Qualitative Interpretation of Magnetic Anomalies and Progress Report on Geologic Mapping in the Foothills North of Eagle, Ada and Gem Counties, Idaho

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by

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MAGNETOMETER SURVEY

Summary: The survey clearly identifies a down-to-SW fault along Willow Creek Road (Fig.1), and width of the anomaly suggests the sediment section over volcanics is at least 3,000 feet deep (a surprisingly deep estimate, which if important, needs verification by more detailed survey and interpretation). The fault aligns with the NW extension of the previously identified West Boise – Eagle fault. Another major down-to-SW fault is identified near the mouth of Big Gulch, and crude estimate of thickness of sediment section over faulted volcanics is 2,300 to 4,600. Better definition of faulting on the M3 properties could be obtained by a long magnetometer line (14 km), along ridgetop roads between Willow Creek and Big Gulch, with close supervision of data quality.

Measurements: Data was acquired under the supervision of Dr. Paul Donaldson, mostly by graduate student Carlyle Miller.

The first data set was acquired in about June, 2006 as lines along Little Gulch and Big Gulch. The data set is generally of good quality with a noise level of ± 5 nanoTeslas (nT).

A second set of data was acquired later in the summer of 2006 along Willow Creek and Chaparral Road ("north line"), along the Farmers Union Canal ("south line"), an extension of the Big Gulch Line to the southwest, and a short line near Highway 16 between Big Gulch and Willow Creek (Figs. 2 and 3). This data set is quite noisy with a level of ± 15 nT, and many unexplained excursions exceeding 80 nT. It is likely that the magnetometer malfunctioned intermittently. The instrument was subsequently sent to Geometrics for repair by Lee Liberty, and a number of problems were repaired. However, the majority of measurements cluster along a trend, so that the larger anomalies were measured. Nevertheless, it is recommended that anomalies detected by the second data set be verified by running an additional line between Willow Creek and Big Gulch, along the ridge top roads through the northern M3 properties and as far SW and NE, as is possible on other lands. The fluctuation in altitude along such a line, greater than 20 m along such should be noted, but it is not likely to significantly affect the measurement of anomalies arising from buried volcanics over 300 m deep (see for example Figs. 5 and 6), which shows that elevation (depth) difference from 300 to 400 m causes a diminishment of 80 to 60 nT, or 20 nT. These anomalies also have an associated long wavelength, greater than 600 m, and should be easily distinguished from elevation effects. However, for shallow anomalies, shallower than 300 m depth, the effect is greater, and elevation effect over a few hundred meters distance could be mistaken for a shallow anomaly if not noted or corrected.

The instrument used is a Geometrics G-858 cesium magnetometer with two sensors spaced one meter apart, on a vertical staff, the lower sensor about 1 meter off of the ground. This instrument measures the total magnetic field of the earth on each sensor to a precision of 1 nanoTesla (nT. The field values ranged from 53,600 to 53,900 nT. The survey was made by walking and continuously recording. Locations were obtained by simultaneous recording from a GPS unit with an accuracy of ± 8 m. No base stations measurements were made, but tie lines on the Big Gulch and Little Gulch lines gave agreement measurements, indicating no drift or large secular variation in the first set of data. It is possible that gradual diurnal variation of up to 60 nT may occur over a period of 12 hours. I was not provided with detailed field notes showing times of measurement – so one cannot evaluate that source of error – when splicing data together taken at very different times of day.

Source of magnetic anomalies: Magnetic anomalies arise from faulted rock sequences or topographic variation in rocks having a substantial magnetic susceptibility (k), i.e. greater than 0.0001 SI units. (note: SI values are 4π times cgs units, and both are dimensionless). Anomalies may also arise from spatial variation in k of rocks. Basaltic volcanic rocks range from 0.001 to 0.05, dependent largely upon the percent and grain size of the mineral magnetite. For example, a rock with 7 per cent magnetite will have a volume susceptibility of 0.038 SI units (Breiner, 1999). In addition to the magnetism induced in rocks by the prevailing magnetic field, basaltic rocks in particular may have a frozen remnant magnetism set by crystallization of magnetite when the lava cooled. Polarity of the frozen magnetism may be of different or opposite polarity from the induced magnetism, on account of reversed polarity of the earth's magnetic field at the time of crystallization. Remnant effects are difficult to predict without detailed sampling and modeling. For this qualitative interpretation, it is assumed that anomalous magnetism is entirely caused by induced magnetism of the present earth's field.

Qualitative interpretation of anomalies of this survey is based on an assumption that most of the magnetic features are faulted volcanic rocks beneath the Idaho Group sediments. Mapping the in the Pearl area by Clemens (1993) indicates that above the granitic rocks is about 100 m thick section of basalt, locally overlain by as much as 120 m of rhyolite, which is in turn overlain by another 25 m of basalt. Overlying this volcanic section are the Idaho Group sediments which are at least 200 m thick over most of the area. The faulted basalt and rhyolite would produce magnetic anomalies. The deeper granite may produce broad anomalies of longer wavelength and lower amplitude than the volcanics. Very low k of sediments indicate they to not contribute to the field. A reasonable model is 100 to 200 meter thick slab of volcanic rock, overlain by sediments and faulted by normal faults.

