PRELIMINARY

GROUND WATER DEVELOPMENT PROGRAM
REFLECTION SEISMIC EXPLORATION PHASE

FOR KLAMATH DRAINAGE DISTRICT,
KLAMATH FALLS, OR

COOKSLEY GEOPHYSICS, INC

CGI JOB NUMBER 01-013
August, 2002

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INTRODUCTION

In May, 2002, Cooksley Geophysics, Inc., Redding California, conducted seismic exploration along three lines, each approximately 1.25 miles long in the Klamath Basin situated in T.R. see the program maps on pages 2, 3 and 4. This work was executed at the request of the Klamath Drainage District, Klamath Falls, Oregon, as part of a ground water supply and development program.

The purpose of this seismic exploration program was to obtain the first seismic profiles depicting the subsurface geologic conditions beneath two areas within the basin, about 20 miles south of Klamath Falls, Oregon. In particular, the survey was directed to the observation of the stratified clastic and volcanic units and the geologic structural features which might underlie the areas. This information will be used by the client to plan and direct a drilling program for the purpose of developing ground water resources for the Klamath Drainage District.

The seismic traverses were located on dirt roads constructed along six-foot (+) deep ditches. The water-filled ditches provided excellent coupling for the linear, primacord source. Primacord and two-pound booster (point source) explosive sources were used for initiating seismic waves.

