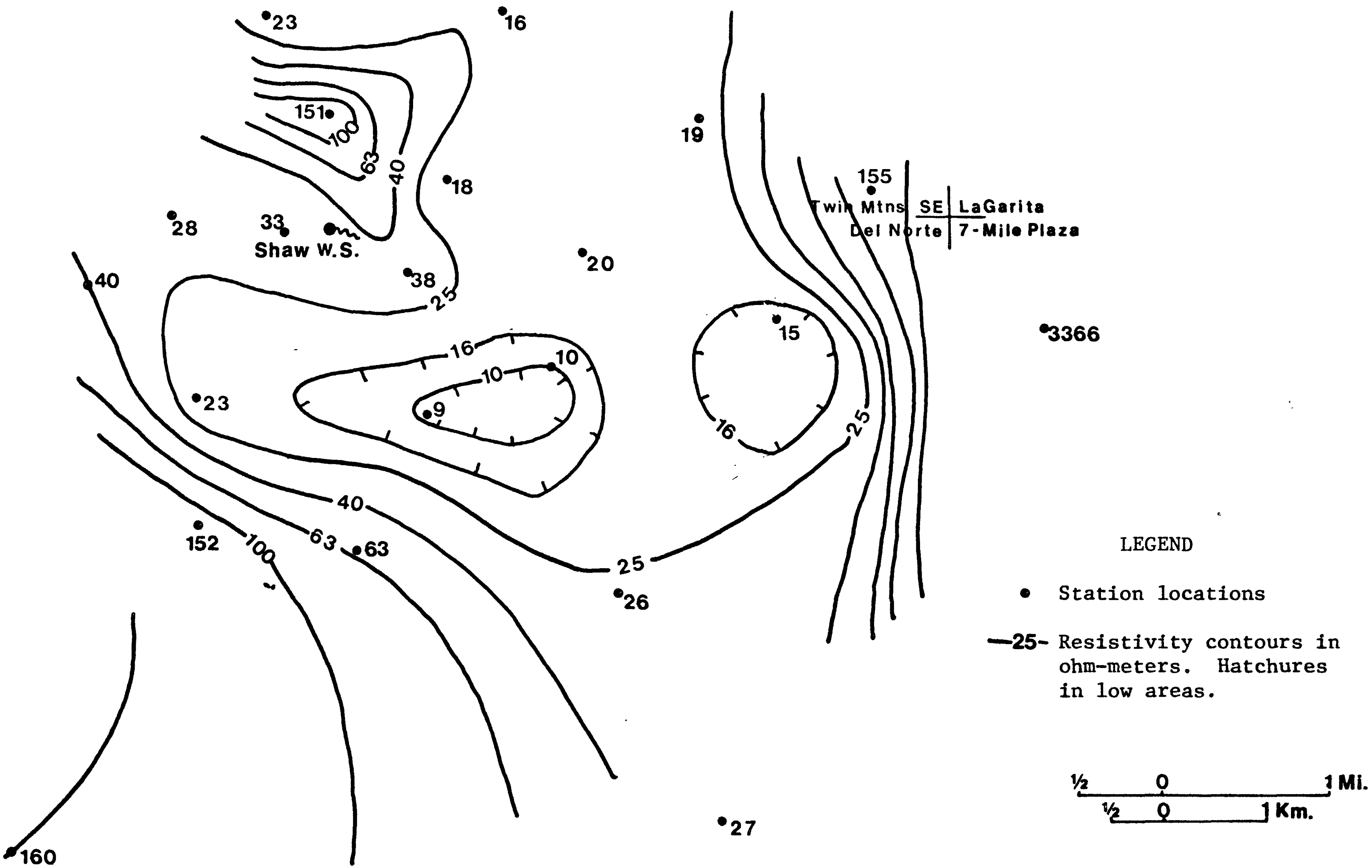


Fig. 5: Audio-magnetotelluric apparent resistivity map at 7.5 hertz, electric line N-S
Shaw Warm Springs area, Colorado