Models of faulted volcanic rocks at depth:

Analytical models of the total-field magnetic anomalies for a 2-dimensional faulted slab are published int Telford et. al. (1990). The model is for a cross section of a plate of thickness, t, extending infinitely in the 3rd dimension. The formula on p. 100, Eqn 3.59b was calculated to visualize the effect of depth, thickness and susceptibility, for offset volcanic rocks. Figures 5 and 6 show a simplified version, of just the upthrown block, assuming an offset of 100 m, of a 100 meter thick section of volcanic rocks of susceptibility of 0.003 SI.

$$F(x) = +2\,k\,t\,F_e\,\{1/(d^2 + x^2)\}\{d \sin 2I \sin\beta - x(\cos^2 I \sin^2\beta - \sin^2 I)\}.$$

In terms for EXCEL:

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F(x) = + 2*(k)*(t)*Fe*((1/((d^2)+A5^2))*(d*(SIN(2*RADIANS(I)))* (SIN(RADIANS(strike))) -
A5*(((COS(RADIANS(i)))^2)*((SIN(RADIANS(strike)))^2) - ((SIN(RADIANS(I)))^2)))).
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Where
k = magnetic susceptibility, SI units
t = thickness of slab of magnetic rock, in meters.

F(x) = total field measured by the magnetometer.
F_e =Approximate total field of the earth in the area, which induces the anomalous field in susceptible rocks. i.e., the background value, estimated to ± 1000 nT (used a value of 54,000 nT) for model calculations,

d = depth to top of slab
x = horizontal distance from fault edge (parameter A5 in EXCEL code above) (assumed vertical fault plane)
I = inclination of the earth's magnetic field, which for this area is 60 degrees.
β = strike angle between magnetic north, and the strike of the fault. For a fault with strike of N45W, and down to SW, use 45 degrees. For a fault N45W and down to NE use 225 degrees. Telford et. al. (1990) are not clear on their conventions, and to make their formula reproduce their Fig. 3.22b on page 103, I had to change the sign of the equation above from – to a +.

In all formulas for 2D bodies of uniform cross section, the amplitude varies as $2\,k\,t\,F_e$, so that for any given fault depth and offset, at a given orientation to the earth's magnetic north, the anomaly varies linearly with the thickness of the magnetic slab (*t*) and the susceptibility (*k*).

Figures 5 and 6 show results of calculation for NW-SE trending faults with vertical planes. The model is appropriate, since faults in the area generally trend NW-SE. The anomaly shape is the same, and changes sign, if faulting sense is opposite (i.e., up to southwest, or up to northeast)

Figure 5 shows that a down-to-SW fault, with 100 m of displacement on the volcanic section will have a positive bulge in the field of 100 to120 nT, if top of upthrown block is 200-m deep, the width of anomaly will be about 600 m. If top of the block is 600-m deep, the anomaly will diminish to 20 to 40 nT, and width will be about 1200 m.

Figure 6, is the anomaly of a down-to-NE fault, and is just the negative value of Figure 4. This calculation for a 700-m deep anomaly show a width of about 1700 m, and an anomaly of 20 to 40 nT for the 100 m thick volcanic section, offset 100 m.

To re-iterate again, the strength of the modeled anomaly is linearly related to the magnetic susceptibility and thickness of the section of volcanic rocks, and diminishes with depth as 1/d.

Specialized and costly software exists for more exact modeling of anomalies (QUICKMAG-PRO $2850 from Rockware), however it was not immediately available for this study. However, I just became aware of a freeware GEOMODEL, also from Rockware, that allows 2.5 D modeling, and that will be done subsequent to this report.

Simple estimates of depth to anomalous features: Because distance breadth of the anomaly increases with increasing depth of the anomalous feature, the width is an indicator of depth to rock feature or susceptibility giving rise to the change in the earth's field. A rule of thumb is that depth is about ½ the width of the anomaly. For example, if an anomaly is 1200 m wide, the depth is about 600 m. Such depth estimates are crude and may be off by 50 per cent (Breiner, 1999).

Another simple measure is to measure the map distance, x_z, of the straight portion of the slope of one of the limbs of an anomalous bulge or depression in field values. "Straight portion" is the distance between the inflection point (i.e.curvature changes from concave upward to convex upward, for positive anomalies). In this estimate, the depth, z, is simply calculated from:

$$z = C\ x_z$$

where C varies from 0.5 to 1.5 (Breiner, 1999).

Discussion of observed anomalies along survey lines. All survey lines trend approximately SW-NE, so that they will yield profiles perpendicular to strike of SW-NW trending faults, believed to be the dominant structures in the area (Fig. 1). Their location will be discussed in terms of UTM km easting coordinate for easy reference on profiles and map. Because the lines are oriented mostly SW-NE, the easting km coordinate separation is multiplied by 1.4 to determine the width of anomaly along the SW-NE oriented survey line. Anomalies are labeled by circled letters on Figure 1, and the following sections discuss the profile lines in terms of those lettered anomalies.

North Line (Chaparral Road – Willow Creek Valley), 9 km long

A: A +20 nT positive anomaly, with a (600-m x 1.4) = 840-m width can be discerned from the rather noisy data at the NE end of the line, centered at 546.15 east (Fig. 2). Anomaly is not well defined, and large excursions of 100 nT in the data are probably instrument malfunction – indicating the data should be re-run if this anomaly is of interest.

B: Field values rise to the SW to point 544.0, 30 to 40 nT, and then fall off sharply to the SE to point **C**. Interpretation of point B is uncertain. Elevation drop of 33 ft between point is not enough to explain rise in values.

C: Most profound anomaly along this 9-km line is a negative anomaly centered at UTM km 543.0, of -60 to -80 nT, and a width of (1.2 km x 1.4) = 1700 m. The negative value indicates a down-to-SE fault, with more than 100 m displacement, and at an estimated depth to volcanic section on the upthrown block of (½ x 1700 m) = 850 m (2,800 ft).

