GL02211

TELLURIC-MAGNETOTELLURIC SURVEY
AT
TUCSARORA PROSPECT

ELKO COUNTY
NEVADA

Prepared for

AMAX EXPLORATION, INC.

Geothermal Group

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Abstract

A telluric-magnetotelluric (TMT) survey was conducted in the Tuscarora prospect, Elko county, Nevada.

Rotated tensor data were obtained at 11 base stations and 19 remote sites. An in-field computer processing system was implemented and six stations were processed in the field.

A low resistivity zone of 4 ohm meters at depths of 300 to 600 meters is indicated at station M1. This may be reflecting geothermal fluids associated with the surface hot springs in the area.

There is the suggestion of a conductive conduit at depth in the area. A zone of 4 ohm meters is indicated starting at a depth of 10 km at station M1.

A conductive zone of 4 ohm meters starting at a depth of 5 to 6 km is suggested in the Chicken Creek Summit area at stations M5 and B5 and possibly extends 4 km to the south to station A10 and the hot springs area.

Introduction

Terraphysics conducted a telluric-magnetotelluric (T-MT) survey in the Tuscarora prospect, Elko county, Nevada on behalf of Amax Exploration Inc. The field work was conducted during the period of 13 October to 21 November 1979.

Survey Objective

The objective of the survey was to aid in the evaluation of the geothermal potential of the area.

Many geophysical techniques are used to evaluate a geothermal area. Since a decrease in resistivity usually occurs where the temperature of the earth increases, an electrical resistivity survey can be a useful diagnostic technique. The resistivity change with temperature can be on the order of 2.5%/C° (Keller and Frischknecht, 1970). Consequently, resistivity decreases on the order of a factor a 5 or more may be associated with geothermal brines(Keller, 1970). Intrinsic resistivity values of less than 10 ohm meters may be expected.

If a geothermal area is at a sufficiently high temperature that a vapor phase is present, higher electrical resistivity values are likely. Zohdy, et. al. (1973) report intrinsic resistivity values of about 75-130 ohm meters for a vapor-dominated layer in Yellowstone National Park.

Telluric-Magnetotelluric Instruments and Procedure

A schematic of the equipment and field setup is illustrated in figure 1. Five component MT data is obtained at the base station (two horizonal electric field components and three magnetic field components). At each remote site two orthogonal electric field components are measured. The data is filtered, amplified, and telemetered back to the base station where it is recorded on magnetic tape at the same time as the base station data. Seasoned lead strips are used for the electrodes for the electric field measurements and the magnetic field measurements are obtained with a superconducting magnetometer.

In general, a base station with magnetic field measurements is utilized for each setup. Typical distances between the base and remote stations is one to two kilometers.

In order to solve for impedance tensors, the analog data from the magnetic tape is digitized (12 bits) and evaluated utilizing a LSI-11 DEC minicomputer. The computer system is mounted in the field instrument truck such that data may be processed in the field in real time.

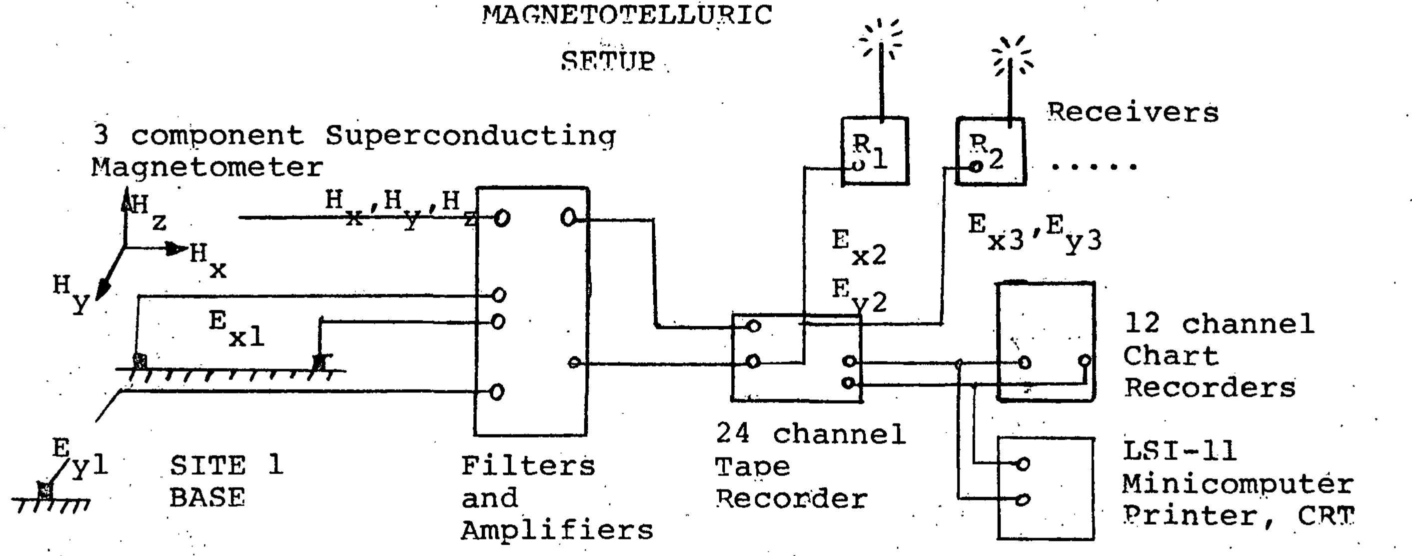
The remote reference method of analysis was used,following a technique described by Gamble et.al.(1978). The remote station data are treated as tensors and evaluated using the base station magnetic fields. In this work, the electric fields were used as the references to calculate the cross powers. This method provides results without bias errors, however poor results may occur if the electric fields are linearly polarized.

