Northwest Geophysical Associates, Inc.

Gravity Survey

Groundwater Investigation

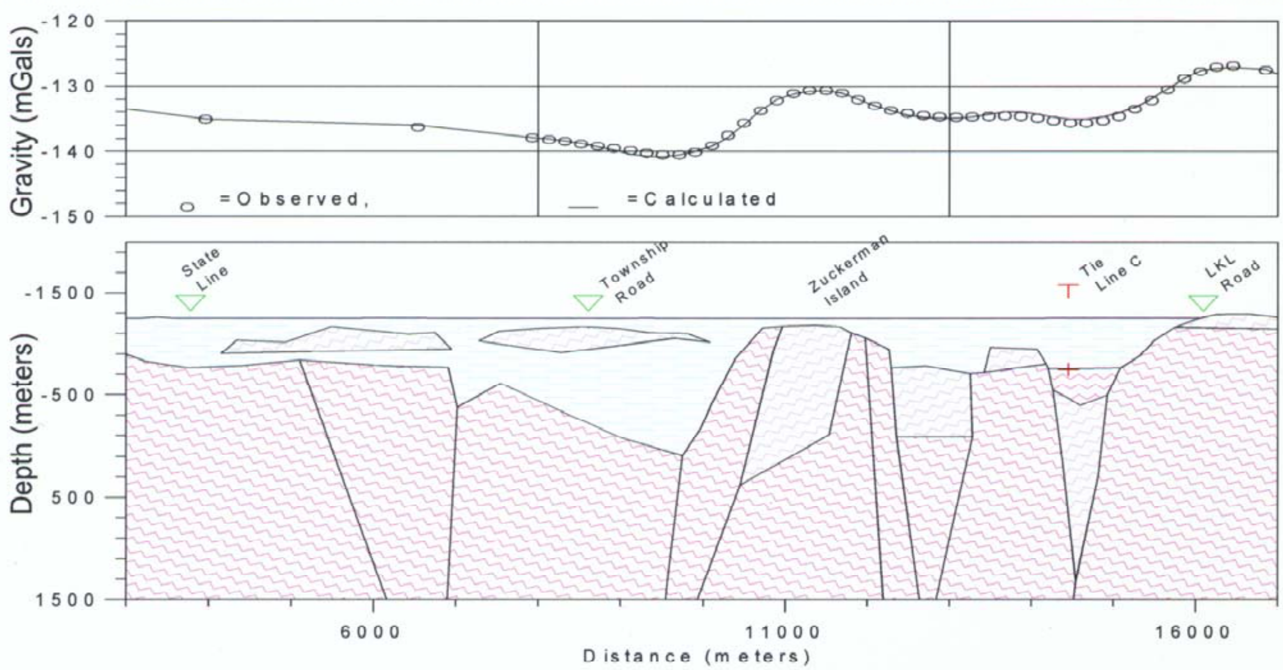
Lower Klamath Lake Basin

Klamath County, Oregon

May 2002

Prepared for:
Klamath Drainage District

Prepared by:
Northwest Geophysical Associates, Inc.



Geophysical Services

Environmental • Groundwater • Geotechnical

Gravity Survey

Groundwater Investigation

Lower Klamath Lake Basin

Klamath County, Oregon

Prepared For:

KLAMATH DRAINAGE DISTRICT
280 Main Street
Klamath Falls, Oregon

With Support From:

Oregon Department of Water Resources
Salem, Oregon

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May 2002

Gravity Survey
Groundwater Investigation
Lower Klamath Lake Basin
Klamath County, Oregon

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1 INTRODUCTION

1.1 Background

During the drought conditions of 2001, irrigation water was severely restricted in the Klamath Basin. In order to explore alternative sources for irrigation water, the Oregon Department of Water Resources provided limited funding to the individual irrigation districts for exploratory/production wells and/or geophysical investigations.

Figure 1 shows the location of the Klamath Drainage District (KDD) which comprises approximately 100 km^2 (40 sq. miles) in the Lower Klamath Lake Basin. The KDD embarked upon a three part program of geophysical exploration. Part 1 was a ground magnetic survey, conducted by Geopotential of Gresham, Oregon in December of 2001. Part 2, reported on in this document, is a gravity survey covering the northern portion of the District. Part 3 is a seismic reflection survey, for which field work was completed in May 2002 by Cooksley Geophysical of Reading, California.

In the surrounding basins, irrigation wells generally produce from the fractured fault zones in the "basement" basalts (personal communications, M. Jenks). Hence, the objective of the geophysical investigations in to map those subsurface fault zones.

1.2 Utility of Gravity Surveys

Gravimetric surveys measure the changes in the gravitational attraction of the earth. More dense rocks (e.g. basalts) have a greater mass, and therefore a greater gravitational attraction, than less dense rocks (e.g. lake bottom sediments and basin fill). Hence, the gravimetric data allows us to ~~the~~ make inferences about the density distribution of near-surface rocks and the distribution of near-surface rock types.

Our geologic concept of the Lower Klamath Lake Basin is that of a graben, or down-dropped fault block, or fault blocks. The basin is bordered on the east by the Klamath Hills, and on the west by the Cascade foot hills. As the central basin was formed by successive motion on the bounding faults, the resulting "graben" was filled with sediments from the surrounding hills and from Lower Klamath Lake which formed in the graben. Sediments filling the basin are generally less dense than the surrounding basalts and older sedimentary "basement" rocks.

If we know the densities of the basin sediments and the densities of the basement rocks, we can calculate the thickness of sediments, or the depth of the basin, required to produce the observed gravity response across the basin. We can also estimate the location of the bounding faults which form the basin. There may be a series of faults on each side of the basin rather than a single fault.

2 FIELD SURVEY

Geophysical field work was carried out on March 7 through 14, 2002. Data were acquired along the irrigation levees throughout the area at a nominal interval of 500 meters (1,500 feet). The survey area was bounded by Township Road on the south, Lower Klamath Lake Road on the northeast, and US Highway 97 on the west.

Figure 2 shows the locations of all gravity stations acquired during this survey. The cover photo shows the field crew operating the gravimeter (seated) and the GPS rover unit (standing).

2.1 Gravity Data Acquisition

NGA utilized a Scintrex CG-3 automated gravity meter for the KDD survey. This meter has a "reading resolution" of 0.01 milliGal (mGal) and a "standard deviation of measurements from the mean" of 0.05 mGal using normal procedures. The instrument automatically integrates the signal over time, using spike noise rejection filters, to obtain ~~the~~ a mean and standard deviation for each station. The instrument makes automatic corrections for instrument tilt, temperature, and earth tides.

Measurement statistics, repeat station statistics, and terrain correction accuracy indicate that an accuracy of 0.1 mGal was reached or exceeded throughout the survey.

2.2 Survey Control

Survey control, horizontal and vertical position, was obtained using a Trimble Real-Time Kinematic (RTK) GPS system. The RTK system provided vertical control to within 3 cm and horizontal control to within 2 cm.

Location control was taken from the National Geodetic Survey benchmark (Midland 2, NY0735) adjacent to the pumphouse 150 m (500 feet) NE of the corner of highway US 97 and North Cross Road, approximately 300 m (1000 feet) south of the Midland rest area on US97. Two temporary GPS base stations with a radio link to the rover unit were utilized during the survey (see Figure 2). The base station provides a real time differential correction over the radio link to the rover unit to provide the centimeter accuracy. One of the temporary base stations was at the north end of the Rangeline Drain. The second temporary base station was on the east side of the Klamath Strait 100 m (300 feet) north of the Bureau of Reclamation pump station.

3 DATA PROCESSING

The following corrections have been made to the observed gravity data:

1. earth tide correction
2. instrumental drift correction (from loop closure)
3. latitude correction including spheroid and centrifugal effects (theoretical gravity)
4. free air (elevation) effect
5. simple Bouguer correction (density 2.45 gm/cm^3; "infinite slab")
6. Complete Bouguer correction (terrain effects)

Reduced data are available in digital form from NGA.

Gravity data processing was carried out using the Geosoft OASISmontaj gravity processing software. The corrections are discussed below:

3.1 Earth Tides

Earth tides are the deformation of the solid earth in response to the gravitational forces of the moon and the sun. Like the ocean tides they have periods of approximately 12 hours and 24 hours. Solid earth tides are much more predictable than the ocean tides.

Theoretical values for the earth tides, given the date, time, latitude and longitude, are calculated by the microprocessor contained in the CG-3 gravimeter, and the appropriate correction is made to the data. Earth tide displacements can be up to 10 cm. (Sheriff, 1984). The gravity corrections applied for this survey were up to 0.1 mGal.

Tide corrections used for the final data compilation were calculated and applied in the OASISmontaj processing using algorithms from the Dominion Observatory of Canada.

3.2 Instrument Drift

Instrument drift is corrected for assuming a linear drift over time, between the previous base station reading and the subsequent base station reading. Base station readings were taken at the beginning and at the end of each survey day.

3.3 Theoretical Geoid

"Theoretical Geoid" takes into account the shape of the earth (a flattened oblate ellipsoid) and includes the latitude effect and the effect of centrifugal force. Geoid calculations were carried out and applied in the OASISmontaj processing using the 1967 gravity formula:

$$g_l = 978031.846 \cdot [\ 1+0.005278895\sin^2(l)-0.000023462\sin^4(l)\ ]$$

where:

g_l theoretical gravity in mGal (latitude correction) and

l latitude of the station.

3.4 Free Air Correction

This correction is made for the differences in distance of the observation points from the center of the mass of the earth. Free air corrections were calculated and applied in the OASISmontaj processing using the formula:

$$g_f = 0.308596 \cdot h_s$$

where:

g_f free air correction in mGal, and

h_s station elevation in meters.

The free air anomaly is:

$$g_{fa} = g_{obs} - g_l + g_f$$

where:

g_{fa} free air gravity anomaly,

g_{obs} observed gravity (tide and drift corrected), and

g_l theoretical gravity in mGal (sect 3.3).