D: Values rise irregularly from edge of the point **C** anomaly to the end of the line, 60 nT, over a distance of 2.5 km. Data is so noisy (±20 nT) that shape of any individual anomalies, if they exist, cannot be discerned.

Big Gulch Line and the SW extension, 12-km long.

E: A positive +50 nT anomaly, centered at 550.5 east, has a width of (1.4 x 3 km) = 4.2 km (Fig. 2). The same anomaly is larger on the Little Gulch line (Fig. 3), and the tie line (Fig.4), where its magnitude is + 100 to + 180 nT, and breadth is 3 to 4 km. The positive value and width suggest a down-to-SW faulted volcanic section, perhaps 1.5 to 2 km (4,800 to 6,000 ft) deep. Magnitude of the anomaly suggests large displacement (>200 m). The depth estimate seems large, and it is possible that the diminishing NE limb may be a thinning of the volcanic section, and the anomaly width due to faulting is less.

F: A well defined low of -20 nT, with a width of (1.4 x 2 km) = 2800 m. Possibly a down to NE fault at depth, but associated with anomaly at E, may indicate complicated geometry of faulted volcanics.

G. Slight rise and decline with amplitude of about 20 nT, and width of less than (1 km x 1.4) = 1.4 km may indicate a down to SW fault of small displacement (< 100 m).

H: A + 80 nT anomaly centered at 544.5 east with a width of at least (1.4 x 2 km) = 2.8 km, suggests a large down to SW fault, with top of upthrown block about 1.4 km (4,600 ft) deep; however, the SW definition is very noisy due to malfunction of the magnetometer when that SE extension data of this line was obtained (i.e., data SW of 545.0 east). The "south line" point **M,** indicates a 2,300 to 3,300 ft sediment section over the volcanics here, but in both cases the data is very noisy, and needs to be re-run for more precise estimates.

Little Gulch line

I: The largest and best defined anomaly of the survey is this +100 nT, (1.4x 2km) 2.8 km wide positive anomaly, centered at 550.8 east (Fig 3). The positive value suggests a large-displacement (>200 m), down-to-SW fault, with top of faulted volcanics on the upthrown block of about 1.4-km (4,600-ft depth. As discussed above under point E, depth estimate seems much larger than expected, and none of the lines fully defines the full NE limb of the anomaly. NE extension of line could allow better modeling, and also tie to the known volcanic section in upper Little Gulch area drilled by Conolley's wells about 1000 ft deep, 4 km west of here, and the exposed volcanic contact about 4 km to the NE (Fig. 1).

J: A negative anomaly of about -20 nT and a width of (1.2 x 1.2 km) = 1.4 km is centered at 547.3 east, suggesting a small displacement fault at a depth of 700 m (2,300 feet).

K: The rise from anomaly J, at end of line, may be the NE limb of the larger positive anomaly detected by the SW end of the "south line". That SW continuation is shown on this profile, and defines a + 80 nT anomaly centered at about 544.8 east.

South Line (Farmers' Union Canal)

L: Values rise at the east end of the line at 551.7, and are likely the west limb of the anomaly I on the Little Gulch line (Fig 3).

M: Values rise continuously to the west along this line, and then jump up sharply at 547.2 (Fig. 3). The sharp jump may be a splice of data taken at different times, and a result of diurnal variation and of no geologic significance. The peaking of values at 545.5 suggest a large displacement, down-to-SW fault, shown by a positive anomaly of at least + 100 nT, and a width of (2 to 3 km x 0.7) = 1.4 to 2 km. Because this is an EW line, the width of the anomaly, measured perpendicular to a NW-SE strike fault, is reduced by multiplying by 0.7. This same feature is also defined on the Big Gulch line at point **H** (Fig.2) confirming its NW-SE trend, and together suggest a volcanic-section feature at least ½ x 1.4 to 2 km (2,300 to 3,300 ft) deep beneath the sedimentary section.

Willow Creek Road Line ("perpendicular tie line")

N: Data on this line is displayed on both the northing coordinate and the easting coordinate, to better define this large (+200 nT) anomaly centered at 550.4 east (Fig. 4). This is the same feature detected on the Little Gulch line at point **I** (Fig. 3), and probably also at lesser magnitude as point **E** on the Big Gulch line (Fig. 2), and defines a large down-to-SE fault with NW-SE strike.

GEOLOGIC MAPPING PROGRESS & DISCUSSION OF FAULTS

Mapped geologic features are compiled on Fig. 1. Thorough geologic mapping is shown in the northeast corner of the area from Clemens (1990). Mappable faults shown in Fig. 1 are from a number of unpublished mapping projects by S.H.Wood.

Oolitic sands: Occurrence of oolitic sands has been mapped as a part of this project, because they are one of the few cemented rock outcrops in the sedimentary section. Oolitic sands are carbonate coated grains of lake shore deposits, and their origin and significance is discussed in Swirydczuk et al (1980), Wood and Clemens (2002), Wood (2004), Wood and Squires (2007). Significant to this study is the observation that these carbonate-cemented sands occur over a stratigraphic interval, limited to a few hundred feet, in the upper part of the Terteling Springs Formation, on the north side of the western Snake River Plain. Therefore these outcrops are considered a rough geologic marker bed, and the elevation of their occurrence a rough indicator of the tectonic tilting or faulting across the area. Elevations of oolite outcrops are posted on the map (Fig. 1). In the SE Pearl area, their elevation is 3,100 to 3,200 feet. Along Willow Creek, near Lynn's Ranch they occur at 2,900 to 3,000 feet, and along the Old Freezeout Hill Road they occur at 2,700 to 2,750. From these elevations, it is concluded that the vertical-fault offset combined with tectonic tilt of the sedimentary section is about (3,200 - 2,700), 500 ft, from the Pearl area (NE corner of map) to Old Freezeout Hill Road.