The computer analysis is separated into two parts utilizing Gamble's (1979) computer programs. The first program digitizes the data (12 bits) into segments 1024 points long. The segment is tapered, Fourier transformed, and the cross powers are calculated.

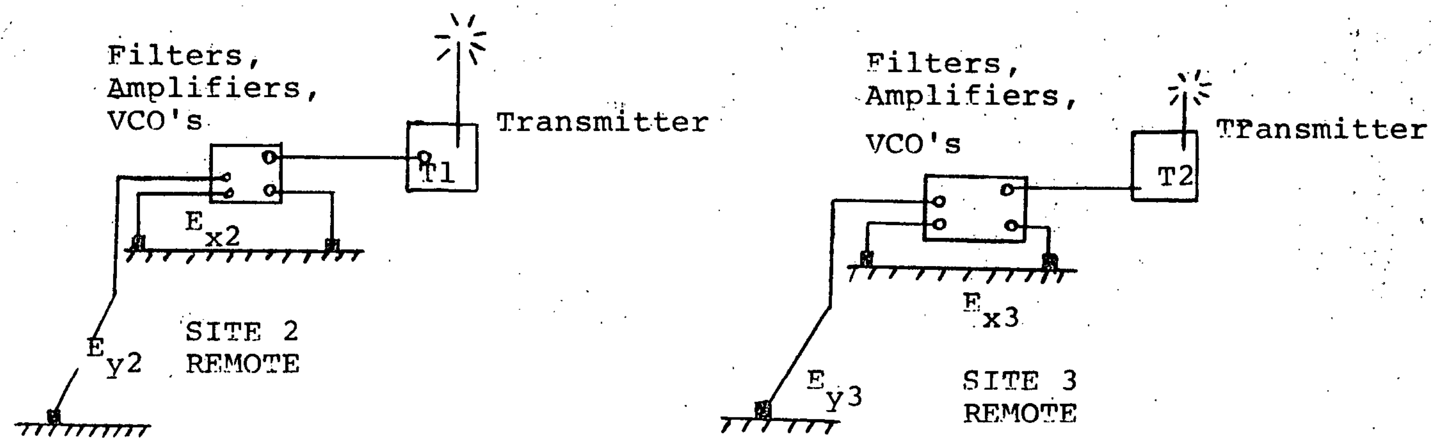
TELLURIC

MAGNETOTELLURIC

SETUP



MAGNETOTELLURIC SETUP



TELLURIC SETUP

Figure 1. Magnetotelluric-Telluric Instruments

The process is repeated for subsequent data sets with the option of rejecting any segment due to noise spikes or signal level saturations. The accumulated average cross power values are stored. This process can be performed in real time. After a data run is completed the second computer program utilizes the average cross powers and calculates the impedances, principal axis directions, rotated apparent resistivity values, skewness, impedance phases, tippers, and tipper strike directions.

