GL02677

RAFT RIVER INJECTION

HPRoss
10-13-82

GEOPHYSICAL STUDIES

A. FOUR ASPECTS TO UURI GEOPHYSICAL STUDIES

1) Evaluate & Interpret Existing Geophysical Data, if it can significantly improve the present geologic model after injection.
2) Conduct and interpret hole-to-surface resistivity survey
3) Conduct and interpret self potential survey during injection
4) Integrate new results with other data in support of the hydrologic, reservoir engineering, and geochemical studies

B. EXISTING GEOPHYSICAL DATA

Ross, Sill

1. Broad data base acquired by the USGS over several years: To date, these data have been interpreted and results presented only in a qualitative manner. No models.
2. Seismic Data - have obtained the detailed reflection seismic data from Hans Ackerman, USGS, together with his interpretative results to date. His work relates to velocity units. I am presently trying to identify structural features, i.e. faults, dips, etc consistant with Ackerman.
   Interpretation is not simple:
   - many abrupt velocity changes; fluvial environment
   - several probable faults in Salt Lake Fm.
   - line spacing & orientation makes it difficult to connect "fault picks" between lines.
3. Also acquired detailed
   - Aeromagnetic
   - Gravity
   - Schlumberger soundings ≃ 50
   - Total Field resistivity
   - Telluric Profiles
   - MT

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B. Existing Data

4. Results of Preliminary Studies
   - Conductive Salt Lake Formation
   - Pronounced east-west trend in Total Field Resistivity
   - Realistic predictive models for SP and Resistivity experiments
   - Worthy of an in-depth integrated geophysical interpretation but will require considerable time

C. Hole-to-surface resistivity study — Ross, Mackelprang, Sill

1. Resistivity methods often useful in delineating geothermal reservoirs because hot, saline fluids are conductive.
2. Not really successful at Raft River to date due to 2 factors:
   a) Salt Lake Formation is conductive and thick
   b) Geothermal reservoir is deep, with limited leakage above it (?)
3. Better Definition by: a) energizing reservoir area
   b) using injection of low resistivity fluids
4. Two ways to introduce current into reservoir:
   a) Use drill casing as an electrode
      i) easy logistically
      ii) 1/5 current left at depth
   b) Electrode below drill casing, in conductive fluid
      i) specalized current cable
      ii) current lost uphole as leakage is less.
      iii) improved resistivity anomaly (more current in fracture).
5. Model Results
   a) generally low amplitude resistivity anomaly, 2-5%; possibly 35%.
   b) improved by before - after injection surveys
   c) good delineation of reservoir area may be possible, if

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D. SELF-POTENTIAL SURVEY — SILL, MACKELPRANG.

1) Due to low amplitude resistivity anomaly as modeled, UURI geophysicists discussed other possible techniques to couple with the injection test. Bill Sill, UU & UURI one of foremost SP experts (in world), developed a generalized model for convective flow, geothermal.

2) Natural (non-injection) SP anomalies associated with several geothermal systems due to electrokinetic or thermoelectric mechanisms.

3) Theory and observation (other areas) indicate enhanced SP anomalies during fluid injection.
   a) -300 mV for 150 g/m for fracture zone model with top at 1000 feet; (less for deeper).
   b) SP distribution, properly modeled, will aid in reservoir delineation and properties

4) Results from 48 hour injection (4 Km) test, & baseline survey (7 Km) @ 100m
   - Noise level $\simeq \pm 5$ mv; Probable real -ve bias E of RR5 → E, N of RR5 → N
   - Need more complete survey grid ⇒ longer observ. time ⇒ 2+ days
   - Plan before & during long term test.

V9-V11

E. HOLE-TO-SURFACE RESISTIVITY (CONT.)

d) Detectible if:
   - low noise level - natural & artifical currents
   - Inject enough conductive fluid, i.e. enough time to access a large volume of rock surrounding the fractures; 14 days +
   - Survey lines traverse reservoir volume
   - Leakage into structures cutting Salt Lake Fm.
   - Favorable reservoir geometry w.r.t. RRGP #5; surface facilities

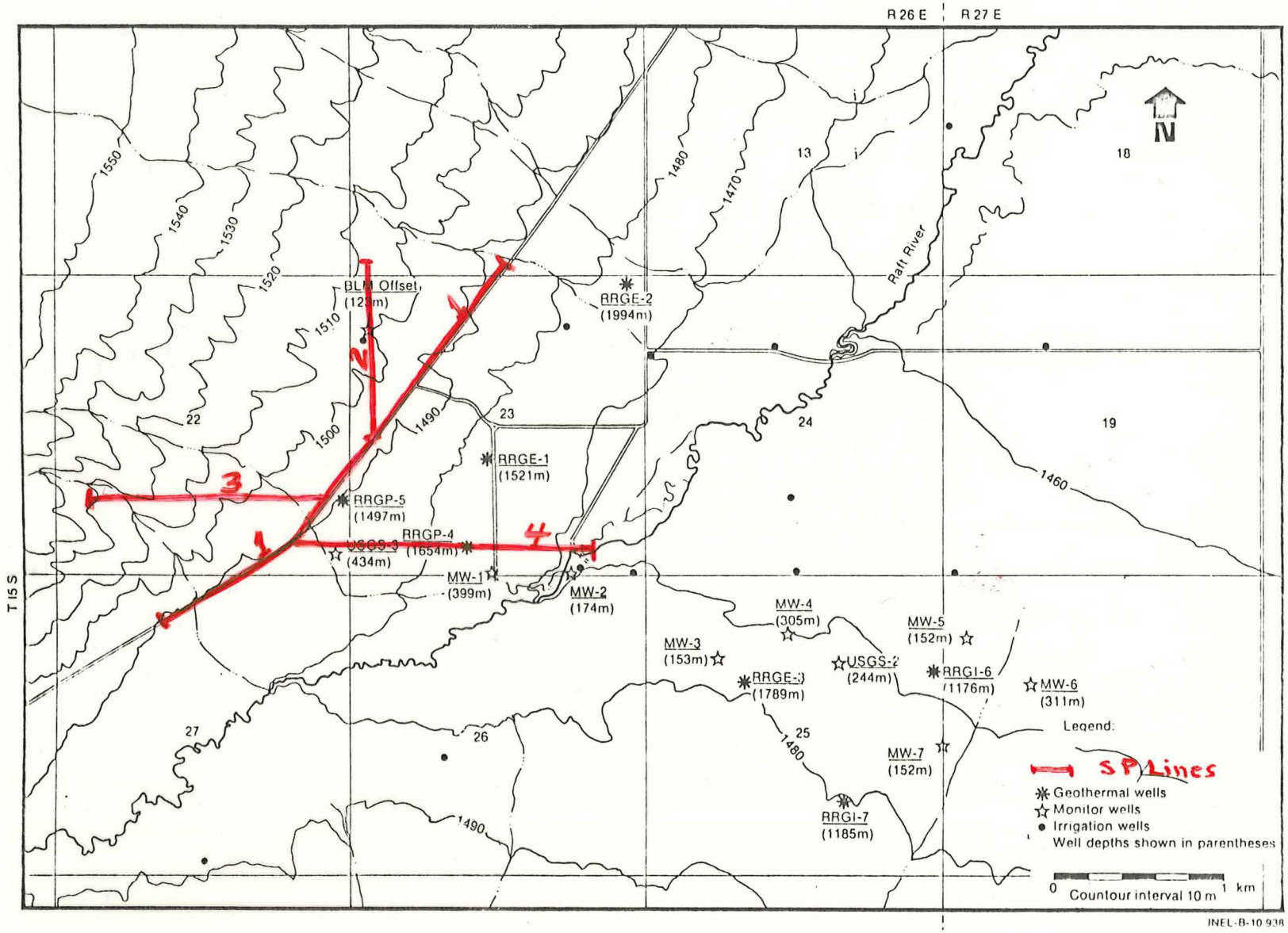
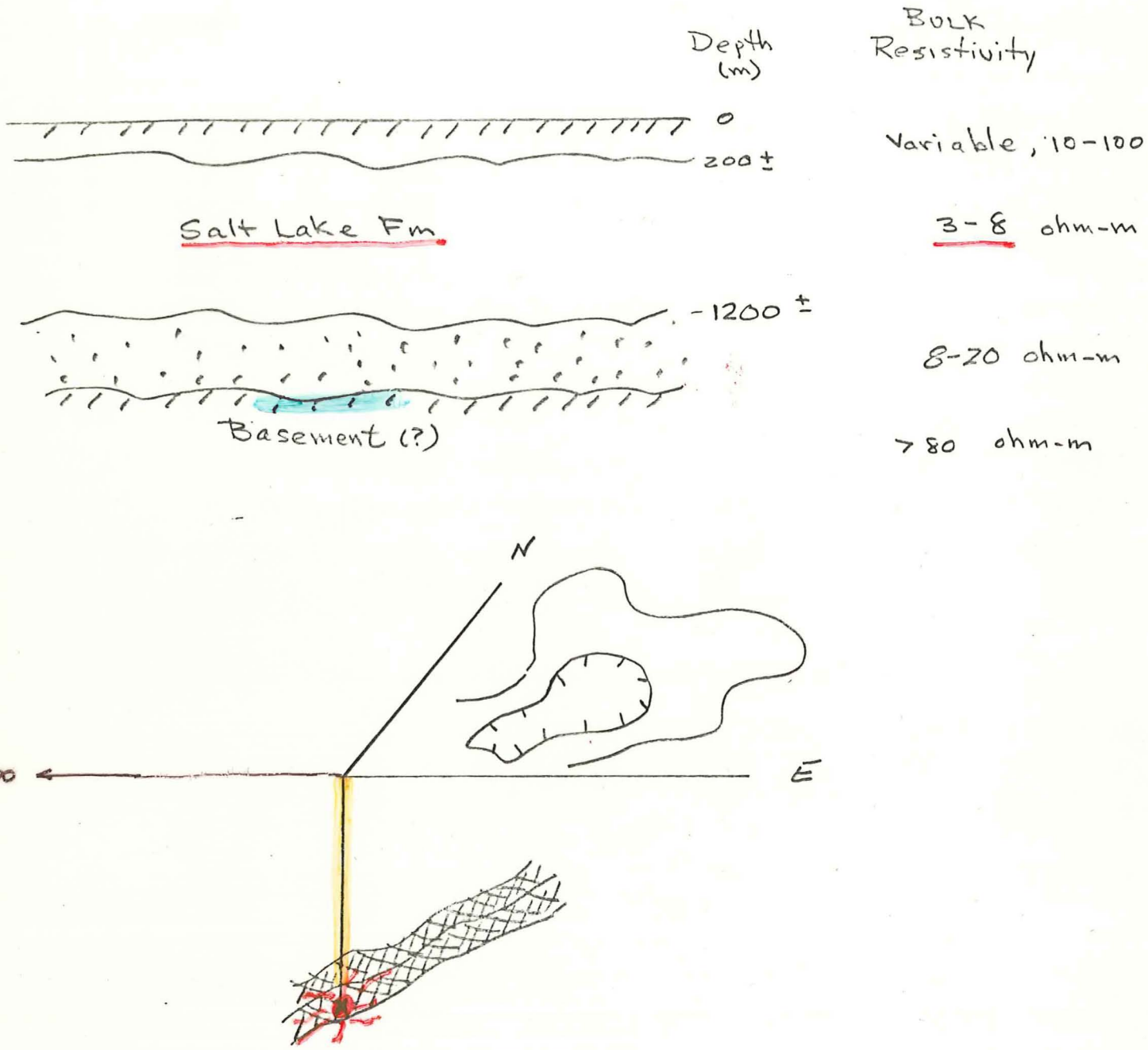
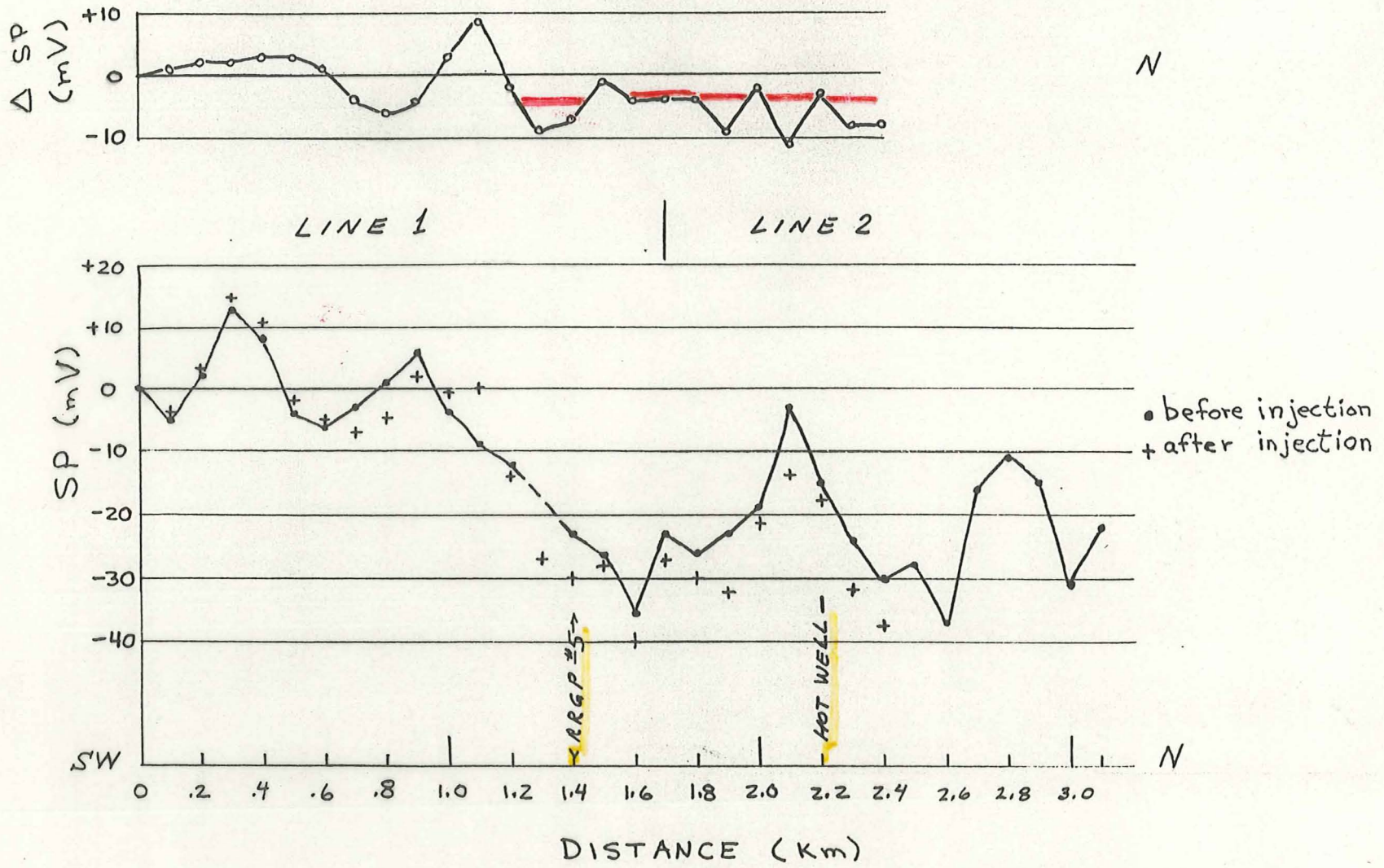
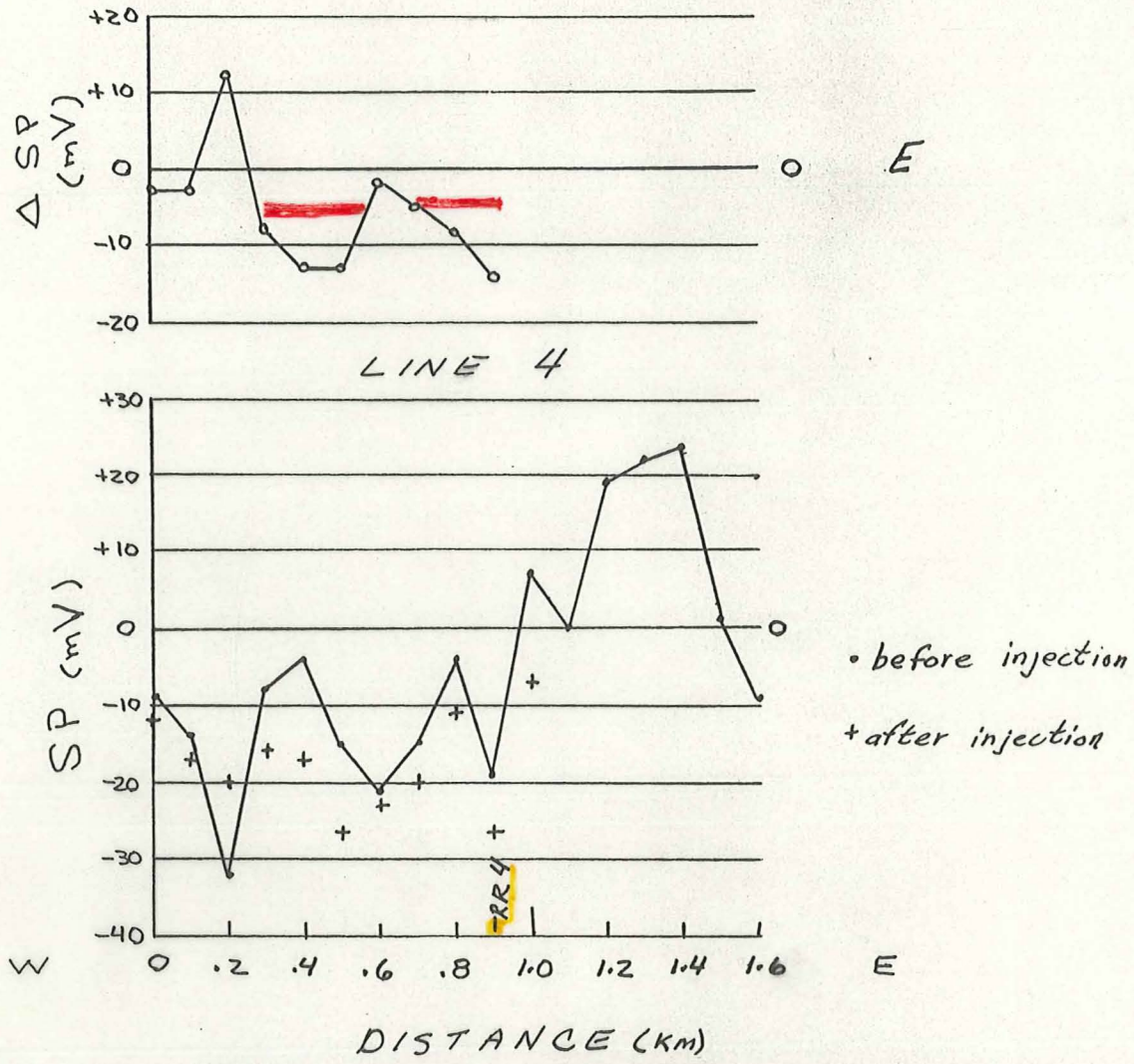


Figure 1. Raft River well field locations.



