Well Testing For G&G guys (and gals)

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Santos, Adelaide

What is Well Test Interpretation?

- Looking at squiggly lines in pressure and/or rate data to divine what's happening in the completion and/or reservoir
- A science?
- A religion?
- Both?

- Maybe it's just a tool to aid in understanding the well/reservoir?

Well Testers Agree (Usually) On

- Skin
- Perm (kh)

- The model we used for the analysis is right until we're proven wrong
  - If wrong, blame the data
  - If data's good, blame fluid and/or rock properties

- We're always right→You need to change Your model

What is Permeability?

- The ability of the rock to flow fluids
- A measure of the cross-sectional area of the connected pores in a rock.
- Permeability is a variable. It can change!
- It allows you to calculate what your well SHOULD be producing.

What is Skin?

- A reduction in POTENTIAL flowrate caused by ANYTHING, aka an additional resistance, or pressure drop, to overcome.
  - Damage
  - Non-Darcy effects
  - Partial perforation
  - Plugging
- Just a Fudge factor extra pressure drop in the near wellbore region.

What is Damage?

- Reduction in POTENTIAL flowrate caused by reservoir or foreign material.
  - Drilling mud
  - Plugging with fines
  - Clay swelling
  - Compaction
  - Perforation damage
- Damage can be reduced!

Common Terms
(and what they really mean)

- Wellbore Storage :
  - Something at the beginning of the test that I don't understand and can't explain – err, if I stimulate a well & improve the completion, I change the Wellbore Storage without changing the volume of the well bore…but, no one's going to ask…

- Non-Uniqueness:
  - Something at the end of the test that I don't understand and can't explain – err, there's a good chance that I'm wrong but can't admit it…just too many unknowns & not enough equations…what's a fancy word I can use for this so I'm still the smartest person in the room (be sure to pat self on back)?

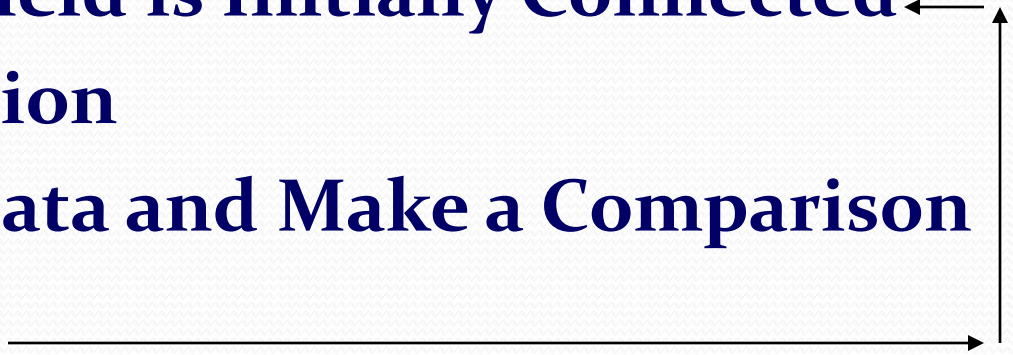
More Terms…

- Condensate Banking:
  - Something in the middle of the test that looks like liquid dropped below the downhole gauge…Oh, crap! I rented them the gauge & they're going to do the "blame the gauge" trick…hmmm, it IS a gas condensate well…
- Phase Re-segregation:
  - Well…that's weird…what can I call that?
- Smoothed Data:
  - I couldn't get a model to match it, so I "fixed" the data

State of the Art

What We Do Now

- Set Capillary Entry Pressure to Zero
- Derive Diffusion Equation
- Guess a Fixed Reservoir Boundary
- Assume Flow Field is Initially Connected
- Compute Solution
- Smooth Real Data and Make a Comparison
- Guess Again



A Bit of Controversy:

ISN'T LOOKING AT THE MAP FIRST…Just…

CHEATING?

Does Blind Mapping Increase the Validity of the Model?

What if…

- Instead of performing mathematical manipulation with the data and pre-setting the boundaries, we:
  - Apply Thermodynamic Constraints (1st & 2nd Law)
  - Include the Higher Order Terms in the Diffusivity Eqn
  - Include the Concept of Threshold Pressure (pressure drop required to initiate flow from a pore)
  - Treat the System Like a Mass Transfer/Energy Dissipation Process

R&D Session: Blind Energy Map

(After Many Beers…)

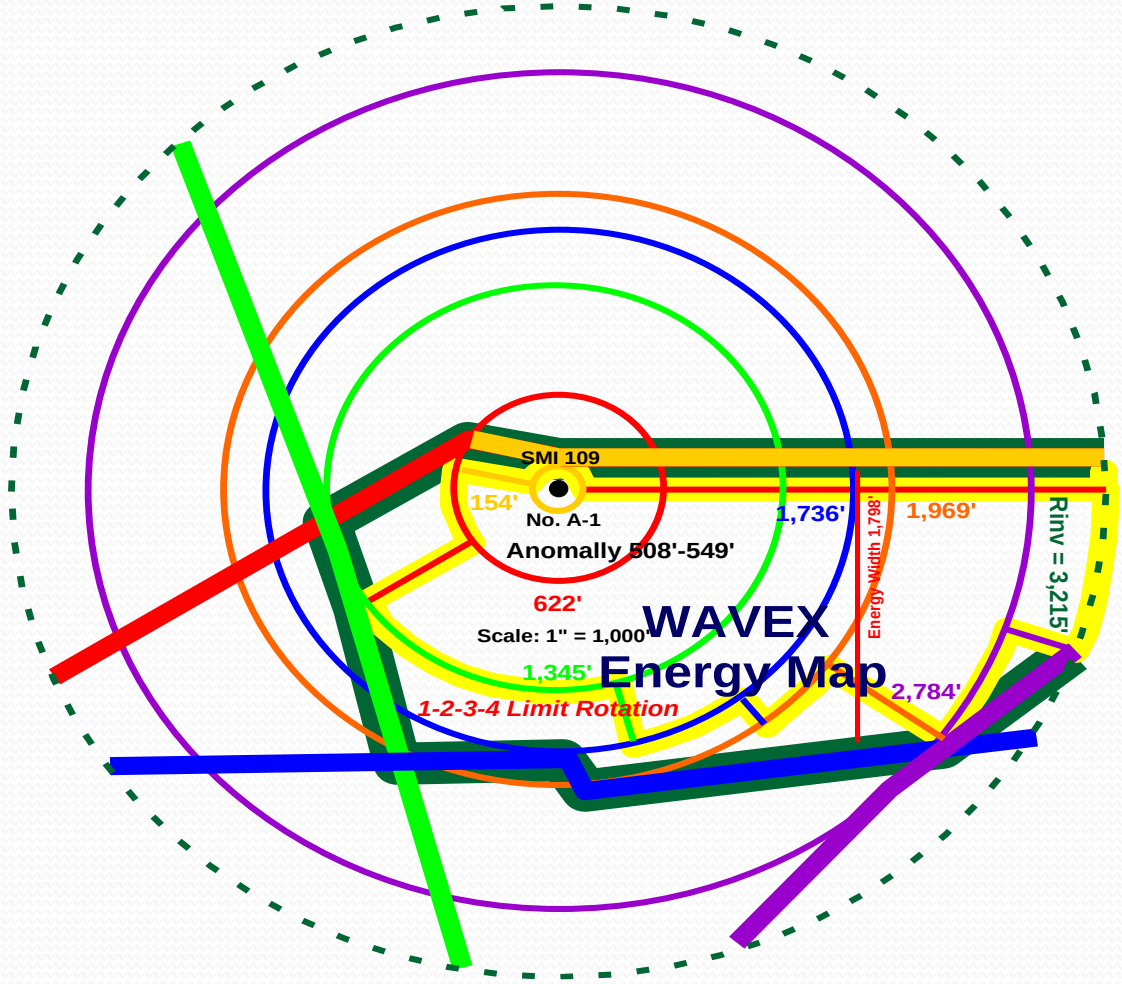
- A Closed Solution
- Running Volumetrics – don't have to reach PSS to get a volume
- More Accurate Permeability-Thickness
- More Accurate Distances to Limits
- Differentiate between Faults, Strat-outs & Gas-Liquid Contacts
- Relative Position of Limits to Each Other
- A Map You can show the G&G guys without getting laughed out of the room

Blind Energy Map – Example 1

From pressure/rate data ONLY

…Now, let's meet with the G&G team

This is the point to begin integration of Well Testing & Seismic.



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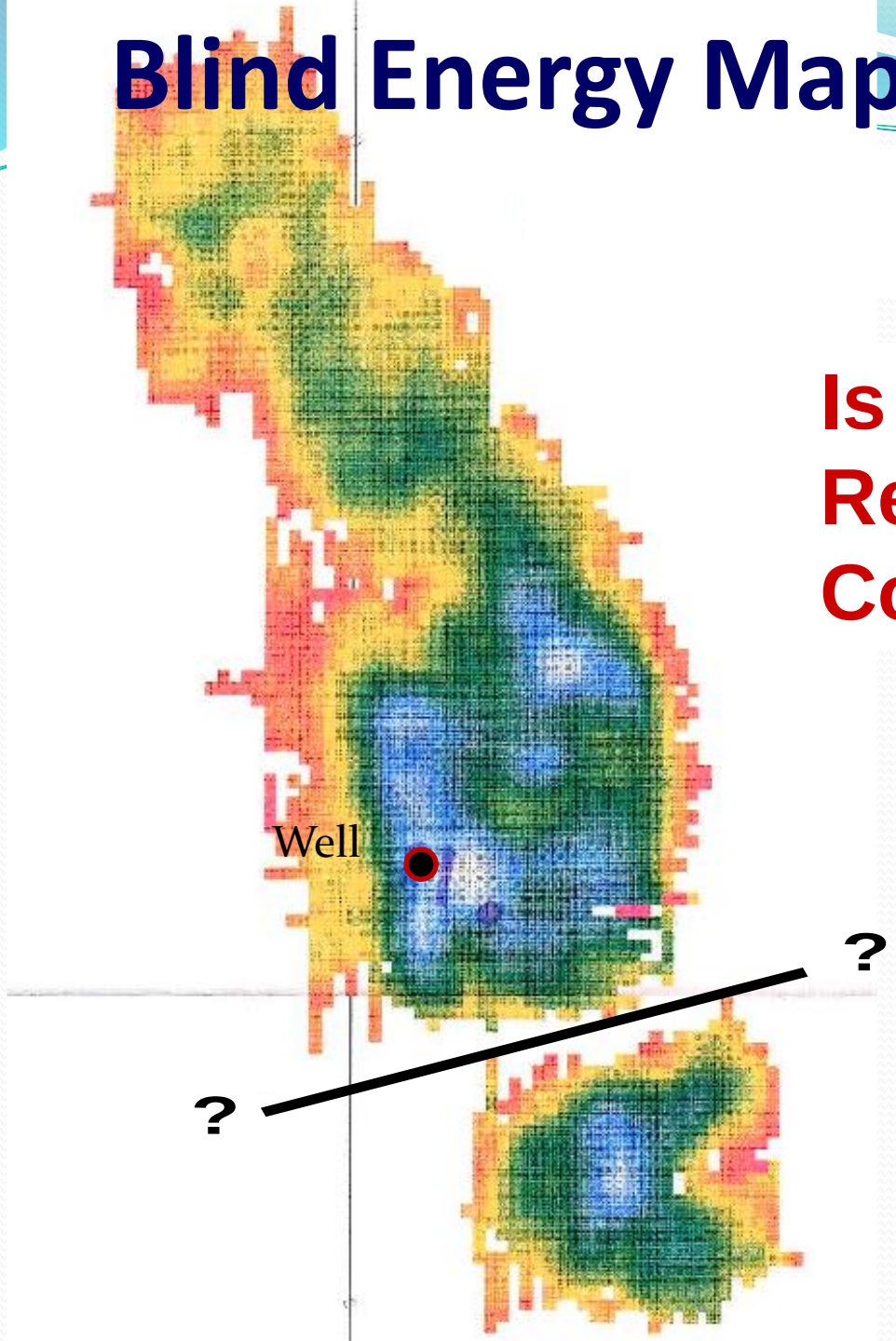

Is This One or Two Reservoir Compartments ?