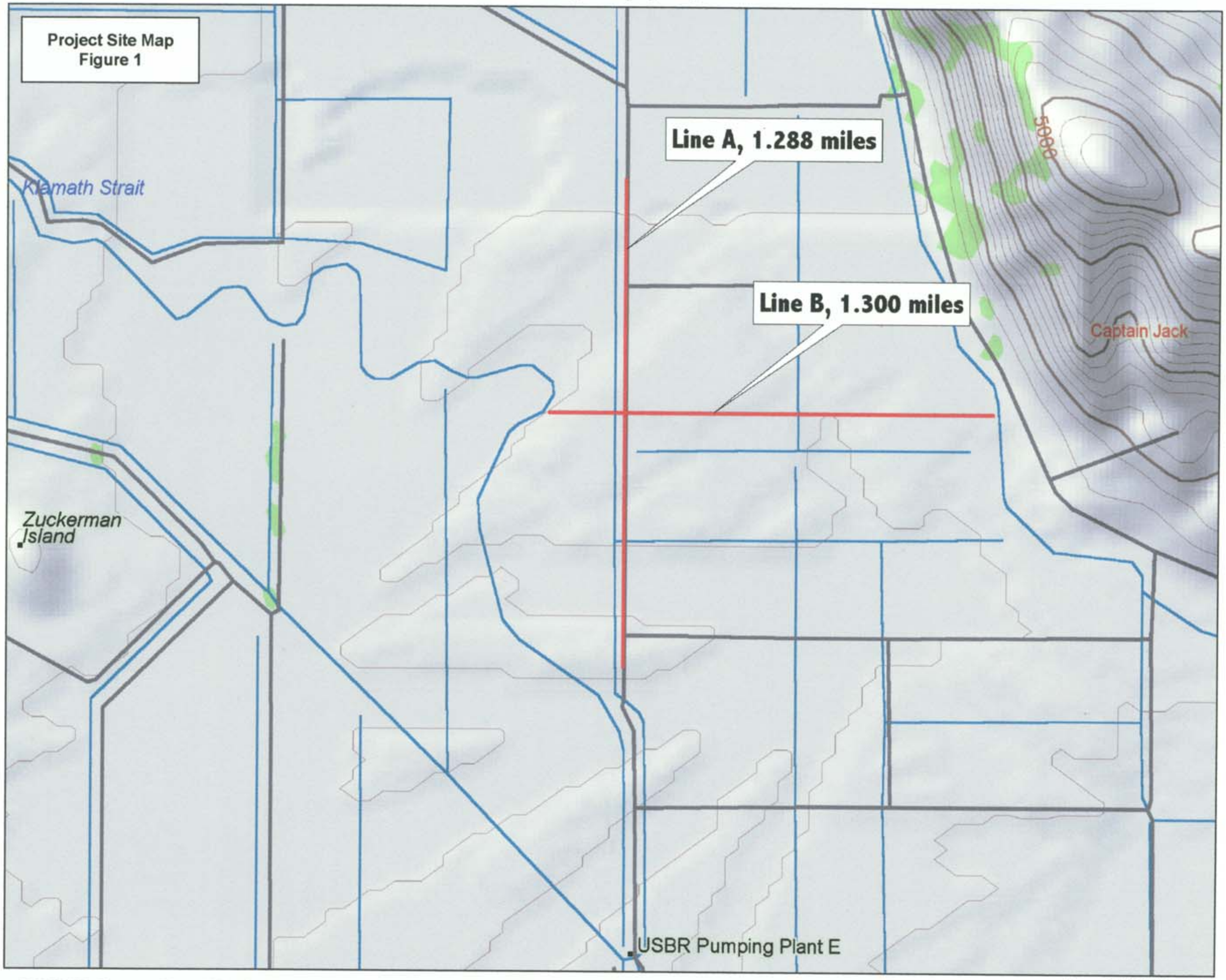
DATA ACQUISITION

Seismic field operations were conducted from May 1st through May 16th, 2002. The weather was ideal except for one or two days of high wind. The temperature was cool in the mornings and stayed in the 50s and 60s (F) in the afternoons. The terrain along the ditch-roads was flat. Approximately 20,000 total line feet of seismic data was acquired along the three traverses.

The locations of the seismic lines are listed in the Table I below, and shown on the program maps on pages 2, 3 and 4.

Table I

Line	Location	Direction
A	Sections 17 and 19, Township 40 S., Range 9E. (along Motschenbacher Drain)	South to North
B	Sections 19 and 20, Township 40 S., Range 9E.	West to East
C	Sections 12 and 13, Township 41 S., Range 9E.	South to North