BURIED ELECTRODE STUDY


Δ SP (mV)
+10
0
-10
N
LINE 1
LINE 2
+20
+10
0
-10
-20
-30
-40
SP (mV)
• before injection
+ after injection
KRGP #5
HOT WELL
SW
N
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
DISTANCE (Km)

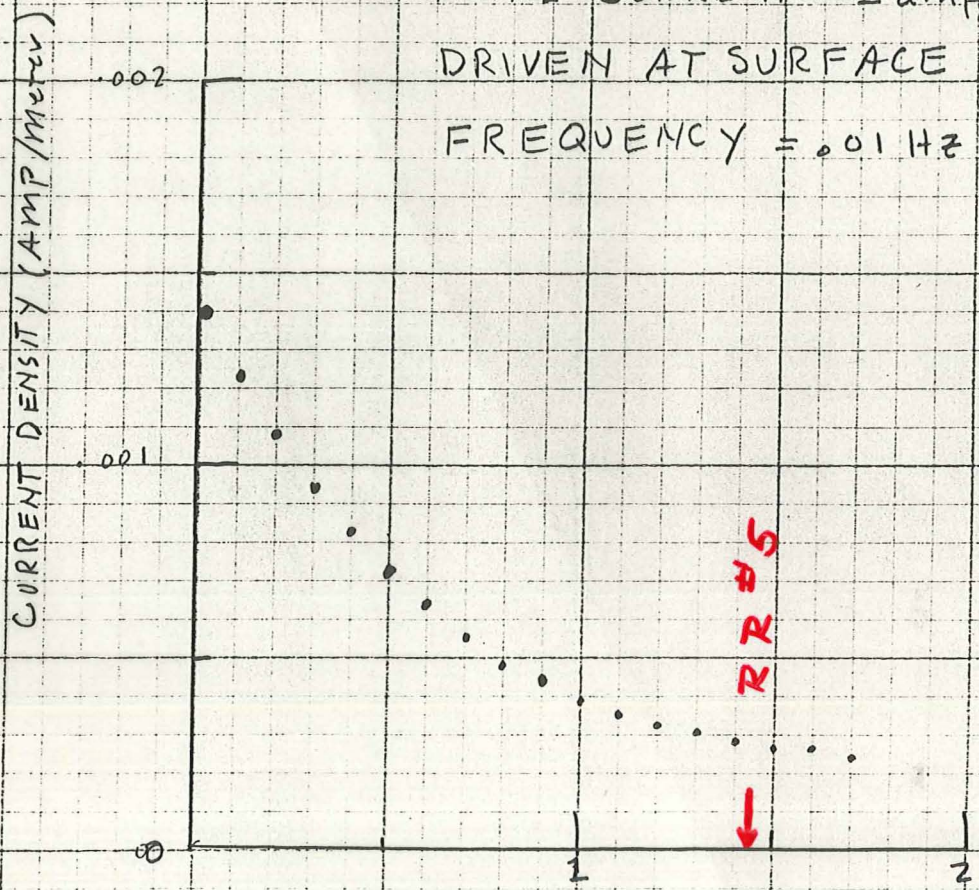

+20
+10
0
-10
-20
Δ SP (mV)
E
LINE 4
+30
+20
+10
0
-10
-20
-30
-40
SP (mV)
TRR 4
W
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
E
DISTANCE (KM)
• before injection
+ after injection

CASING ELECTRODE

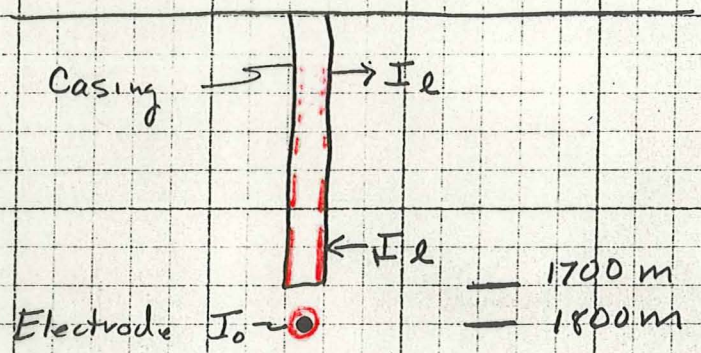
TOTAL CURRENT = 1 amp

DRIVEN AT SURFACE

FREQUENCY = .01 Hz



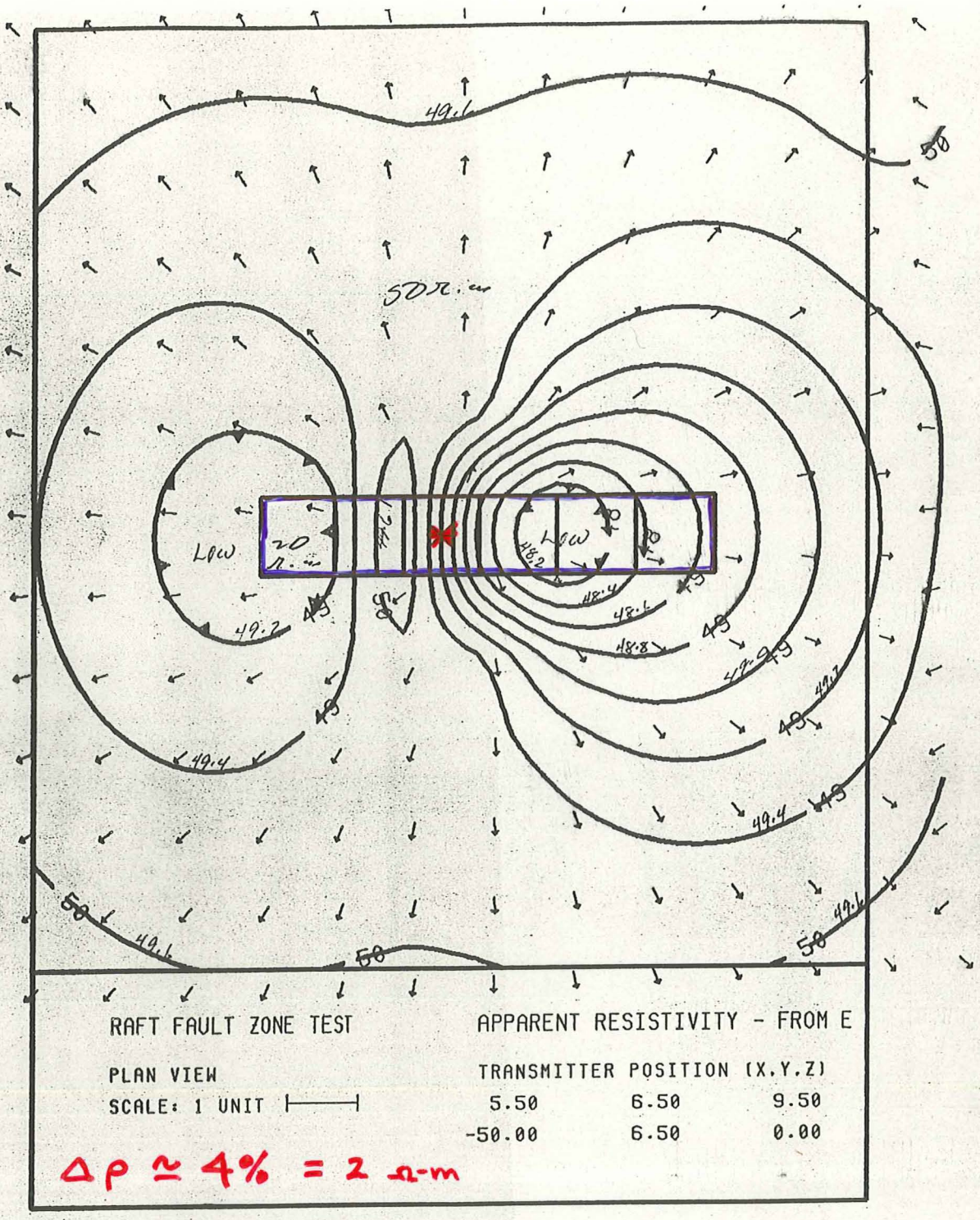
DOWNHOLE ELECTRODE



I_e LEAKAGE CURRENT

Top $\frac{I_e}{I_o} = 10^{-4}$/meter

Bottom $\frac{I_e}{I_o} = 10^{-3}$/meter



RAFT FAULT ZONE TEST

APPARENT RESISTIVITY - FROM E

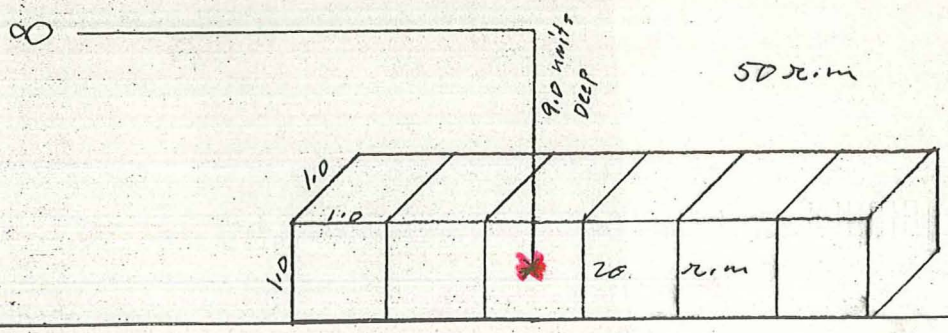
PLAN VIEW

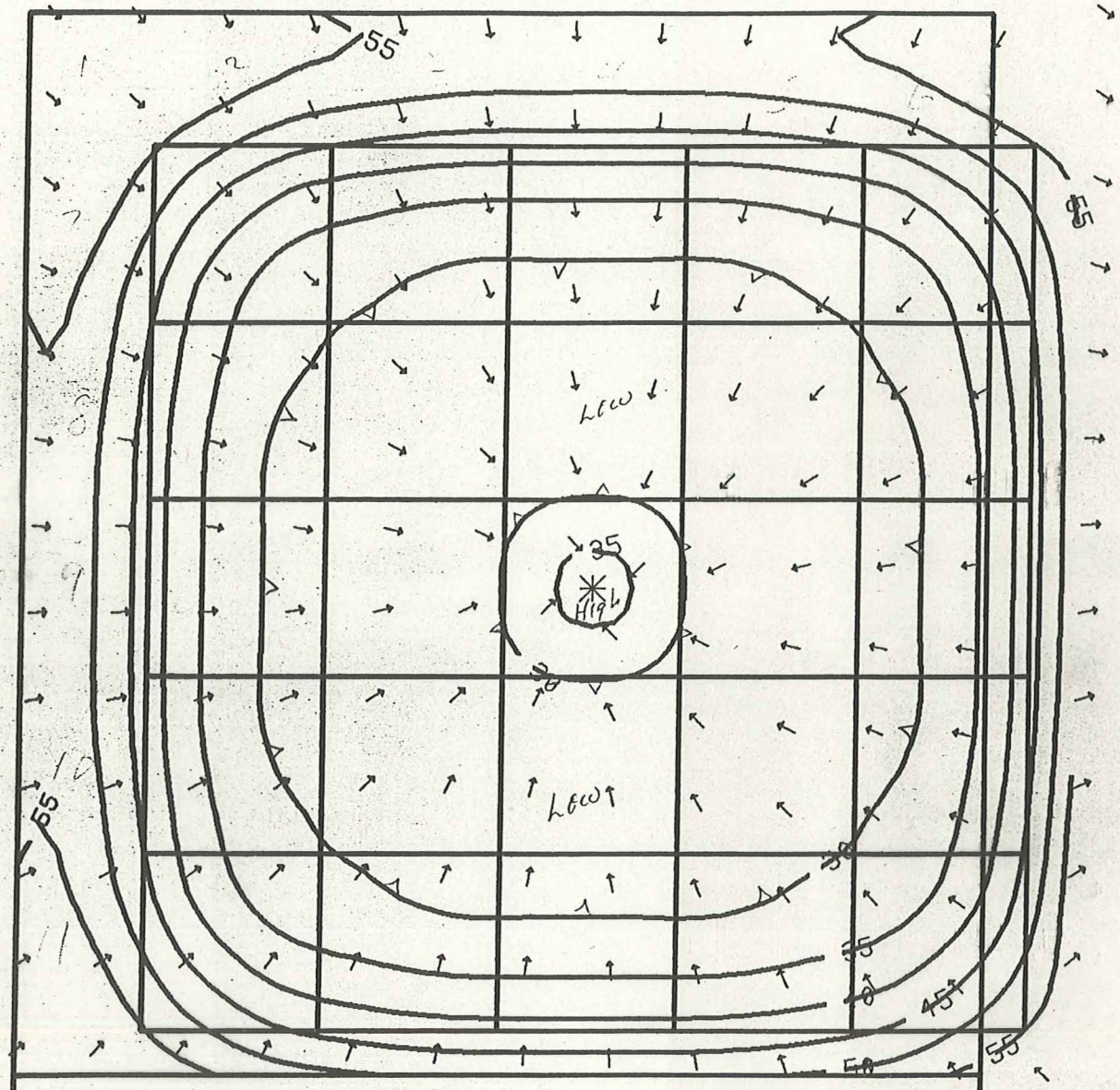
SCALE: 1 UNIT

TRANSMITTER POSITION (X.Y.Z)

5.50	6.50	9.50
-50.00	6.50	0.00

$\Delta\rho \simeq 4\% = 2\ \Omega\text{-m}$





RAFT PA TEST-COND.OVERBURDEN APPARENT RESISTIVITY - FROM E

PLAN VIEW

SCALE: 1 UNIT ⊢——⊣

TRANSMITTER POSITION (X.Y.Z)		
-250.00	6.50	0.00
6.50	6.50	9.40

8 Ω-m

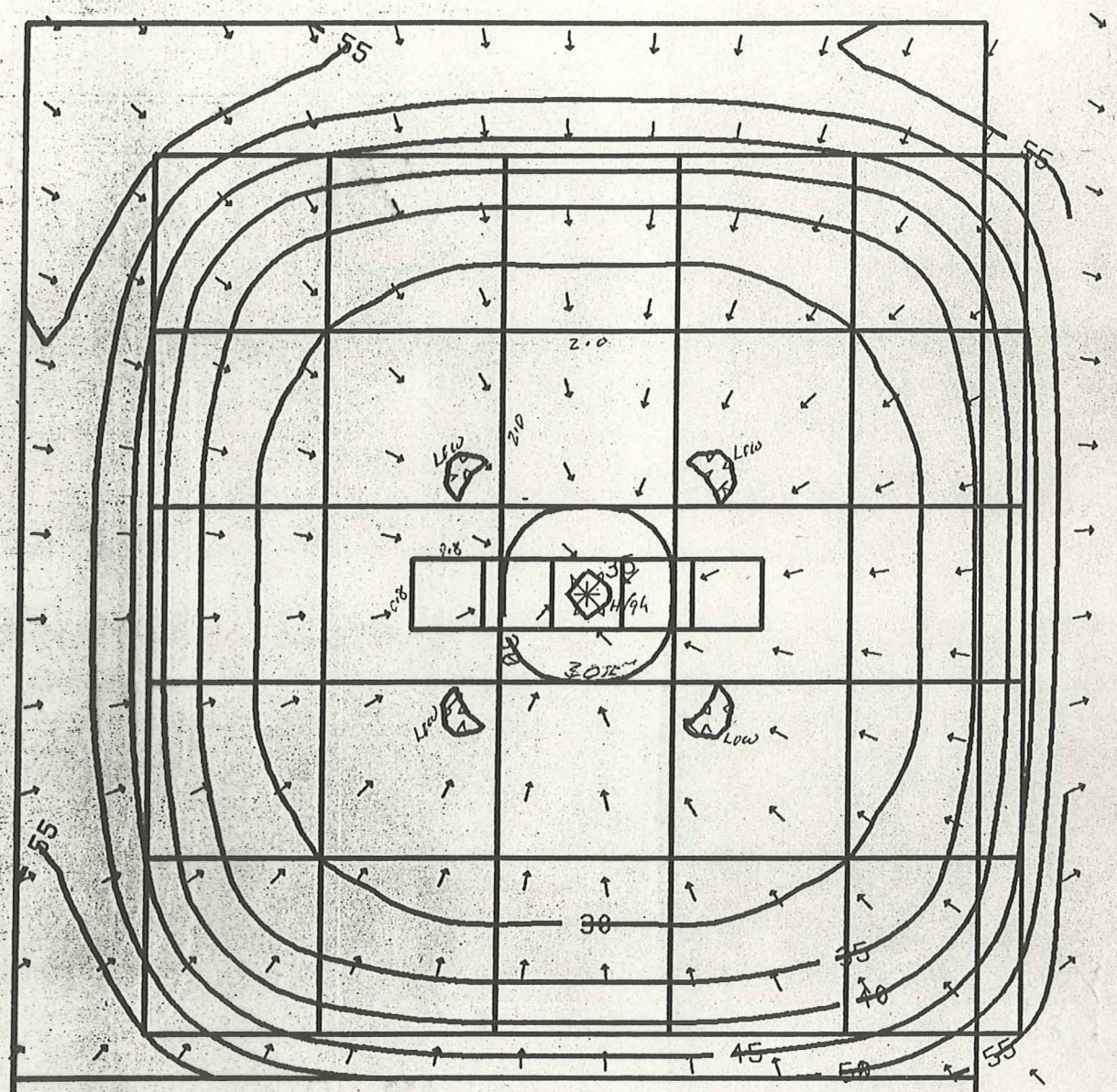
50 Ω-m

No Fault Zone

Conductive overburden limited 1 unit

Prisms 2x2x2 units @ 8 Ω-m

Background 50 Ω-m



RAFT PA TEST-COND. OVERBURDEN APPARENT RESISTIVITY - FROM E

PLAN VIEW

SCALE: 1 UNIT

TRANSMITTER POSITION (X.Y.Z)