3.5 Simple Bouguer Correction

The simple Bouguer correction accounts for the attraction of the mass of rock between the station elevation and the datum (mean sea level). That mass is assumed to have a density equal to a chosen "Bouguer correction density". This correction should remove or reduce elevation effects in the data.

The Bouguer correction density of 2.45 gm/cm3 was selected on the basis of previous studies (Veen, 1981).

The Bouguer anomaly calculations were carried out and applied in the OASISmontaj processing using the formula:

$$g_{ba} = g_{fa} - 0.0419088\ (\rho \cdot h_s)$$

where:

g_{ba} Bouguer anomaly in mGal,

g_{fa} Free air anomaly (sect. 3.4),

ρ Bouguer density of rock in g/cm^3 (2.45 gm/cm^3 for this survey),

h_s station elevation in meters.

Simple Bouguer terrain correction was calculated and applied in the OASISmontaj processing.

3.6 Complete Bouguer Correction

The complete Bouguer or terrain correction accounts for the topography of the land surface, and variations from the horizontal slab which is assumed for the simple Bouguer correction.

For this survey a digital topographic database from the U.S. Geological Survey (http://edcwww.cr.usgs.gov/Webglis/glisbin/glismain.pl) was used. The digital elevation model (DEM), with a 10 m cell size was used for the topography in Oregon, and a 30 m grid was used for California. Beyond approximately 100 km, a 1 km topography grid from the USGS (http://www.ngdc.noaa.gov/seg/topo/globe.shtml) was utilized. The terrain correction included topography up to 250 m from the survey area. Geosoft OASISmontaj™ gravity reduction suite was used to calculate the terrain correction.

3.7 Near field Terrain Correction

Additional manual, near-zone terrain corrections were made for a dozen stations where there was significant topographic relief within 50 m of the station. These corrections were calculated from field notes made at the time of the survey. Near field corrections were generally less than 0.1 mGal.

4 ADDITIONAL GEOPHYSICAL AND GEOLOGIC DATA

4.1 Geologic Information

Geologic information for the structure of the Lower Klamath Lake Basin is minimal. The entire basin is covered with Quaternary lake sediments from the former Lower Klamath Lake.

Reconnaissance geologic mapping was carried out in the early 1990's and reported by Sherrod and Pickthorn, *Geologic map ot the west half of the Klamath Falls 1° by 2° quadrangle, south-central Oregon* (1992). Their mapping shows the Klamath Hills as a combination of Tertiary basalts and continental sedimentary rocks. They reported Hamaker Mountain and the hills to the west of the basin as Tertiary basalts. Presumably, basement, beneath the Quaternary basin deposits, is also Tertiary basalt and possibly continential sedimentary rock.

There are numerous water wells along the edge of the Klamath Hills. These are generally shallow wells, some of which encountered basalt in the first 300 feet. Generally, our models are consistent with this information but are not detailed enough to include individual wells. There are no deep wells in the center of the basin.

We also acknowledge Margaret Jenks, contract geologist for the Oregon Department of Geology and Mineral Industries (DOGAMI), for her numerous conversations concerning the geology of the Klamath Basin.

4.2 Regional Gravity Data

Regional gravity data available from the NOAA, National Geophysical Data Center, (Hittelman et al., 1992) was integrated with the KDD gravity data to provide a regional gravity framework in the areas surrounding the KDD survey. The regional data is a compilation of gravity data from several sources, including the work of Couch, et al. (1981b).

4.3 Terramagnetic Data

Geopotential, of Gresham, Oregon, collected ground magnetic data under contract to the Klamath Drainage District in December of 2001. Results of that survey are presented in two reports, *Terramagnetic survey; acquisition and processing,* (Geopotential, 2002a) and *Terramagnetic survey; integrated interpretation* (Geopotential, 2002b).

The terramagnetic data was collected using a sensor on a 10 foot boom mounted behind a Chevrolet Blazer. Profiles, nominally spaced 250 meters apart, were acquired in the east-west direction in order to reduce heading error. Geopotential reports a noise level/repeatability of approximately 25 nT.

We have shown an edited version of the Geopotential data in Figure 7. We have regridded that data for display on a basemap consistent with the gravity display.

5 RESULTS AND INTERPRETATION

Figure 2 is a gravity station location base map at the scale of 1:100,000, to provide location reference. Locations of the modeled cross sections A, B, and C are also shown, as are the locations of the seismic lines shot by Cooksley Geophysical in May 2002.

5.1 Bouguer Gravity Map

Figure 3 is the final Bouguer Gravity map. In the detailed area of our March 2002 survey, we show the Bouguer Gravity field as obtained from that survey. In order to extend the regional shape of the gravity field outside our survey area, we have incorporated regional gravity data available from the USGS (Hittelman, et al., 1992) discussed in section 4.2 above. Regional data includes all gravity data south of Township Road and east of Lower Klamath Lake Road.

There is an excellent fit between our data and the regional data set in the region of overlap. The misfit was a maximum of 3 milliGals, (mGal) and generally less than 1 mGal. At each of the regional stations within the NGA survey area, the misfit could be accounted for in differences in station location and elevation determination, since the regional dataset locations were generally scaled off the topo sheets, whereas NGA locations were surveyed using the differential GPS (±3 cm). In the areas of overlap the regional was removed from that data set. There was no coherent trend or offset between the March 2002 data set and the regional dataset, hence no adjustments were made prior to merging the two.

5.2 Gravity Models

Three gravity models (interpreted cross sections) are shown in Figures 4, 5, and 6. The basic procedure for the modeling was generally to model the overall thickness of sediments from the gravity data, and then assign a magnetization (induced and remanent) to the basement rock to best fit the magnetic data.

5.2.1 Thickness of Sediments

Gravity and magnetics both can be used to estimate the thickness of sediments in the basin. Both techniques can provide the form, or shape, of the basin. However, without additional well control or geologic constraints ~~and~~, they can only provide an estimate of absolute depth. (With known densities, the absolute depth could be calculated or with deep well control the absolute depth could be "calibrated" to the wells.) When both normal and reversely magnetized flows are present, the magnetic response can be very complex, making ~~of~~ the thickness of sediments more difficult to resolve with magnetics.

5.2.2 Rock Types and Stratigraphy

For the gravity models we have divided rocks into three types:

Dense basement rocks: This probably includes a sequence of volcanic basalts, and continental sedimentary rocks of Pliocene and Miocene age (5-24 million years before present) (Sherrod & Pickthorn, 1992). The gravity technique cannot resolve individual units or flows within this section. In the models, the section is shown as one massive unit, although it contains many flows and probably interbeded sedimentary layers. We have used a density of 2.69-2.70 gm/cm^3 for these rocks which is a typical value for Tertiary basalts of the Pacific Northwest based on our previous work in the Northwest and density logs from Meyer and Price (1983).

We know from the regional geology that the Tertiary basalts contain flows with both normal and reversed magnetization (Connard, et al., 1983). Hence, we have utilized rock units of both magnetizations to model the magnetics from Geopotential's terramagnetic survey.

Basin sediments: These are mostly lacustrian (lake bottom) sediments, deposited as the Lower Klamath Lake graben formed. As these sediments have not undergone extreme compaction and consolidation these units are less dense than the basement rocks. There are certain to be variations within this section, with density increasing with depth. However, in the absence of additional well control or geologic information, we have modeled this as a single unit with a density of 2.25 gm/cm^3.

Shallow basalt flows: In the southern Oregon portion of the basin, south of township road, we have introduced several volcanic "flows" to the section. In this area, the regional gravity data indicates a thick sequence of basin sediments. However, the strong magnetic response and the short wavelength (i.e., rapidly changing over short distances) of the magnetics indicates that magnetic rocks (basalts) are relatively close to the surface. A shallow basalt flow(s) with a thick underlying sedimentary section fits both the gravity and magnetic data.

We have not attempted to model the magnetics closely over these shallow flows because the models tend to be non-unique and it is likely that some of the short wavelength anomalies are due to "cultural" (i.e., non-geologic) sources. Furthermore, the shallow basalts in that area are not of interest for groundwater production.

5.2.3 Fault Locations

Faults are identified on the models as a steeply dipping contact between the dense basement rocks and the basin sediments. The faults continue into the basement rocks. However, within the basement rocks, there may be no density contrast across the fault, and hence the gravity signature of the fault arises from the steep contact between the basement and the basin sediments. If the fault offsets basalts with differing magnetic properties there may be an additional magnetic response from the fault in the basement section.

In many instances we have drawn a line through the basement rocks in the modeled profiles where we expect a fault to occur on the basis of the steeply dipping contact in the shallower section. The fault traces within the basement section are not well constrained.

5.3 Fault Trend Analysis

5.3.1 Technical Approach

Trends or horizontal lineaments in the gridded gravity data were analyzed using the "Boundary" method of the USGS (Cordell and Grauch, 1985; Blakely and Simpson, 1986). That technique looks for lineaments where the horizontal gradient of the gravity field is a maximum, i.e. where the gravity field is changing most rapidly.

The vertical offset along faults forms a zone of transition between the deeper basement and the more shallow basement. The gravity response will transition from a gravity low over the deep basement (thick sediments) to a gravity high over the shallow basement (thin sediments). By nature, the gravity and magnetic transition will be spread over some horizontal distance, with the sharpness of the transition depending on the depth of the geologic feature.

In order to quantify and automate the selection of possible fault trends, the Boundary technique calculates the horizontal gradient at each grid node and plots a "peaks" where maximums occur. Linear trends in those "peaks" may be interpreted as fault trends with a vertical offset. We have utilized the Geosoft/NGA implementation of the Boundary technique.

5.3.2 Fault Trend Interpretation

Figures 8 & 9 show our interpreted fault trends overlain on the boundary peak picks. Figures 8 & 9 also show gravity and magnetic contours respectively.