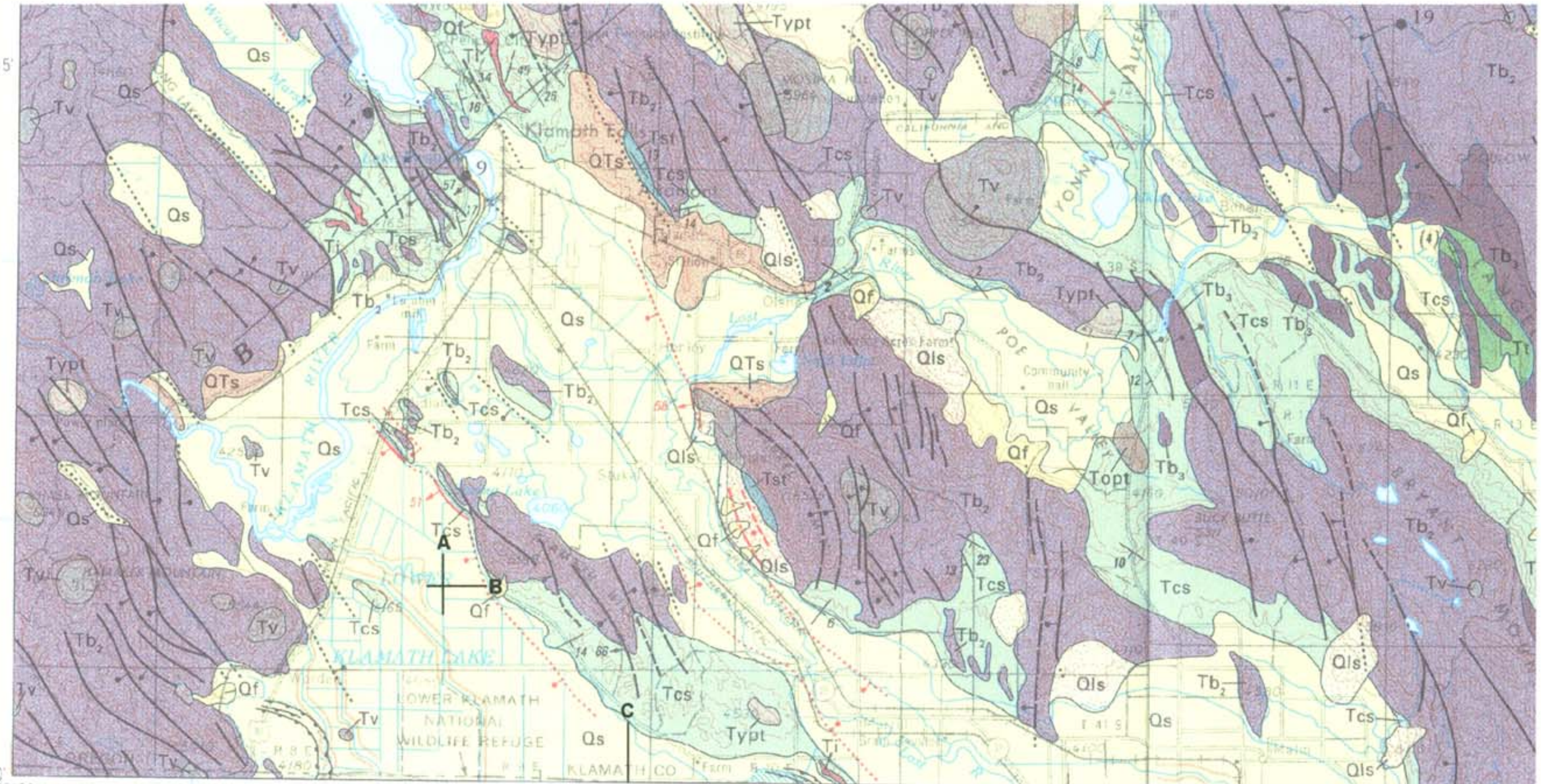


© 2001 DeLorme. Topo USA® 3.0
Scale: 1 : 24,000 Zoom Level: 12-1 Datum: NAD27 Map Rotation: 0° Magnetic Declination: 16.5°E

Scale: 1 : 24,000 Zoom Level: 12-1 Datum: NAD27 Map Rotation: 0° Magnetic Declination: 16.5°E

Figure 3

15'



42°00'
122°00'
45'
30'

Base from U.S. Geological Survey, Klamath Falls, 1955. Bathymetry in Upper Klamath Lake from Johnson and others (1985)
Universal Transverse Mercator projection

SCALE 1:250 000

5 0 5 10 15 MILES

5 0 5 10 15 20 KILOMETERS

CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Line Location Map

Cooksley Geophysics, Inc.

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Seismic lines

FIELD OPERATIONS

Field Parameters

The data was acquired using a 48-channel Bison 9048 seismic recording system. An explosive charge consisting of either a 33-foot length of primacord or a 2-lb booster charge was used as the seismic source.

The following tabulates the field parameters used in recording the refraction data in this study.

Table II

Channels recorded	48
Sensors per channel	1
Sensor frequency	10 Hz
Sensor spacing	10 m
Spacing of source points	20 m
CMP (common mid-point) coverage	12 fold
Recording sample rate	1.0 ms
Low cut filter	16 hz
High cut filter	1,000 hz
S.P. - sensor geometry	24-1-0-1-24 for 10 m Sensor spacing

A four man crew was used in the data acquisition phase of this program. The party chief/observer managed and supervised the crew, operated the seismograph, and transferred the seismic data to 3.5-inch, 1.4 megabyte disks. Three field assistants deployed seismic cables and sensors, prepared the recording site, and operated the seismic source.

Importance of Source Point-Sensor Station Geometry

There is inherent difficulty in obtaining near surface data using the reflection seismic method. This difficulty is made up of two basic problems. Both problems arise from the necessity of locating the seismic source close to the sensors and using a sensor spacing which is closely spaced. The nearer the surface the reflections are, the closer the distance the source must be to the sensors and the smaller the sensor spacing must be.

A conservative assumption for recording reflection data entails a maximum angle of incidence (angle of impingement of the ray path which represents the least time path of the reflected seismic wave) of 45 degrees. That portion of the wave front which exceeds this angle is assumed to experience too much convolution, dispersion and phase shift to be reliable and useful in the CMP stacking process. The equation relating the depth versus source point to sensor distance which yields less than 45 degrees is:

$$Z = X/2$$

Where Z is the depth to the reflector and X is the distance from the source point to the sensor station.

The first of the two basic problems that must be confronted is to separate usable reflection data from the large amplitude, lower frequency seismic waves which commonly propagate at lower velocity through the soil and weathered layers. This problem is commonly solved by employing certain field and data processing techniques which filter unwanted noise. Such techniques discriminate noise from usable signal by filtering frequency and by filtering velocity of propagation in the horizontal direction.

The second problem is whether there is a stratified unit present in the near-surface unit being investigated. If such a unit is absent, then no combination of closely spaced source-sensor geometry will yield an event.

DATA PROCESSING

Basic Processing

The SEISTRIX 3 software package developed and sold by Interpex, Ltd., Golden, Colorado, was used in processing the reflection data. Initial processing consists of applying corrections to the data which allow for the source point-sensor geometry and for surface topography of the site. The first correction, termed normal moveout (NMO), is designed to allow for the variation in the path length (and therefore travel time) between arrivals at sensors near and distant from the source points. This correction is further discussed in the report under NMO Correction Used in Defining Velocity Units. The second correction is termed the static correction, and allows for elevation differences between the sensors and the elevation differences between the source points. All sensor station data are referenced to datum elevation, using line survey data obtained in the field by Cooksley Geophysics, Inc. During this initial processing additional digital frequency filtering may be applied.