-250.00	6.50	0.00
6.50	6.50	9.40

$\Delta\rho \simeq 2\% = 0.6\ \Omega\text{-m}$

8 Ω-m

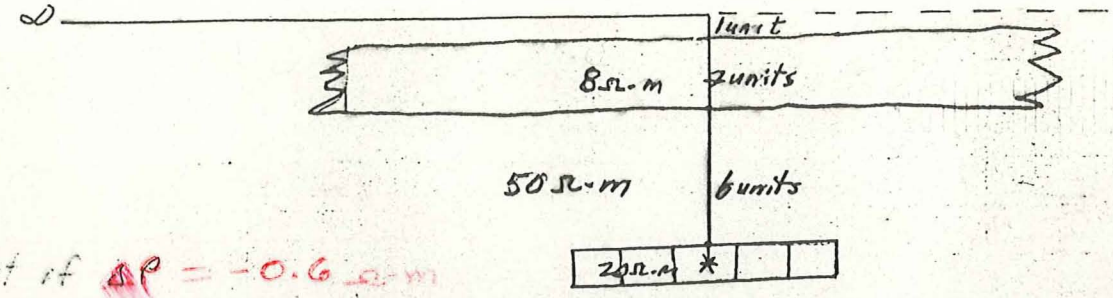
50 Ω-m

120 Ω-m

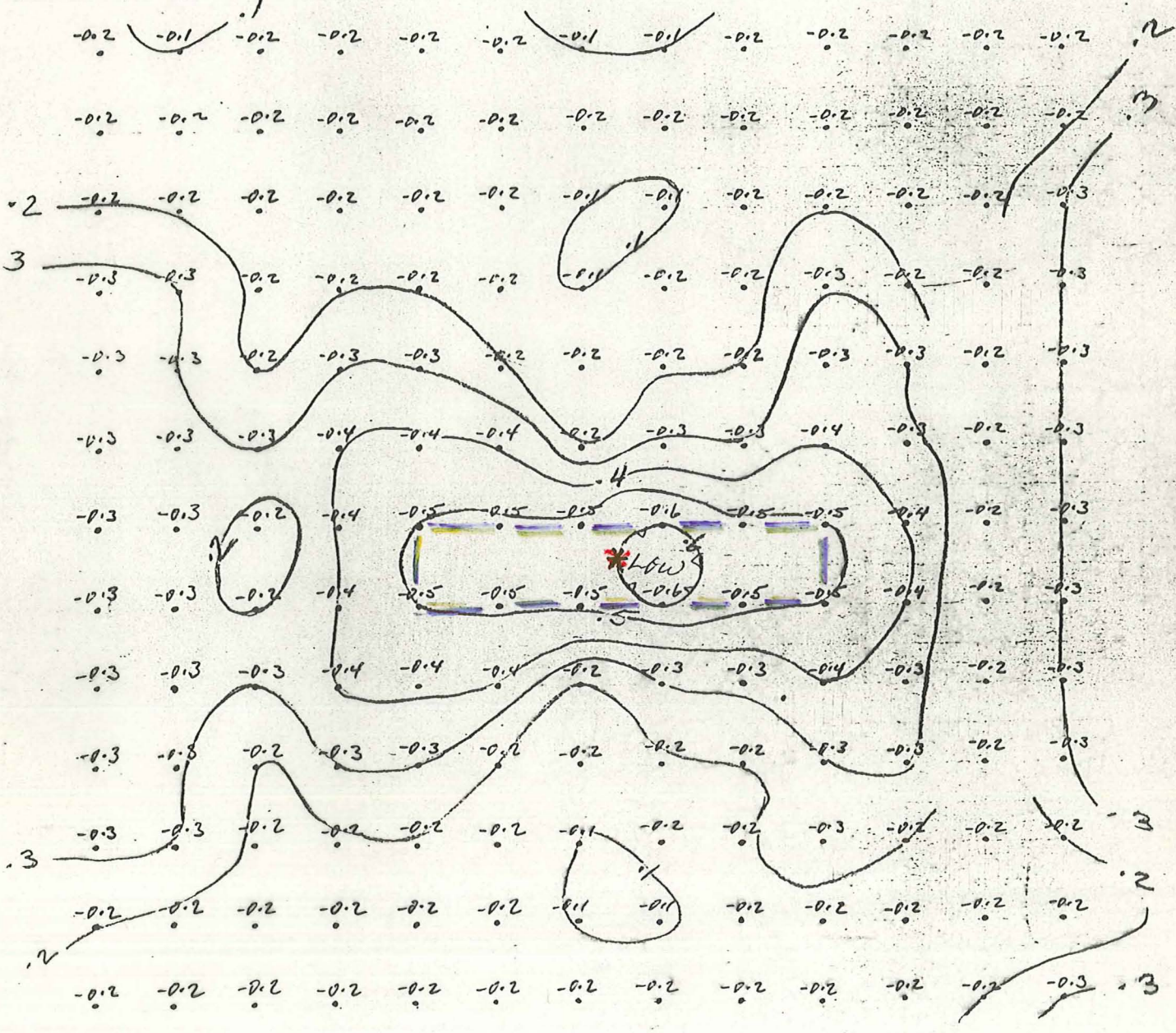
Fault zone ρ_a = 20 Ω-m

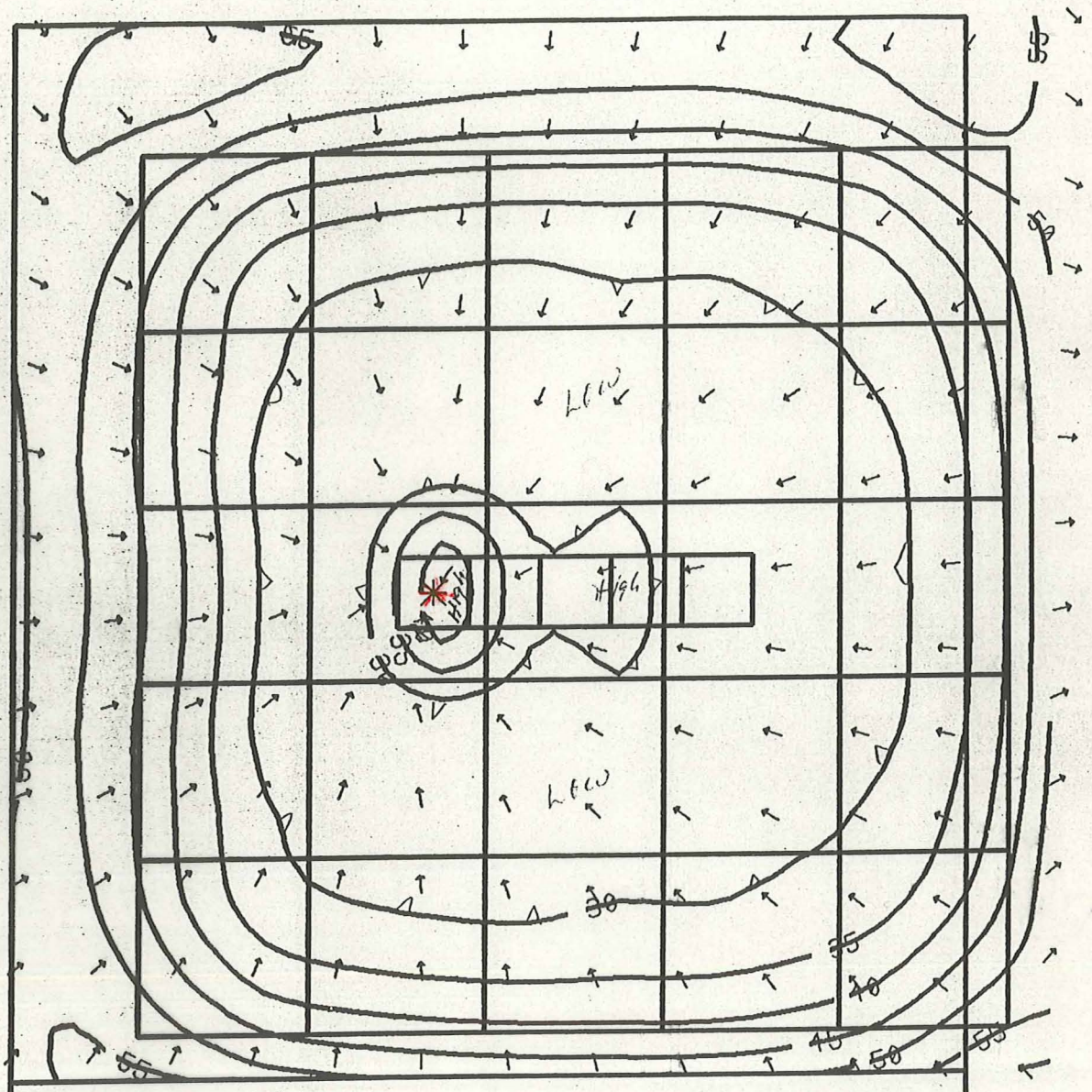
400' x 400' x 400' prisms buried 9 units

4 isolated lines @ corners due to fault zone.



plot of $\Delta P = -0.6$ sq.m
(with body − without body)





RAFT PA TEST-COND.OVERBURDEN APPARENT RESISTIVITY - FROM E

PLAN VIEW

SCALE: 1 UNIT ⊢——⊣

TRANSMITTER POSITION (X,Y,Z)

-250.00	6.50	0.00
4.90	6.50	9.40

← Input 127

Δρ ≃ 10 Ω-m
≃ 33 %

fault zone ρ_a = 20 Ω-m

electrode in end

460 × 480 × 400 prism.
if grid = 600'

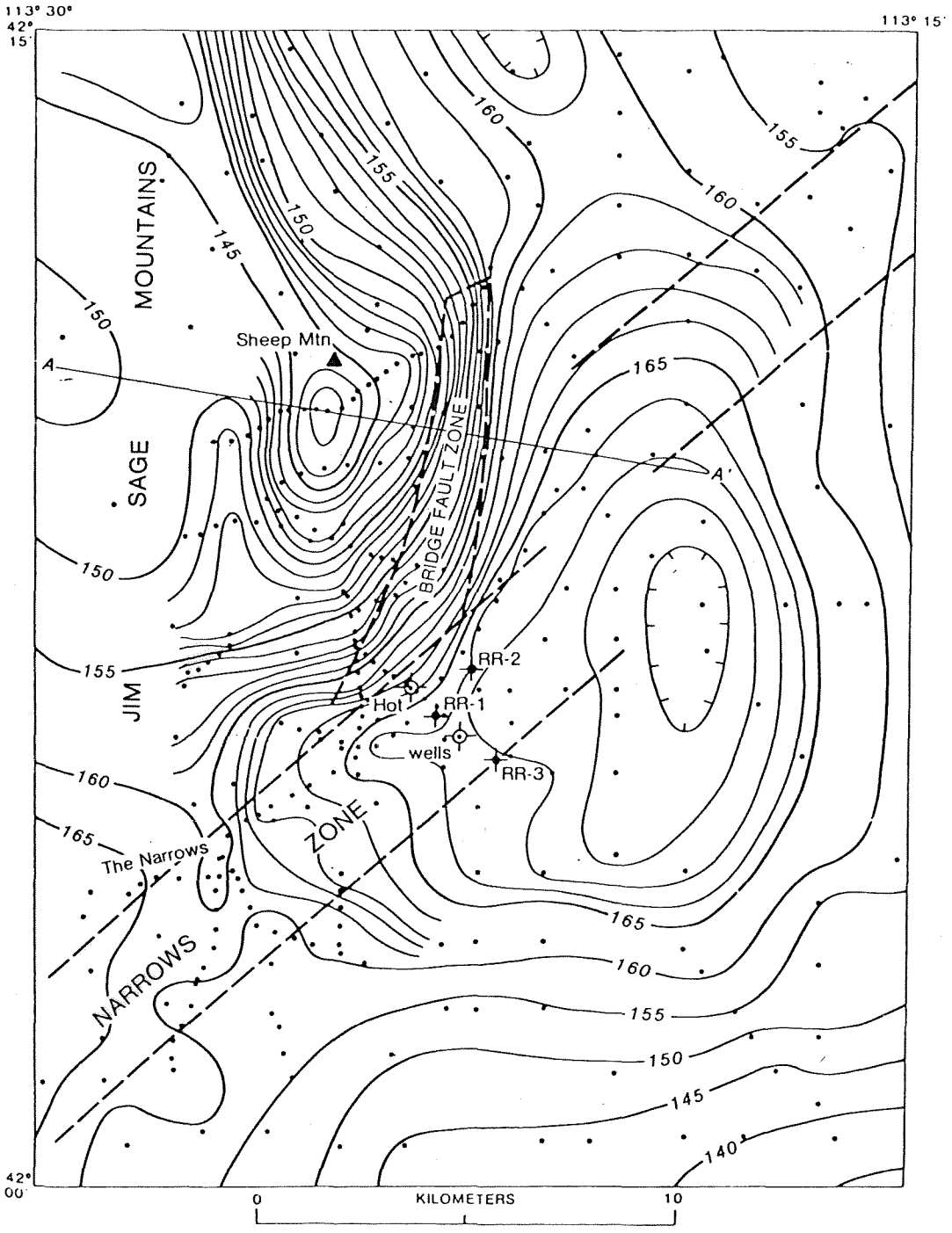


FIG. 4. Complete Bouguer gravity anomaly map of the southern Raft River Valley. Contour interval is 1 and 5 mgals. Deep drill holes are shown and numbered. Dots are gravimeter stations.

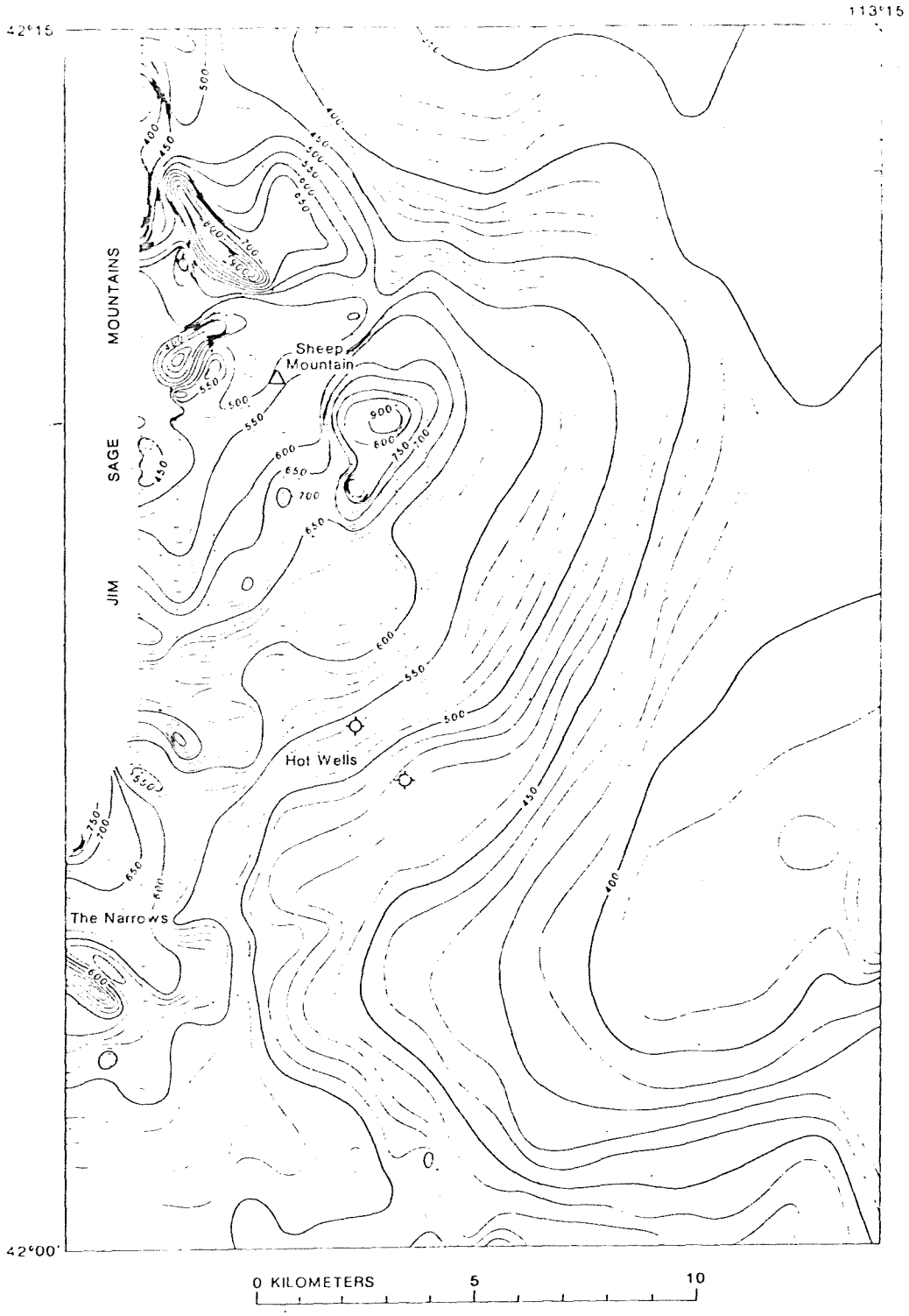
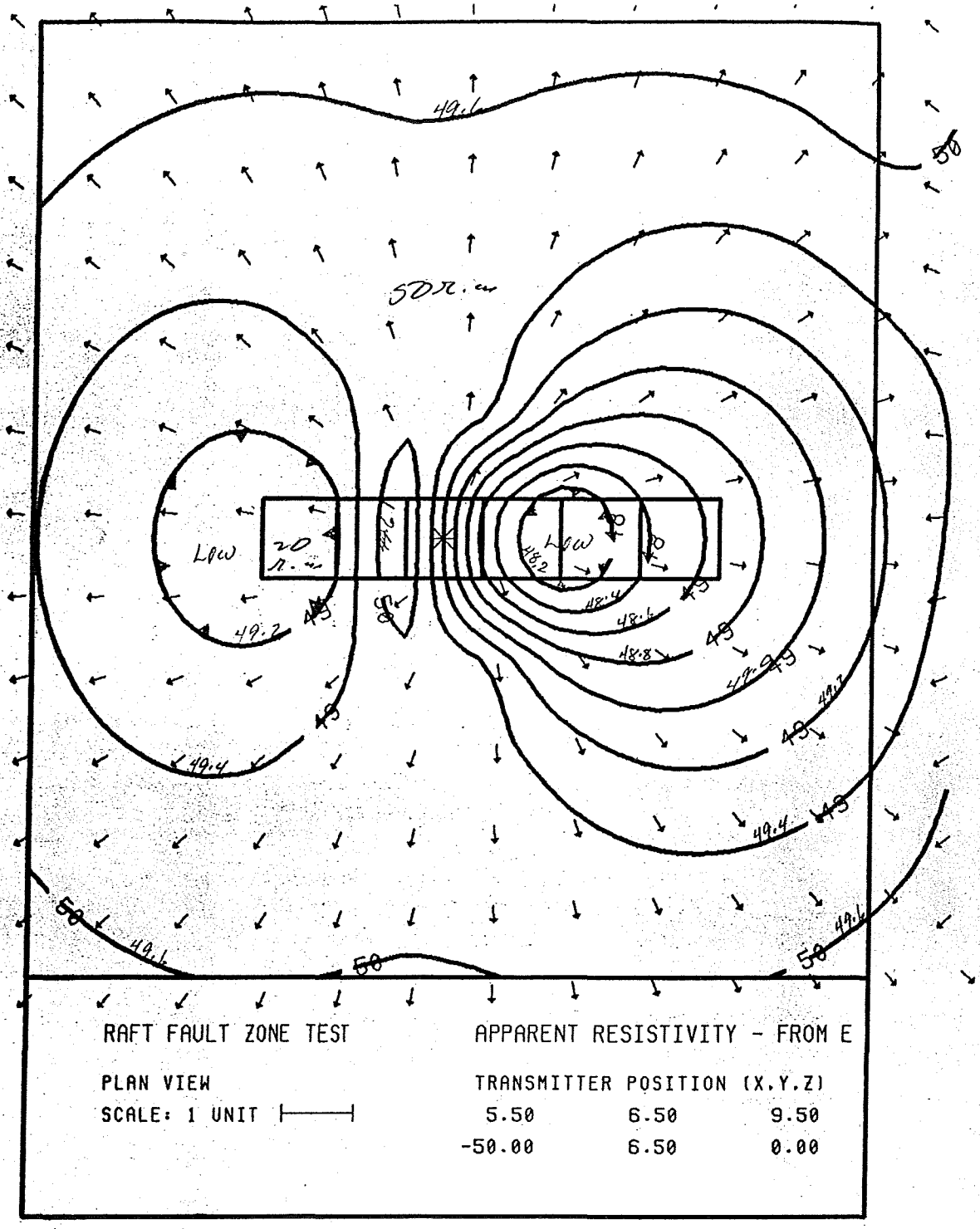
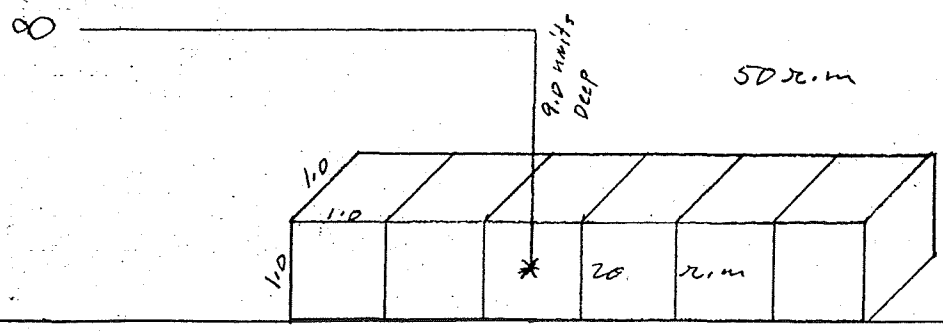
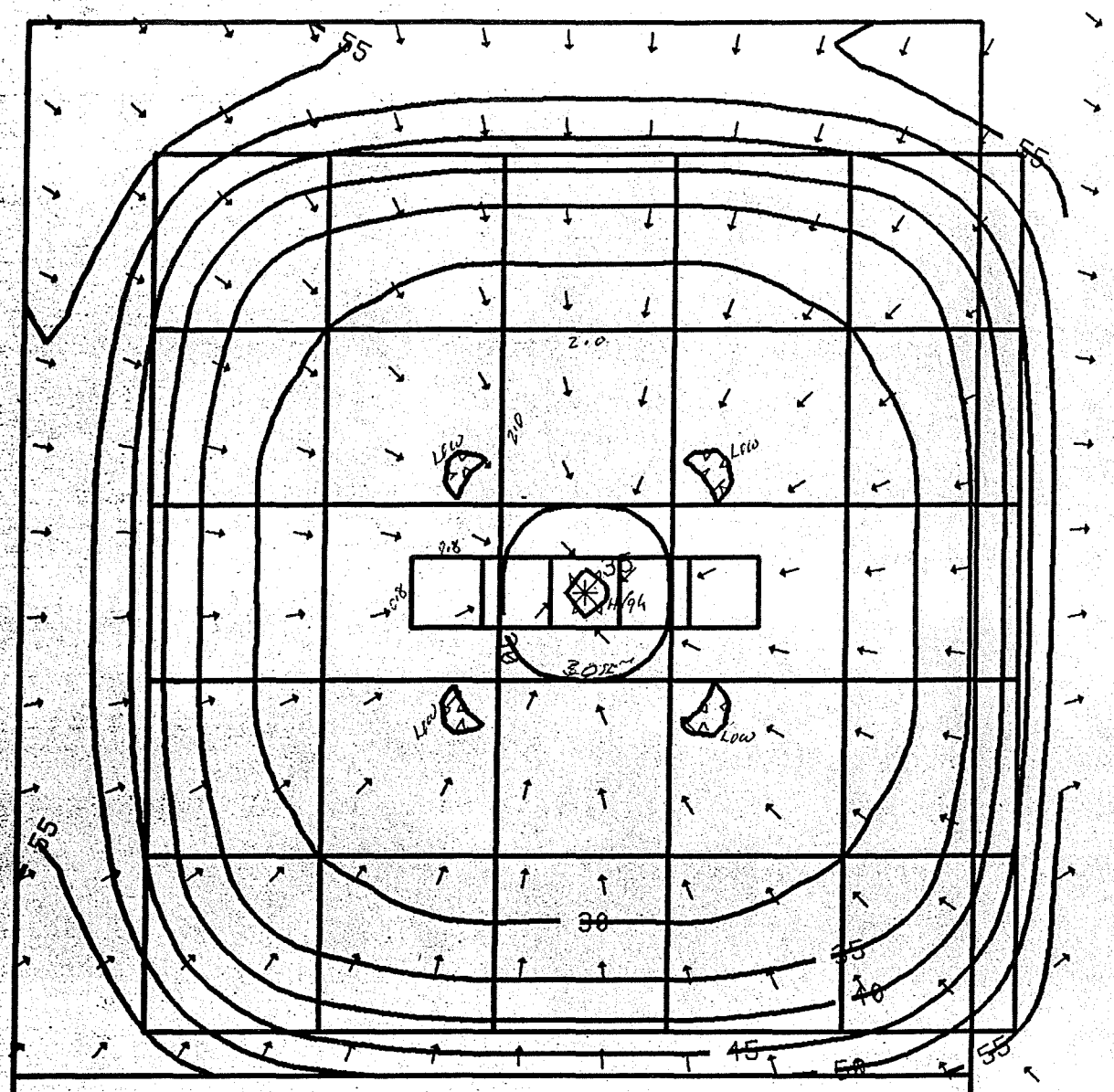


FIG. 5. Residual intensity aeromagnetic map of the southern Raft River Valley. Flight lines are 2800 m above sea level and 0.8 km apart. Contour interval is 10 gammas.