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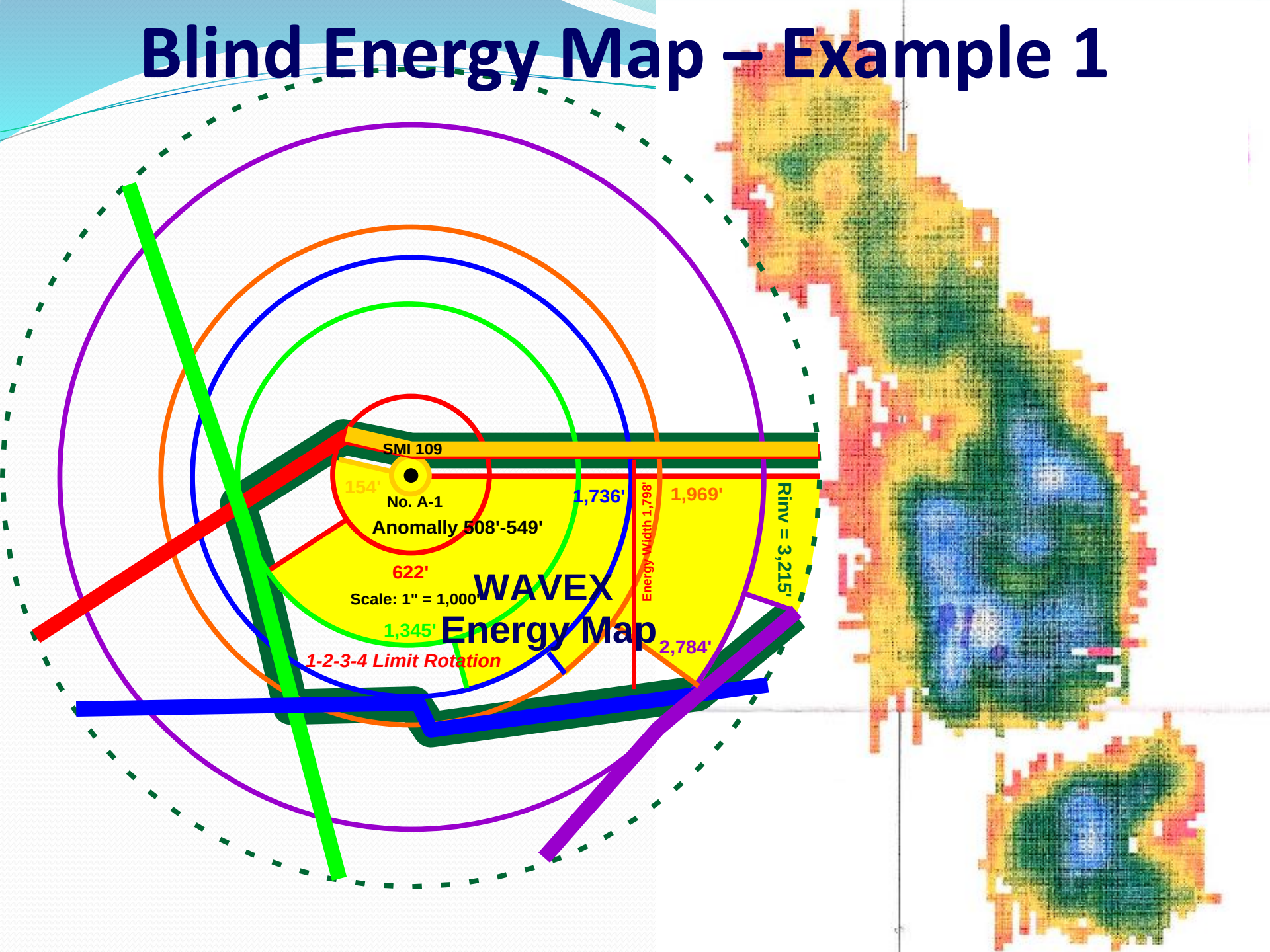
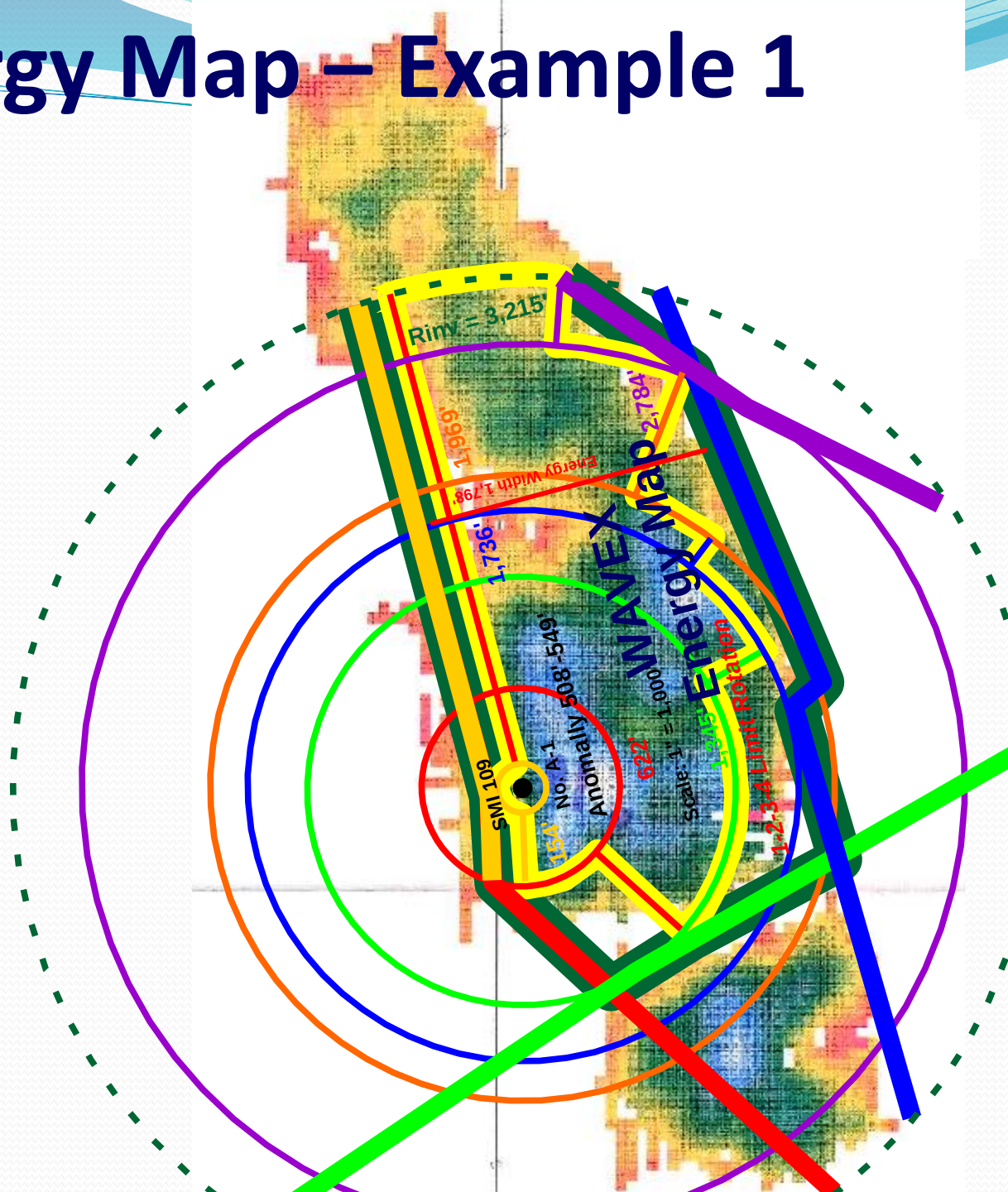


Blind Energy Map – Example 1

Conclusion:

- The reservoir compartments are NOT connected
- The study improved operator's geological interpretation
- ODSI evaluated 18 BFC of gas in place; the well produced 12.7 BCF (depletion drive; high compressibility rock)
- Once the 'Top' compartment was depleted, the operator side-tracked to the 'Bottom' compartment and encountered virgin pressures



Questions?

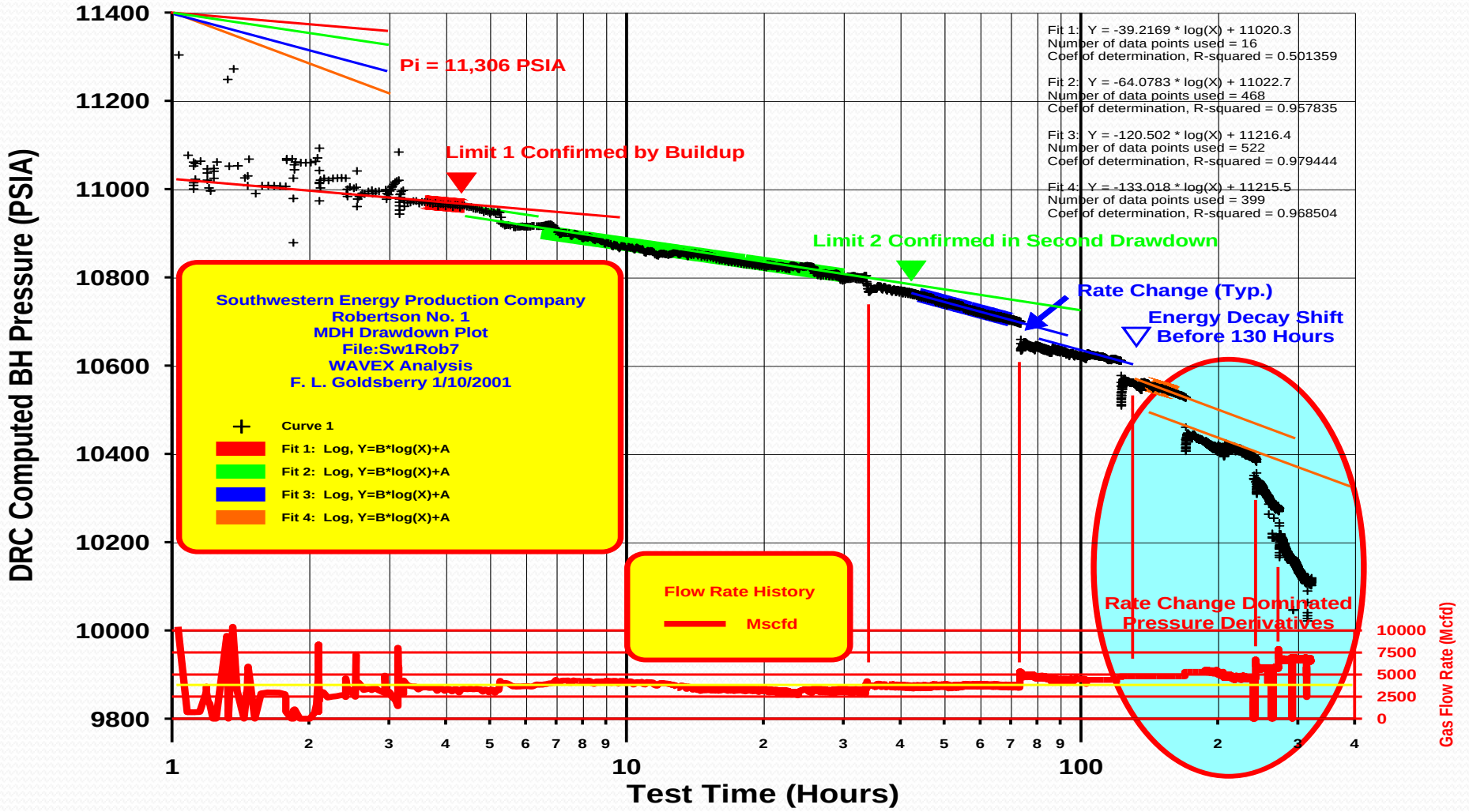
- How Long to Generate Results? 2-5 days
- How Much? <$35,000 plus data acquisition costs
- Besides the Pressure & Rate Data, What do You Need?
  - Logs
  - Core/SWC data
  - Fluid Properties
  - Completion/Wellbore Diagram
  - NOT Your Map

Full Study – Example 2

- Working Session with G&G Team
- Well Test Analysis Performed
- Energy Map Generated
- Overlay made of Energy Map
- Energy Map compared to Geologic Map
- Back to the G&G workstation…
- New View of Geology

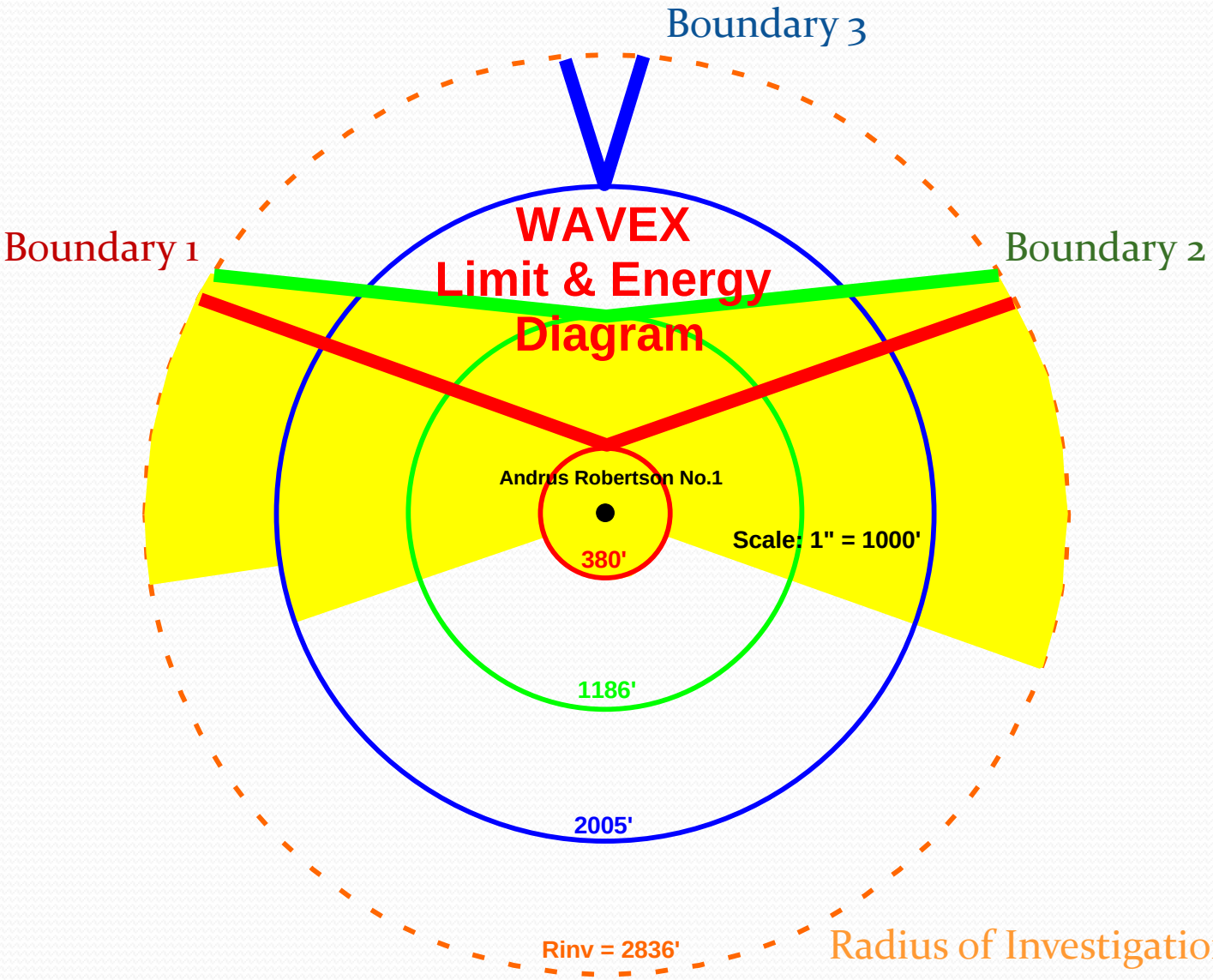
Blind Energy Map – Example 2

- Reservoir Boundaries, types of boundaries and shape of the reservoir were identified **from pressure/rate data only**