We have highlighted only the major, and most evident faults. Undoubtedly there are additional faults, as evidenced by additional linear trends in the Boundary peaks. However, with the thresholds set too low, the boundary analysis will also pick noise in the data and artifacts of the gridding algorithm. Hence, we have erred on the conservative side in interpreting fault locations.

We have shown our fault interpretation of the magnetic data acquired by Geopotential (2002). Our interpretation is considerably more conservative than that reported by Geopotential. South of Township Road the magnetic data indicates the presence of volcanic flows within the sedimentary section. Hence, south of Township Road, the boundary analysis will identify trends in those flows, and edges of those flows, masking the basement faults.

5.4 Depth-to-Basement Analysis

Figure 10 shows the depth to basement estimated using a simple 3D gravity model with the USGS software, GI3 (Cordell et al., 1992; Cordell and Henderson, 1968). This model assumes one density for the basin fill sediments, 2.25 gm/cm^3, and one density for basement rocks, 2.69 gm/cm^3, for a density contrast of 0.44 gm/cm^3. The program adjusts the model depth-to-basement until the calculated gravity for the geologic model best fits the observed gravity field. Depth to basement was calculated on a grid spacing of 400 meters. That grid spacing is appropriate for the resolution we may expect from the dataset.

This interpretation is poorly constrained since we do not know the rock densities, or have any independent depth-to-basement information (e.g., wells encountering basement) in the center of the basin. However, the form of the basin (the positions and relative magnitudes of the peaks and valleys) is likely to be accurate although the absolute depth may be in error.

6 INTERPRETATION SUMMARY

The geophysical program, using both gravity and magnetics, has identified several fault trends within the Lower Klamath Lake Basin. It has also provided the basic form of the basin, although absolute depths are less certain.

The eastern bounding fault is a well defined structure running along the western flank of the Klamath Hills. Gravity data indicates that this fault may have as much as 1 km (3,000 ft.) of vertical throw in the south and perhaps somewhat less in the north.

The western bounding fault is far less evident. Usually the two faults bounding a graben are roughly parallel. There is some evidence in the magnetics and gravity for a fault passing between the town of Worden and Zuckerman Island and extending on the north side of Pearson Butte. If that is the major fault location, it intersects the corner of the gravity survey area, and is not defined in that data. A trend is present in the magnetics at this location, but is masked further south by shallow basaltic flows in the vicinity of Skull Island.

Zuckerman Island is a gravity high, indicating that is a horst block, an up thrown fault block within the graben. The strong magnetic low on the north side of the fault block would suggest the presence of reversed flows within the horst complex.

The gravity data in the northern part of the KDD, between Zuckerman Island on the southwest and the extension of the Klamath Hills on the northeast, indicates the bifurcation of the graben structure, with two lows on either side of a central horst block This central horst can be seen in Profile B, Figure 5. The bifurcation is consistent with the magnetic data, although it is much better defined in the gravity data. The magnetic data would suggest the presence of some reversed flows, as indicated in Profile B.

A strong east-west trend is evident in the gravity data passing south of Captain Jack in the Klamath Hills extending across the basin and passing south of Zuckerman Island. This lineament separates the shallow, bifurcated basin to the north and northwest from the deep basin to the south.

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8 CLOSURE

Northwest Geophysical Associates, Inc. has performed this work in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions. No warranty, express or implied, beyond exercise of reasonable care and professional diligence, is made. This report is intended for use only in accordance with the purposes of the study described within.

We thank you for the opportunity to work with the Klamath Drainage District on this project and trust that the information obtained will aid in the siting of productive irrigation wells.

Yours truly,

Northwest Geophysical Associates, Inc.

Rowland B. French, R.G.
Vice President

Gerald G. Connard, R.G.
President

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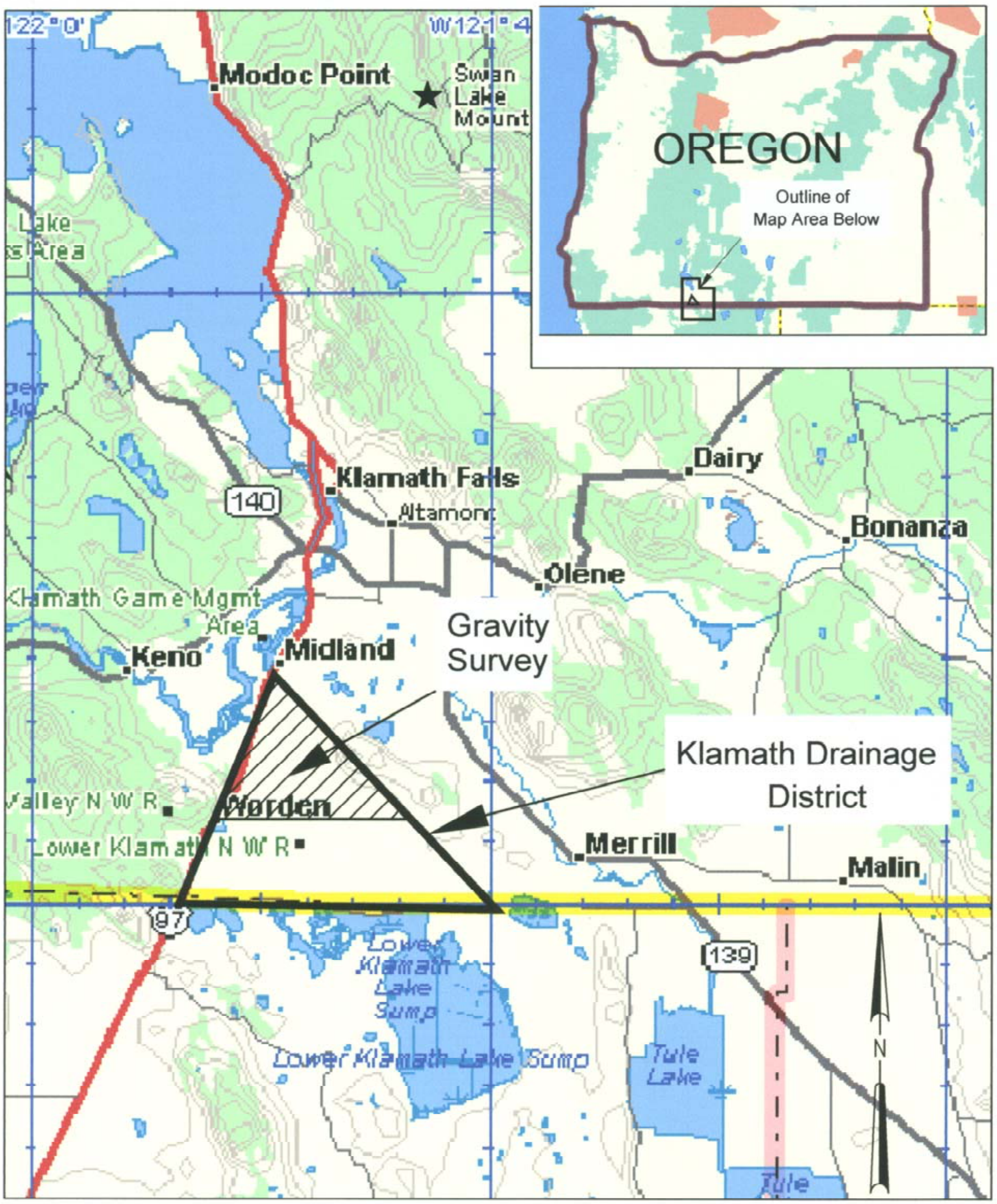

from: DeLORME 3D TopoQuads

FIGURE 1

SITE LOCATION MAP

Gravity Survey
Groundwater Investigation
Lower Klamath Lake Basin
Klamath County, Oregon

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Prepared for:

Klamath Drainage District

NGA Project #: 517 FILE: Klamath_LOCATION.dwg DATE: March 2002 REVISION: B-21-MAY-02

LEGEND

NGA GRAVITY STATION

REGIONAL GRAVITY STATION

GPS BASE STATION

PROFILE B — LOCATION OF MODELED PROFILE

SEISMIC LINE LOCATION

FIGURE 2

GRAVITY STATION LOCATIONS

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Lower Klamath Lake Basin
Klamath County, Oregon

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Northwest Geophysical Associates, Inc.