Common Depth Point Stacking

In preparation for the stacking of twelve-fold coverage, each subsurface reflection point is defined according to the geometry of the source point-sensor configuration. Then each trace from the records that corresponds to energy reflected from a particular depth point is assigned to that depth point's "trace gather". During the stacking process, all data traces in a trace gather are summed to generate the resultant trace which represents data recorded at that point on the record sections. This stacking process has the effect of causing cancellation of signals which are not in phase on all traces of the gather, and causes enhancement of those signals which are in phase. Theoretically, this results in enhancement of the reflected energy and improvement of signal to noise ratio (S/N).

Fk Filtering

Fk filtering is normally employed to diminish the affect of that component of the noise which horizontally traversed the seismic line. Fk filtering was not employed on this line.

<u>NMO Correction Used in Defining Velocity Units</u>
Routine seismic data processing employs a velocity function which applies a time variant normal moveout (NMO) correction to the seismic recordings. This function accounts for the increase in RMS (average) velocity with depth, and thus the time of recording. The average velocity at a given depth and recording time is, of course, the weighted average of the various velocities of propagation the seismic wave experiences while traversing down to and returning from that given depth. This velocity function makes possible the display of the shallow, low velocity events along with the deeper, higher velocity events.

If an erroneous NMO velocity is used in processing a given common depth point (CDP) data set, seismic events become indistinct or disappear completely. This particular condition can be used as a powerful interpretational tool. By applying an NMO correction based on a constant velocity instead of a velocity function, one sees only that data which possesses that RMS velocity on the section. With an NMO correction based on a low velocity, events at or near the upper portion of the section appear. As one reprocesses the data using an increase in the NMO velocity, the upper events dissolve and events lower in the section appear. Consequently, the velocity upon which a given NMO correction is based is a function of the interval velocity or velocity range which defines a <u>velocity unit</u>.

In physics, the correlation of the consolidation of sedimentary deposits and the competence of rock units with the velocity of seismic waves has been demonstrated and equations have been derived which express these relationships. Consequently, rather definitive geologic inference can be drawn from defining subsurface strata and contacts which appear based on NMO computed from a given velocity.

GEOLOGIC SETTING

<u>General</u>
The project area is located in the Klamath Basin on the Oregon side of the state line with California. The basin appears to occupy, at least in large part, a down-dropped fault block resembling a graben which has subsequently been filled with lacustrine deposit. A large portion of the perimeter of the basin coincides with normal faults along which the younger lacustrine deposits of the basin are in contact with the older volcanic rocks that surround the basin. The area is flanked to the east and west by hills in which volcanics are well-exposed and the valley extends southward into California and northward beyond the city of Klamath Falls, Oregon.

Margaret Jenks, the resident geologist of the Oregon Department of Geology and Mineral Industry in Klamath Falls, is presently (2002) geologically mapping much of the area within and adjacent to the Oregon side of the Klamath Basin. Her mapping depicts three general categories of faulting according to strike. She has also mapped volcanics cropping in the valley at Zuckerman's island and Skull Island.

U.S.G.S. geologists, Sherrod, D.R. and Pickthorn, L.B.G., (1992) mapped the project area. Their map records many volcanic units ranging in age from Miocene (10 to 25 million years before present to recent) All the volcanic units mapped within and adjacent to the project area are older than 5 mybp. Sedimentary units also range in age from Miocene to the present. In the Klamath Hills forming the northeast perimeter of the valley, Pliocene (2 to 10 mybp) sediments crop extensively.

Sequence of Rocks

Older volcanic units

The oldest rock units identified in the subject area are volcanic beds of Miocene (10 to 25 mybp) age. This unit crops in the low hills surrounding the valley and probably underlies the lacustrine deposit which filled the valley. Basalt forms the northwest-trending ridges along west side of the Klamath Basin. The east and northeast perimeter is marked by a low ridge composed mainly of basalt cap overlying a sedimentary and pyroclastic (tuff) unit of Tertiary age.