Blind Energy Map – Example 2

Overview of identified reservoir boundaries



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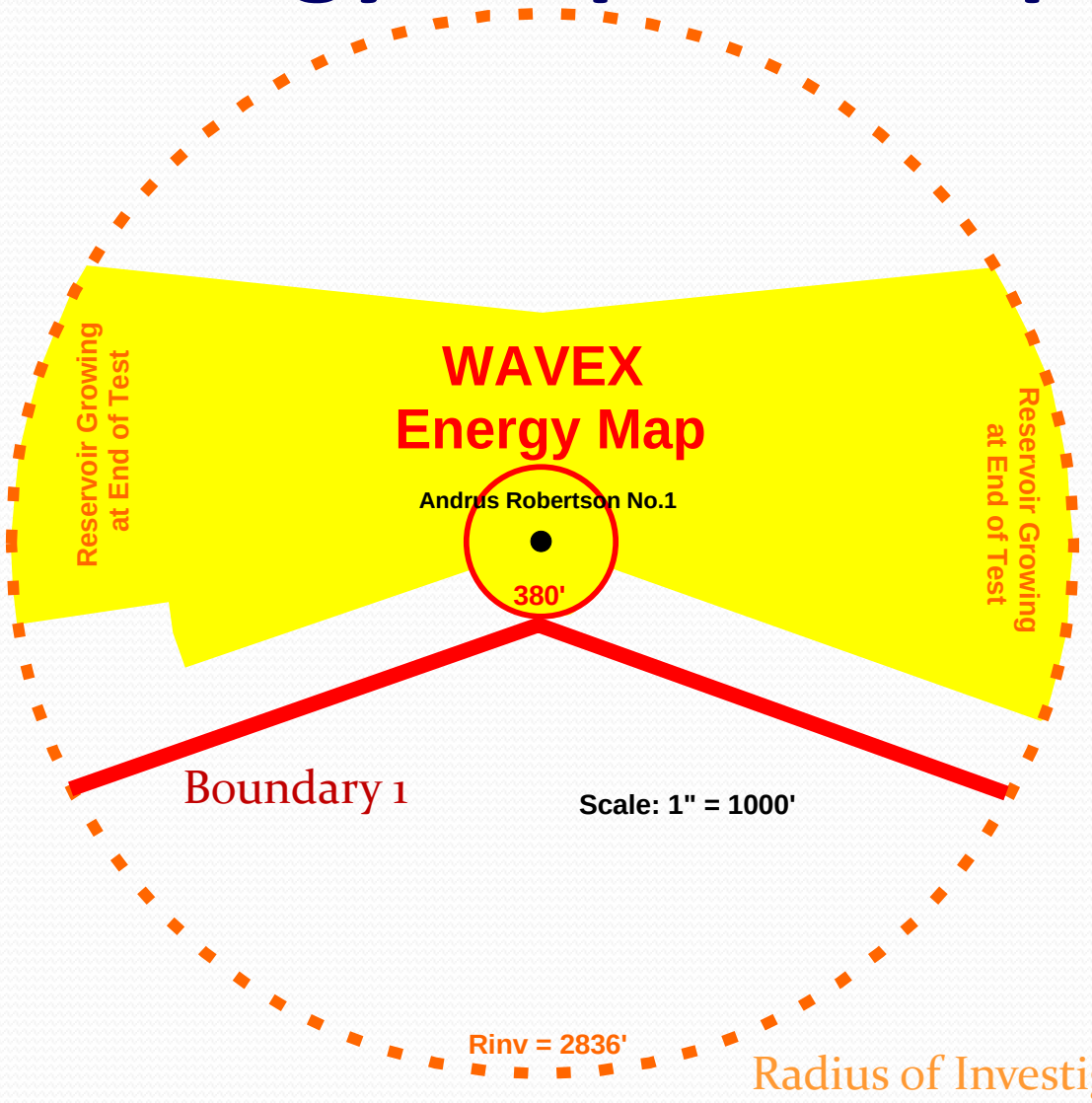
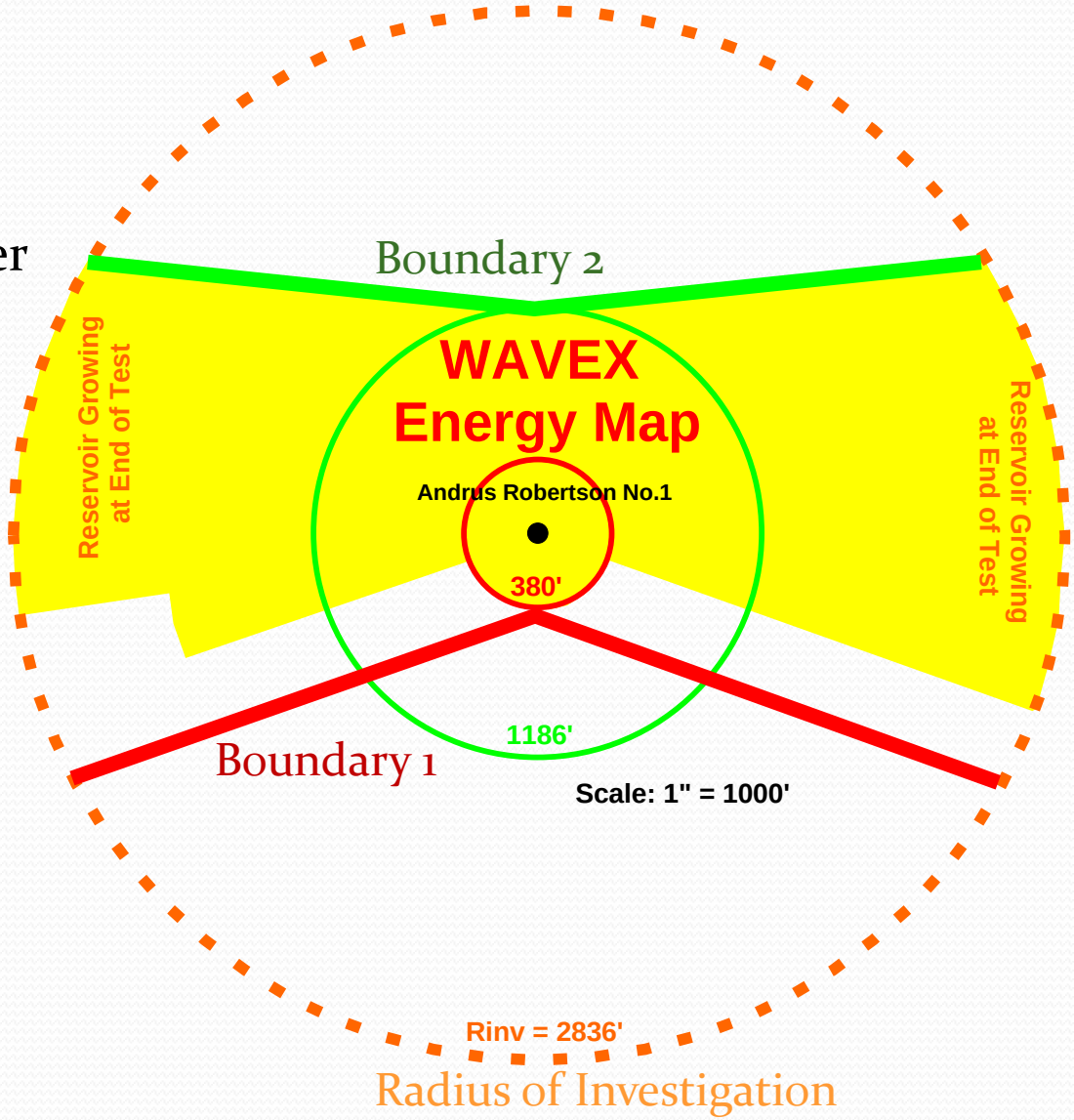


Blind Energy Map – Example 2

Comments:

- Boundary 1 and Boundary 2 appeared parallel to each other (Observed linear flow on the pressure data)



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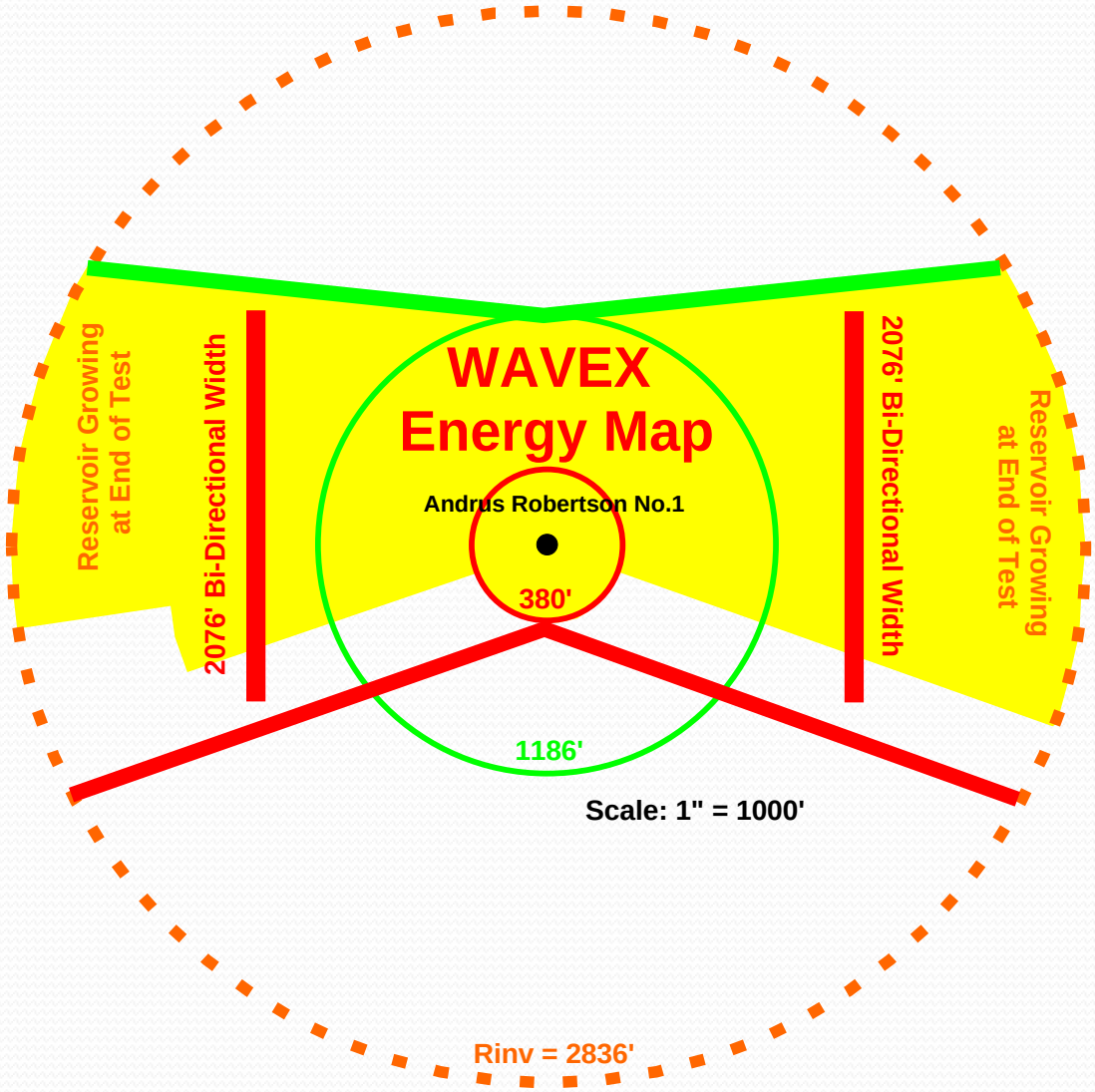

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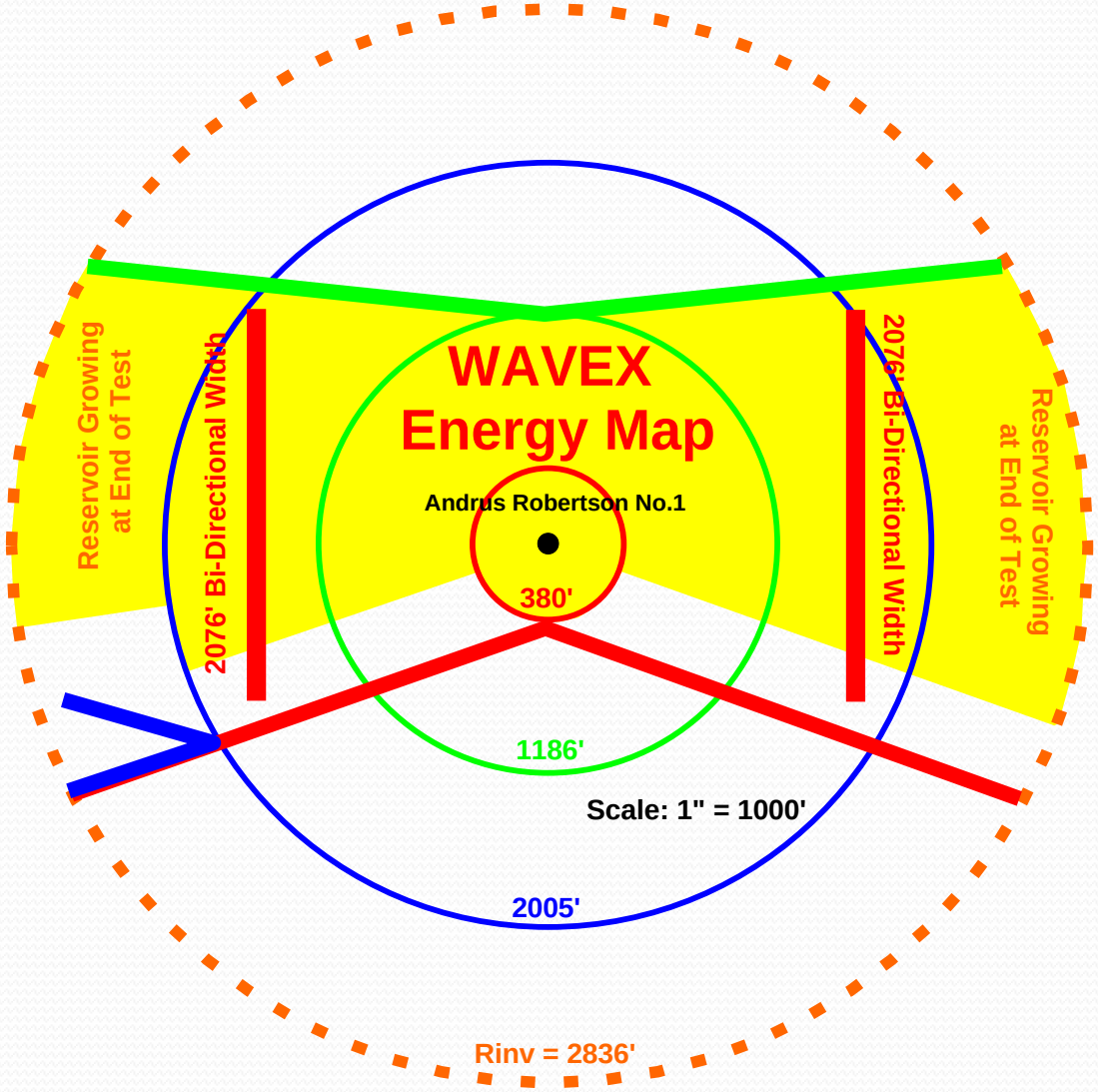