5A

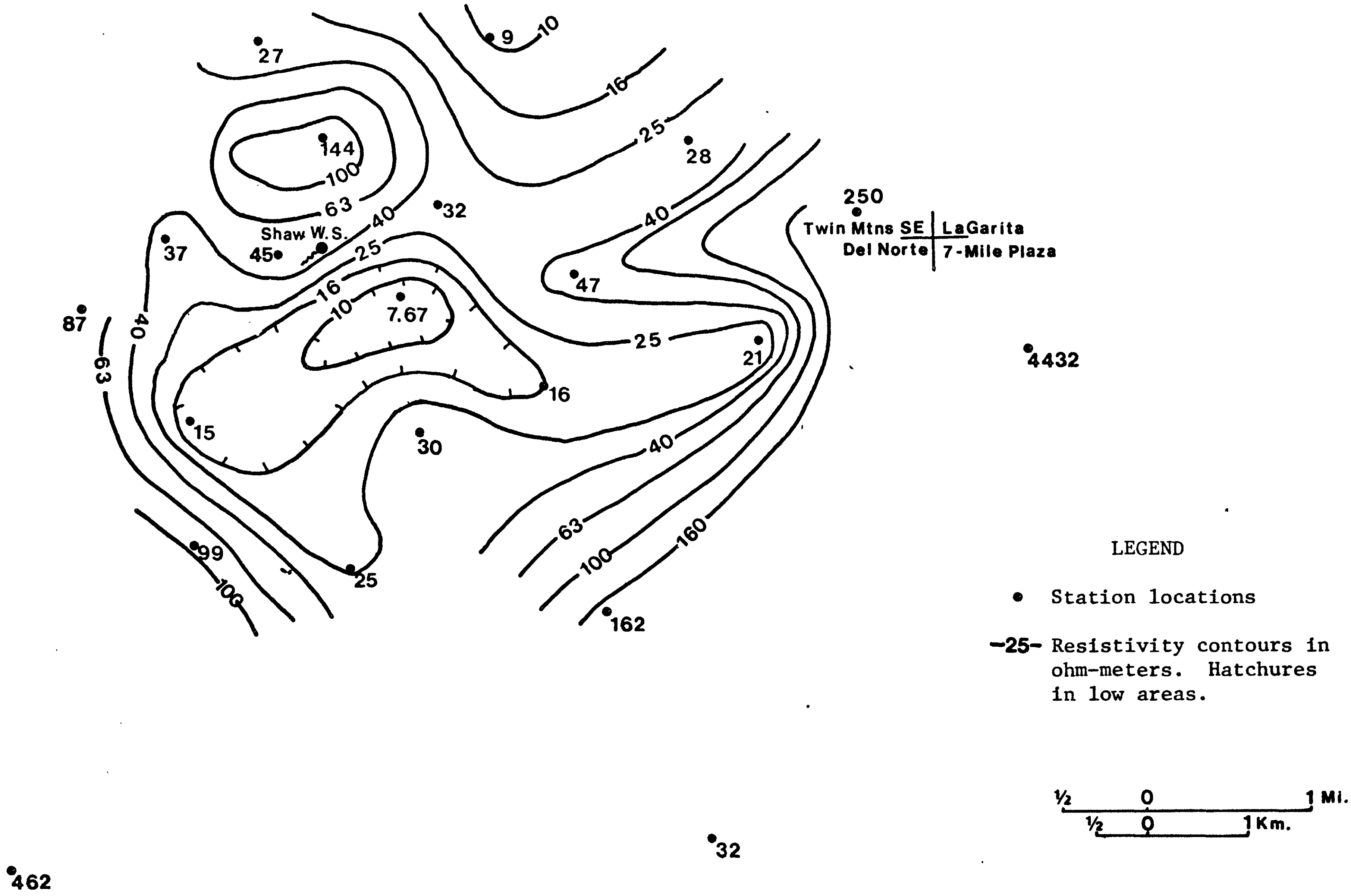


Fig. 6: Audio-magnetotelluric apparent resistivity map at 7.5 hertz, electric line E-W Shaw Warm Springs area, Colorado