Oolitic sands and the Terteling Springs Formation: The oolite deposits are also an identifying feature of sand facies of the Terteling Springs Formation, a facies that lies within several miles of the contact with the Idaho batholith, and grades basinward to the SW to the mudstone faceies (Wood and Clemens, 2004). Therefore, the thick sand section observed along the Old Freezeout Hill Road is Terteling Springs Formation, and is not the overlying Pierce Gulch Sand.

Pierce Gulch Sand: Apparently the Pierce Gulch Sand, with a significant thickness in the western part of the M3 properties, is in a downfaulted section exposed along the bluffs of the Payette River Valley, west of the Old Freezeout Hill Road. I believe the strata in the bluffs in Section 28, T2W, R6N is the Pierce Gulch Sand, because a characteristic white volcanic ash bed (locally 2-ft thick) occurs at elevation 2,610 ft within the dominantly coarse sand deposits. A similar volcanic ash bed occurs in the bluffs of sand sediment along the north side of the Payette River near Birding Island, 18 miles to the northwest. However mapping of the section exposed along the Payette River is in the very preliminary stages, and these correlations are tentative.

Faults: Exposures of strata in the M3 area are scarce; however faint stratification lines are apparent on Google-earth imagery and BLM aerial photography. The faults indicated by the magnetometer survey do not have obvious surface expression, except for one small fault exposed in the roadcut along Willow Creek Road in the hill just north of Big Gulch (Fig.1). That fault is associated with the major down-to-SW fault along Willow Creek Road detected by the magnetometer survey (points **E, I, L,** and **N**), and also known in the southwestern part of the map area from drillers logs and geophysical logs (Fig. 1). Width of the magnetic anomaly suggests a thick sediment section over the volcanics here; however these depth estimates of 4,800 ft are crude. If one uses the formula $z = Cx_z$, and

x_z = (1.4 x 1.5 km) = 2000 m, and a constant for C of 0.5, the depth of sediment over volcanics computes to 1000 m (3,300 ft). The fault is a NW extension of the West Boise – Eagle fault system identified by Squires (1992).

It is puzzling that the down-to-SW fault exposed in the Highway 16 roadcut at Freezeout Hill (Fig. 1) does not have a strong expression on the magnetometer survey (as noted above, that data on the "north line" is very poor in quality on account of instrument malfunction, and another traverse is needed to understand this puzzle). Because the exposed fault shows strata that cannot be matched up in the 60 ft vertical exposure, the offset on this down-to-SW fault must exceed 60 ft. However I believe that the sands at this exposure are entirely the Terteling Springs Formation sand facies. The fault projects SE to the oolite bed exposures on the north side of Willow Creek, near Lynn's Ranch, but the oolite beds are not faulted; therefore, if it is a significant fault, it must project to the SW or to the NE of these beds.

The magnetometer survey of Big Gulch and the "south line" shows a major down-to-SE fault at the western M3 property, labeled points **H, K**, and **M** (Fig. 1). Thickness of sediment over the volcanic section is crudely estimated at 2,300 ft based on width of magnetic anomaly. This fault could be better defined by a survey along the ridgetop roads between Big Gulch and Willow Creek, west of Highway 16 (not M3 property).

The fault indicated by point **C** on the "north line" has an unexpected down-to-NE magnetic signature (negative anomaly) (Figs 1 and 2). Data is very noisy along this line, and the data between points **C** and **D**, while suggestive of complicated faulting, need to be repeated before a more confident interpretation can be made.