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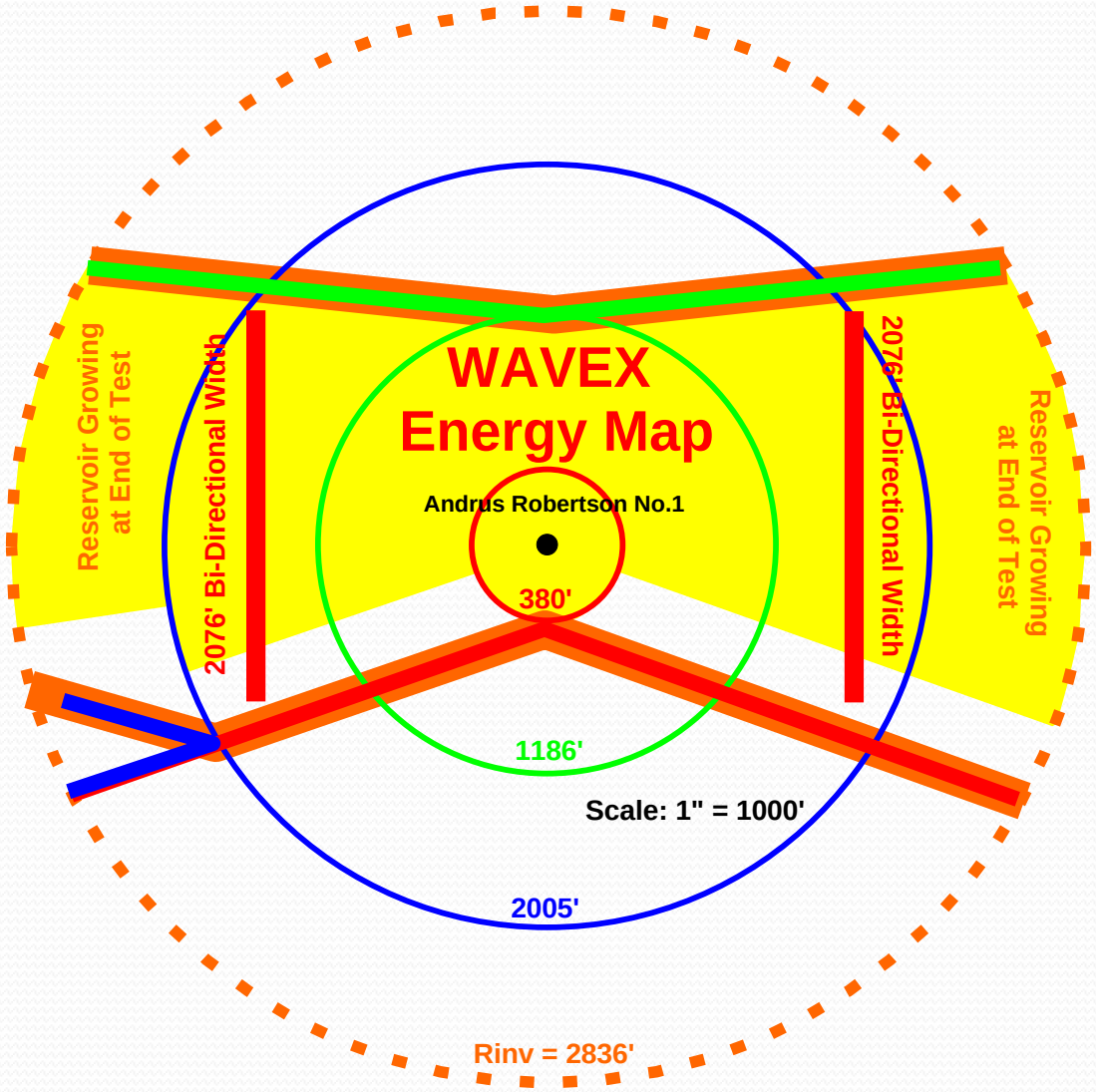
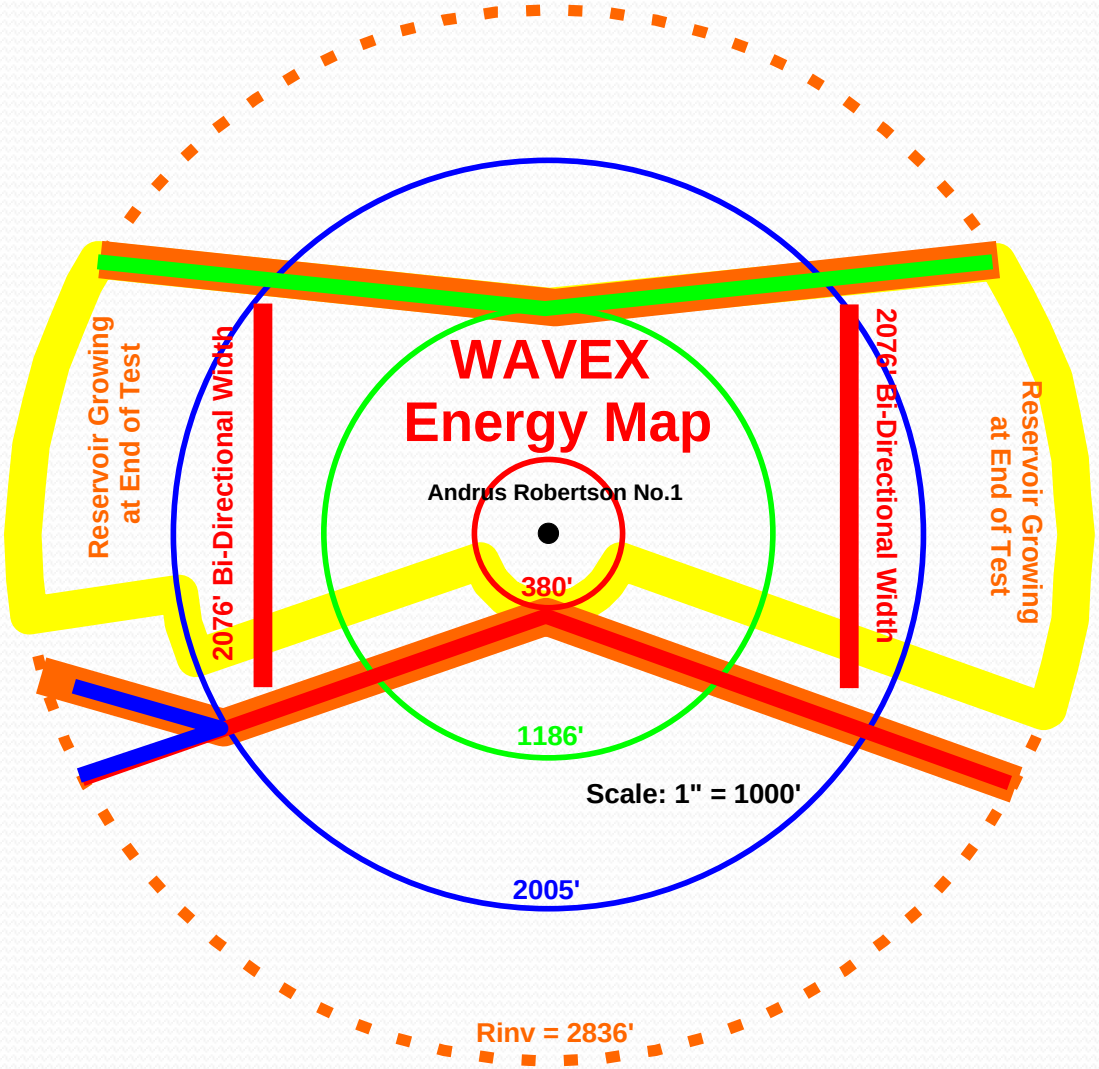
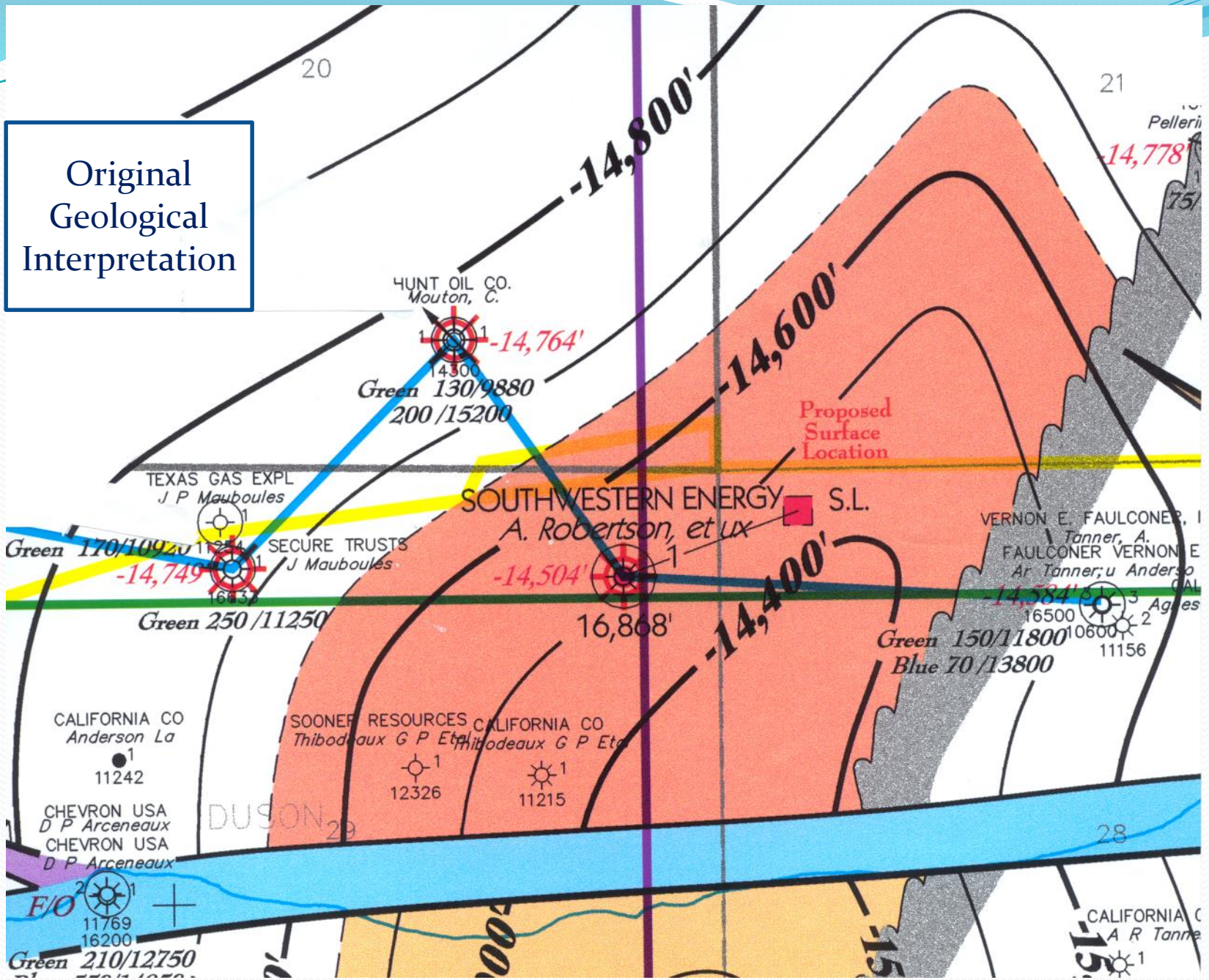