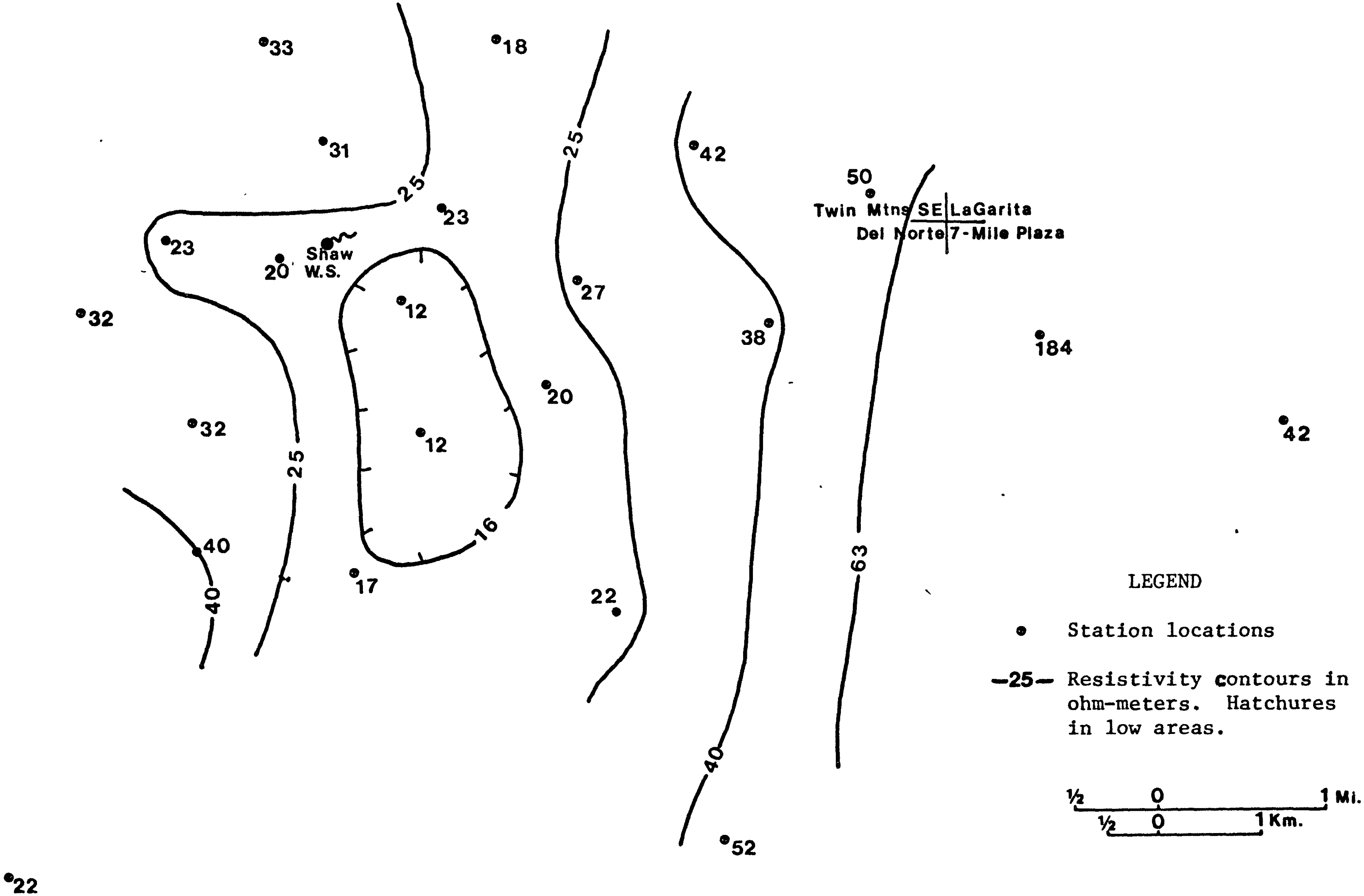


Fig. 7: Audio-magnetotelluric apparent resistivity map at 27 hertz, electric line N-S Shaw Warm Springs area, Colorado