The principal axis direction is calculated such that the impedance tensor quantity $|Z_{xy}|^2 + |Z_{yx}|^2$ is maximized. This defines the direction for the principal impedance terms Z_{xy}' and Z_{yx}'. For a two dimensional structure, the diagonal terms Z_{xx}' and Z_{yy}' are zero at this rotation angle. An indication of the three dimensional nature of the area can be represented by the ratio of the magnitude of the rotated diagonal to off diagonal terms. This is called the skewness, S.

$$S = \frac{|Z_{xx}' + Z_{yy}'|}{|Z_{xy}' - Z_{yx}'|}$$

Principal apparent resistivity values are calculated from

$$\rho_x = 0.2\ T\ |Z_{xy}'|^2 \qquad \text{and}$$

$$\rho_y = 0.2\ T\ |Z_{yx}'|^2$$

where T is the period in seconds.

The vertical magnetic field is utilized to determine the strike direction. For a normal incident plane wave over a two dimensional structure, the vertical magnetic field arises only from the TE Mode, H_x field perpendicular to strike (Vozoff, 1972).

We assume $H_z = AH_x + BH_y$ and calculate a rotation direction such that A is maximized.

For the two dimensional case $H_z = A'H_x'$ and the rotated X axis defines a direction perpendicular to strike. In the present work the strike direction is indicated in the computer printout. The magnitude of the vertical field, A', the tipper, gives some indication of any lateral resistivity variations.

Monitoring different frequency bands provides various depth information. An indication of the depth penetration is sometimes given by the apparent skin depth, δ_a. This is defines as the depth where the amplitude of the electric field has fallen to 1/e of its value at the surface and is calculated from the expression

$$\delta_a = 503 \left(\frac{\rho_a}{f}\right)^{\frac{1}{2}}$$

where ρ_a is the apparent resistivity in ohm meters, f the frequency in HZ, and the resulting skin depth is in meters. The lower the frequency, the deeper the penetration.

The actual sensing depths are usually much less than the skin depths. Complete model solutions are required to determine the intrinsic properties and depths. Two dimensional computer modelling would be required to interpret the results if significant lateral variations occur. However a preliminary interpretation can be obtained with a one dimensional model based upon the TE Mode apparent resistivity data. The rational for this approach is that for a deep sounding, the TE Mode is less affected by near surface lateral changes than the TM Mode (Patrick and Bostick, 1969). In the present work a continuous one dimensional inversion method described by Bostick, 1976, was used.

Field Operations

In the present survey, telluric dipoles of about 200 meters were used in an "L" configuration. They were orientated north-south and east-west.

The field system filters prewhitened the spectrum such that data could be obtained wide band from 0.01 to 10 Hz. From 4 to 6 hours of data were recorded for each setup. After the elimination of poor sections of data, this resulted in about 1½ hours of processed data. Two overlapping frequency bands were used, 0.01 to 1.0 Hz, and 0.1 to 10 Hz. A summary of the processed data is indicated in Table I.

Eleven setups of data were obtained consisting of 11 base stations and 19 remote sites. In field processing was only performed for stations M1,A1,B1 and M2,A2,B2. The remainder of the stations were processed after the entire survey was completed. This was done to take maximum advantage of a short period of relatively good field weather.

High winds were encountered on 7 days. The magnetometer was buried about 2 feet and surrounded by a wind shield. The telluric wires were carefully lain out on the ground and weighted down with rocks or buried every 2 meters. Because of the brush in the area this proved to be very time consuming. Even with this precaution the data at the 4th setup possibly suffered from wind noise. The poor data obtained at station B3 may have been due to the presence of power lines or noise from nearby ranches. This high frequency noise was evident in the field even after considerable filtering.

Snow, hail and rain delayed the survey 12 days. Over 12 inches of snow fell on one storm and lasted on the northern slopes the remainder of the survey period. The 4 wheel drive vehicles became stuck three times due to the mud,ice and snow. Over 20 hours

TABLE I

Magnetotelluric Processed Data

High frequency band sample period .03 seconds

Low frequency band sample period .300 seconds

Data segments 1024 points long

STATIONS	# SEGMENTS High freq. band 10 to .1 Hz	# SEGMENTS Low freq. band 1 to 0.01 Hz	DATA QUALITY
M1,A1,B1	114	31	Good
M2,A2,B2	100	18	Fair to Good
M3,A3,B3	104	11	Poor to Fair
M4,A4,B4	122	12	Poor
M5,A5,B5	210	23	Fair
M6,A6	113** 186	23	Fair
M7,A7,B7	210	24	Very Good to Good
M8,A8	168	20	Fair
M9,A9	81** 123	7	Fair
M10,A10,B10	156	17	Poor to Fair
M11,A11,B11	99	10	Poor to Fair

** More than one set was processed from different data sets were expended in freeing them.

The personnel stayed at the Markee Motel in Elko, Nevada and at the Taylor Canyon Club near Tuscarora. Commuting time to the survey area was about 80 to 100 minutes from Elko and about 30 to 60 minutes from Taylor Canyon.