Blind Energy Map – Example 2

Final Reservoir Area/Shape




Original Geological Interpretation
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Mouton, C.
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Proposed Surface Location
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J P Mauboules
SOUTHWESTERN ENERGY
A. Robertson, et ux
S.L.
SECURE TRUSTS
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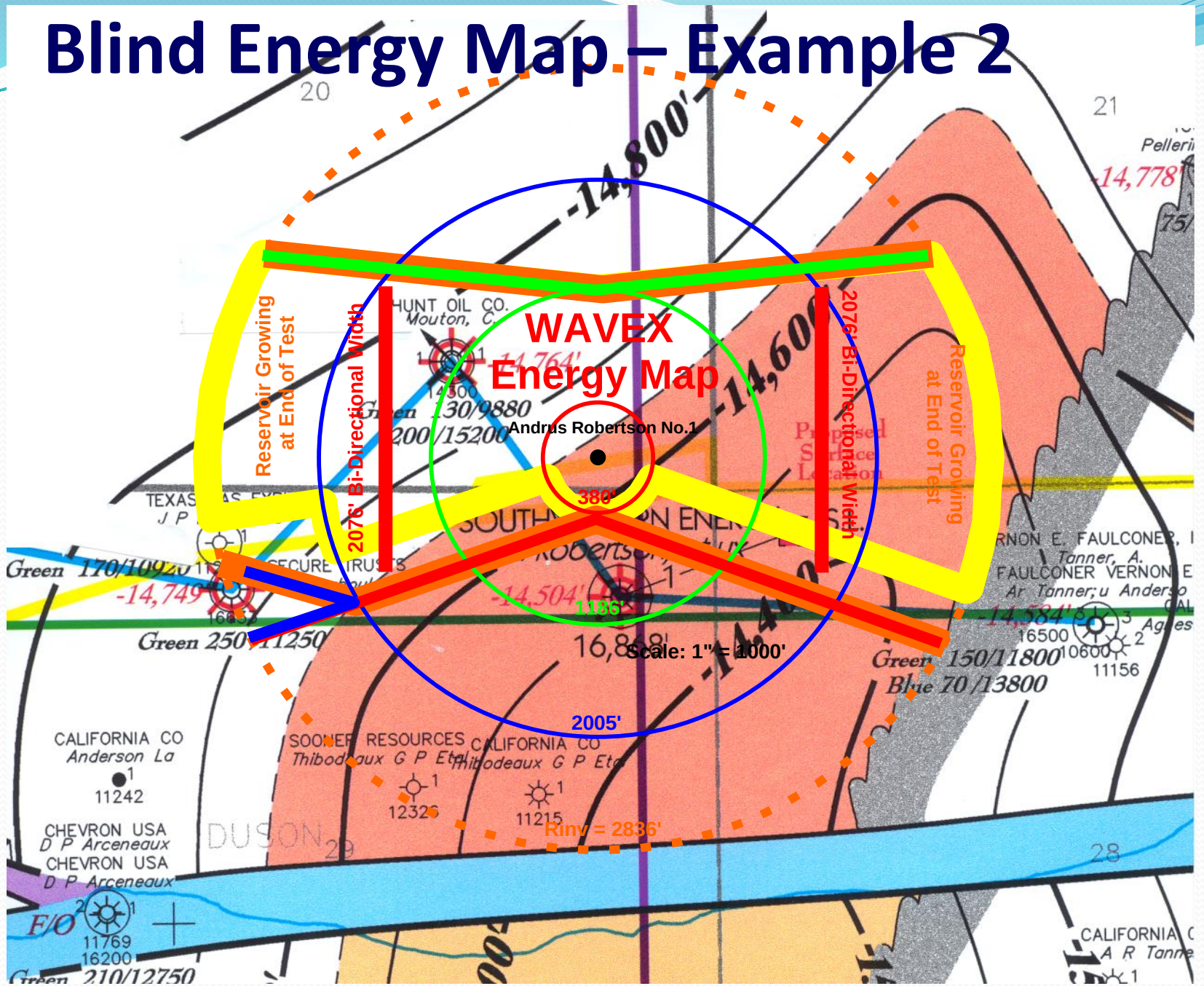
Blind Energy Map – Example 2



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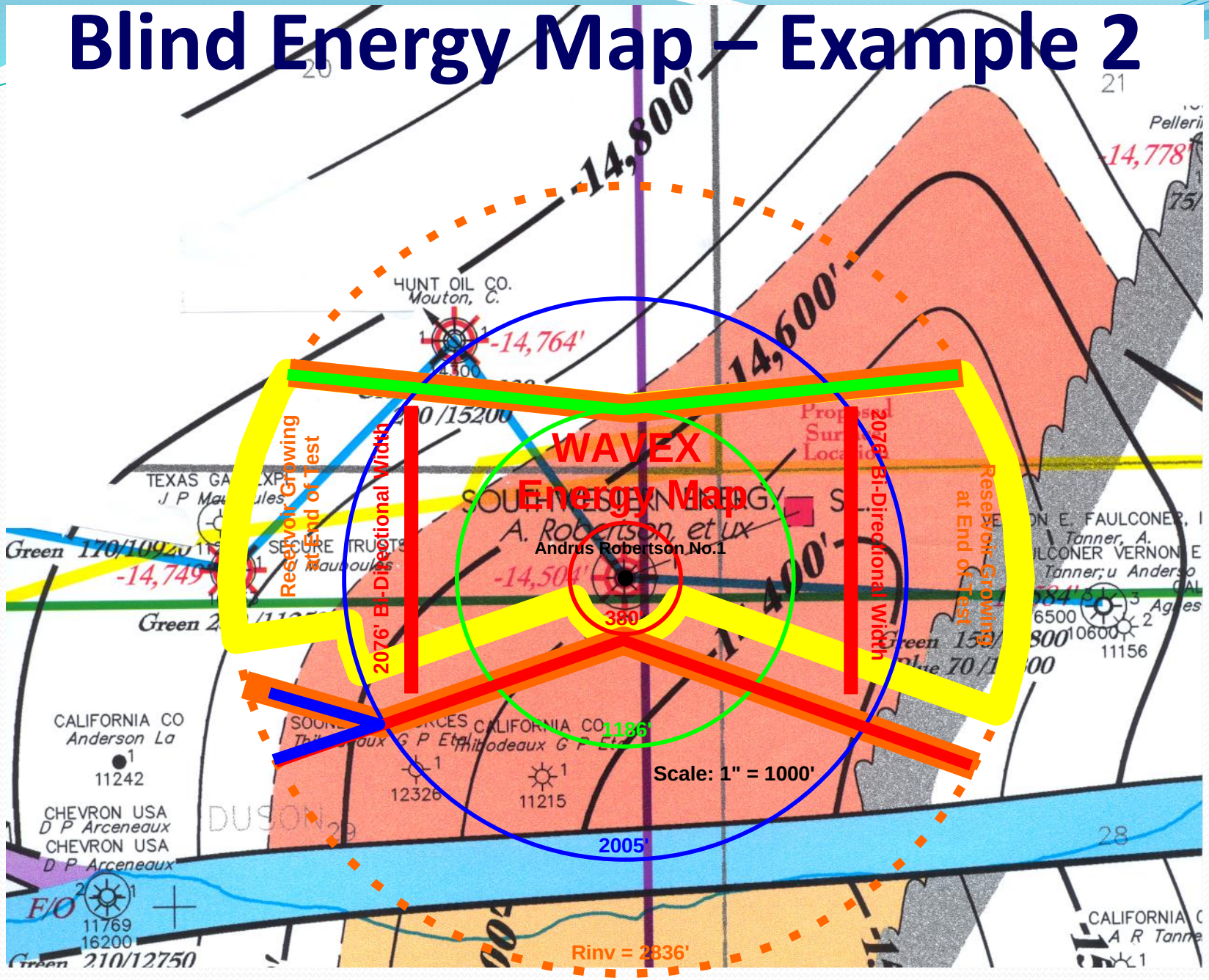

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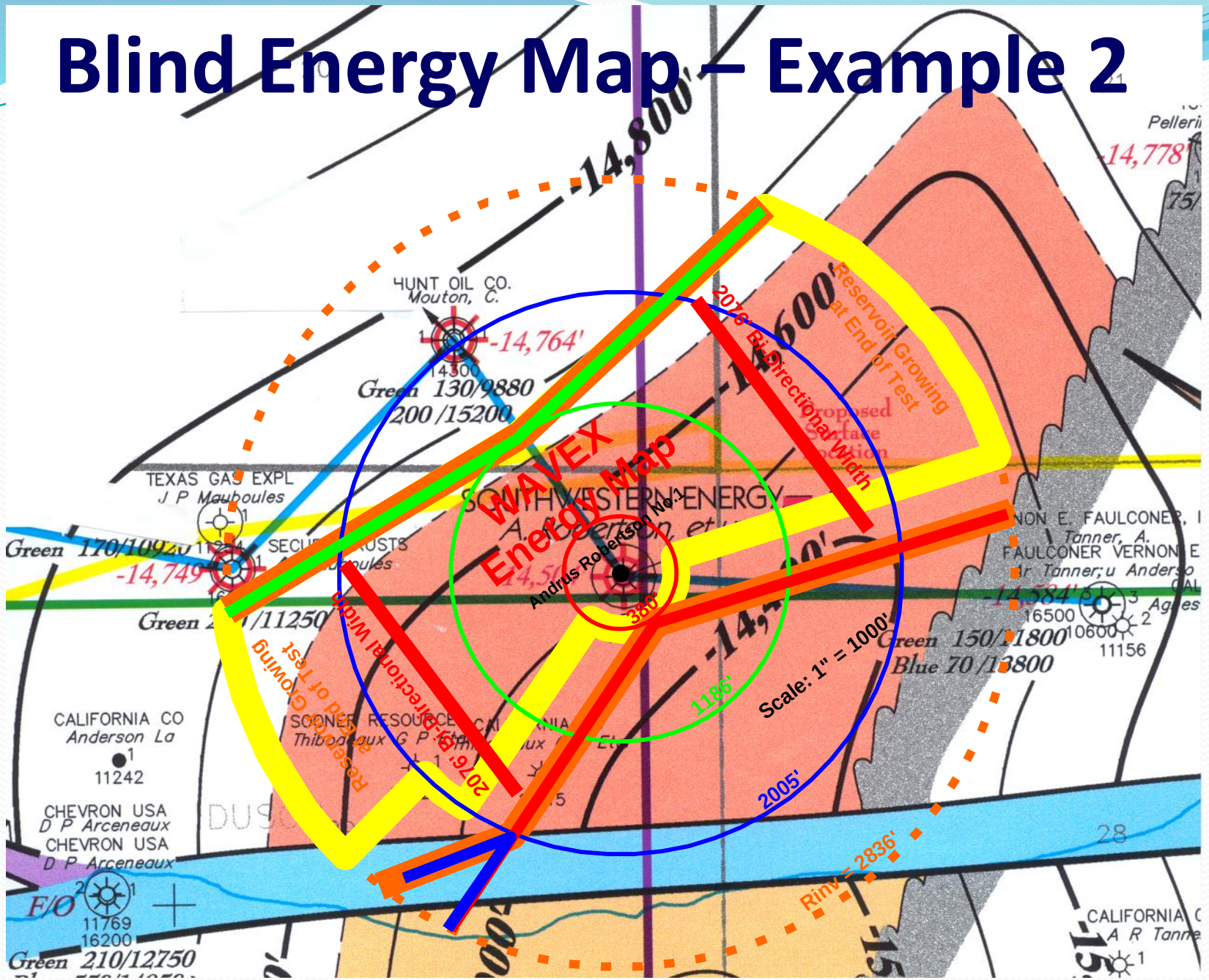