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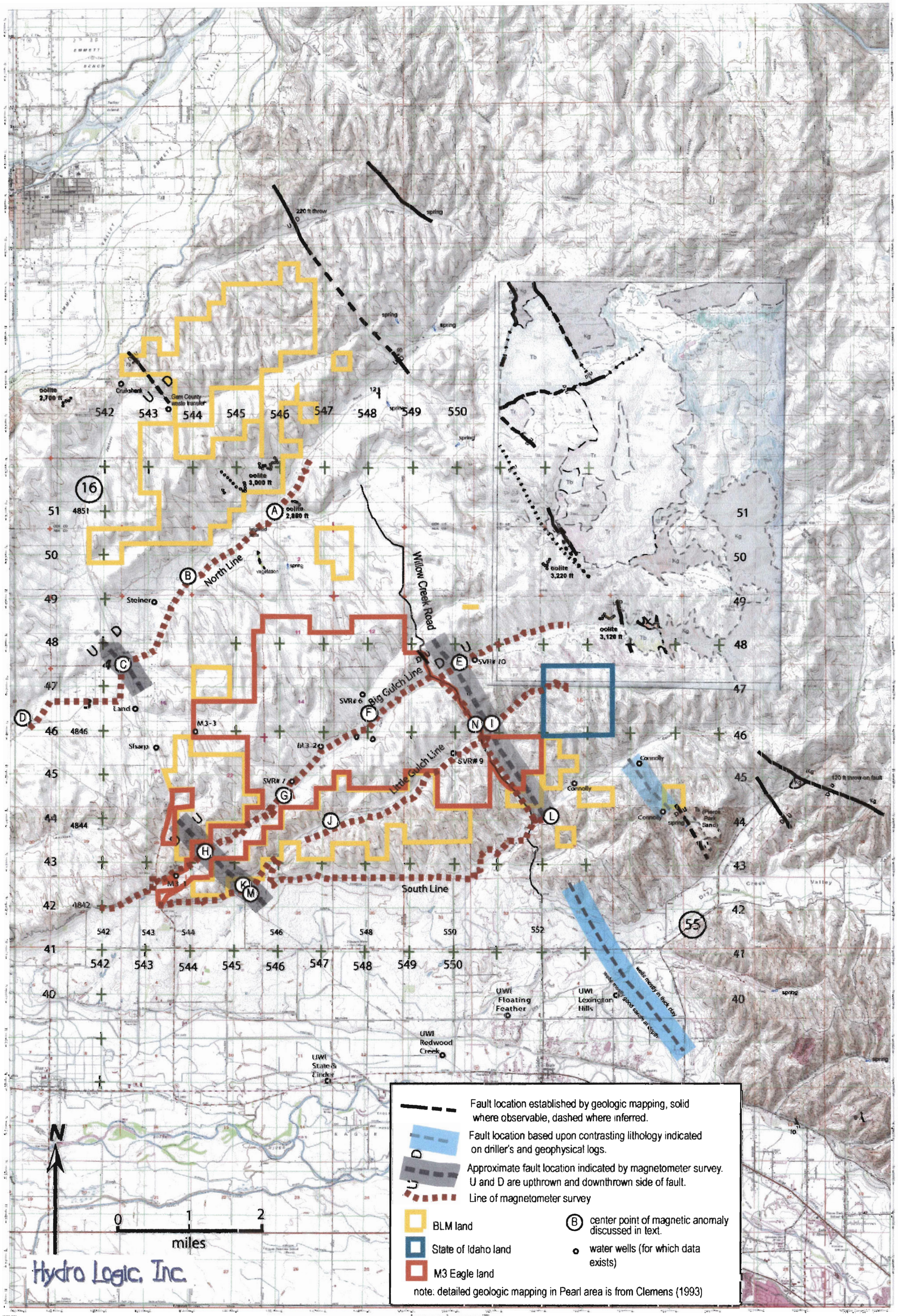


Figure 1. Map showing M3 property, geologic mapping in progress, and location of magnetometer lines. Center point of magnetic anomalies are circled - refer to text for discussion.