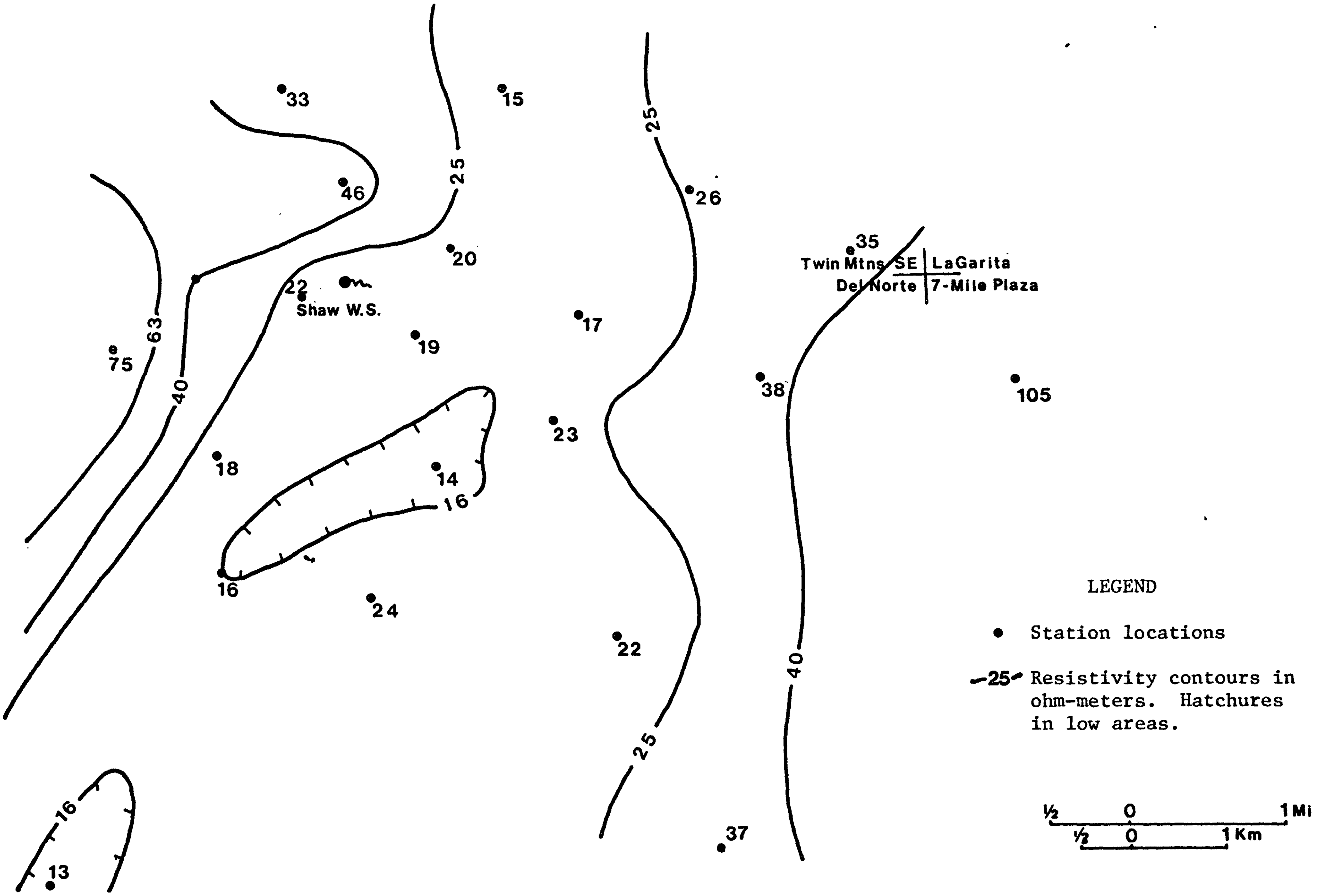


Fig. 8: Audio-magnetotelluric apparent resistivity map at 27 hertz, electric line E-W Shaw Warm Springs area, Colorado

(see fig. 1). The boundary faults for the graben would trend northerly along the two outcrops of tuff.

To conclude, the telluric data was quite useful in locating two faults. The Elephant Rocks fault was traced to the east and west of its mapped location by voltage drops on both telluric lines. Although the voltage change on traverse 2 is small, it is still probably a result of lower resistivity along the fault zone. Two other faults seem apparent running south of and parallel to the Elephant Rocks fault. Each fault also is identified by a voltage drop on one of the telluric lines. A fault just south of the Elephant Rocks fault is very obvious from topography and shows expression as a decrease in voltage at dipole 2-3 on traverse 2. Another fault farther south and nearly parallel to the other two creates the voltage decrease at dipole 3-4 on traverse 1. Extension of this fault to the southeast does not cross traverse 2.

It appears that Shaw Springs is the result of deep circulation of water ascending along the southeast-trending fault shown by the telluric data south of the Elephant Rock fault. There may be some leakage in the valley fill east of the spring but no significant reservoir is apparent, other than what may be present in the valley fill.

References

Beyer, J. H., 1977, "Telluric and D.C. resistivity techniques applied to the geophysical investigations of Basin and Range Geothermal Systems, Part I: The E-field ratio telluric method", Ph.D. Thesis, Lawrence Berkeley Labs, Univ. of California, Berkeley, Report LBL-6325.

Hoover, D. B. and C. L. Long, 1975, "Audio-magnetotelluric methods in Reconnaissance Geothermal Exploration", Proceedings, 2nd United Nations Symposium on the Development and Use of Geothermal Resources, vol. 2, 1059-1064.

Lipman, P. W., 1976, "Geologic map of the Del Norte Area, Eastern San Juan Mountains, Colorado", USGS Misc. Investigations Series Map I-952, scale 1:48000.