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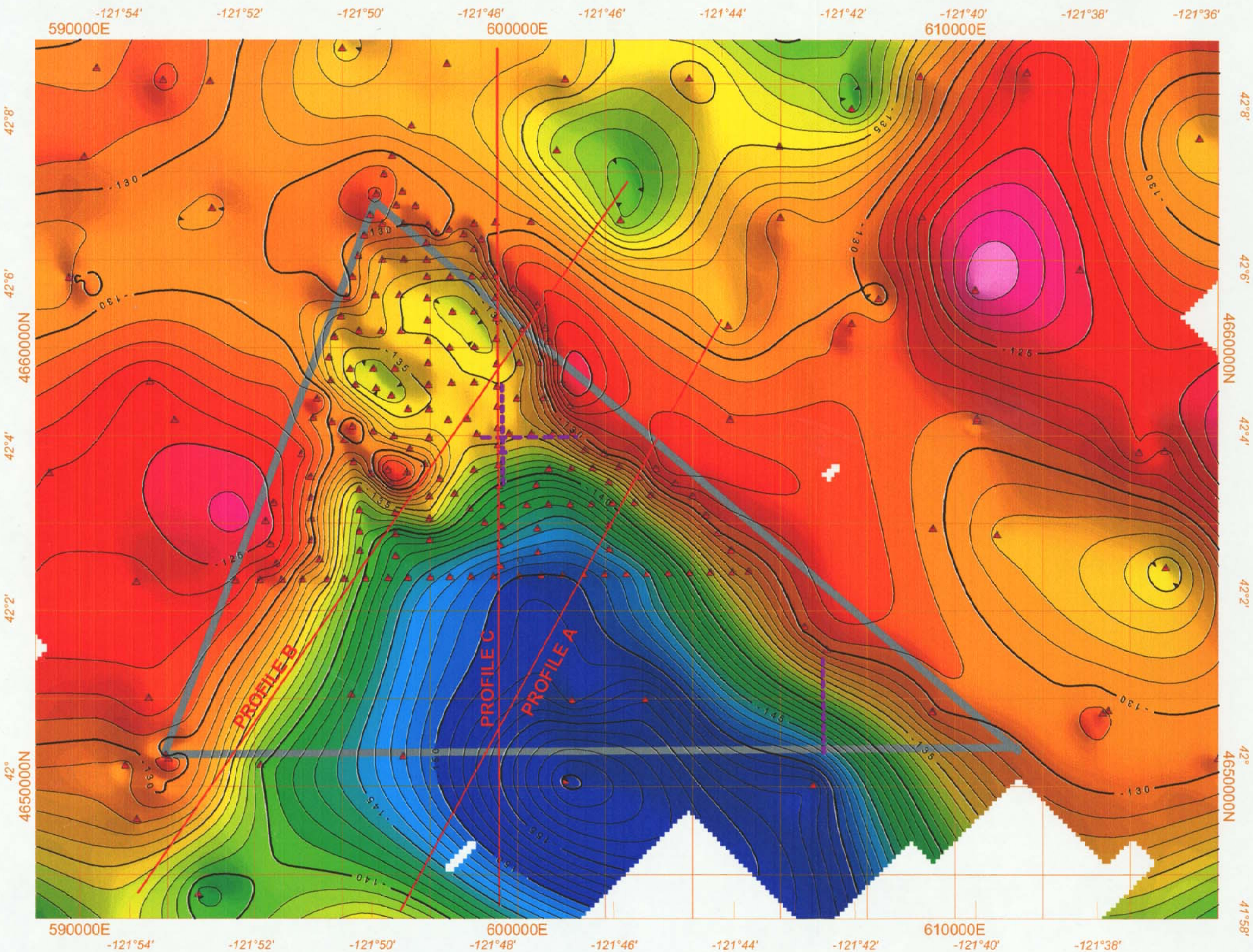
Klamath Drainage District

NGA PROJECT #: 517; Klamath FILENAME: KDD5_CB245.map DATE: MARCH 2002 REVISION: E-24-MAY-02



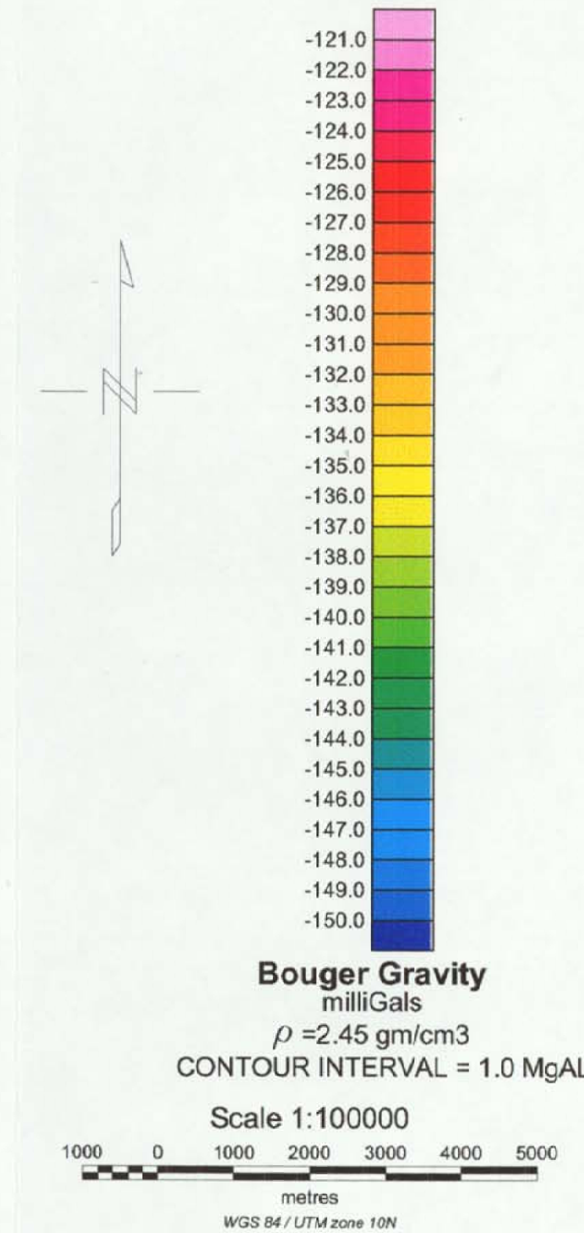


FIGURE 3

BOUGER GRAVITY CONTOUR PLOT

Gravity Survey
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Lower Klamath Lake Basin
Klamath County, Oregon

LEGEND
SEE FIGURE 2

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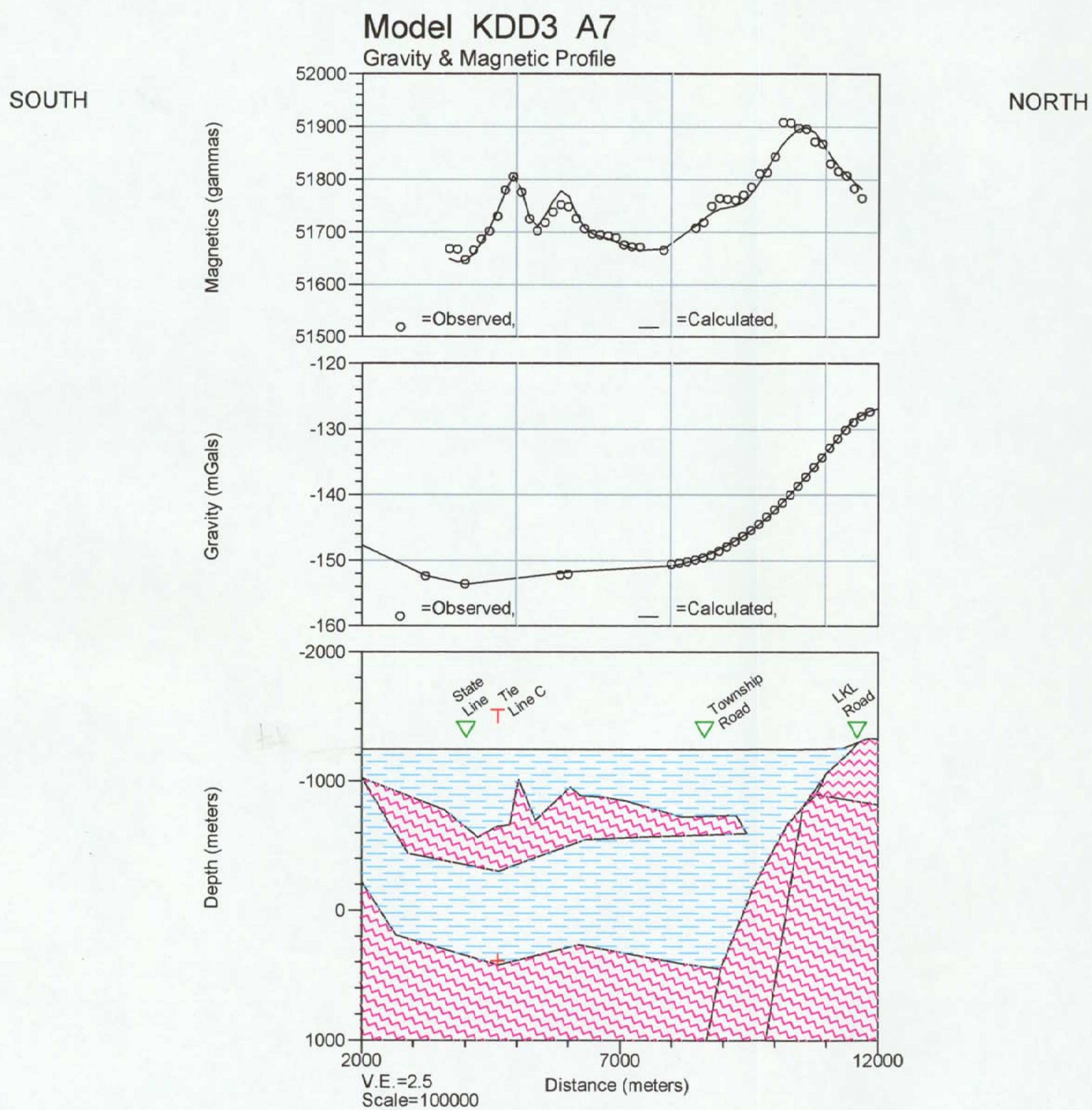

LEGEND

Basin Sediments
ρ=2.25 gm/cc
Non-Magnetic

Basement Rocks
Tertiary Basalts, Volcanics, & Sedimentary Rocks
ρ=2.69-2.70 gm/cc