Older lacustrine deposit

Older lake beds rest on the older volcanic unit, probably throughout the major part of the basin. This lacustrine deposit is well consolidated, but seismic data indicates the possibility that sand or gravel beds might be present in this unit. These beds are believed to range in age from Pliocene to Pleistocene, and their thickness ranges from nil to perhaps in excess of 500 meters in the area studied.

Younger volcanic unit

Presently, it is thought that this unit does not underlie the seismic traverse lines, but is interpreted elsewhere in the valley from the ground magnetometer and gravity-meter surveys. This unit, if it were present in this survey area, would be within and of the same age as the older lacustrine deposit.

Younger lacustrine deposit

The younger lake beds are differentiated from the older on the basis of their seismic velocity being significantly less than that of the older lacustrine beds. The thickness of the younger unit ranges from 5 to 15 meters (15 to 50 feet) and its age is probably Recent.

Structural Features

Folding

Three forms of folding can be observed on the seismic sections, 1) draping and 2) drag along faults and, possibly, local compressional folds resulting from listric faults and slope failure. In a strict sense, these cannot be regarded as tectonic. One might argue that drag folding is indirectly tectonic, but true compressional folding is not recognizable on the seismic sections.

Faults
A comprehensive depiction of faulting is in the mapping of Jenks, M. (2002, in progress). Normal faulting of very significant magnitude is apparent in the seismic sections at the east end of Line B and the north end of Line C. In both cases, the faults are normal, basin and range type structures, and appear to be transected by the seismic line at an angle significantly less than 90 degrees.

INTERPRETATIONS

General
The uppermost unit encountered in the area investigated (see maps, pages 2, 3 and 4) is a 30-meter (approximate and variable) thick sedimentary stratum consisting of poorly to moderately – consolidated mud that contains a substantial proportion of organic material. This unit is probably of Recent age and it is exposed continuously at the surface of the Klamath Basin. Seismic velocities of less than 1,200 mps (meters per second) are normally encountered within this unit.

Under the poorly to moderately–consolidated mudstone is a moderately competent sedimentary unit which probably includes a substantial quantity of pyroclastic beds and detritus. Seismic compressional wave velocities normally exceed 1,800 mps in these strata. This unit is probably the same as that exposed below the cap rock on the ridge northeast of the subject area. Jenks, M. (2002, personal communication) assigns a Pliocene age to these strata based on fish fossils.

The older, well–consolidated sedimentary and pyroclastic unit rests on top of volcanic flow and pyroclastic units of Miocene and Pliocene age M. Jenks, 2002, personal communication). Seismic velocities in excess of 3,000 mps are common in this unit.

Line A
This 1.288 – mile, south-to-north trending seismic line depicts gently north-dipping strata to depths of about 320 meters at the south end and 400 meters at the north end of the line. The underlying volcanic section either abuts or is in proximity to the base of the well-stratified section the base of which is represented by the strong event between 400 ms at station 40 and 480 ms at station 200 on the seismic section.