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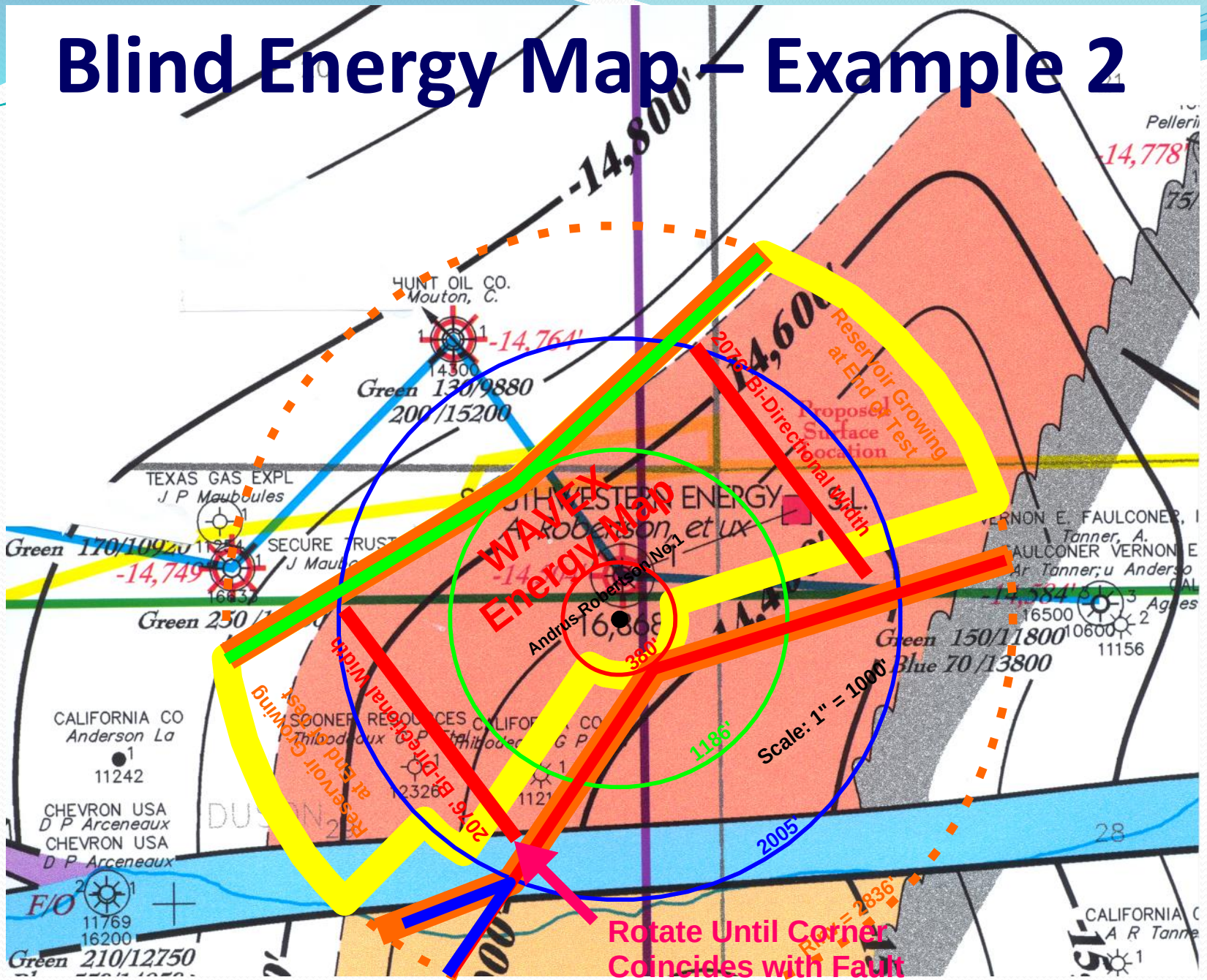
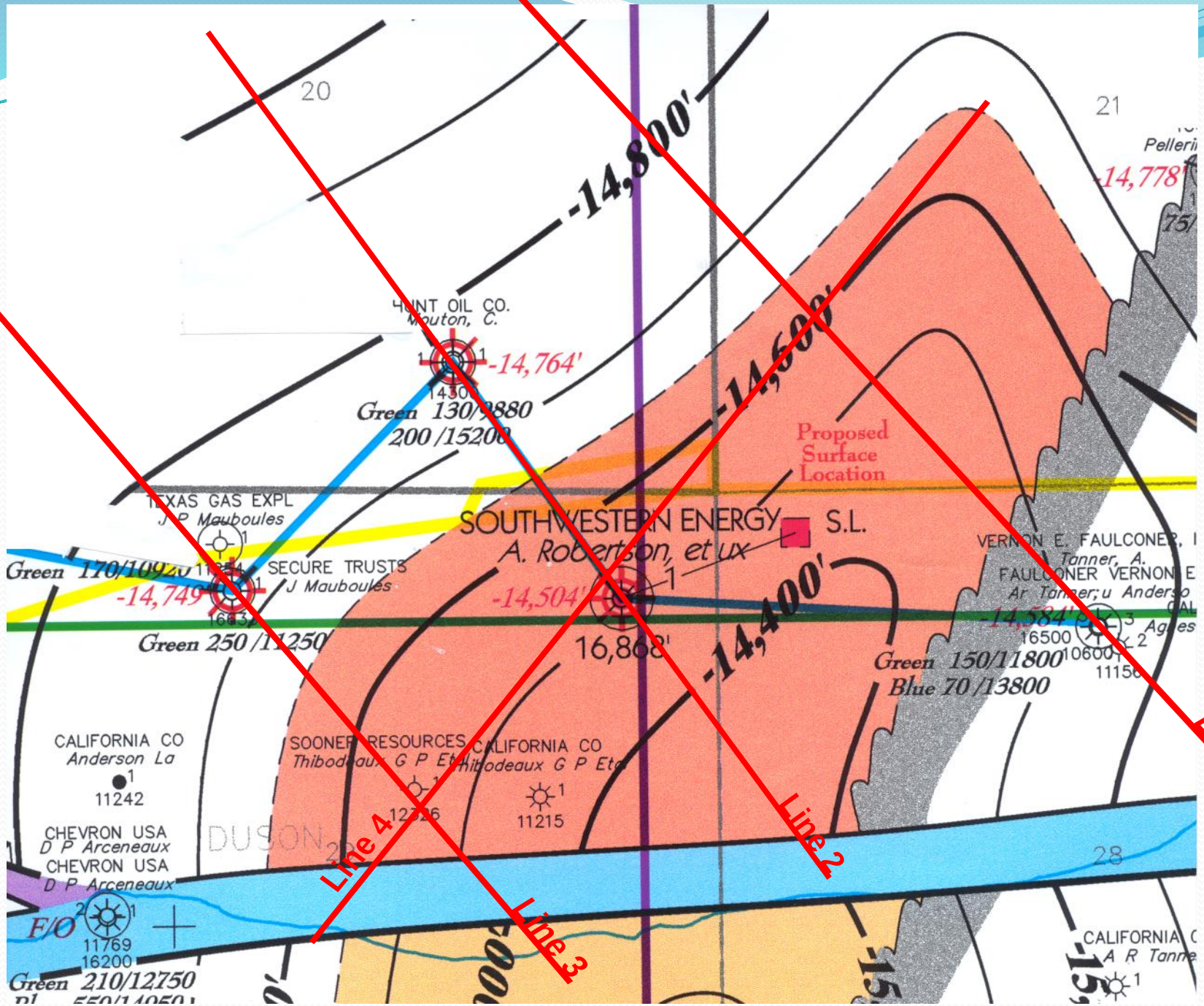


Back to the Geophysical Workstation

The Next Step is to Review the Seismic Data Looking for Amplitude Events along the Edge of the Energy Map.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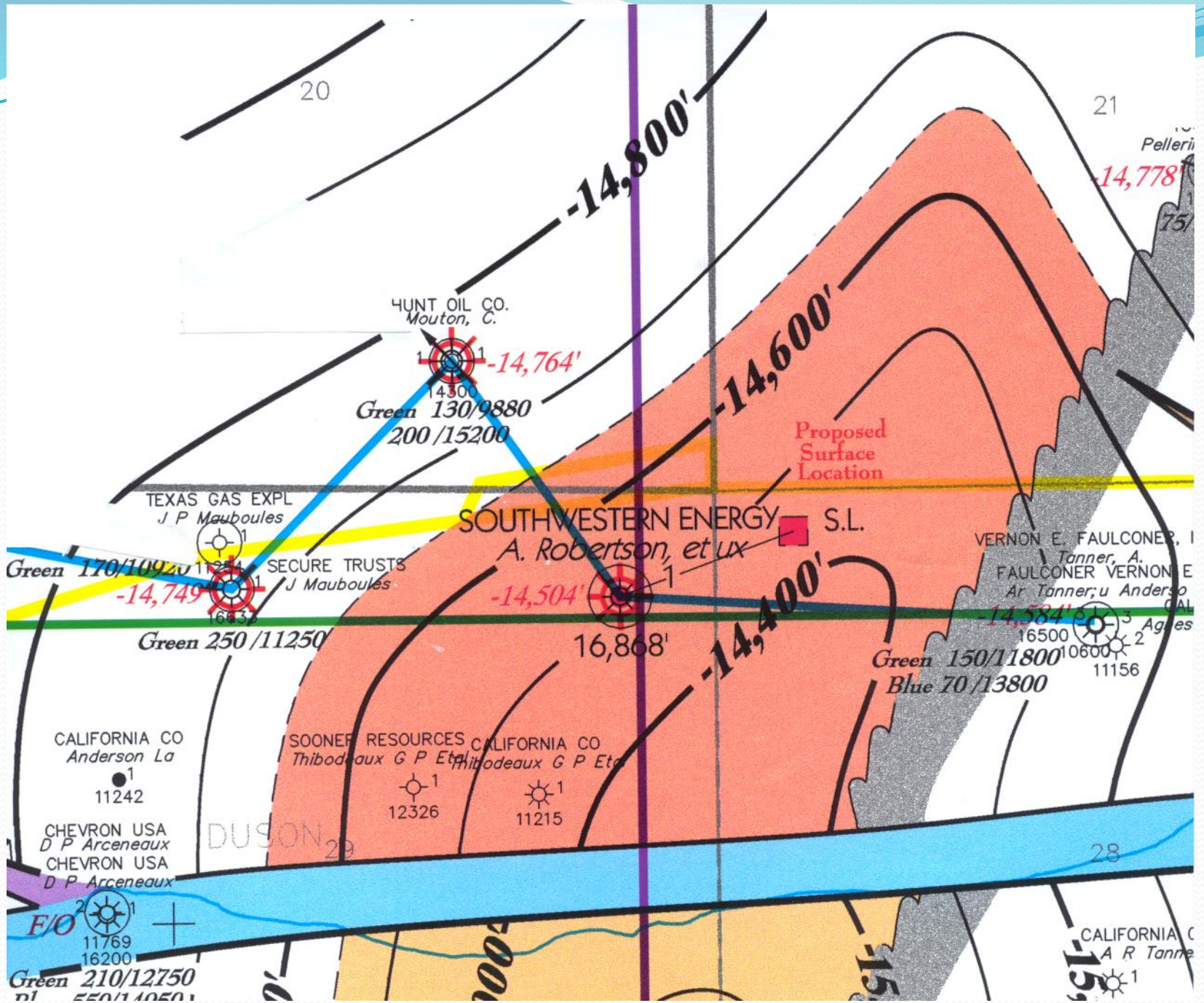
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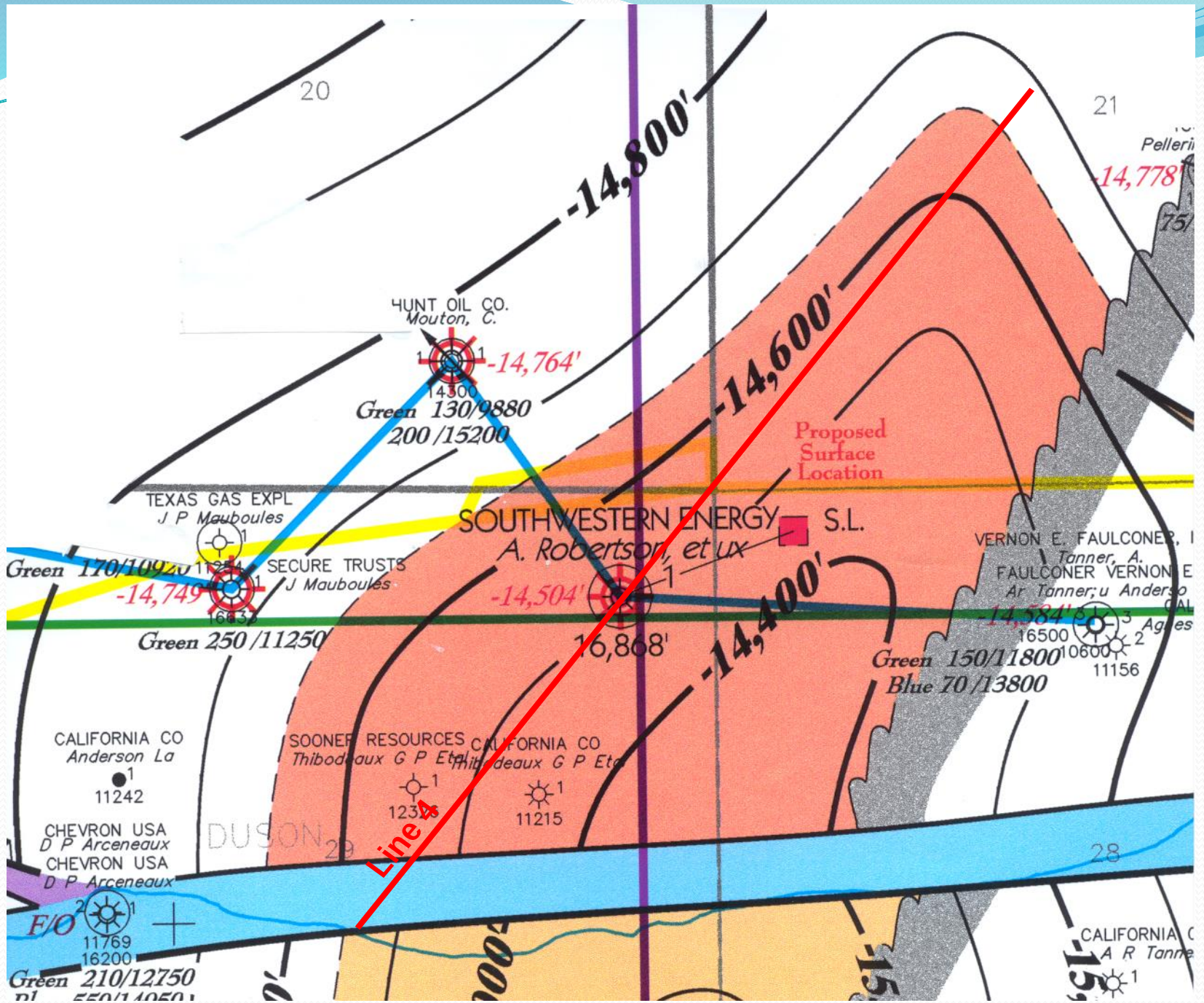
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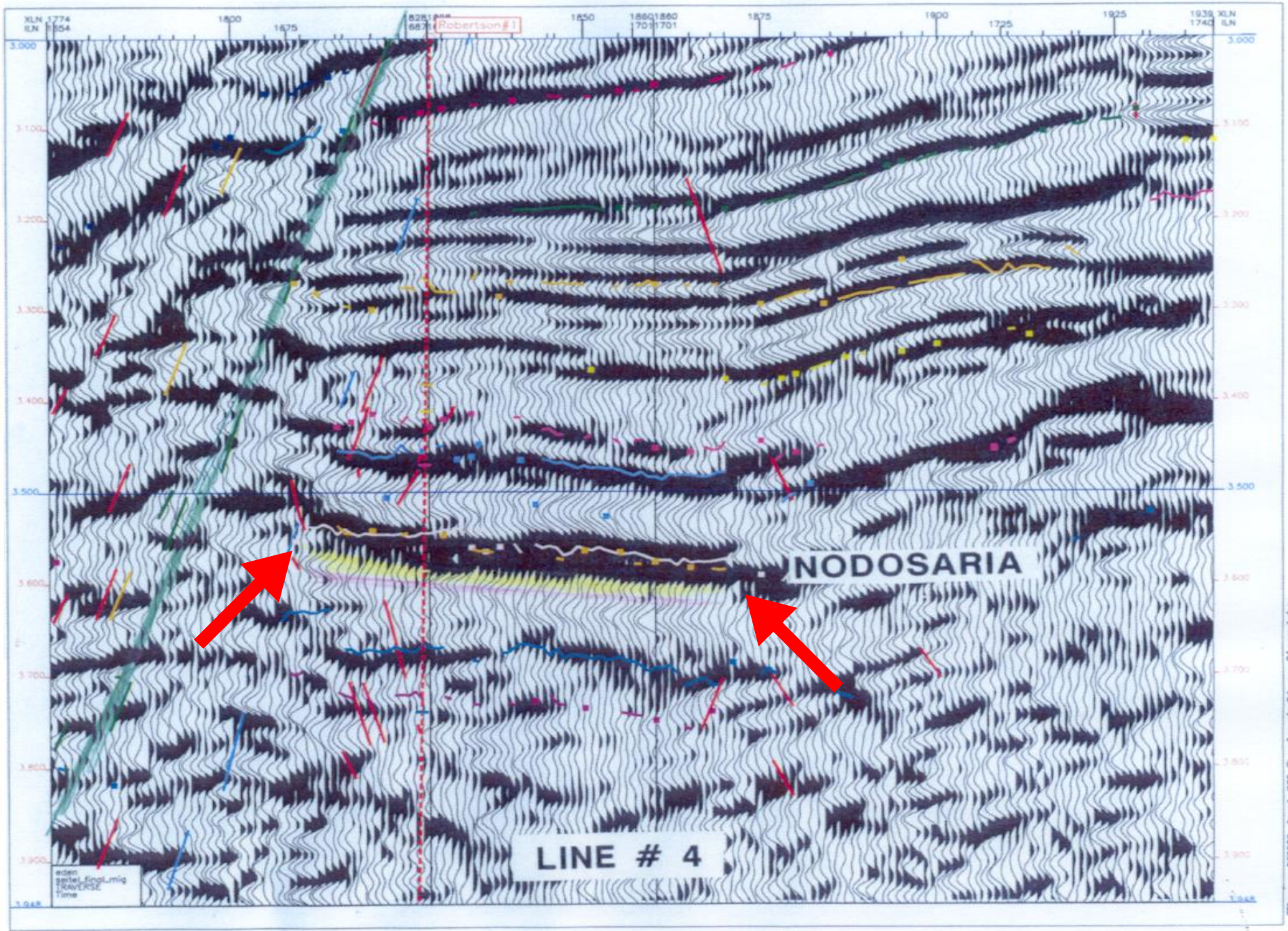