Minimal Magnetization
susc. <0.001 cgs

Normal Magnetization
susc. =0.001 - 0.003 cgs
MI = 0.0 - 0.003 emu/cc

Reverse Magnetization
susc. =0.001 - 0.003 cgs
MI = 0.0 - 0.003 emu/cc

ρ= density
susc. = magnetic susceptibility
MI = remanent magnetization intensity

FIGURE 4

GRAVITY MODEL A

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Klamath County, Oregon

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Klamath Drainage District

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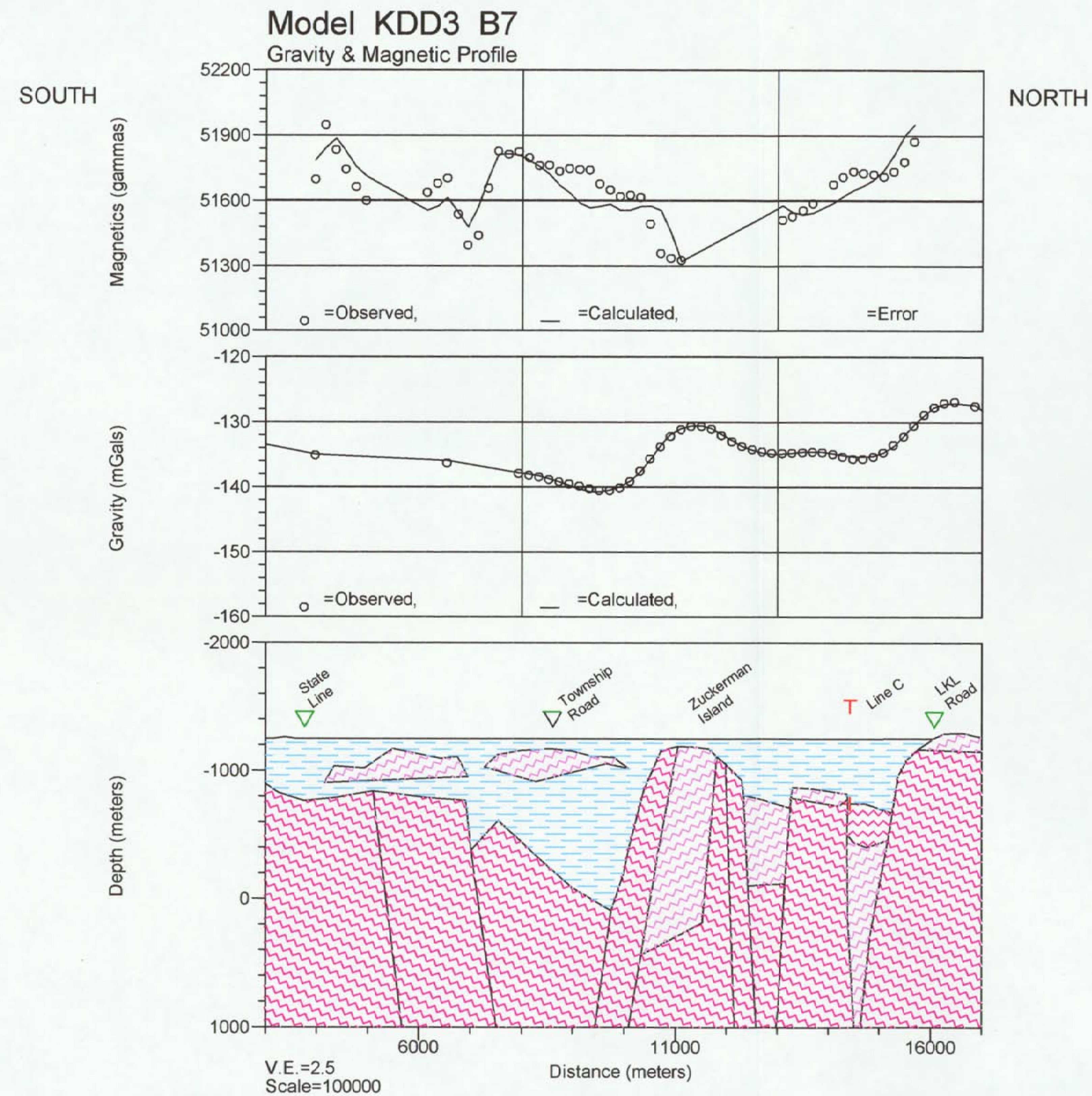


LEGEND

Basin Sediments
ρ=2.25 gm/cc
Non-Magnetic

Basement Rocks
Tertiary Basalts, Volcanics, & Sedimentary Rocks
ρ=2.69-2.70 gm/cc

Minimal Magnetization
susc. <0.001 cgs

Normal Magnetization
susc. =0.001 - 0.003 cgs
MI = 0.0 - 0.003 emu/cc

Reverse Magnetization
susc. =0.001 - 0.003 cgs
MI = 0.0 - 0.003 emu/cc

ρ= density
susc. = magnetic susceptibility
MI = remanent magnetization intensity

FIGURE 5

GRAVITY MODEL B

Klamath Drainage District
Gravity Survey
Groundwater Investigation
Klamath Basin, Oregon

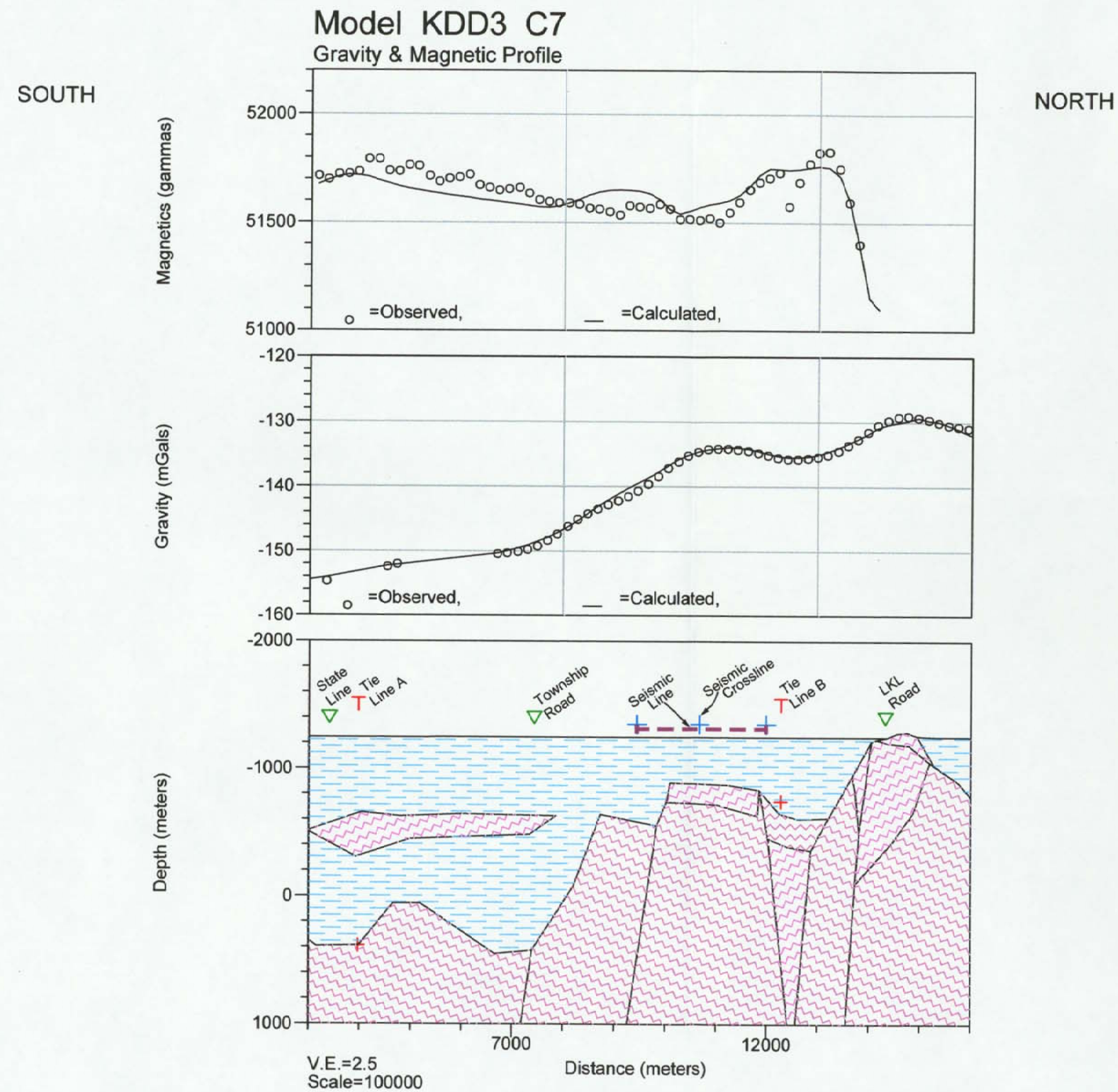
Prepared by:
Northwest Geophysical Associates, Inc.
P.O. Box 1063, Corvallis, Oregon 97339

Prepared For:
Klamath Drainage District

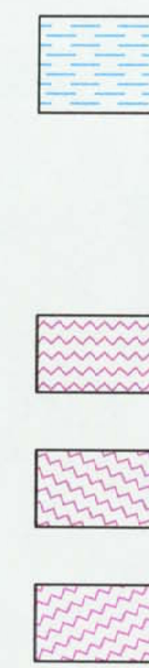
NGA PROJECT #: 517 FILE: KDD3_C7.DWG DATE: March 2002 REVISION: D-27-MAY-02

Model KDD3 C7

Gravity & Magnetic Profile



LEGEND



Basin Sediments
ρ=2.25 gm/cc
Non-Magnetic

Basement Rocks
Tertiary Basalts, Volcanics, & Sedimentary Rocks
ρ=2.69-2.70 gm/cc