49.6
50
50 r.m
Low
20
r.m
Low
49.2
49.4
48.2
48.4
48.6
48.8
49
49.2
49.4
49.4
49.6
50
50
50
RAFT FAULT ZONE TEST
APPARENT RESISTIVITY - FROM E
PLAN VIEW
SCALE: 1 UNIT
TRANSMITTER POSITION (X.Y.Z)
5.50 6.50 9.50
-50.00 6.50 0.00


∞
9.0 units deep
50 r.m
1.0
1.0
1.0
20
r.m



RAFT PA TEST-COND.OVERBURDEN APPARENT RESISTIVITY - FROM E

PLAN VIEW

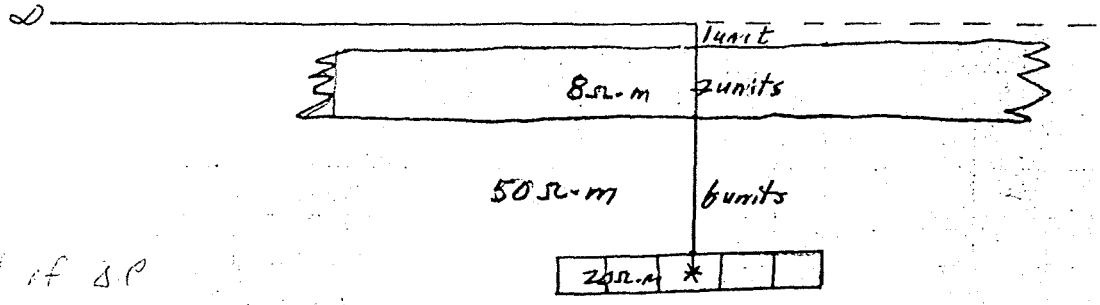
SCALE: 1 UNIT

TRANSMITTER POSITION (X,Y,Z)		
-250.00	6.50	0.00
6.50	6.50	9.40

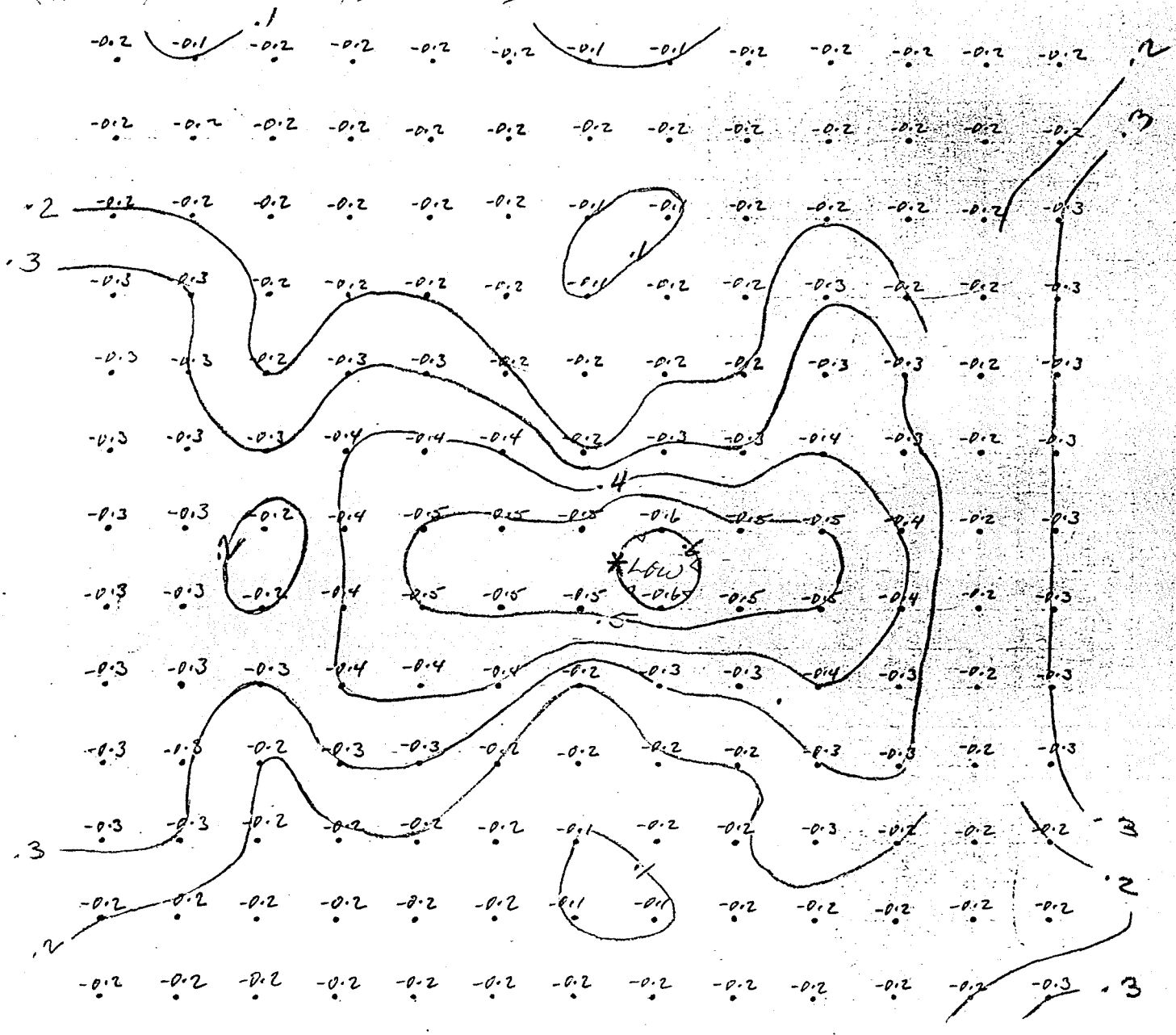
Fault zone

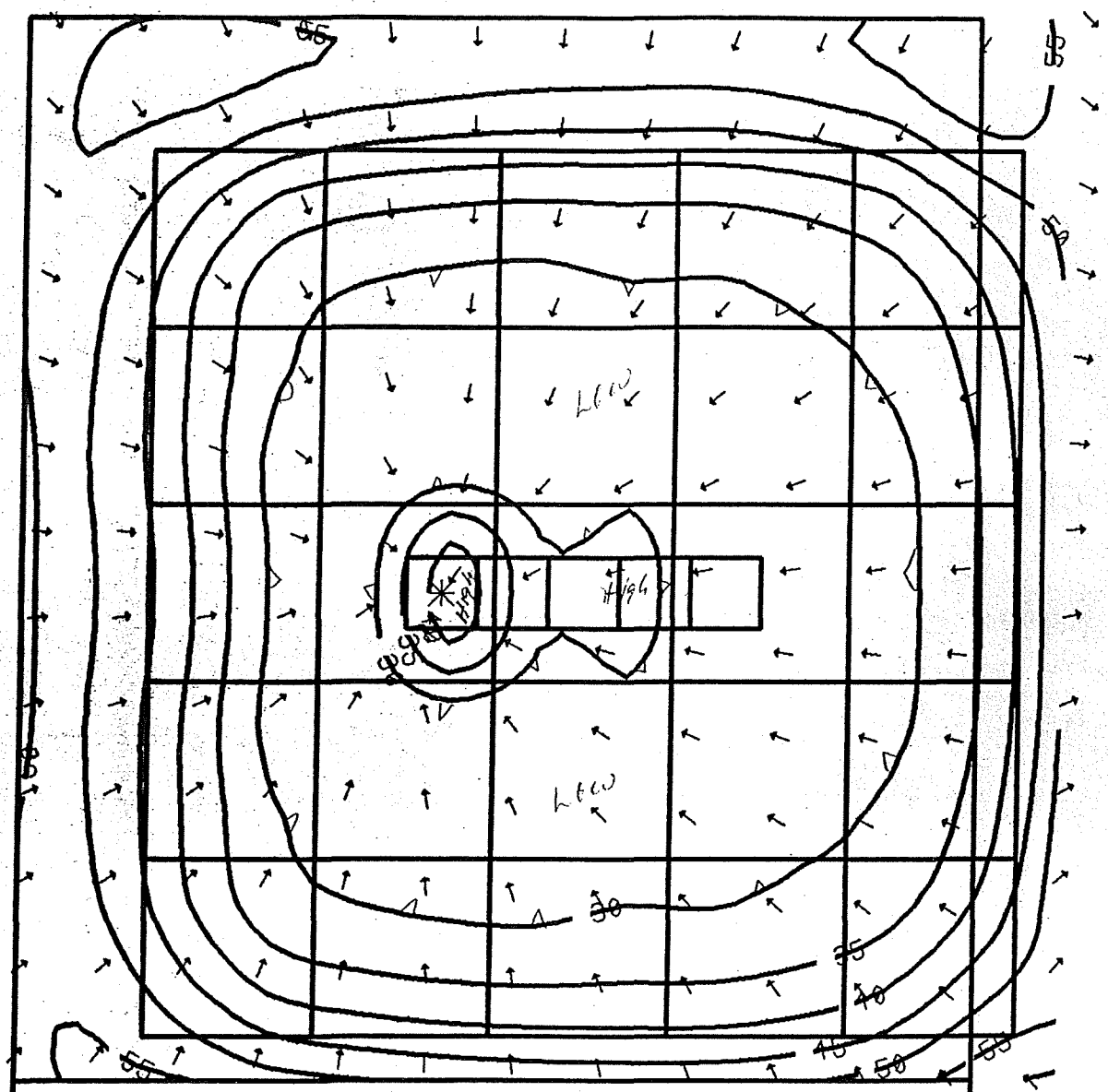
400' x 400' x 400' prisms

4 isolated lines @ corners due to fault zone.



Plot of ΔP
(with body − without body)





RAFT PA TEST-COND.OVERBURDEN APPARENT RESISTIVITY - FROM E

PLAN VIEW

SCALE: 1 UNIT

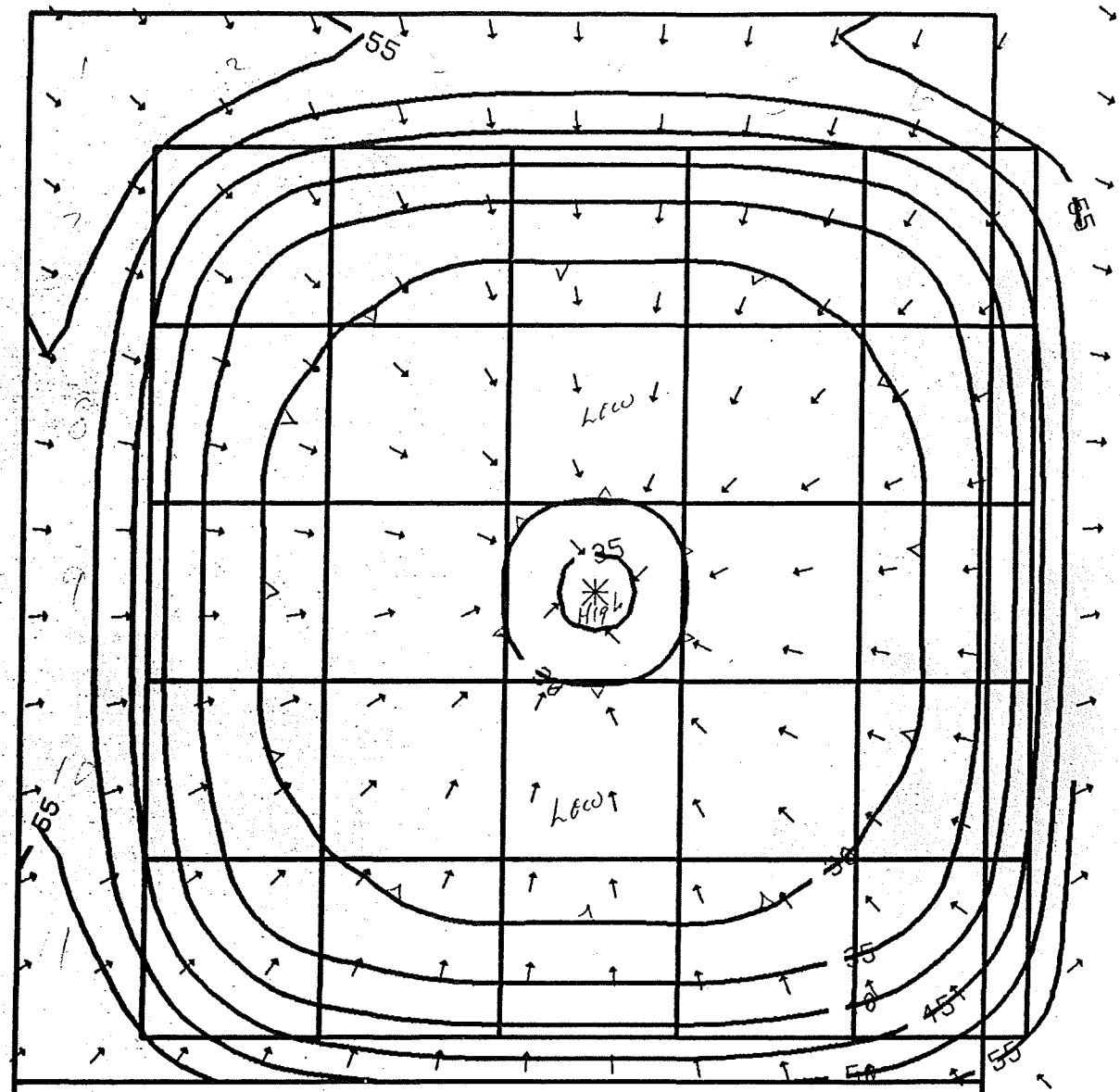
TRANSMITTER POSITION (X,Y,Z)		
-250.00	6.50	0.00
4.90	6.50	9.40

← Input 127

Fault Zone ρ_a = 20 Ω.m

electrode in end

400 x 400 x 400 prism.
IP Grid = 200'



RAFT PA TEST-COND.OVERBURDEN APPARENT RESISTIVITY - FROM E

PLAN VIEW

SCALE: 1 UNIT

TRANSMITTER POSITION (X,Y,Z)