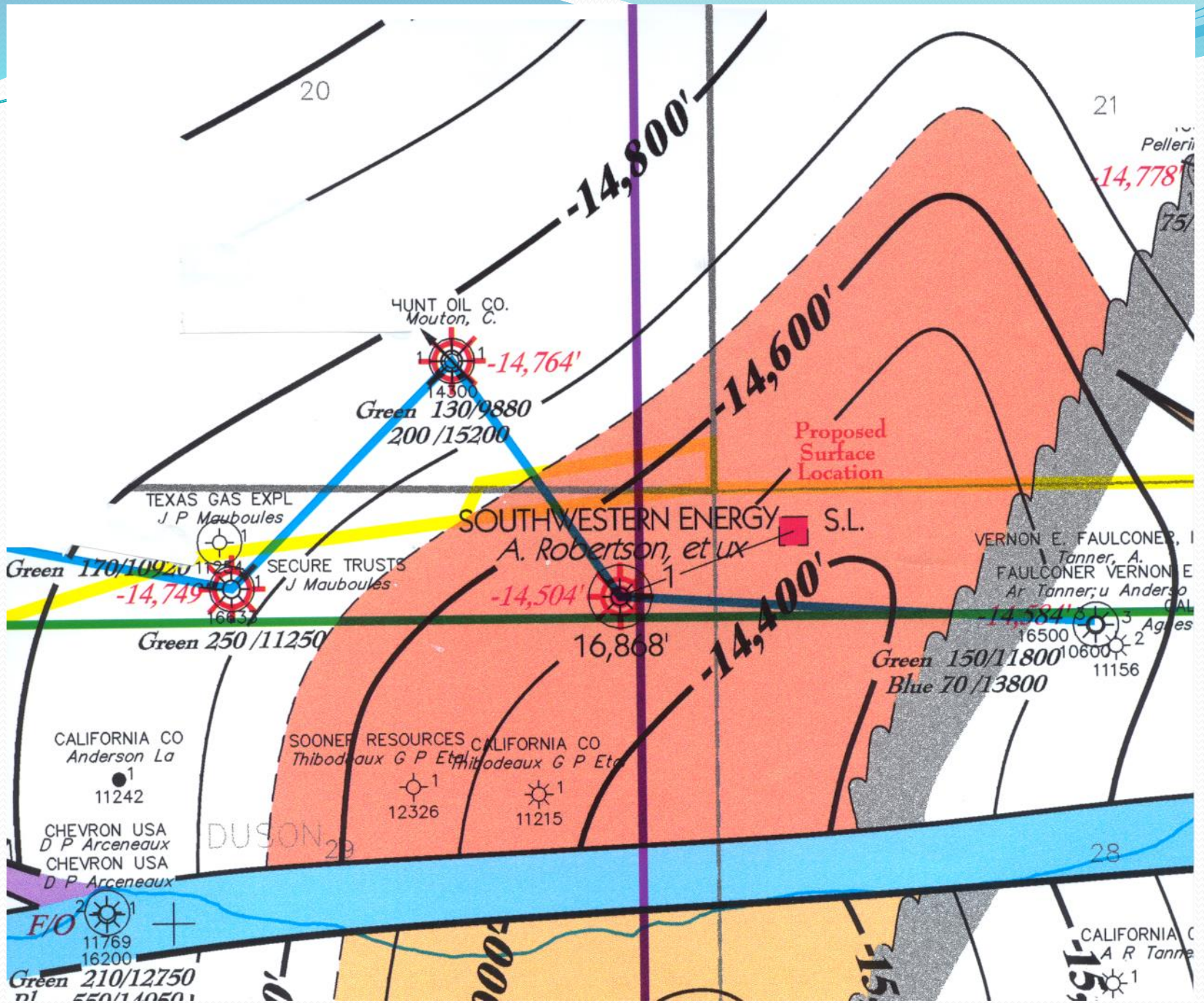
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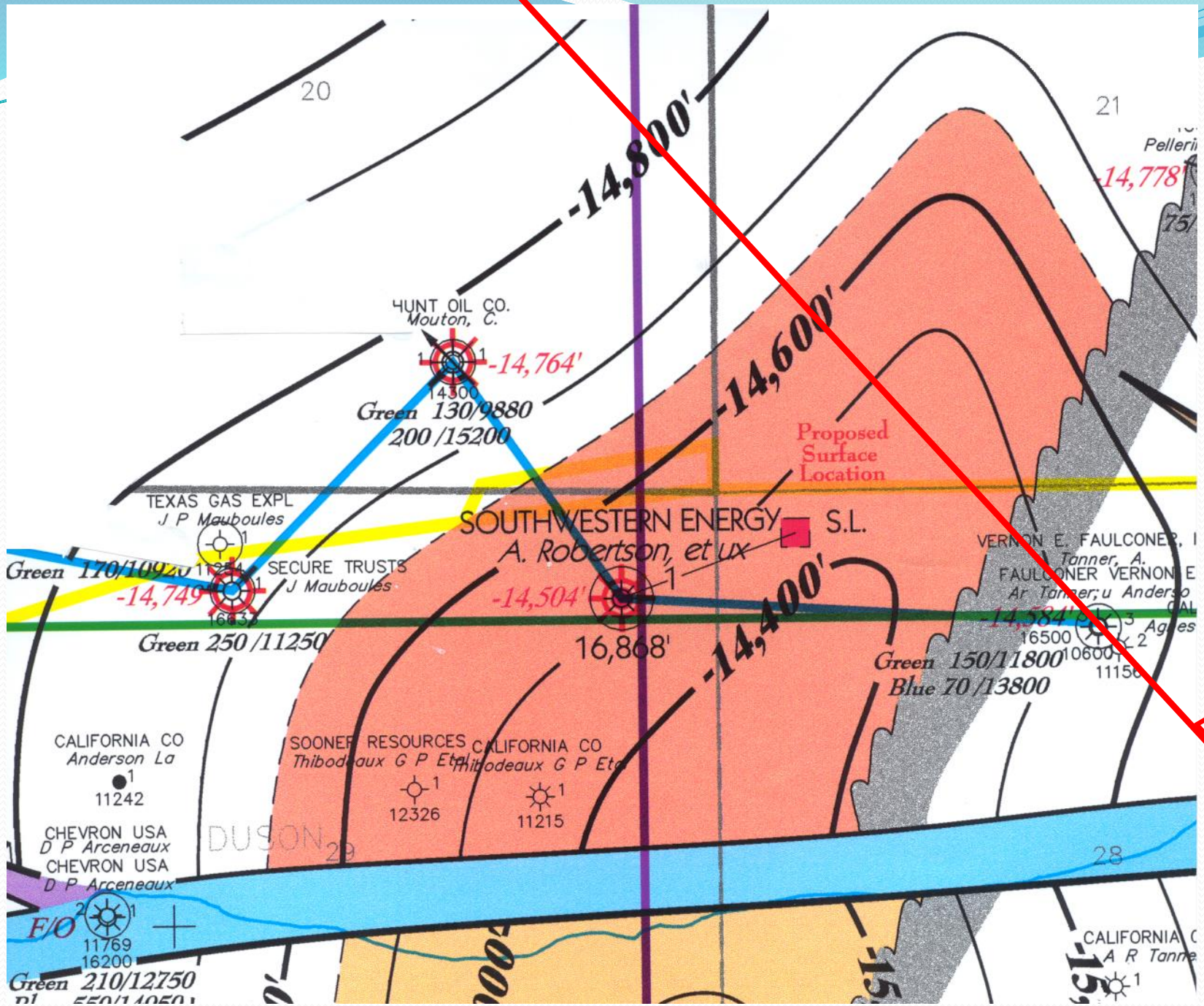
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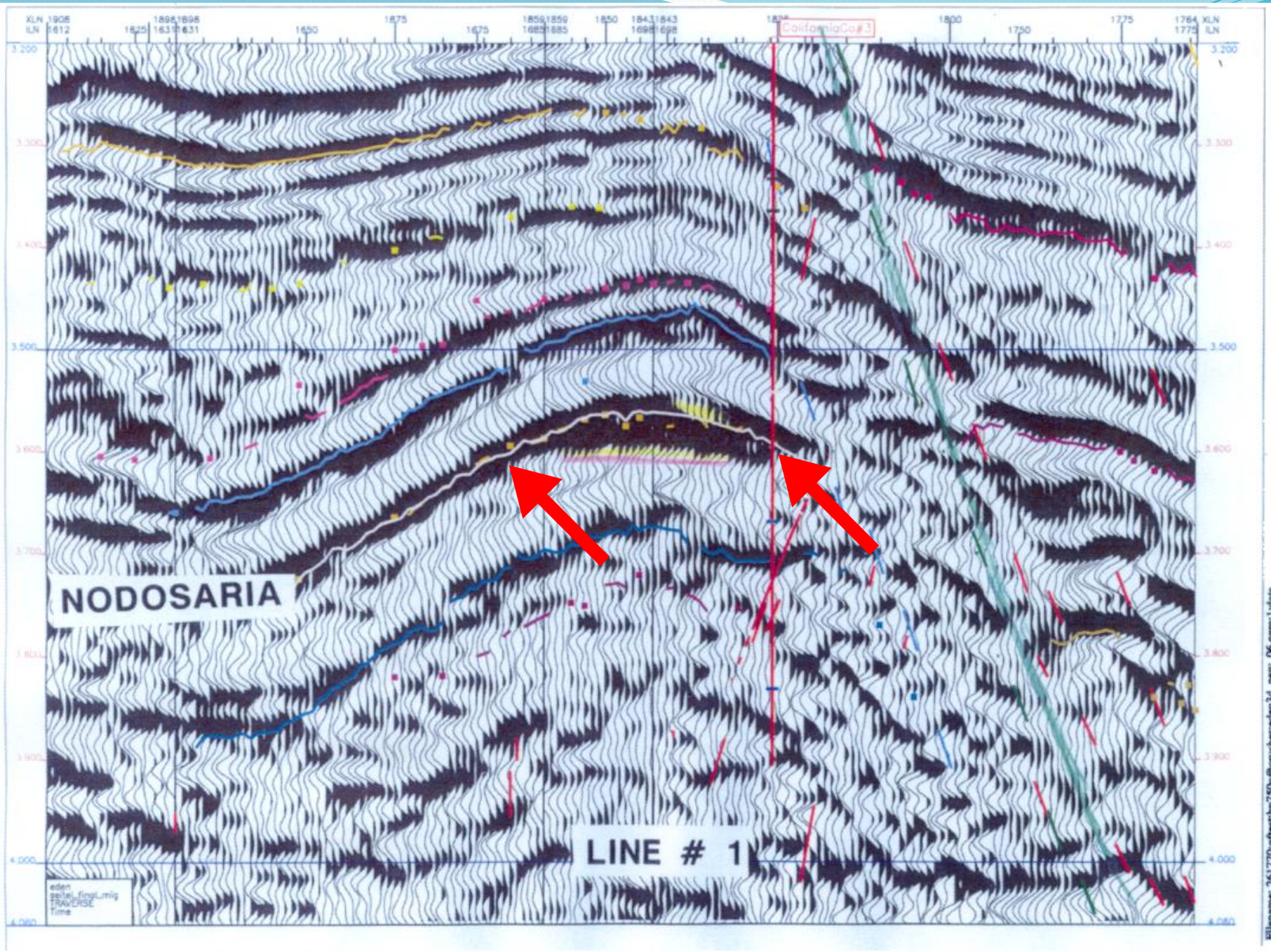
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