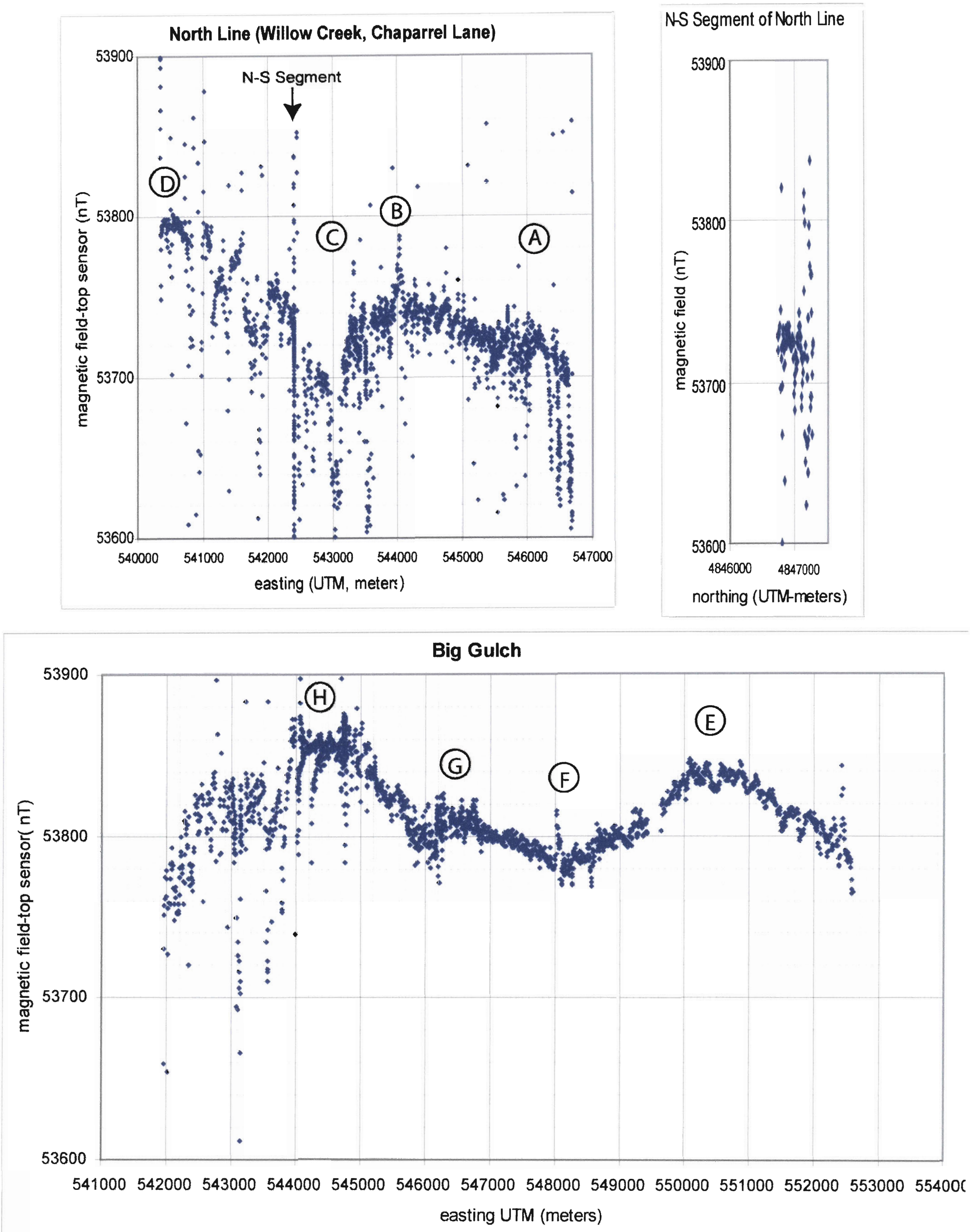


Figure 2. Magnetometer lines along Willow Creek - Chaparral Lane and Big Gulch

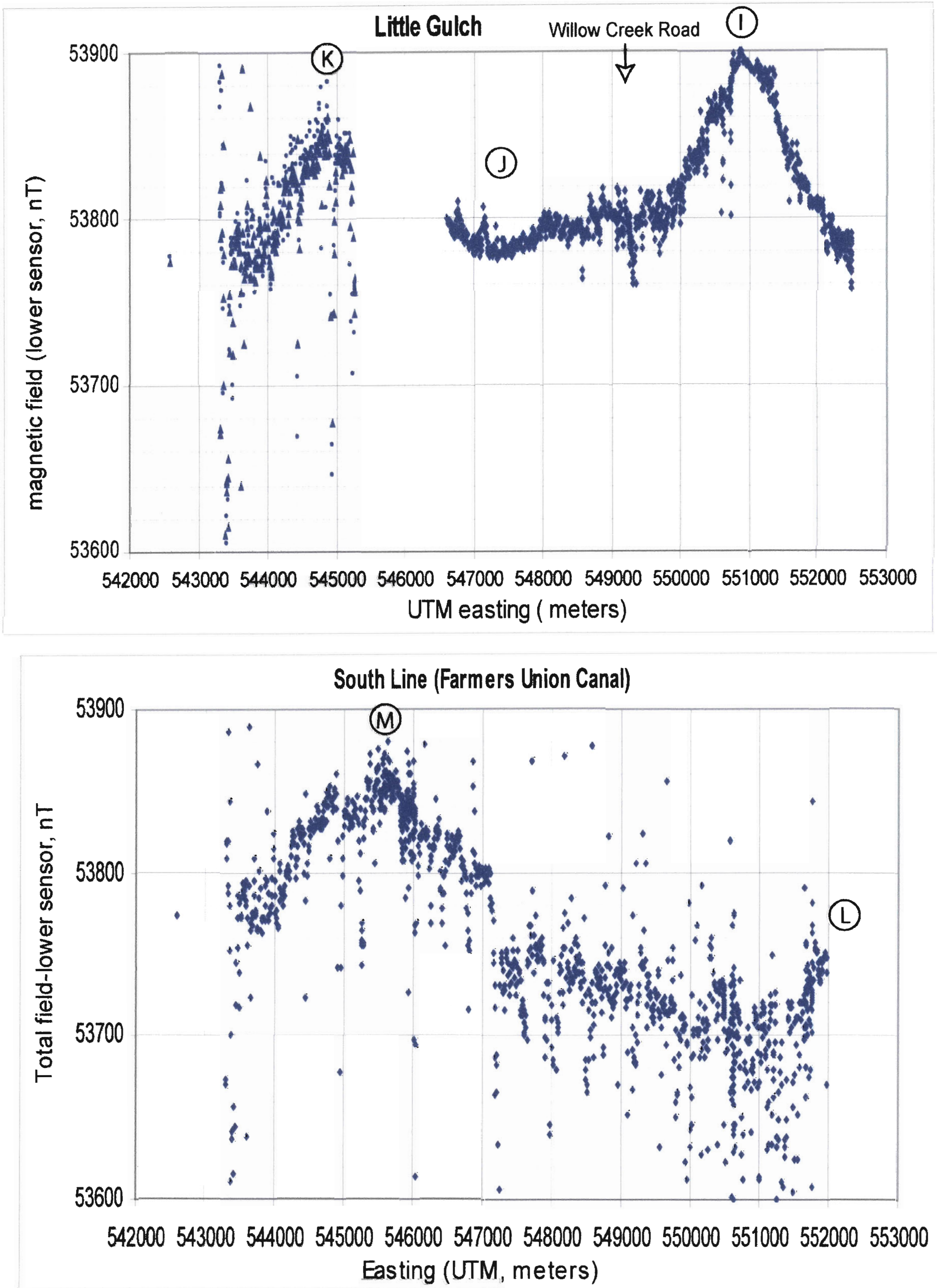


Figure 3. Magnetometer lines along Big Gulch and the Farmers' Union Canal.