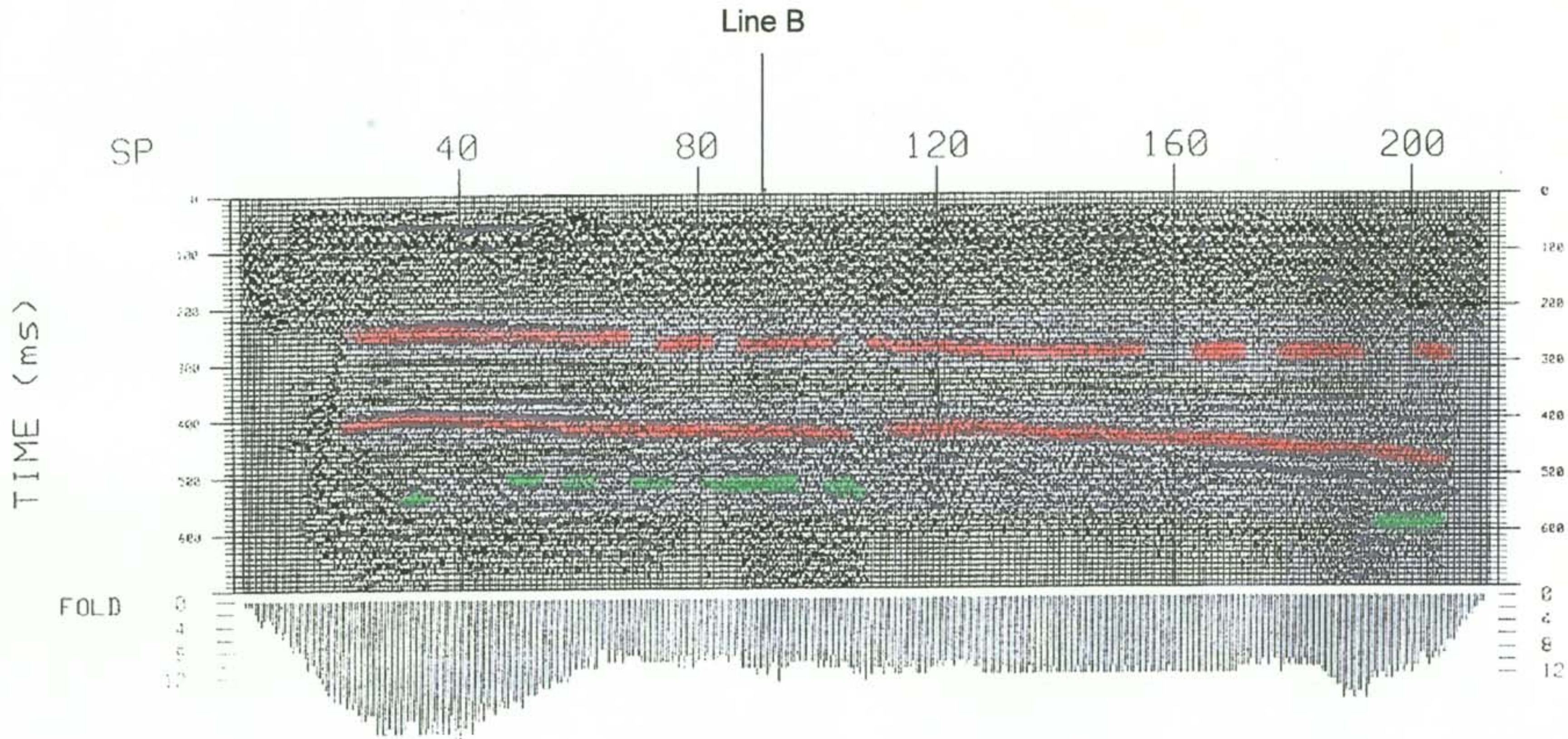
Line B
This line is 1.300 miles long and trends from west-to-east. See map on page 2. Line A crosses Line B at station 151 and the main reflection events coincide. As in Line A, stratified reflection events persist to times in excess of 500 milliseconds except at the east end of the seismic section where the sedimentary strata of the basin abut volcanics along a normal fault. A potential topographic low on the top of the volcanics is indicated in the vicinity of station 200 at about 580 ms. This feature and the faults indicated on the seismic section may have potential for the accumulation of ground water.

Line C
This 1.294-mile, south-to-north trending traverse is located in the southeastern portion of the study area. See map on p.3. The strata are not as well-defined on this line as in lines A and B. This might be the result of folding resulting from drag and subsidence along listric and antithetical faults or perhaps the warping of events denotes strata of volcanic rather than sedimentary origin. The interpreted section in *appended item 3* assumes the former reason for the folding. The south-dipping strata are interpreted as volcanic units.

A rather complex fault system is apparent on the seismic section. The main fault nearly "daylights" at the north end of the section and dips to the south into a region of high-frequency noise between stations 115 and 65. At station 65 and 770 ms, the fault appears to continue after being up thrown along intervening antithetic and reverse (?) faults. The high frequency noise area might be attributable to a water saturated zone of fractures or to intrusive hypabyssal rock, perhaps a buried plug. The sedimentary section appears to deepen significantly along the main fault at the south end of the section. Here the base of the sedimentary section appears to be in excess of 1,300 meters.

Depiction of the sedimentary section in the upper 500 meters is lacking. Depressed areas along the contact at the top of the volcanics are not evident, mainly because this contact is, at least for the most part, the surface of the main, south-dipping fault. The main targets for ground water accumulation on this section appear to be along the faults or at fault intersections.

APPENDED ITEMS



Seismic Line A

Marker event, in sedimentary unit

Marker event, in volcanic unit

Scale: 1in = 1,000 ft or 300 m.