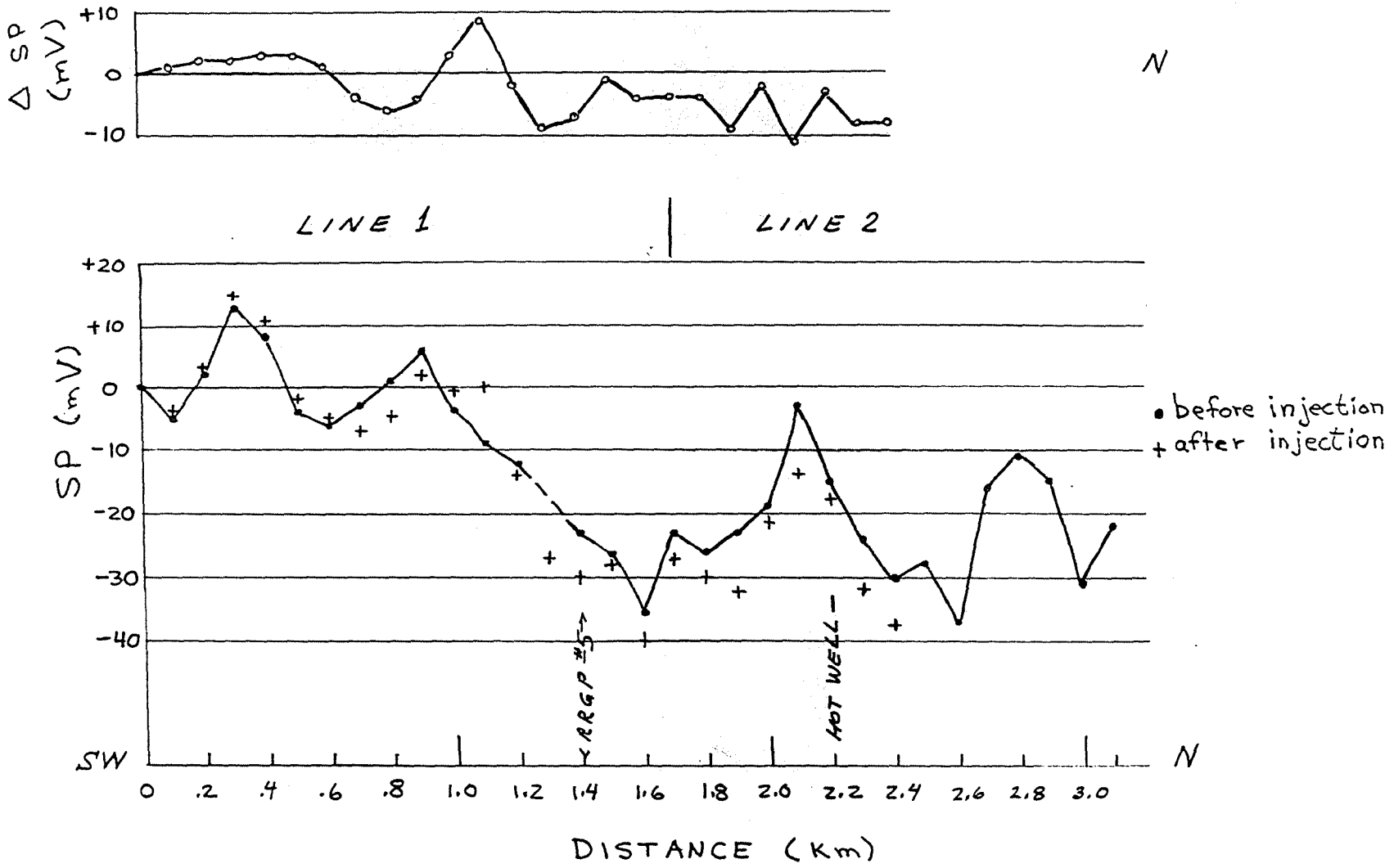
-250.00	6.50	0.00
6.50	6.50	9.40

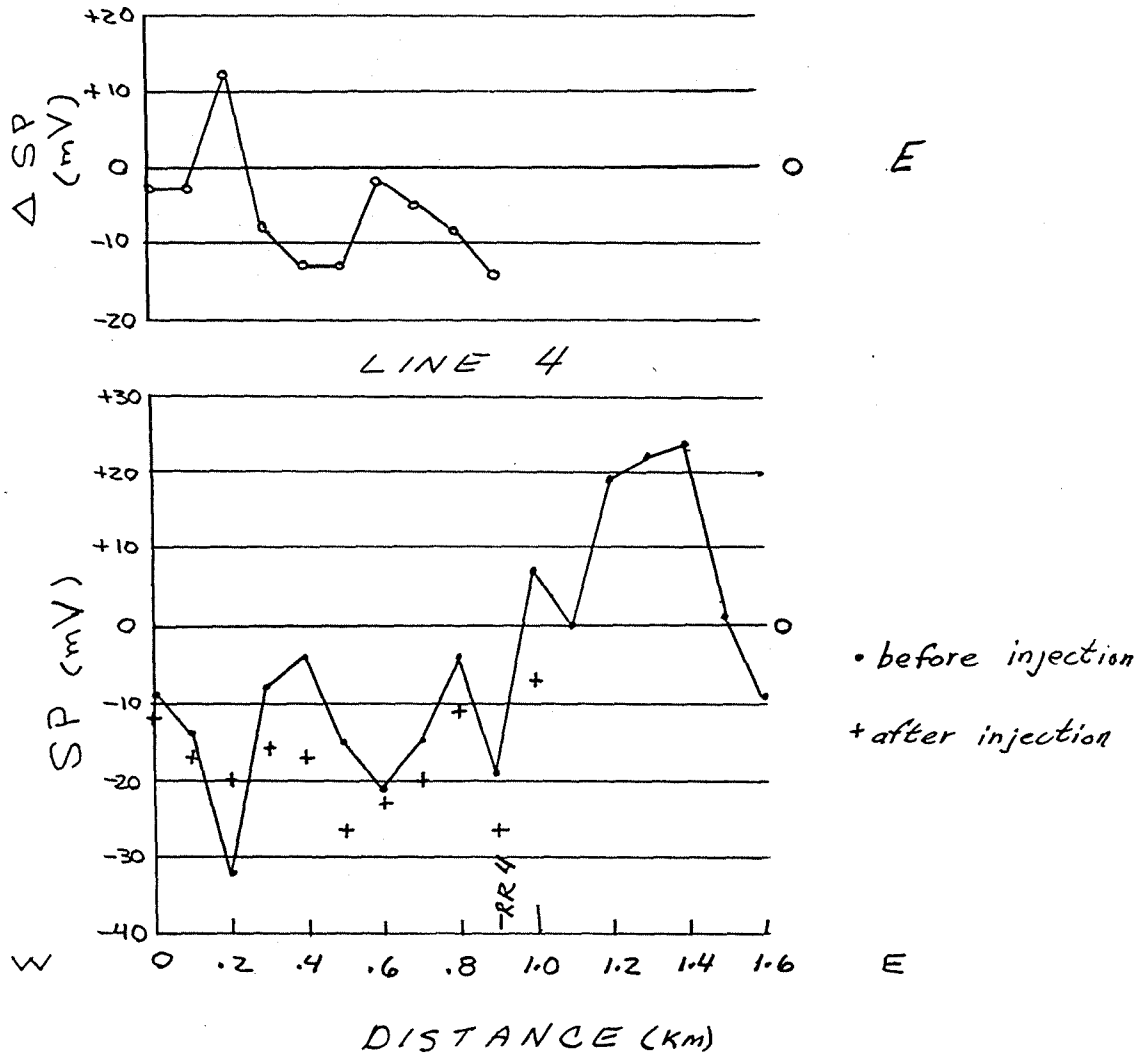
no Fault Zone

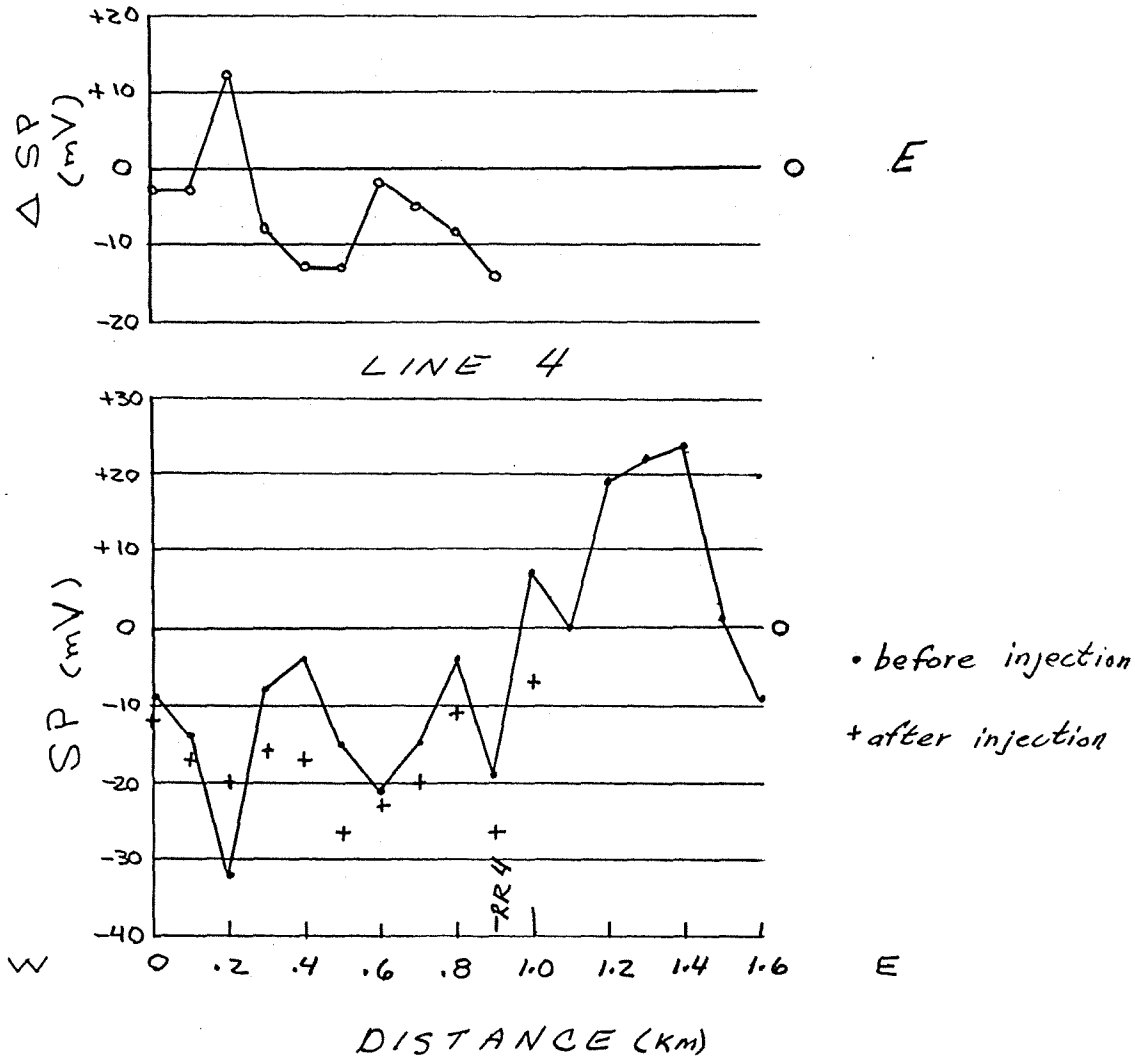
conductive overburden limited 1 unit

Prisms 2x2x2 units @ 8 ohm-m

Background 50 ohm-m


Δ SP (mV)
+10
0
-10
N
LINE 1
LINE 2
+20
+10
0
-10
-20
-30
-40
SP (mV)
• before injection
+ after injection
ARGP #5
HOT WELL
SW
N
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
DISTANCE (Km)


+20
+10
0
-10
-20
Δ SP (mV)
0
E
LINE 4
+30
+20
+10
0
-10
-20
-30
-40
SP (mV)
0
RR 4
W
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
E
DISTANCE (Km)
• before injection
+ after injection


+20
+10
0
-10
-20
Δ SP (mV)
0
E
LINE 4
+30
+20
+10
0
-10
-20
-30
-40
SP (mV)
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
W
E
RR 4
• before injection
+ after injection
DISTANCE (KM)

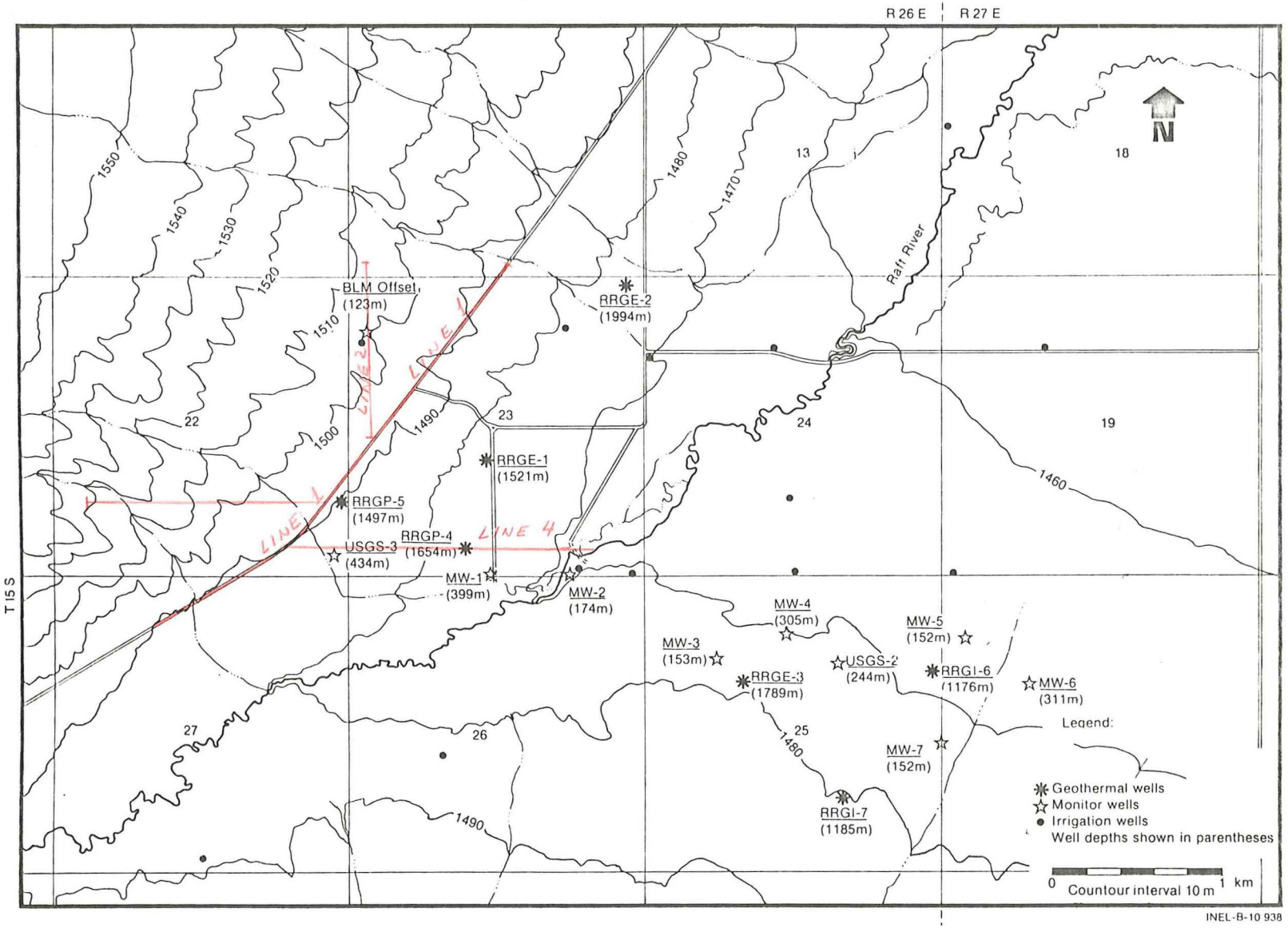
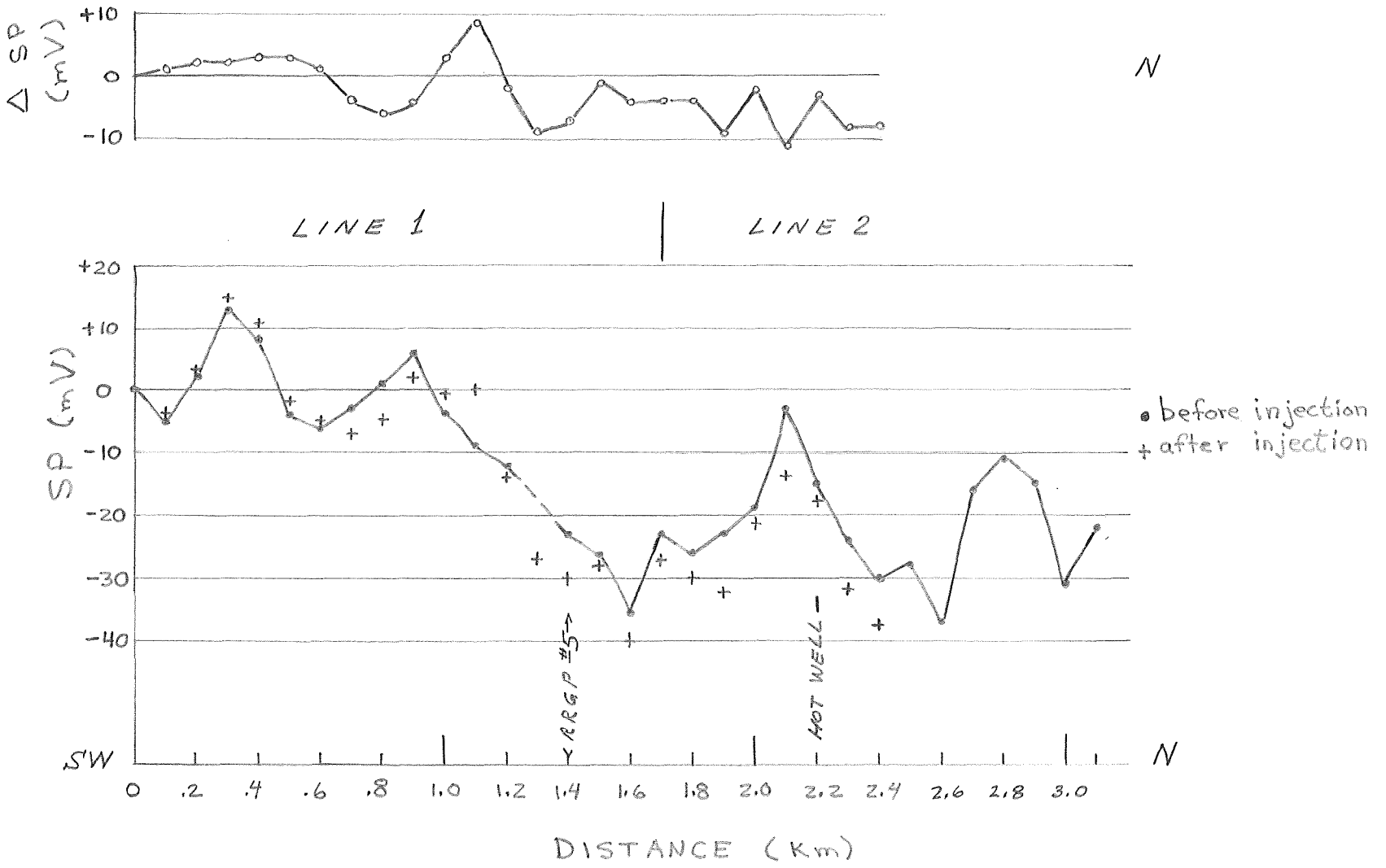
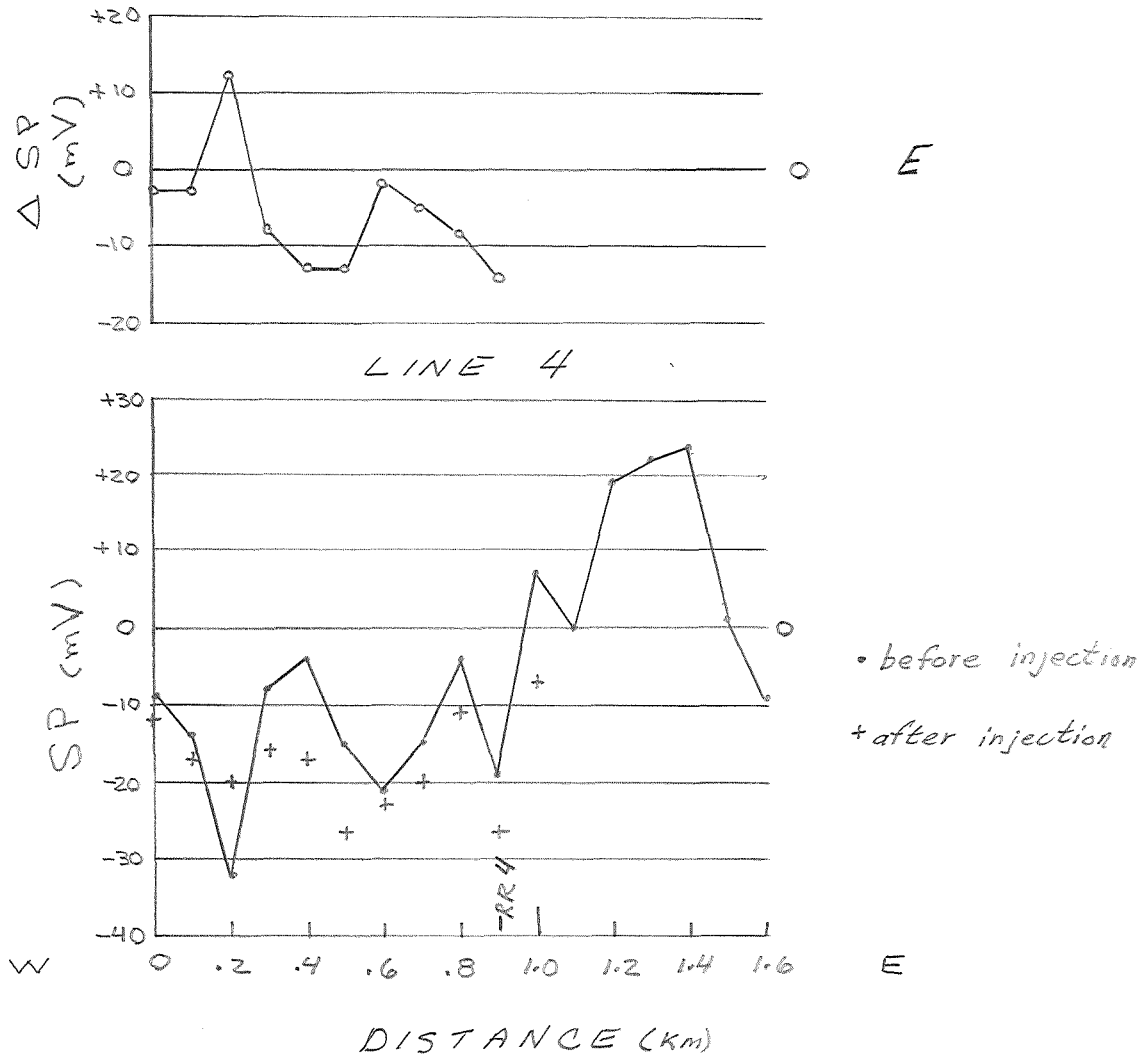
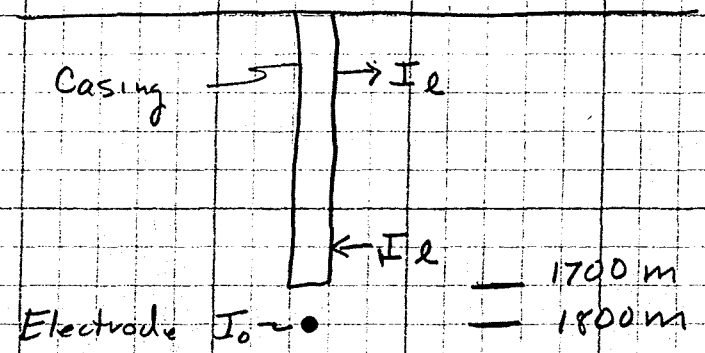


Figure 1. Raft River well field locations.