Specific vehicles used on the project were a Bronco (AMAX's) a Ford 3/4 ton pickup with mounted instrument camper shell (4 wheel drive) and an equipment trailer.

Composition of Crew

A detailed summary of the work and personnel is documented in Appendix A. The personnel involved on the project are listed below:

A. Mazzella	Geophysicist	Instruments, survey, data processing
B. Srygley	Field Assistant	Wire crew

Data

The location of the stations are shown in Plate 1. Plots of the data and the one dimensional inversions are presented in the second binder. Data points are plotted that meet the following criteria:

(1) skewness $\leq$ 0.5 (except for stations M6 and A6 where values $\leq$ 1.0 were accepted)

(2) phase between 0 and -90 degrees

The rotated apparent resistivity values, rotation angle, skewness, phase, tipper and tipper strike angle are plotted for each station.

The interpreted resistivity sections (based upon the one dimensional inversions) along lines AA', BB', and CC' are plotted in plates 2,3 and 4. The stations are projected upon the lines, up to one km in some cases.
The computer printouts are presented in a separate folder.

Discussion of Data

Considerable resistivity variations are observed in the interpretations throughtout the survey area. Resistivity values range from 2 to over 1000 ohm meters.

A low resistivity zone of 4 ohm meters is suggested in the area of station M1 at depths of 300 to about 600 meters. This may be reflecting geothermal fluids associated with the surface hot springs in the area.

At depths below 2 km the one dimensional inversion suggests a thin conductive conduit at M1. A zone of < 4 ohm meters is suggested below 10 km. Adjacent stations indicate high resistivity values at this depth.

The low resistivity zone about 2 km to the east at station B10 (< 4 ohm meters at 2 km) should be taken with caution in view of the high skewness values (> .3) and the scatter in the data.

The interpretation of a conductive zone (< 4 ohm-meters) at depths of 5 to 6 km at station A10 may extent 3 to 4 km to the north to stations M5 and B5.

It is not possible to tell from these results whether the surface geothermal fluids are migrating down from the north or coming up along a narrow conduit in the area of M1. An additional station or two between M1 to M5 and M1 to A7 may aid in resolving this question.

The data at station M4 could not be interpreted due to the very high skewness values over most of the frequency band (> 1). A considerable number of high skewness values were also observed about 3 km to the north at stations M6 and A6. These results may be reflecting a three-dimensional deeply buried high resistivity ridge that was suggested by a dipole-dipole survey in the area.

All the above discussions should be taken with caution in view of the difficulity in interpreting which of the axes was the TE Mode at some stations. In addition, the interpretation was based upon a one dimensional model. A considerable amount of contacts and faults have been mapped throughout the area and the data clearly suggest that 2 and 3 dimensional effects are present.

The quality of the data ranged from very good (M7) to poor (M4) over the area. The majority of it falls in the bracket of fair (M5) to good (B2). Coeherent noise spikes were observed at all the setups and sites. They appeared to be stronger at those stations in the valley near the power line or near cultural activities such as the Jack Creek Guest Ranch, Mori ranch or Spanish ranch houses. These noise spikes were in some cases larger by a factor of 10 than the background signals. Generally, it appears that those stations gave poorer quality data. In one case at station M11, the signals were completely swamped by noise 20 times larger. The noise appeared to abruptly switch off at 10A.M.. Its source was not determined and one can only suspect that a considerable amount of the poor data might be attributed to these cultural activities.