Minimal Magnetization
susc. <0.001 cgs

Normal Magnetization
susc. =0.001 - 0.003 cgs
MI = 0.0 - 0.003 emu/cc

Reverse Magnetization
susc. =0.001 - 0.003 cgs
MI = 0.0 - 0.003 emu/cc

ρ= density
susc. = magnetic susceptibility
MI = remanent magnetization intensity

FIGURE 6

GRAVITY MODEL C

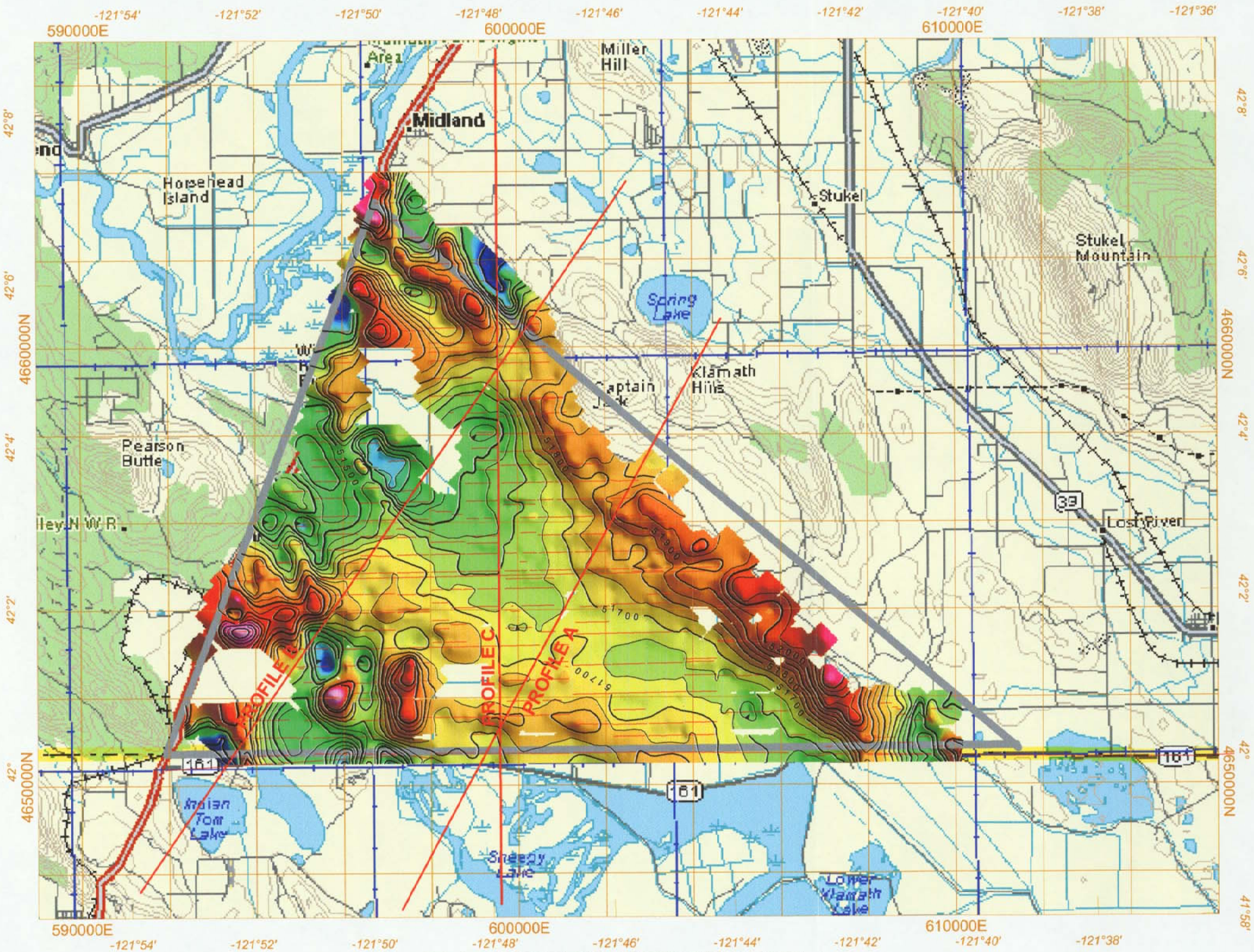
Klamath Drainage District
Gravity Survey
Groundwater Investigation
Klamath Basin, Oregon

Prepared by:
Northwest Geophysical Associates, Inc.
P.O. Box 1063, Corvallis, Oregon 97339

Prepared For:

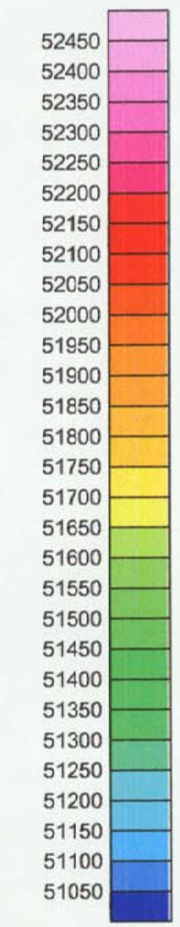
Klamath Drainage District

NGA PROJECT #: Klamath FILENAME: KDD5_Mag30.map DATE: MARCH 2002 REVISION: G-24-MAY-02



Data from: GEOPOTENTIAL TERRAMAGNETIC SURVEY
Acquired DECEMBER 2001
Edited and replotted by NGA, Inc., March 2002

Scale 1:100000
1000 0 1000 2000 3000 4000 5000
metres
WGS 84 / UTM zone 10N



Total Magnetic Field
nanoTesla

CONTOUR INTERVAL: 50 nT

LEGEND

Terramagnetic Data Line Location

GRID: MAG30_SM05
COLORZONE: LINEAR50.itr

FIGURE 7

TOTAL MAGNETIC INTENSITY MAP

Geopotential Magnetic Data
Groundwater Investigation
Lower Klamath Lake Basin
Klamath County, Oregon

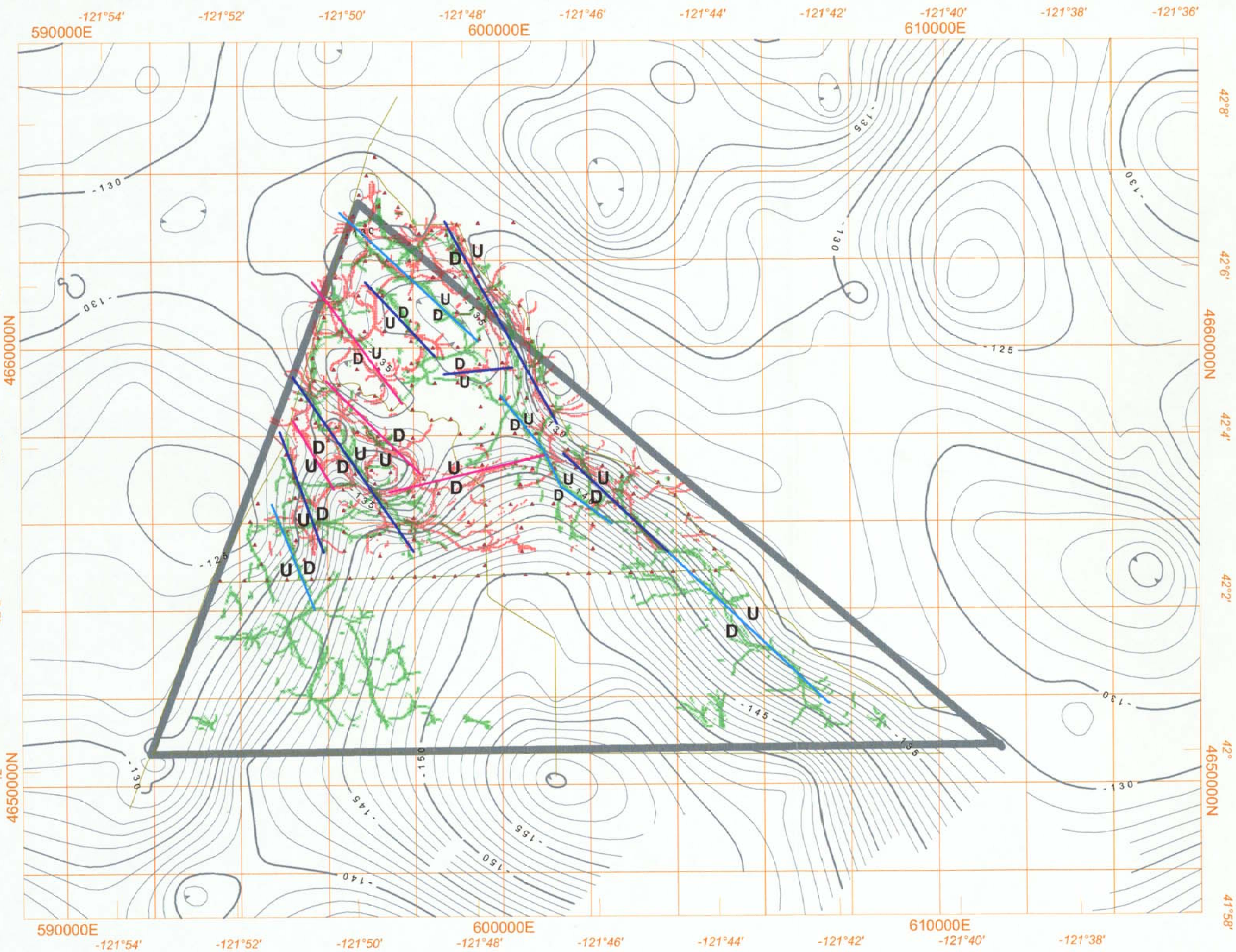
Prepared By:

Northwest Geophysical Associates, Inc.

Prepared For:

Klamath Drainage District

NGA PROJECT #: 517; Klamath FILENAME: KDD5_Boundary.map DATE: MARCH 2002 REVISION: C-24-MAY-02



LEGEND

INTERPRETED FAULT LOCATIONS

GRAVITY
MAGNETICS
BOTH GRAVITY & MAGNETICS

U UP THROWN BLOCK
D DOWN THROWN BLOCK

"BOUNDARY PEAKS"
(MAXIMUM HORIZONTAL GRADIENT)
GRAVITY (RED)
MAGNETICS (GREEN)

BOUGUER GRAVITY CONTOURS
CONTOUR INTERVAL: 1.0 mGal

Scale 1:100000

1000 0 1000 2000 3000 4000 5000
metres
WGS 84 / UTM zone 10N

Prepared By:
Northwest Geophysical Associates, Inc.