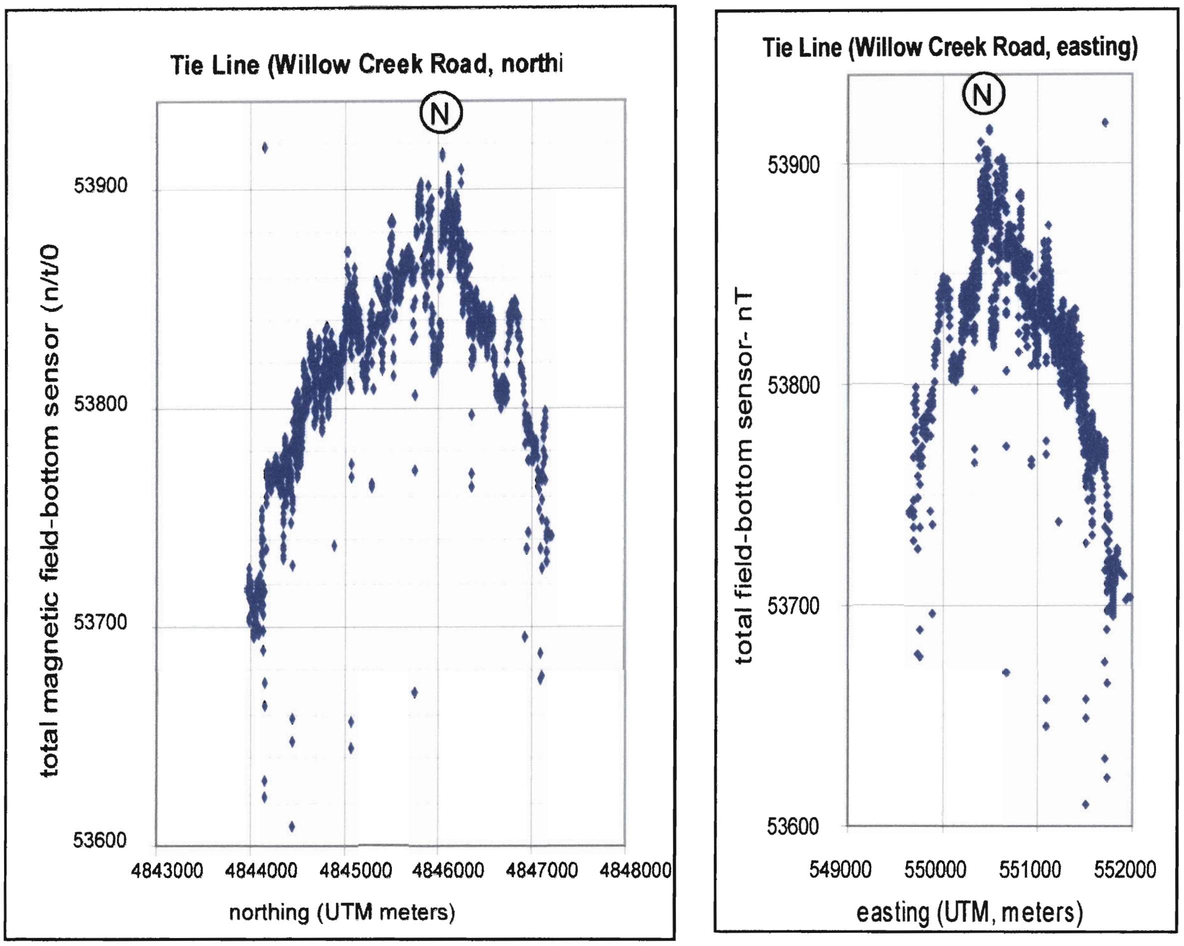
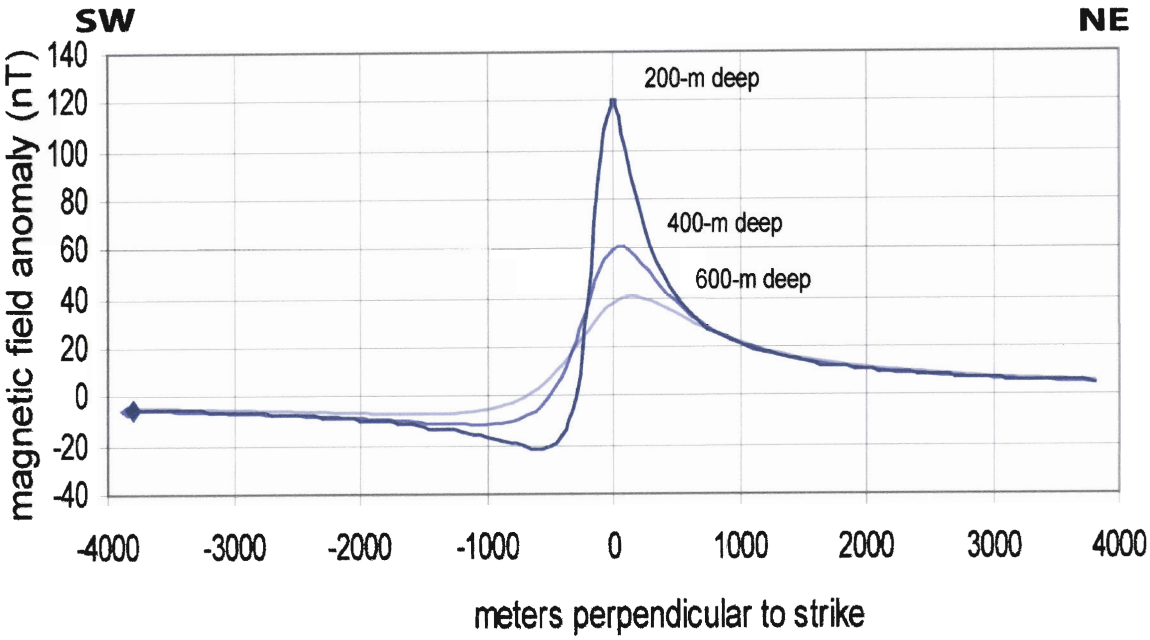


Figure 4. Magnetometer line along Willow Creek Road.