Line length: 2060 m,6798 ft, 1.288 mi

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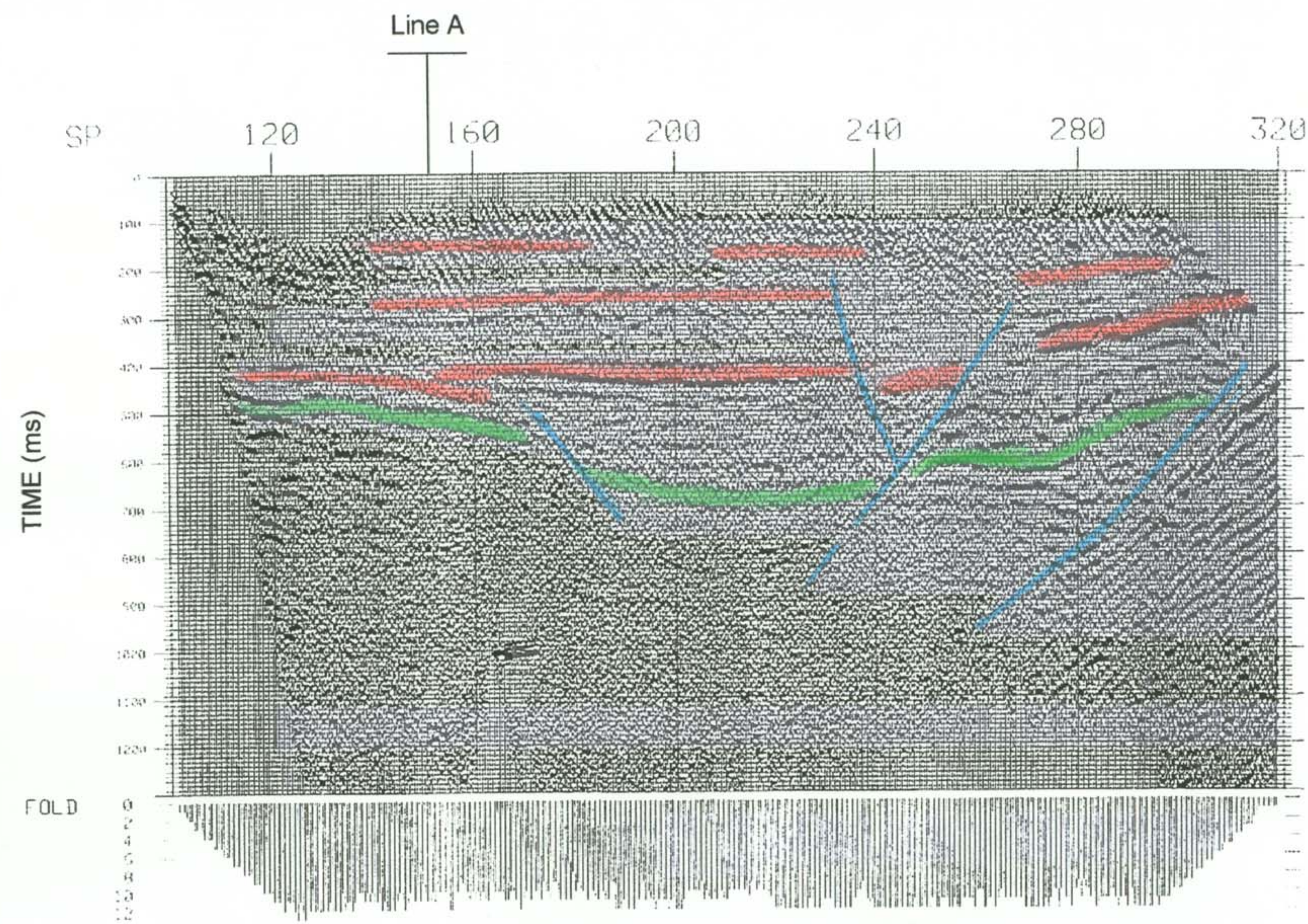

Marker event, in sedimentary unit

Marker event, in volcanic unit

Fault, interpreted form seismics

Seismic Line B

Scale: 1in= 1,000 ft or 300 m.