Δ SP (mV)
+10
0
-10
N
LINE 1
LINE 2
SP (mV)
+20
+10
0
-10
-20
-30
-40
• before injection
+ after injection
YARGP #5
HOT WELL
SW
N
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
DISTANCE (Km)


+20
+10
0
-10
-20
Δ SP (mV)
0
E
LINE 4
+30
+20
+10
0
-10
-20
-30
-40
SP (mV)
0
W
.2
.4
.6
.8
1.0
1.2
1.4
1.6
E
4K
• before injection
+ after injection
DISTANCE (km)

DOWNHOLE ELECTRODE



I_e LEAKAGE CURRENT

Top $\frac{I_e}{I_o} = 10^{-4}$/meter

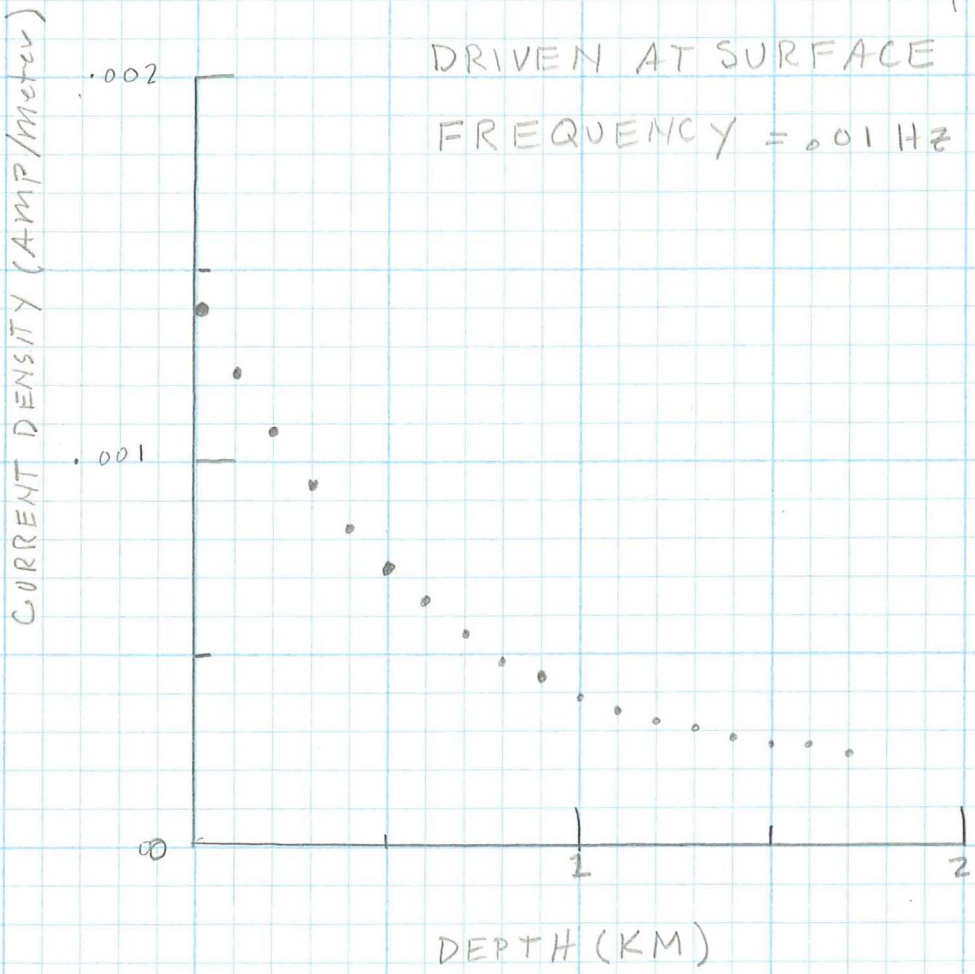
Bottom $\frac{I_e}{I_o} = 10^{-3}$/meter

CASING ELECTRODE

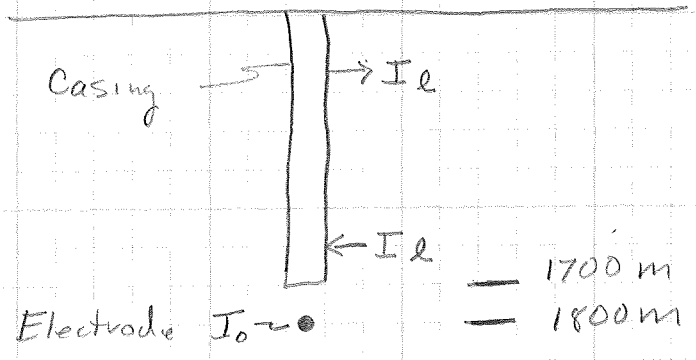
TOTAL CURRENT = 1 amp

DRIVEN AT SURFACE

FREQUENCY = .01 Hz



DOWNHOLE ELECTRODE



Ie LEAKAGE CURRENT

Top $\frac{Ie}{I_o} = 10^{-4}$/meter

Bottom $\frac{Ie}{I_o} = 10^{-3}$/meter

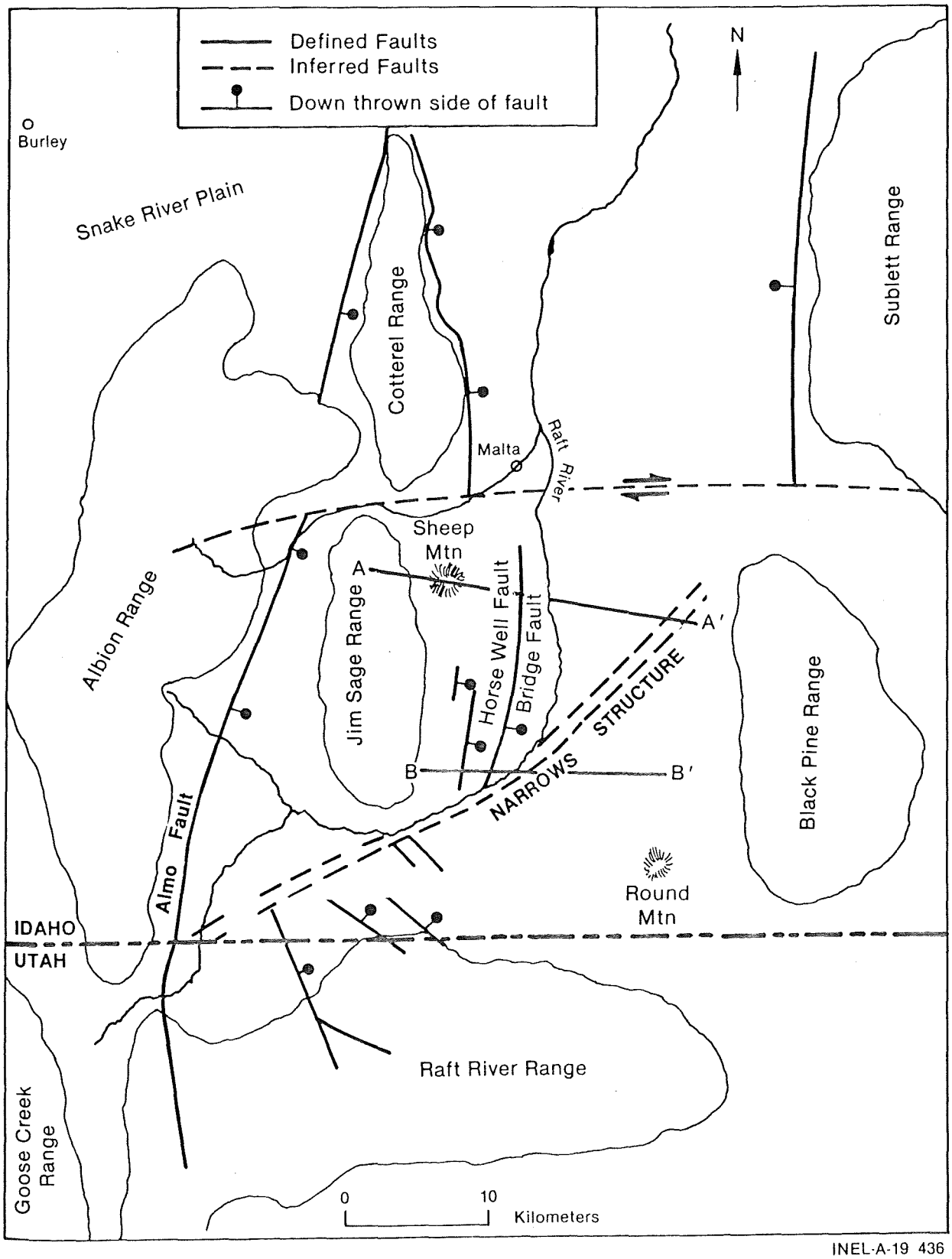


Figure 2. Raft River Valley and major structural features adjoining the valley.

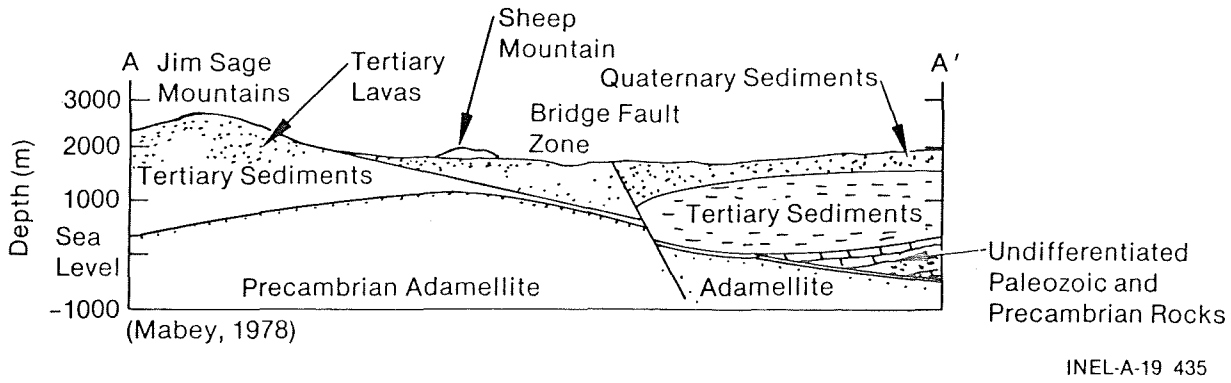


Figure 3a. An early interpretation of the Bridge Fault Zone.

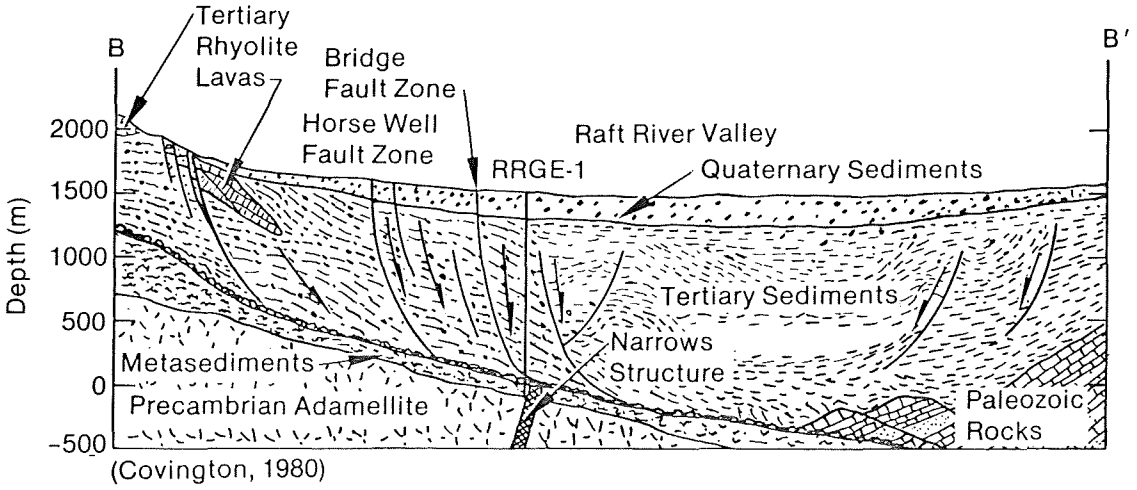


Figure 3b. A later interpretation of the Bridge Fault Zone illustrating no displacement of the basement.

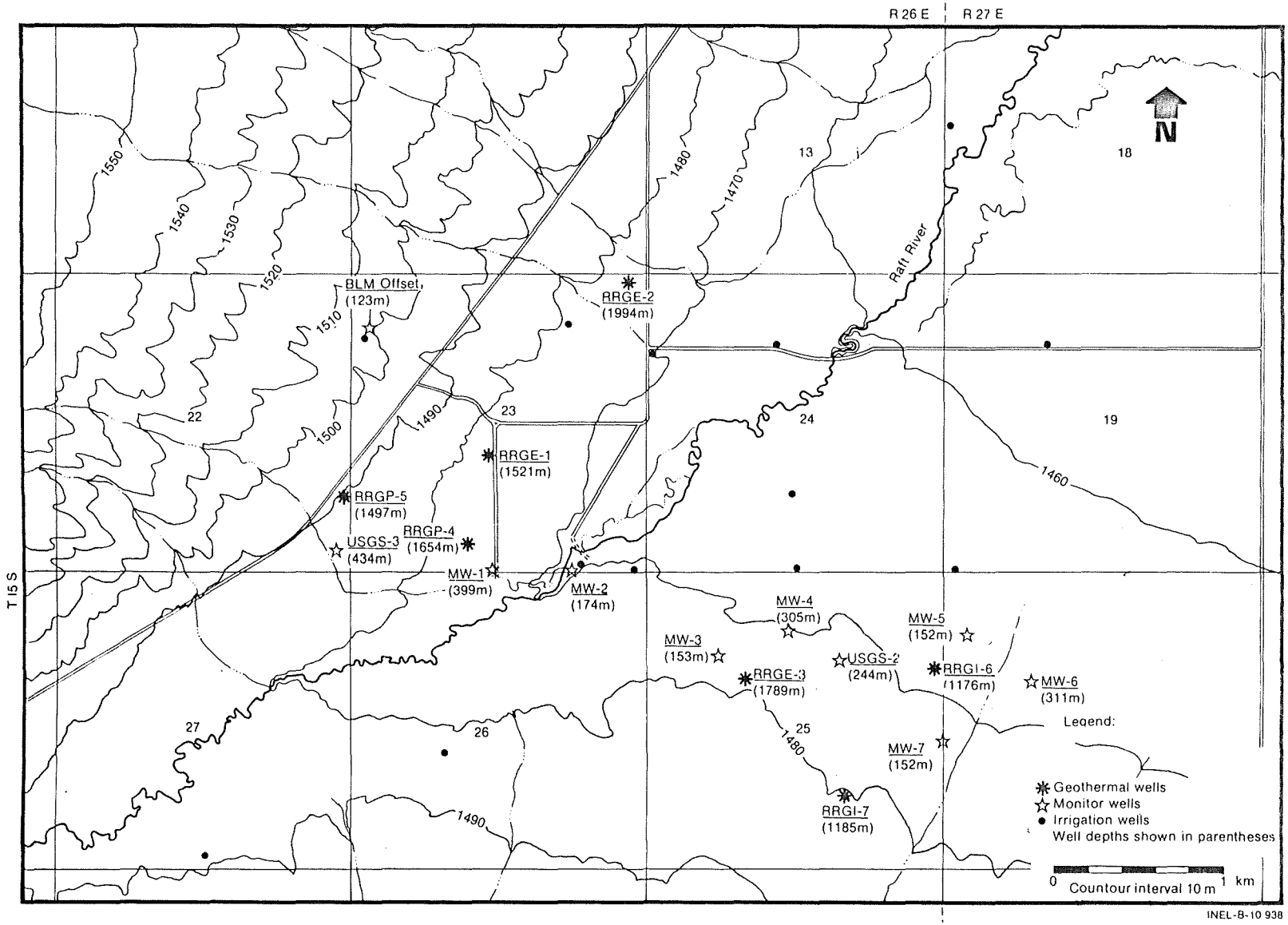
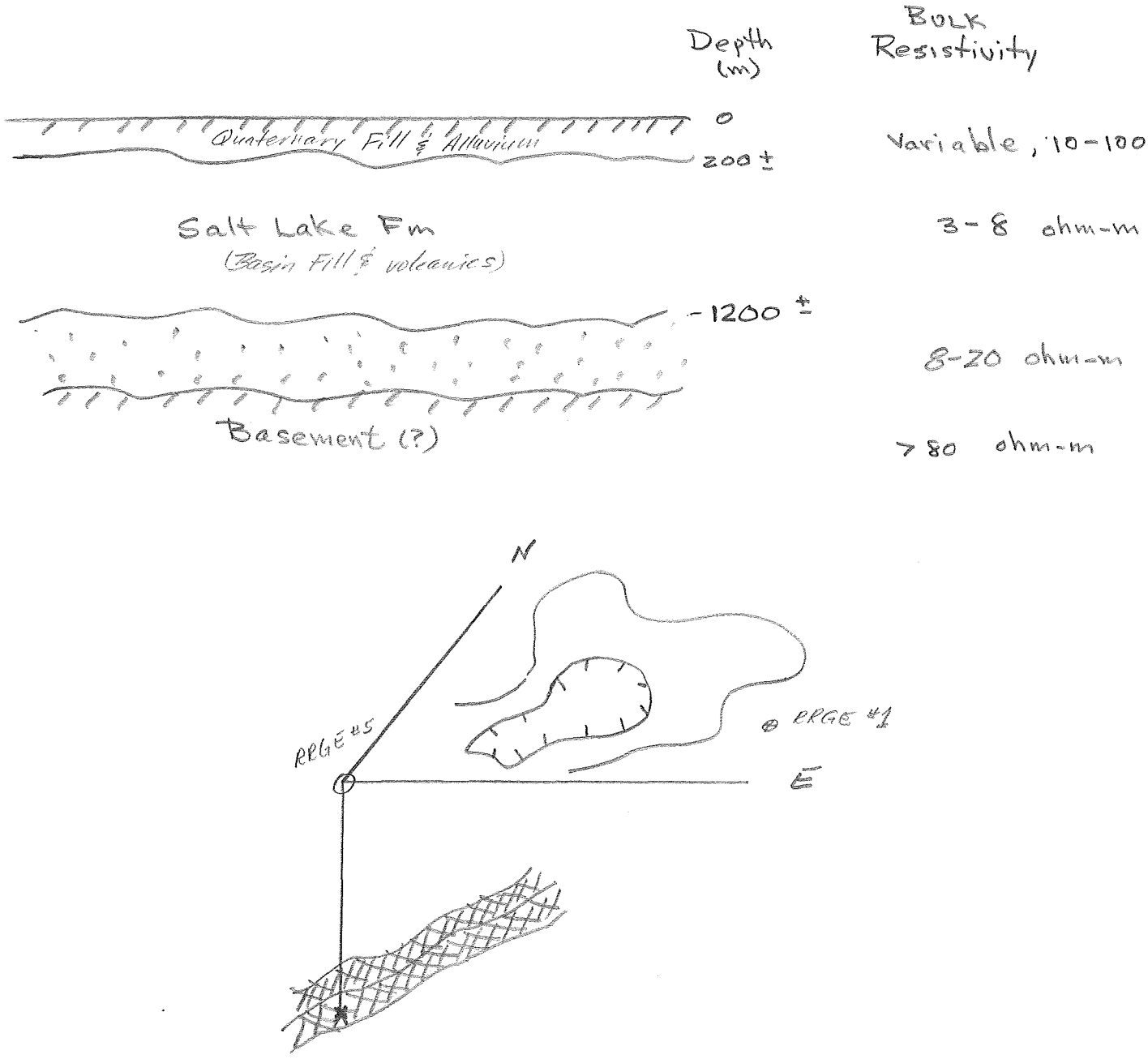
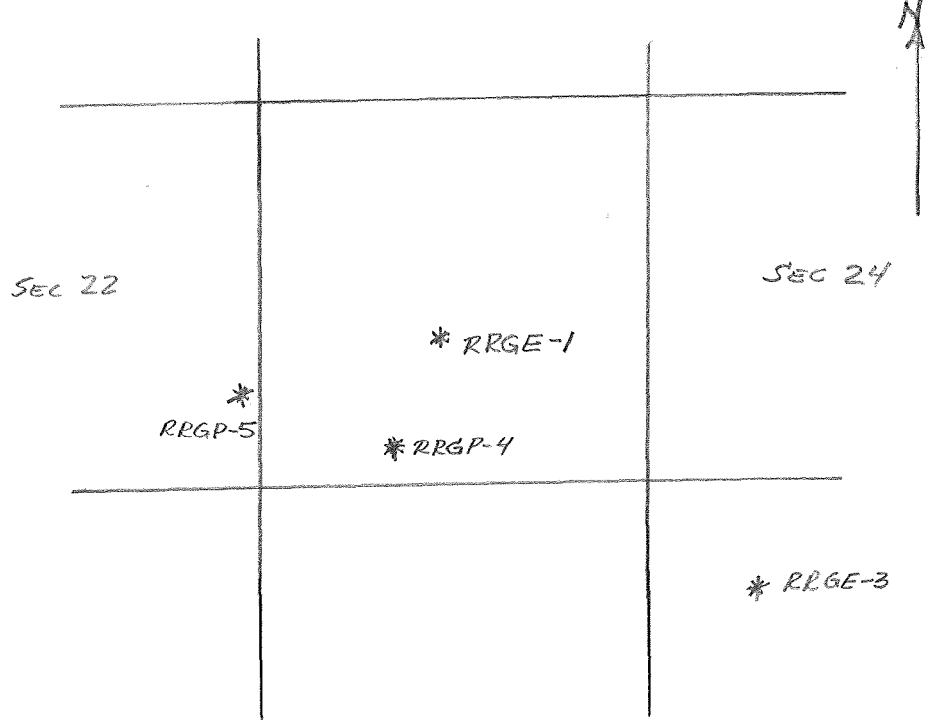
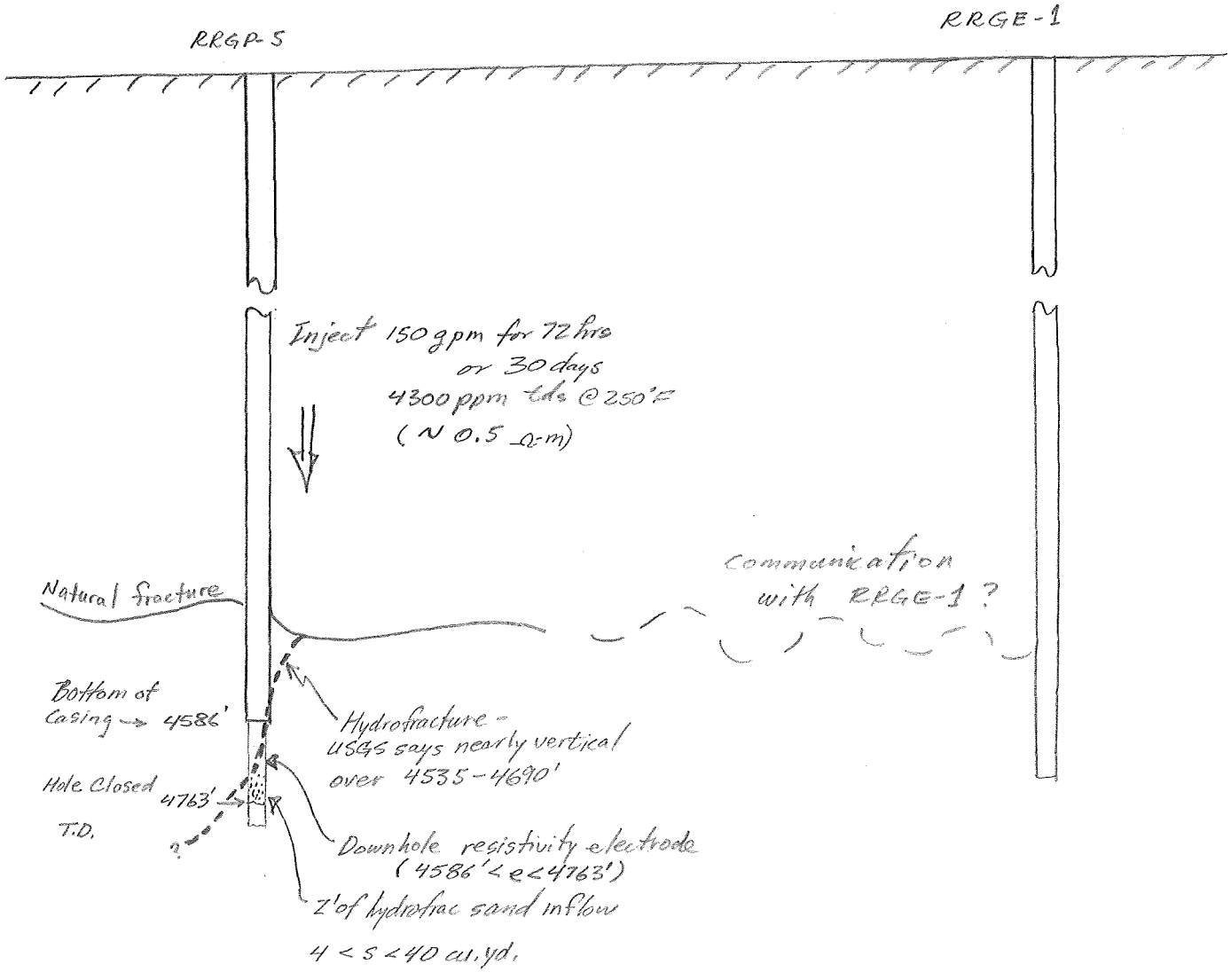