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APPENDIX A

OPERATIONS SUMMARY

MONTH

TERRAPHYSICS

OCTOBER 1979

PROJECT TUSCARORA, NV

CHARGE DAYS	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	PROD. Hz	MAZZELLA
NO CHARGE	8,9,10,11 12,13,			Pickup HE, fill magnetometer, pickup AMT coils, test coils, setup field test Grass Valley NV Rain-snowed out		x
1½M	14,15			Mobilization California to Elko to Tuscarora NV unload trailer,truck-Taylor canyon camp		
1 Survey Data	16	Survey		Survey setup 1, lay out dipoles, bury or place rocks every 1-2 meters on wires , windy. Rough road into site area(road construction) took over 1 hour from Taylor Canyon to site 1.		x
0 NO CHARGE	17	R		Magnetometer failure(rough road?). Repaired.		x
1 weather	18	W	½	Light rain all day, very muddy, some data obtained , in field processing , high freq band, charge as bad weather day.		x
1 weather	19	W		Heavy snow falling, high winds, gusts to 40mph, knocked over magnetometer, damage to RF boxes and cable connectors. Visibility less than ½ mile, can't even survey next sites. Fill magnetometer in snow storm, ice plug developed, froze transfer line,broke vacuum.		x
0 NO CHARGE	20	W-R		Road to site 1 still very rough, tape deck broke Repair Tape deck ½ day. Afternoon,heavy snow still falling, wait it out in Elko,pick up supplies.		x

TOTALS
1½ Mobilization
1 survey ,data
2 weather down

T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS

MONTH OCTOBER, 1979

TERRAPHYSICS

PROJECT TUSCARORA, NV

CHARGE DAYS	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	PERSONNEL: MAZZELLA
NO CHARGE	21	W R		Light snow in morning. Repair transfer line broken when frozen, stuck in snow storm. Drive to setup 1, road very muddy, stuck about 1 hour (total time from Elko 3½ hours to site 1) camp overnight	x
½ Weather ½ Data	22	W MT		Snowed about 2" overnight, everthing covered with snow. Melts in morning, everthing dripping wet. Some data in afternoon. Camp overnight	x
1 Data	23	MT	1	Data setup 1, about 5 hours of recording Road still very muddy and rough, camp overnight	x
NO CHARGE	24	AMT W	½	Setup AMT system, snowed overnight , everything wet. AC generator too noisy even with 50 db,60HZ notch filters, setup completely battery operated system. Obtain some data in afternoon , very high winds start and blow all night, winds blow almost steady until October 26, camp overnight	x
½ Weather ½ Data	25	AMT W		Continue with AMT data , waiting for lull in wind Some AMT data, but wind noise evident- winds 10mph with gusts to 30mph. Afternoon - wind increases in velocity, clouds - overcast - pickup setup-4½ hrs Rain starts about 6 P.M. Drive to Elko for supplies, food, gasoline 2½ hours	x
1 Data	26	MT		Survey setup 2, difficulity getting into area , road very muddy, creek flowing, road undercut	x

TOTALS
1 Weather
3 Data

T - TELLURICS   OT - ORTHOGONAL TELLURICS   MT - MAGNETOTELLURICS

R - D.C. RESISTIVITY   EM - ELECTROMAGNETICS   M - MAGNETIZATION

MONTH October, 1979

TERRAPHYS

PROJECT TUSCARORA, NV

PERSONNEL

CHARGE DAYS	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	MAZZELLA	SRYGLEY
1 Data	27	MT		Continue survey and setup #2, bury or place rocks on dipole wires. Very windy all afternoon. Camp overnight	x	
½ weather ½ Data	28	W MT		Snow, hail, rain overnight till about 2P.M. High winds all day, very muddy and wet. Some data, poor quality. Camp overnight	x	
1 weather	29	W		Snowing in morning, windy all day, Poor data	x	
1 weather	30	W		Heavy Snow falling 6 to 12 inches on ground drifts to 2 feet. Go to Elko for supplies, food, gasoline	x	
1 weather	31	W		Cold, deep snow cover still over area, process some data from setup 1 and 2	x	
1 Data	NOVEMBER 1	MT	1	Drive to setup 2 (3 hours from Elko) , backpack into sites, 1 to 2 feet snow still on slopes. Complete data at setup 2, pickup equipment, dipoles. Very muddy as snow melts, Bronco stuck in creek bed blocking road. Wait until ground freezes overnight (16 hours)	x	x