Line length: 2080 m,6864 ft,1,300 mi

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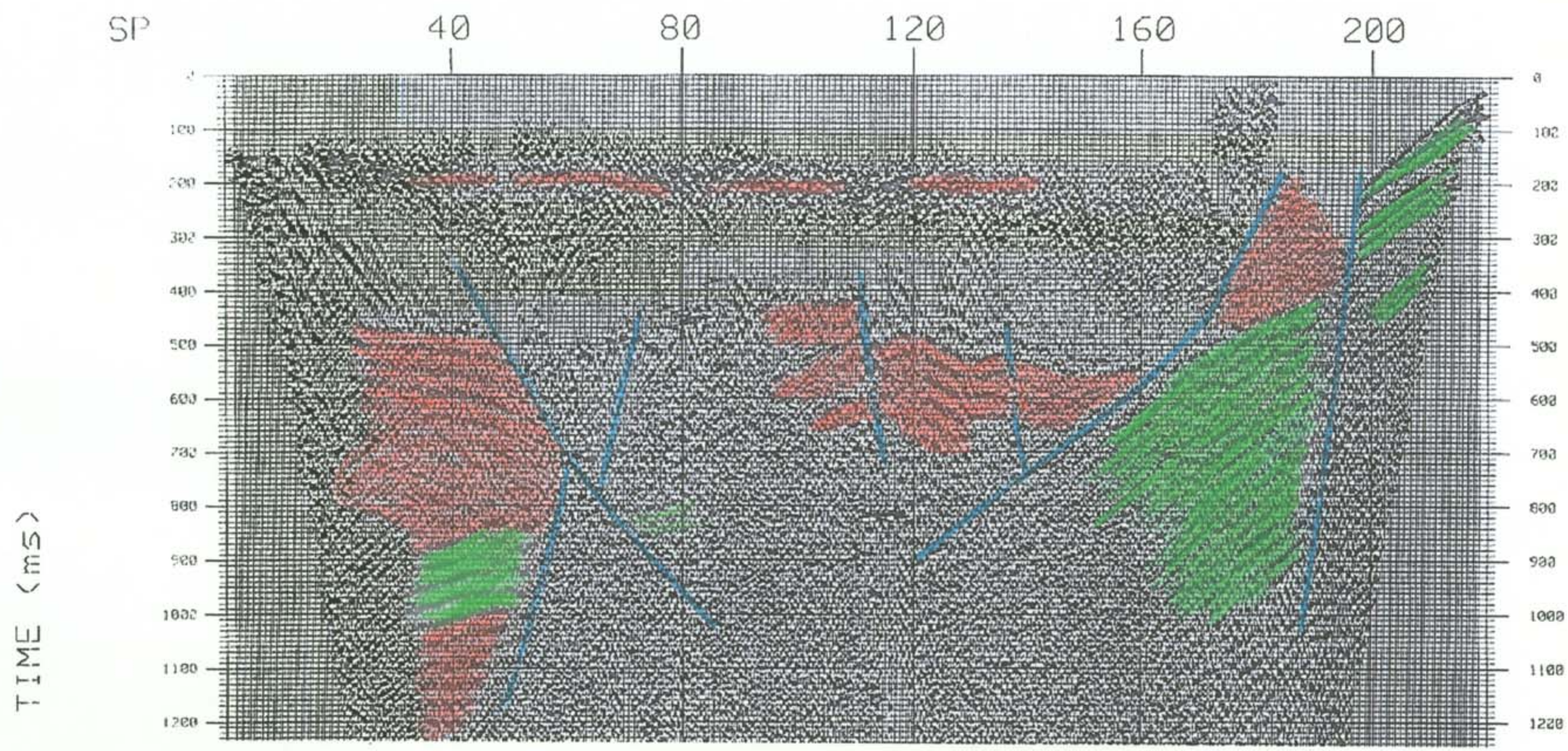

Marker event, in sedimentary unit

Marker event, in volcanic unit

Fault, interpreted form seismics

Seismic Line C

Scale: 1in = 1,000 ft or 300 m.
Line length: 2070 m, 6831 ft, 1.294 mi

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Job # 01-013 August 2002

Klamath Drainage District
Klamath, Oregon

1. View to the southwest into California and Mount Shasta.

2. Seismic shot detonated in irrigation ditch along Line A.

3. Setting explosive charge in irrigation ditch along Line A..

4. View to southwest from Line A.

Klamath Drainage District
Klamath, Oregon

5. Seismic recording instruments and equipment.

6. Laying out seismic sensor cable from small trailer.

7. Checking seismic sensors along Line A.

8. Recording seismic data along Line A.

Klamath Drainage District
Klamath, Oregon

9. Seismic shot at north end of Line C.

10. Cooling off!

11. Seismic shooters Equipment.

12. Seismic recording along Line C.

Klamath Drainage District
Klamath, Oregon

13. Seismic shooters Equipment.

14. Observer's vehicle (instrument truck).

15. Primacord shot, Line C.

16. Primacord shot, Line C.

Klamath Drainage District
Klamath, Oregon

17. two-pound booster detonated on Line C.

18. North end of Line C.

19. Line C, looking south.

20. Mount Shasta