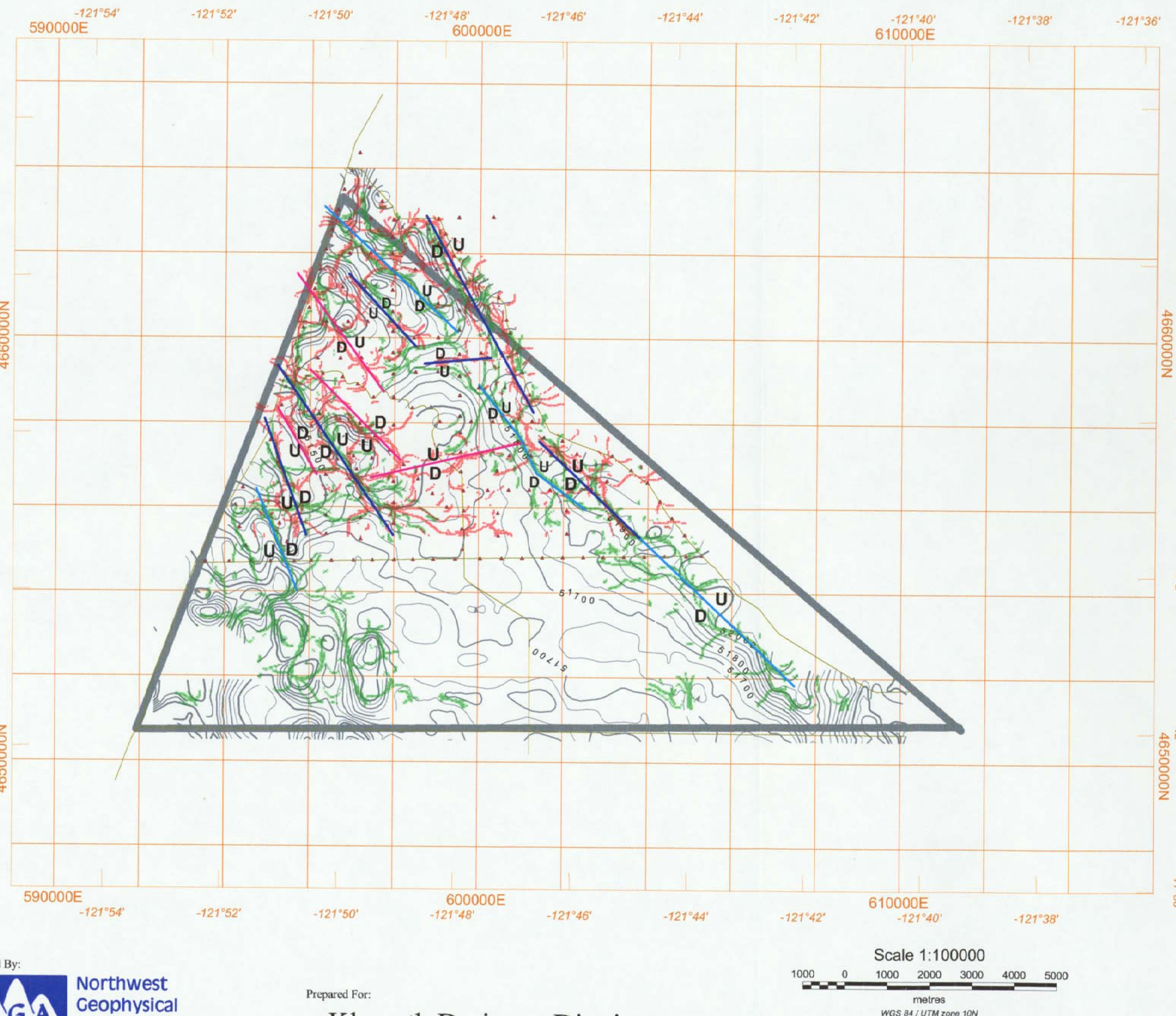
Prepared For:
Klamath Drainage District

FIGURE 8

BOUNDARY PEAK LOCATIONS WITH GRAVITY CONTOURS

Gravity Survey
Groundwater Investigation
Lower Klamath Lake Basin
Klamath County, Oregon

NGA PROJECT #: 517; Klamath FILENAME: KDD5_Boundary_Mag.map DATE: MARCH 2002 REVISION: F-24-MAY-02



LEGEND

INTERPRETED FAULT LOCATIONS

GRAVITY
MAGNETICS
BOTH GRAVITY & MAGNETICS
U UP THROWN BLOCK
D DOWN THROWN BLOCK

"BOUNDARY PEAKS"
(MAXIMUM HORIZONTAL GRADIENT)
GRAVITY (RED)
MAGNETICS (GREEN)

MAGNETIC FIELD CONTOURS
CONTOUR INTERVAL: 50 nT

Prepared By:
Northwest Geophysical Associates, Inc.

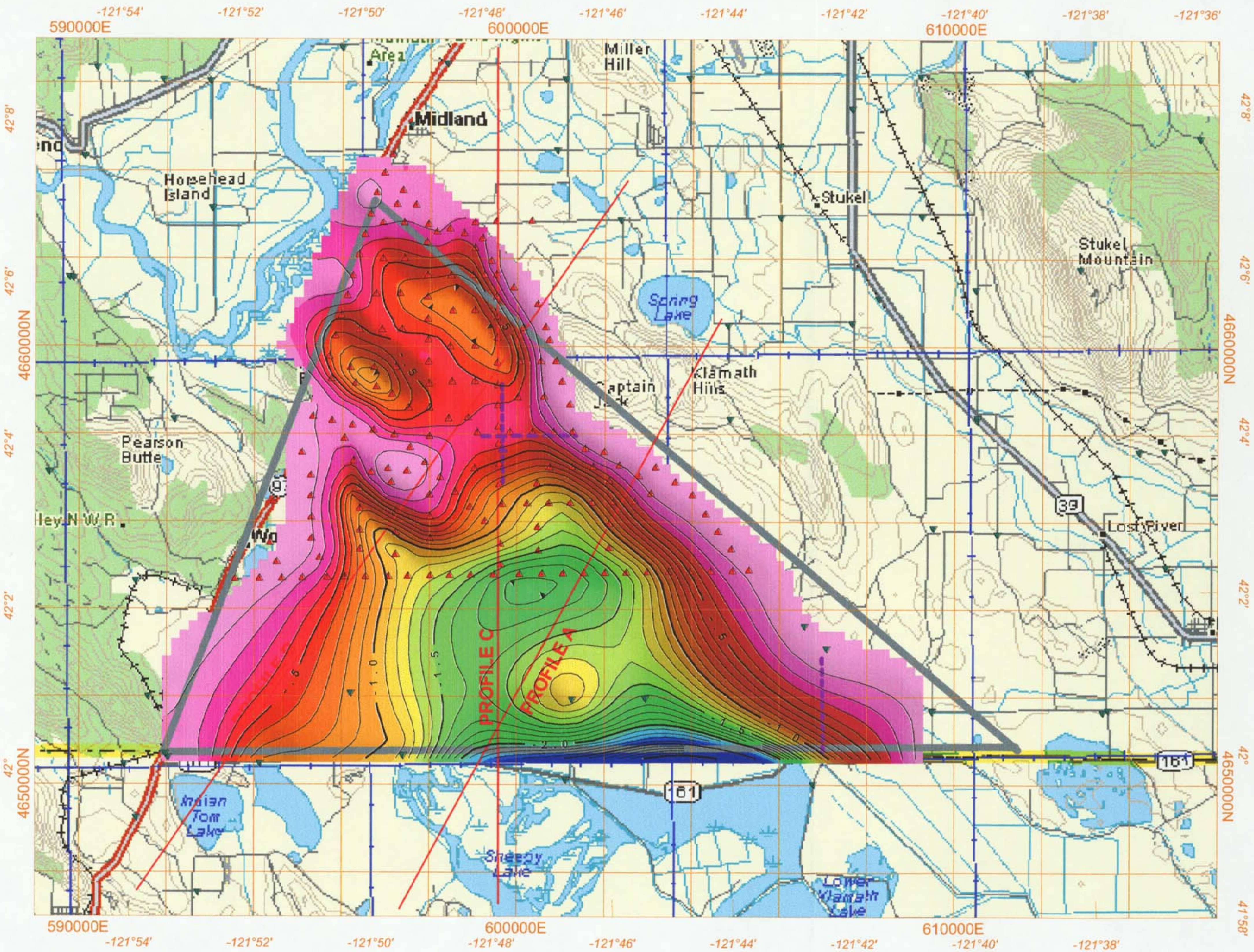
Prepared For:
Klamath Drainage District

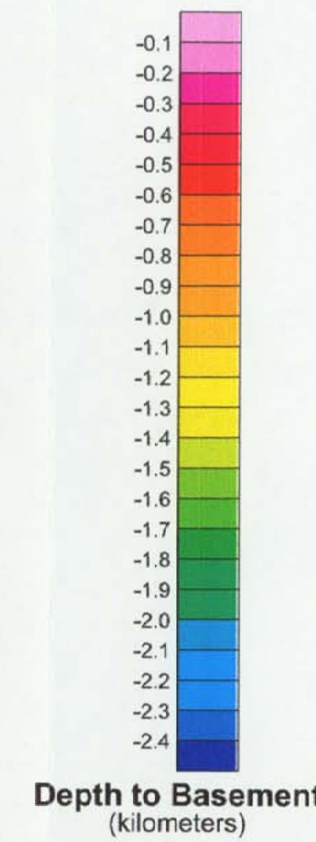
FIGURE 9

BOUNDARY PEAK LOCATIONS
WITH MAGNETIC FIELD CONTOURS

Gravity Survey
Groundwater Investigation
Lower Klamath Lake Basin
Klamath County, Oregon

NGA PROJECT #: 517; Klamath FILENAME: KDD5_D2Bx.map DATE: MARCH 2002 REVISION: E-24-MAY-02





Scale 1:100000

1000 0 1000 2000 3000 4000 5000

metres

WGS 84 / UTM zone 10N

Prepared By:

Northwest Geophysical Associates, Inc.