TOTALS
2½ Data
3½ Weather

T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS

MONTH

NOVEMBER 1979

TERRAPHYSICS

PROJECT TUSCARORA, NV

CHARGE DAYS	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	FREQ. BAND Hz	PERSONNEL: MAZZELLA	PERSONNEL: SRYGLEY
1 Weather	2	W		Finish picking up dipole wires and equipment after getting Bronco out of creek bed. Drive to Jack Creek - NO UNLEADED GASOLINE, nearest station over 60 miles away. Survey Swimmer's Flat area, road very muddy, slippery clay, dangerous down slopes, drops into canyons, took almost 1½ hrs drive from highway. Cloud cover coming over fast. Snow starts in evening. Drive to Elko for supplies and unleaded gasoline.		x	x
1 Weather	3	W		Survey setup 3 in ranch area, rain, snow, hail start to fall. Layout dipoles setup B3,A3, Large 60 Hz noise pickup from powerlines even with notch filters at B3.		x	x
1 Weather	4	W		Rain, Snow, Hail falling all day, too wet. Survey area for setup #4, lots of cattle on west side of highway		x	x
1 Data	5	MT	1	Data setup 3, pickup dipoles, equipment. Start to setup #4, get key to locked gate at Mori ranch		x	x
1 Data	6	MT	1	Complete layout, survey, setup 4 Data. Large correlated noise spikes on all channels about 5-10 times background signal levels. Complete data, pickup dipoles, equipment Windy-data noise		x	x
1 Data setup	7	MT		Survey setup 5 area, Still 12 inches snow on slopes, Ford stuck on steep slope on ice- then developed ice in gas line ? to reserve tank. Return to base camp for reserve gasoline and deicer. Setup B5, M5 dipoles		x	x

TOTALS
3 Weather
3 Data

T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS

R - D.C. RESISTIVITY EM - ELECTROMAGNETIC M- MOBILIZATION

MONTH

NOVEMBER, 1979

TERRAPHYSICS

PROJECT TUSCARORA, NV

CHARGE DAYS	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	FREQ. BAND Hz				MAZZELLA	SRYGLEY			
1 Data	8	MT	1	Setup dipoles B5, Data setup #5 complete pickup setup #5, survey setup #6					x	x			
1 Data	9	MT	1	Layout setup #6, Data completed, jeeps , trucks coming by delay data. Large correlated noise spikes observed throughout data. Pickup setup #6					x	x			
1 Data	10	MT		Survey area setup #7, took 1½hours drive from Taylor canyon to area, Still some snow, ice on shaded slopes. Lots of grounded metal fences in area of B7, have to relocate- now no telemetry to M7 station. Obtain data at M7, A7 only									
1 Data	11	MT	1	Relocate antenna for B7 , Complete data setup 7 Pickup dipoles, equipment					x	x			
1 Data	12	MT	1	Survey, layout setup #8, complete data setup #8 Swimmer's Flat area Setup #9 layout. Camp out at M9 overnight					x	x			
1 Data	13	MT	1	Setup electronics at M9,A9, Complete data setup #9					x	x			

TOTALS

6 Data

T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS

R - D.C. RESISTIVITY EM - ELECTROMAGNETICS M - ...

TERRAPHYSICS

MONTH NOVEMBER 1979

PROJECT TUSCARORA, NV

CHARGE DAYS	DATE	TECHNIQUE	TOTAL STATIONS	LOCATIONS	MAZZ[illegible]LA	SRYGLEY
1 Data	14	MT		Survey layout M10, A10, obtain data M10, A10 only (B10 not setup yet)	x	x
1 Data	15	MT	1	Setup B10, Data M10,A10,B10 completed. Strange noise pickup intermittently on B10,saturates system	x	x
1 Data	16	MT	1	Setup electronics M11,A11,B11, Data-setup #11. Large noise signals observed until about 10 A.M. Completely swamped system. Wind picks up about noon. Go to M9 , dig AMT coil holes, Bronco stuck in mud (1 hour to free) . Wind increases 20-30 mph , higher gusts almost blow us off mountain top, Storm approaching, pick up dipoles, equipment.	x	x
½ Data ½ demobilization	17	MT M		Setup M5 dipoles , dig AMT coil holes, setup electronics; cold,starts snowing, windy,no data Pack up equipment, load trailer demobilization back to California- drive to Elko in evening, Snowing steady	x	x
1	18	M		Demobilization Elko to California 5A.M. to 4 P.M. Snow on road Elko to Battle Mountain,slow driving, Unload equipment - 4 hours	x	x
NO CHARGE	19 21			Return AMT coils, Liquid HE dewar 7 Hours	x	

TOTALS
3½ Data
1½ Demobilization

T - TELLURICS OT - ORTHOGONAL TELLURICS MT - MAGNETOTELLURICS