Figure 1. Raft River well field locations.



BURIED ELECTRODE STUDY


N
Sec 22
Sec 24
RRGE-1
RRGP-5
RRGP-4
RRGE-3


RRGP-5
RRGE-1
Inject 150 gpm for 72 hrs
or 30 days
4300 ppm tds @ 250°F
(~ 0.5 Ω-m)
communication
with RRGE-1 ?
Natural fracture
Bottom of
Casing → 4586'
Hydrofracture -
USGS says nearly vertical
over 4535-4690'
Hole Closed
4763'
T.D.
Downhole resistivity electrode
(4586' < e < 4763')
2' of hydrofrac sand inflow
4 < s < 40 cu. yd.

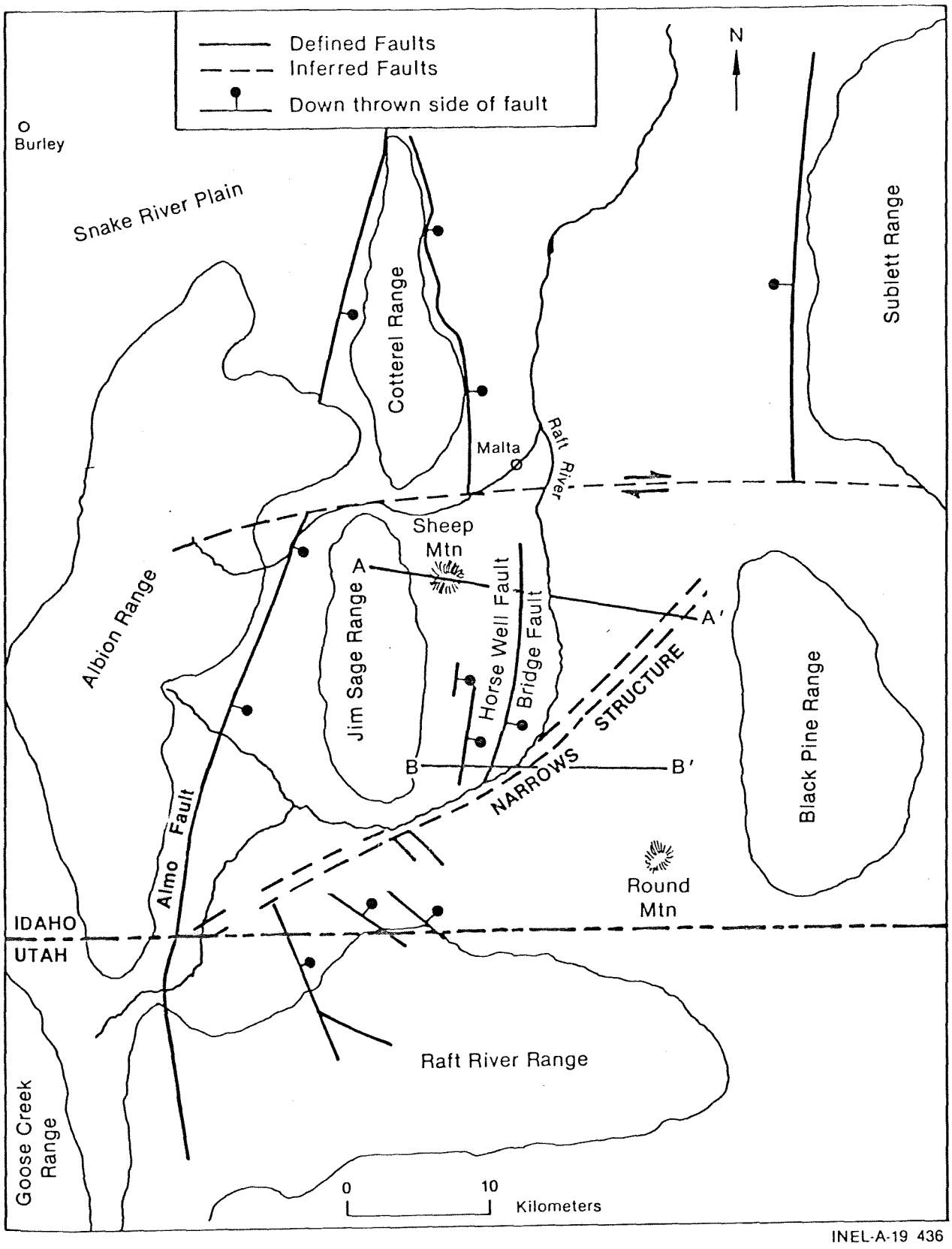


Figure 2. Raft River Valley and major structural features adjoining the valley.

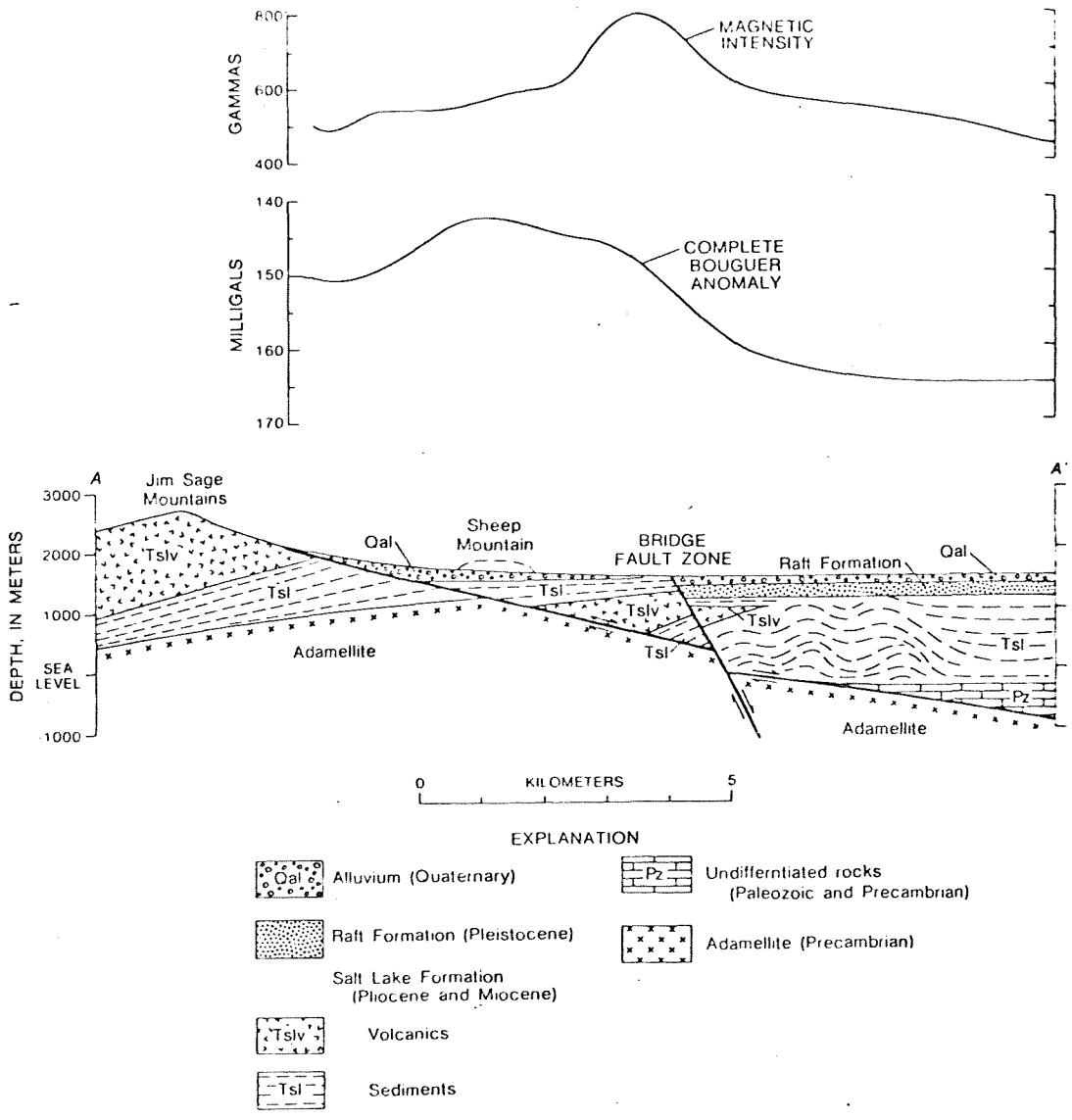


FIG. 10. Interpreted section across the west side of the southern Raft River Valley. Location of section is shown in Figure 4.

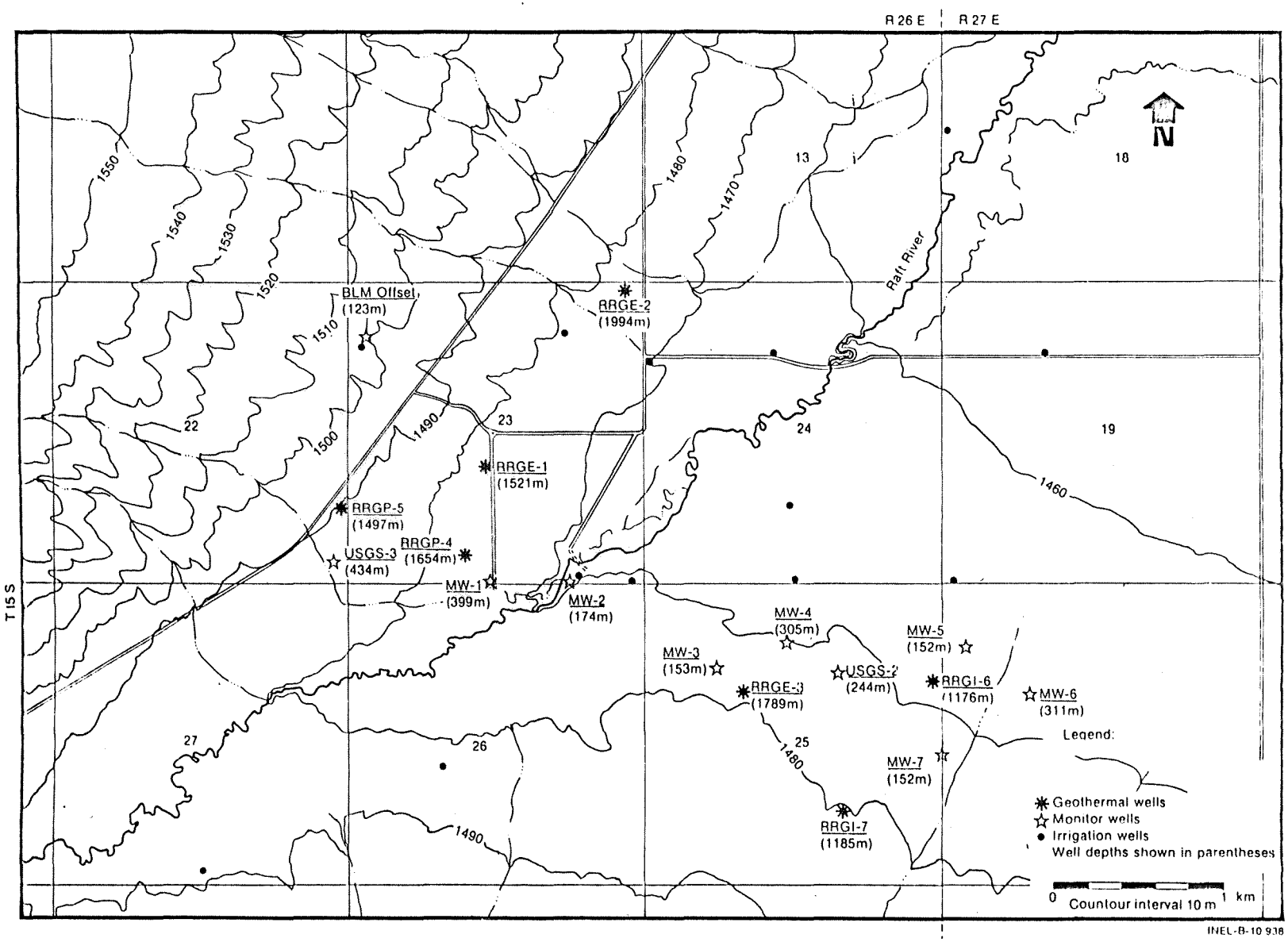
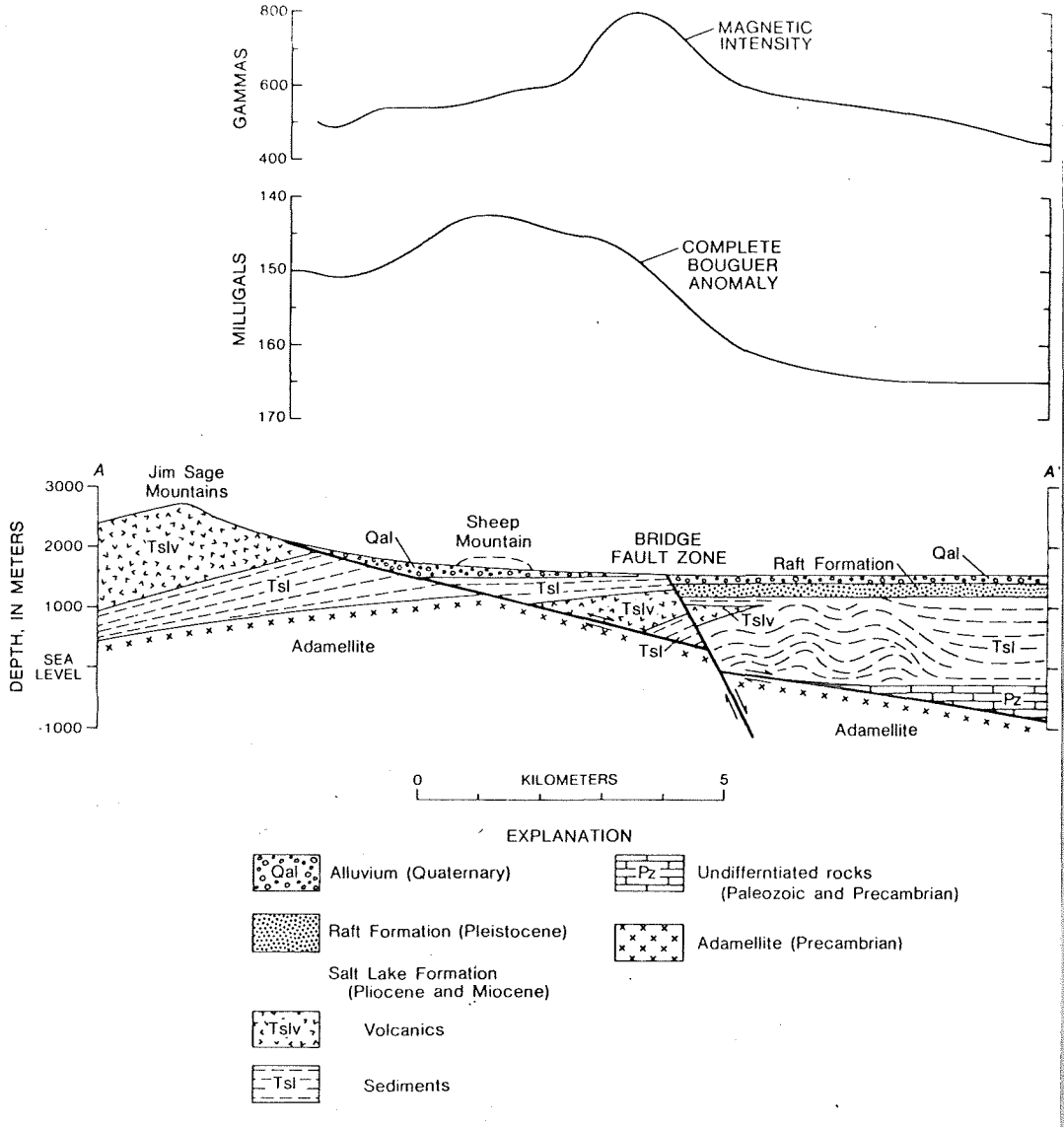


Figure 1. Raft River well field locations.