Prepared For:

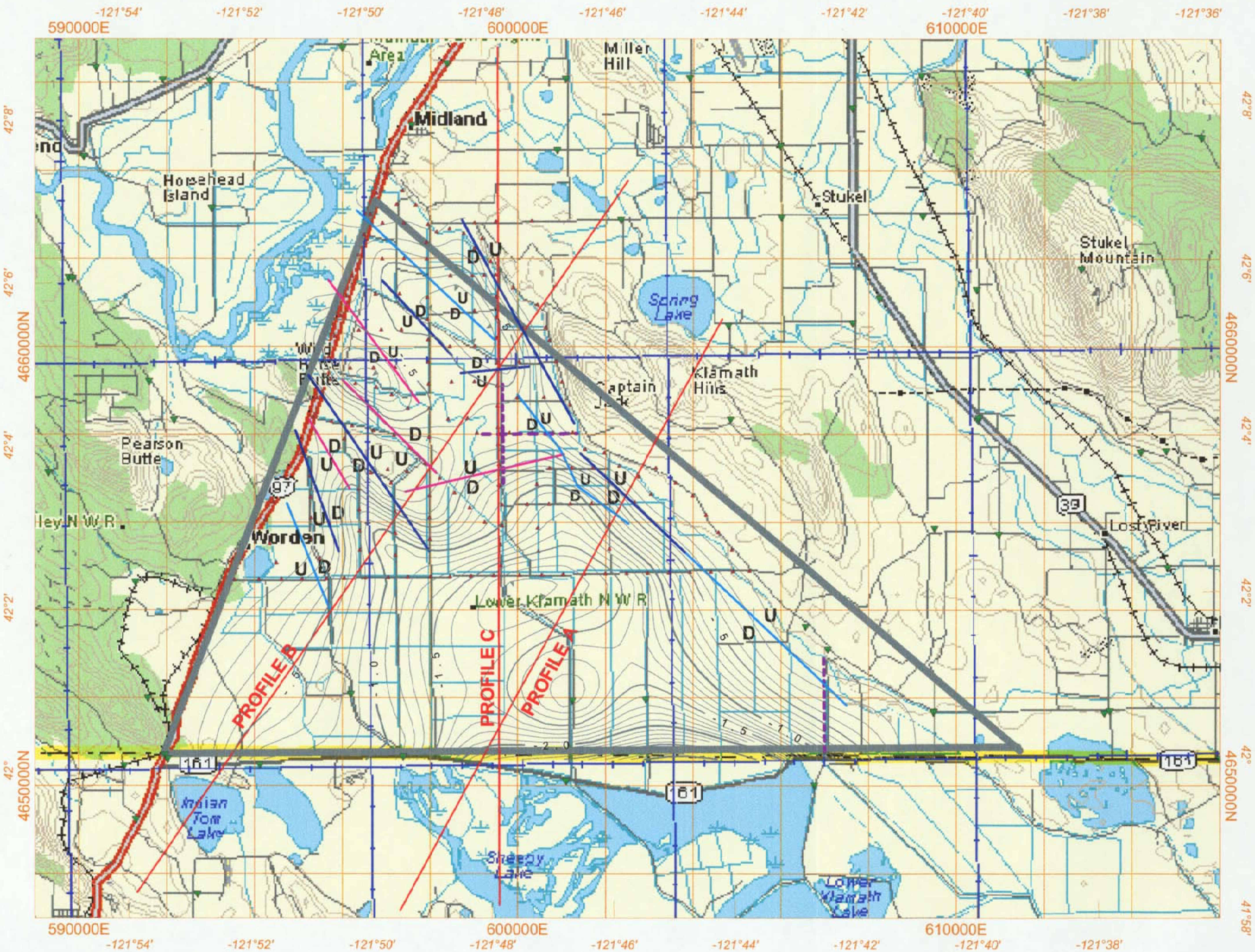
Klamath Drainage District

FIGURE 10

DEPTH TO BASEMENT

Gravity Survey
Groundwater Investigation
Lower Klamath Lake Basin
Klamath Conty, Oregon

NGA PROJECT #: 517; Klamath FILENAME: KDD5_Summary.map DATE: MARCH 2002 REVISION: C-24-MAY-02



LEGEND

INTERPRETED FAULT LOCATIONS
- GRAVITY
- MAGNETICS
- BOTH GRAVITY & MAGNETICS

DEPTH TO BASEMENT
CONTOUR INTERVAL 0.1 km (328 feet)

NGA GRAVITY STATION

REGIONAL GRAVITY STATION

PROFILE B — LOCATION OF MODELED PROFILE

SEISMIC LINE LOCATION

Scale 1:100000
1000 0 1000 2000 3000 4000 5000
metres
WGS 84 / UTM zone 10N

FIGURE 11

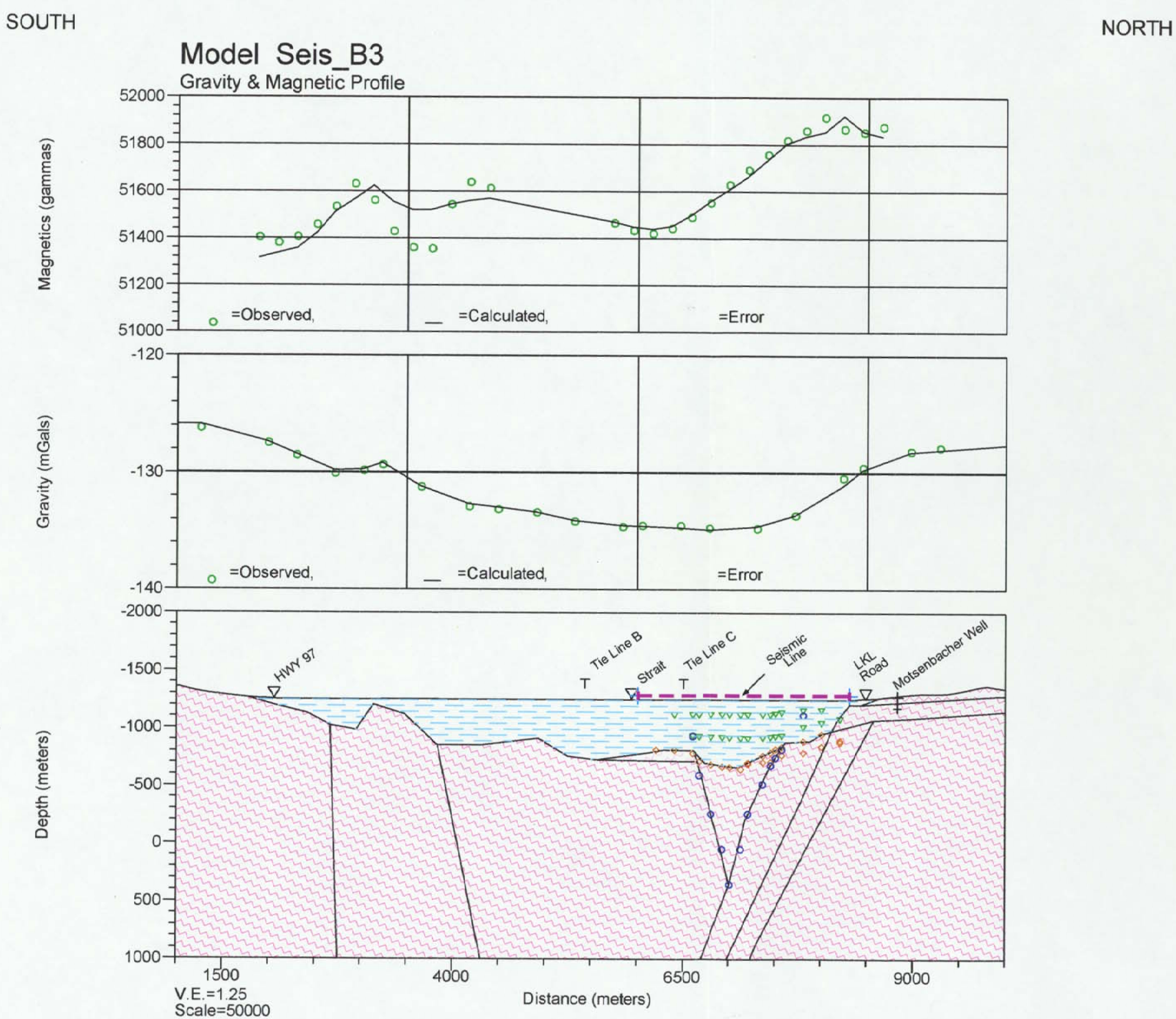
INTERPRETATION SUMMARY

Gravity Survey
Groundwater Investigation
Lower Klamath Lake Basin
Klamath County, Oregon

Prepared By:
Northwest Geophysical Associates, Inc.

Prepared For:
Klamath Drainage District

NGA PROJECT #: 517 FILE: KDD3_LINE_SEISB.DWG DATE: March 2002 REVISION: C-27-JUN-02



LEGEND

Basin Sediments
ρ=2.30 gm/cc
Non-Magnetic

Basement Rocks
Tertiary Basalts, Volcanics,
& Sedimentary Rocks
ρ=2.69-2.70 gm/cc

Minimal Magnetization
susc. <0.001 cgs

Normal Magnetization
susc. =0.001 - 0.003 cgs
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Reverse Magnetization
susc. =0.001 - 0.003 cgs
MI = 0.0 - 0.003 emu/cc

ρ= density
susc. = magnetic susceptibility
MI = remanent magnetization intensity

SEISMIC DEPTH INTERPRETATION

- Sedimentary horizon
- Volcanics horizon
- Fault

FIGURE A1

LINE SEIS B

Klamath Drainage District
Gravity Survey
Groundwater Investigation
Klamath Basin, Oregon

Prepared by:
Northwest Geophysical Associates, Inc.
P.O. Box 1063, Corvallis, Oregon 97339

Prepared For:

Klamath Drainage District