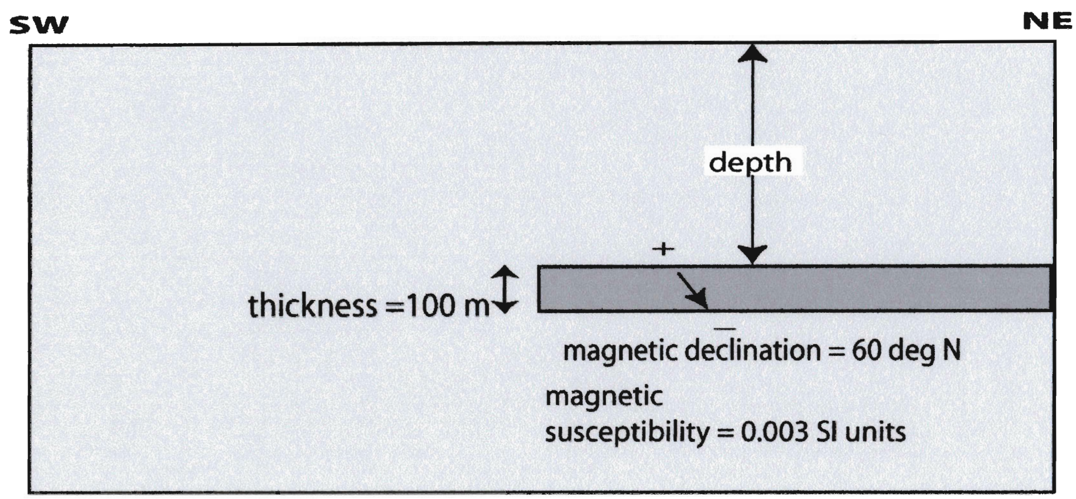


Figure 5. Model calculation of a down-to-SW faulted volcanic slab, fault with a NW-SE strike - simplified to show only the upthrown block.

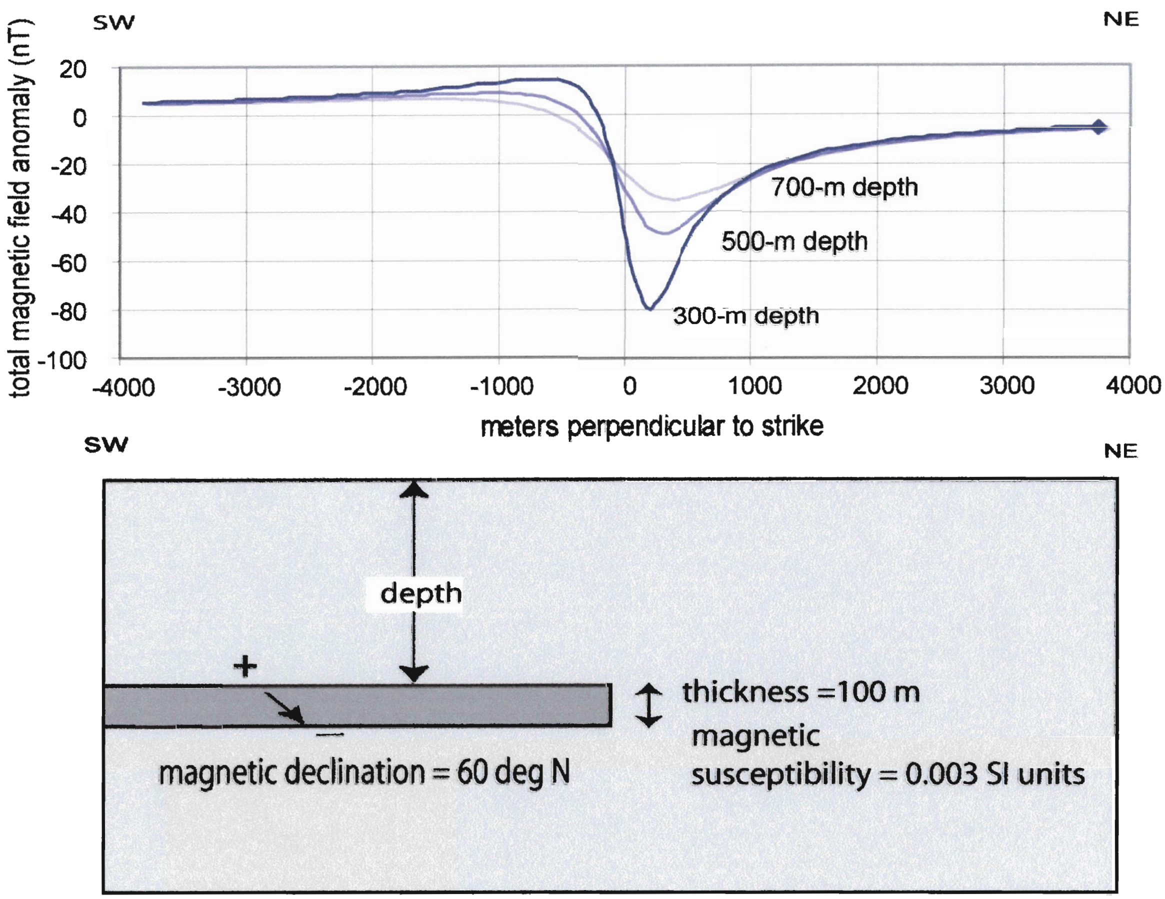


Figure 6. Model calculation of a down-to-NE faulted volcanic slab, fault with a NW-SE strike - simplified to show only the upthrown block.