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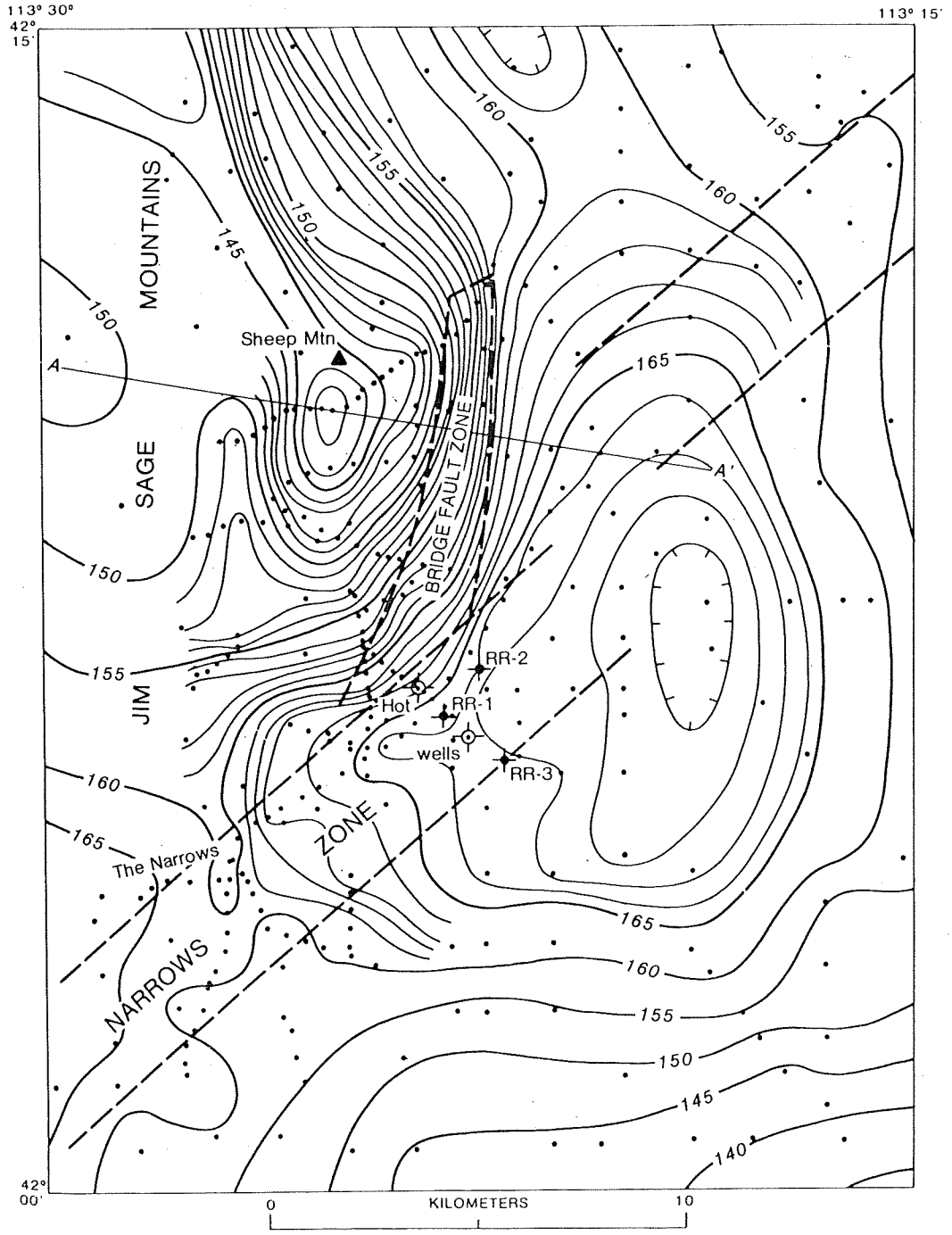


FIG. 4. Complete Bouguer gravity anomaly map of the southern Raft River Valley. Contour interval is 1 and 5 mgals. Deep drill holes are shown and numbered. Dots are gravimeter stations.

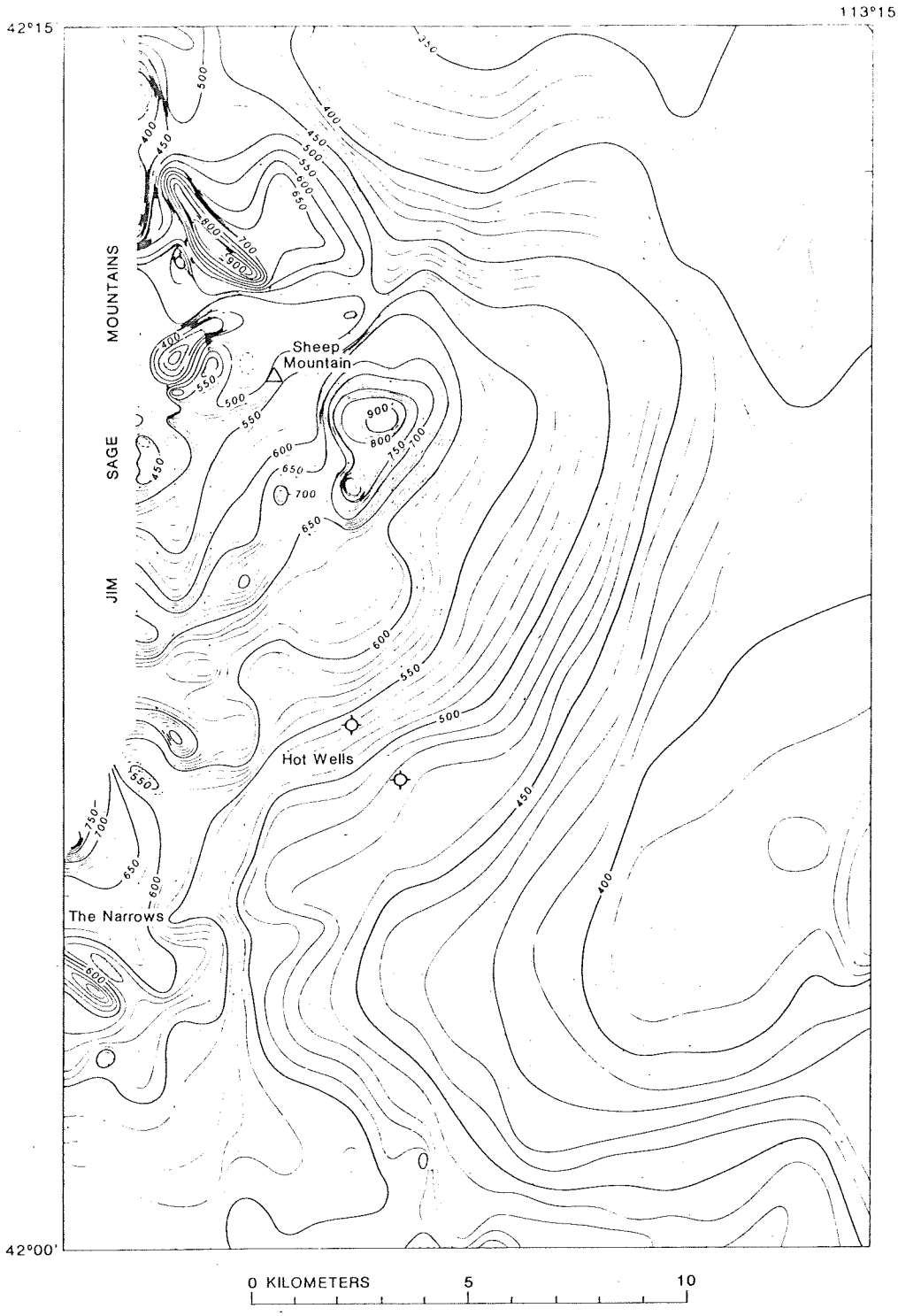


FIG. 5. Residual intensity aeromagnetic map of the southern Raft River Valley. Flight lines are 2800 m above sea level and 0.8 km apart. Contour interval is 10 gammas.

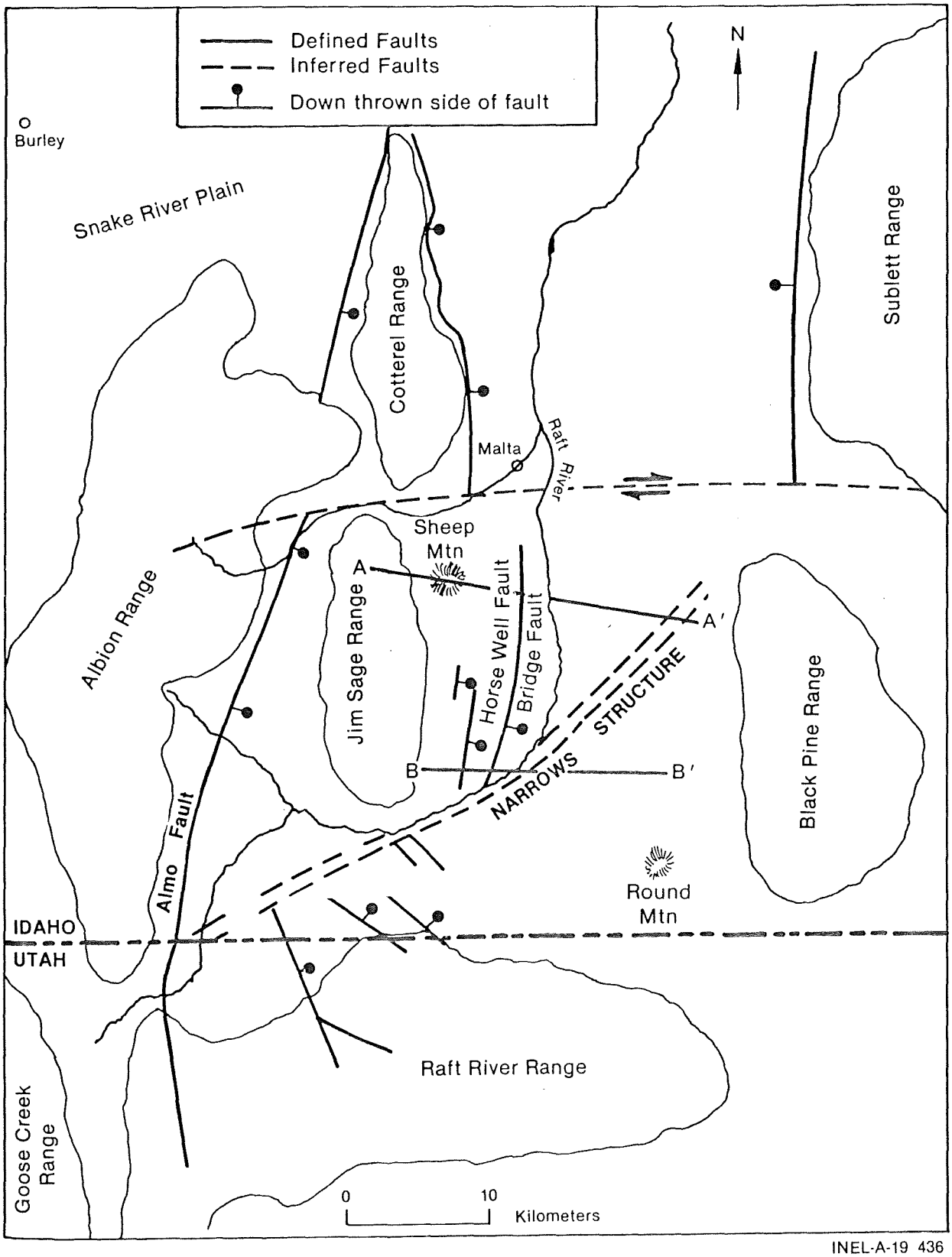
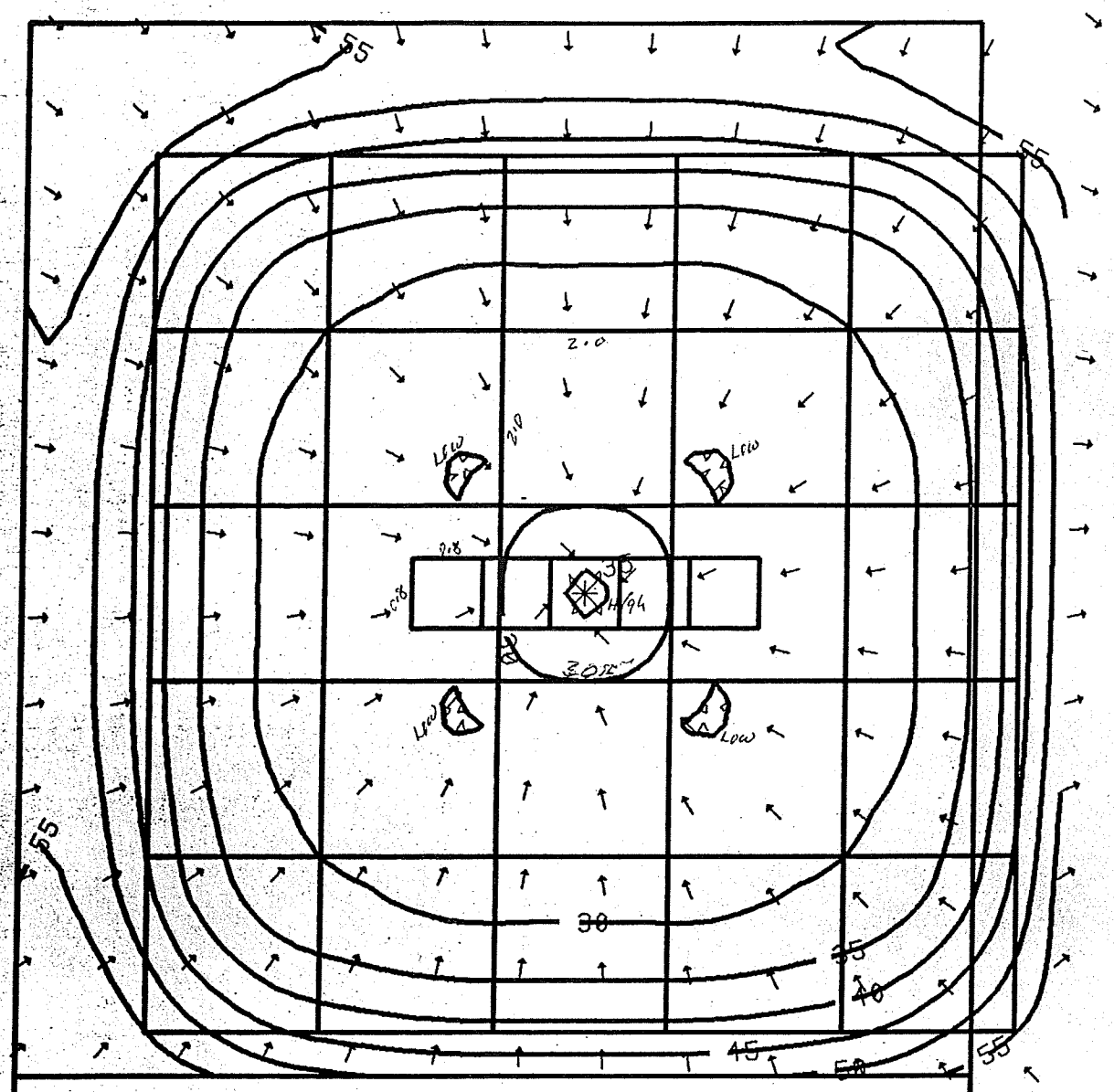


Figure 2. Raft River Valley and major structural features adjoining the valley.



RAFT PA TEST-COND.OVERBURDEN APPARENT RESISTIVITY - FROM E

PLAN VIEW

SCALE: 1 UNIT

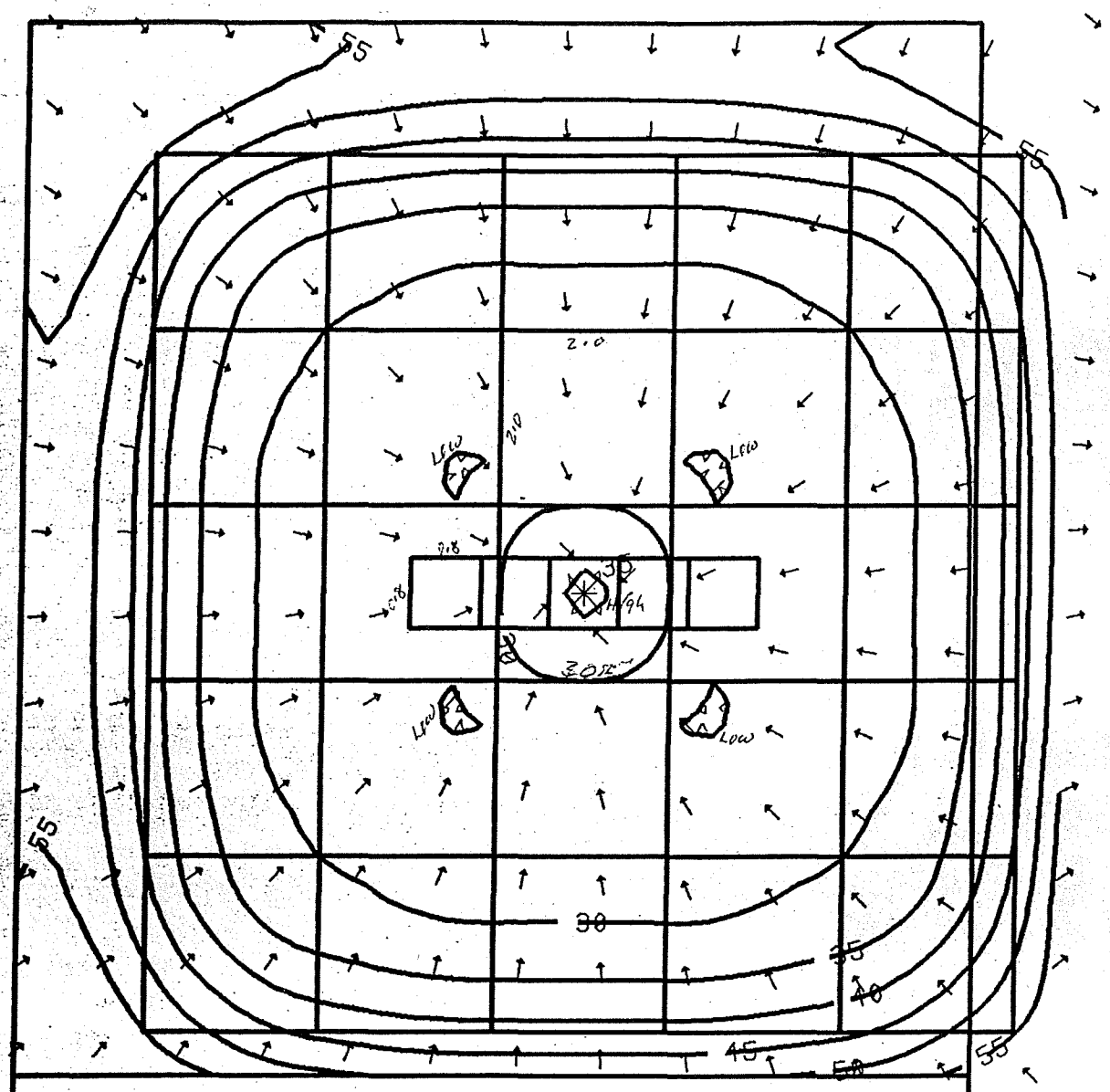
TRANSMITTER POSITION (X,Y,Z)

-250.00	6.50	0.00
6.50	6.50	9.40

Fault Zone PA - 20 ohm-m

400' x 400' x 400' prisms buried 9 units

4 isolated lows @ corners due to fault zone.



RAFT PA TEST-COND.OVERBURDEN APPARENT RESISTIVITY - FROM E

PLAN VIEW

SCALE: 1 UNIT

TRANSMITTER POSITION (X.Y.Z)		
-250.00	6.50	0.00
6.50	6.50	9.40

Fault zone

400' x 400' x 400' prisms

4 isolated lines @ corners due to fault zone.