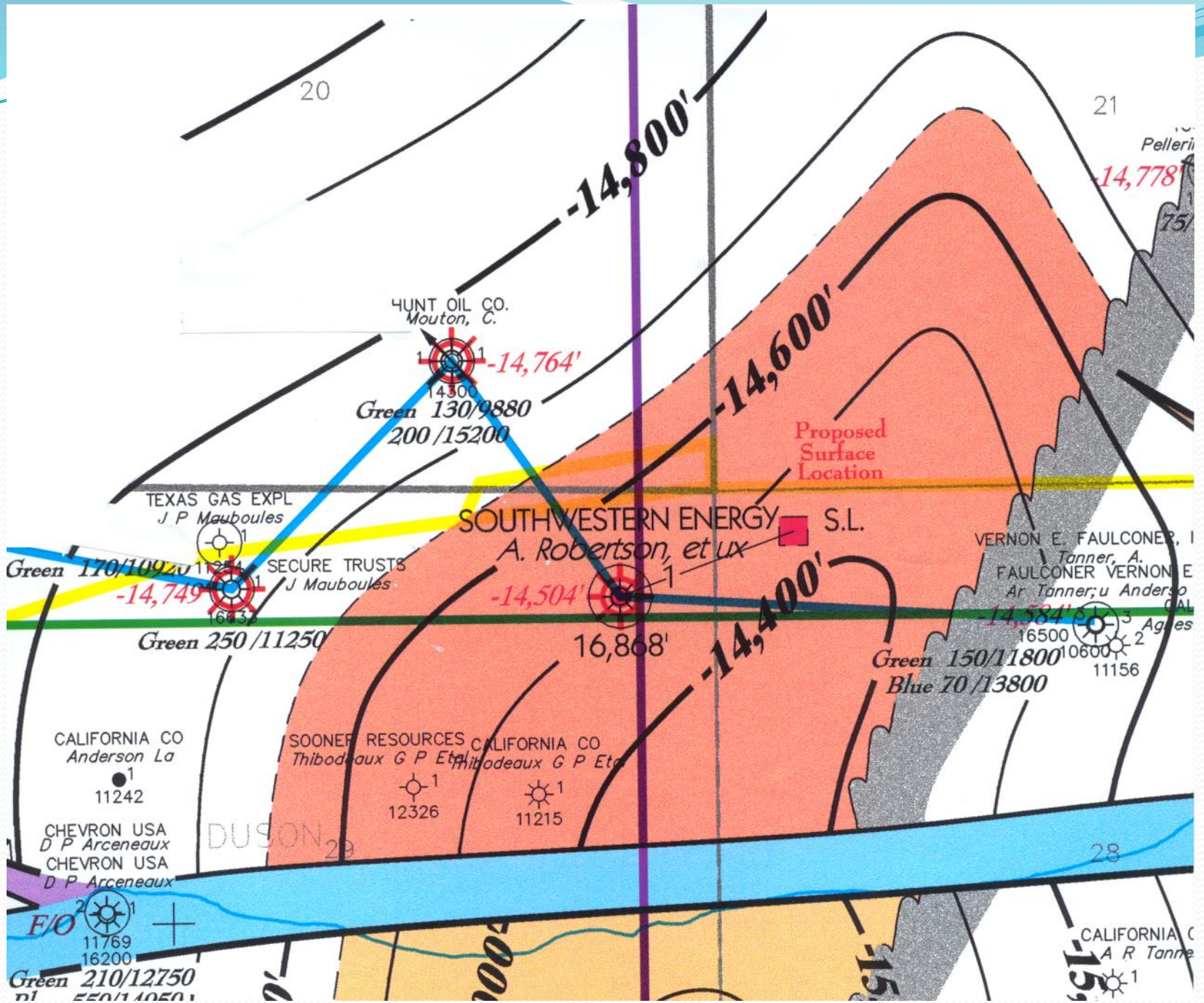
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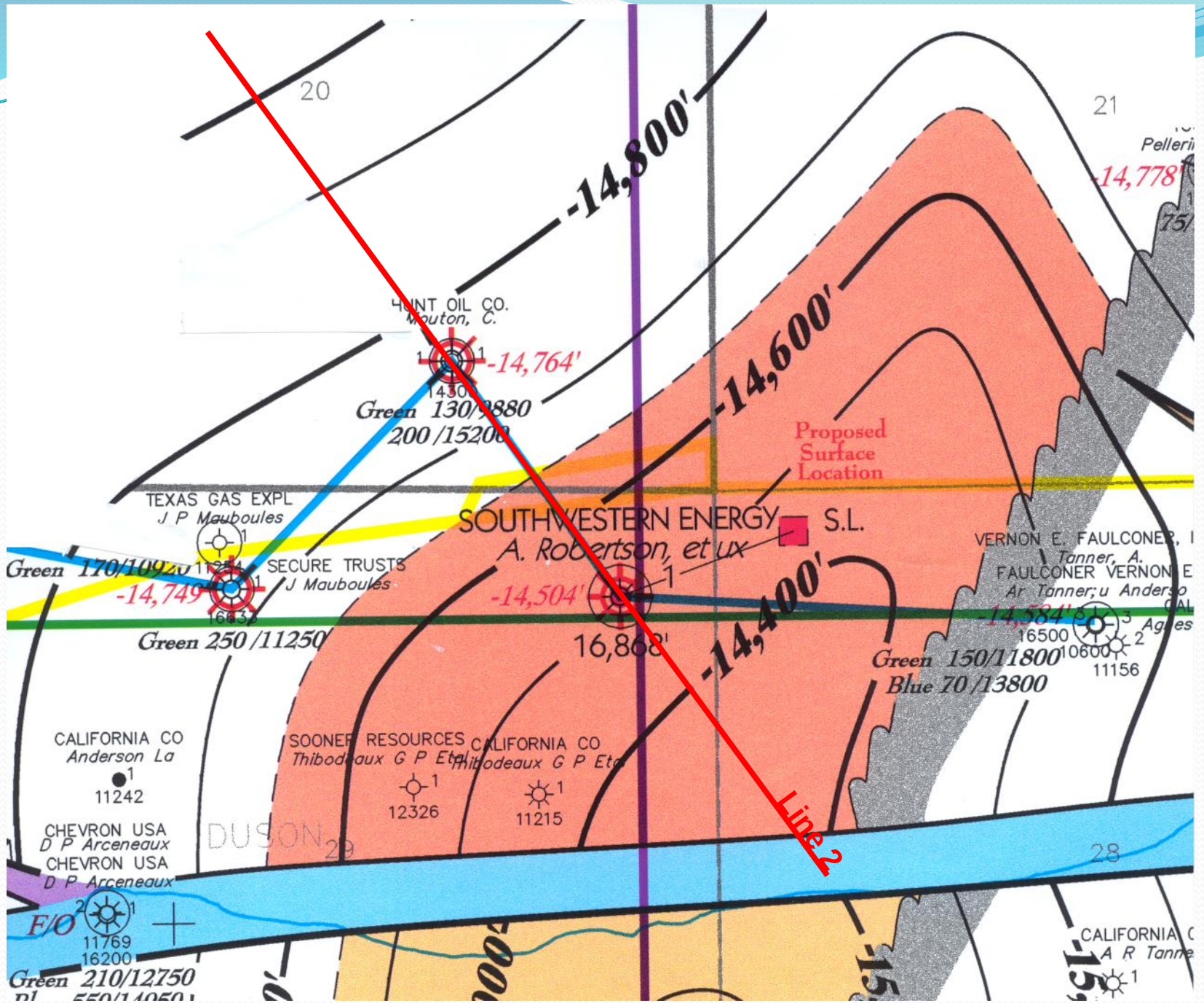
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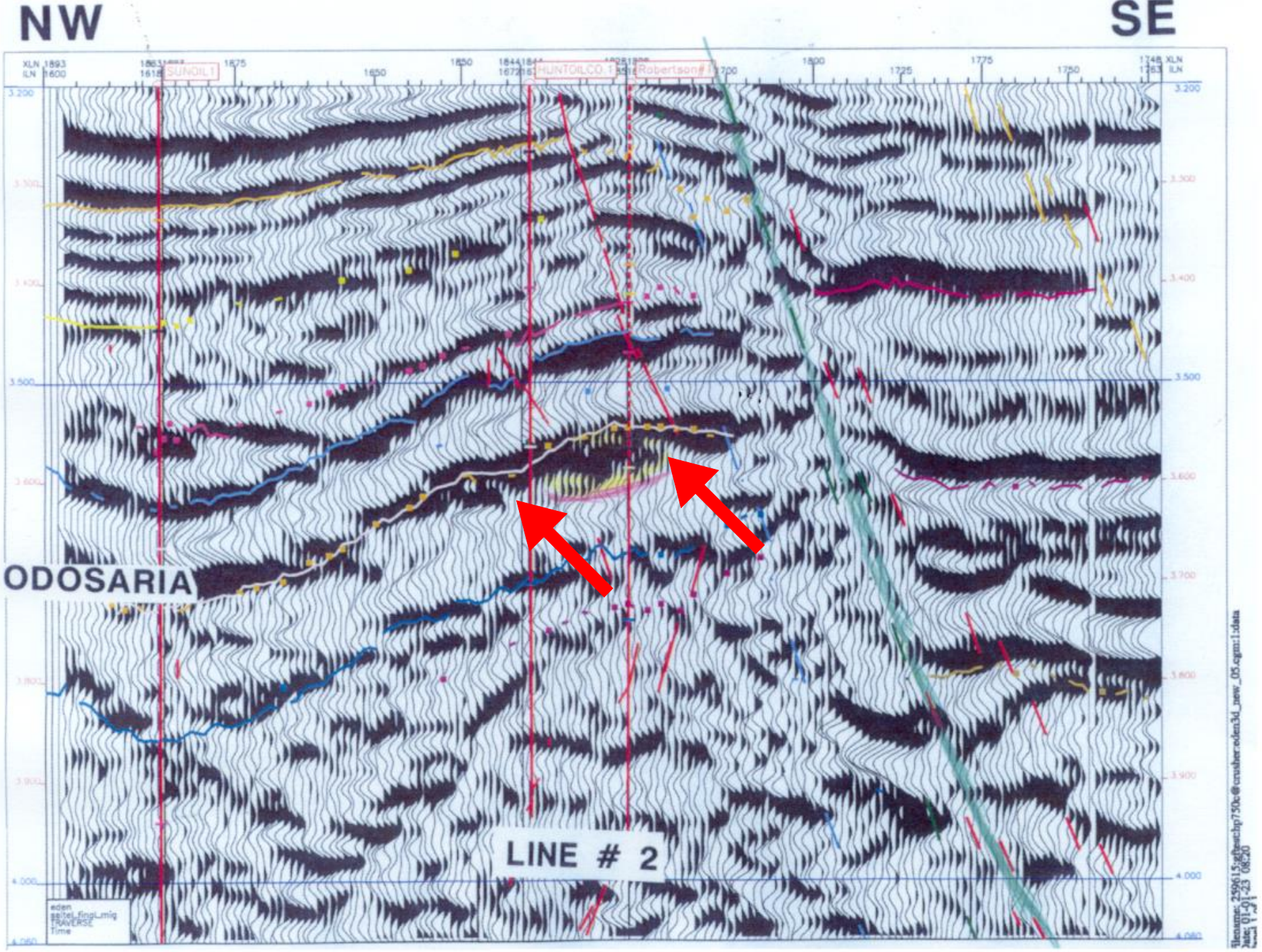
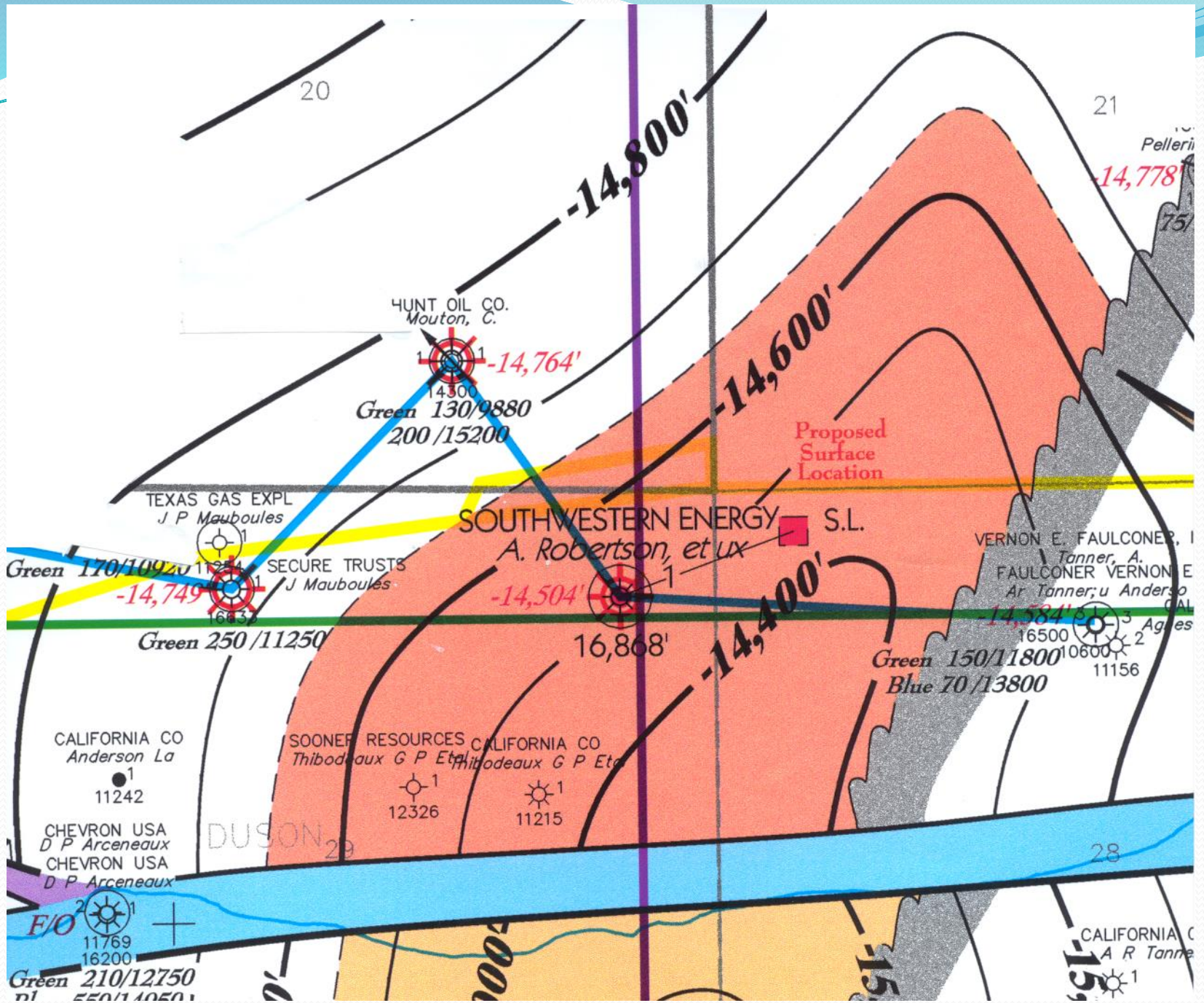
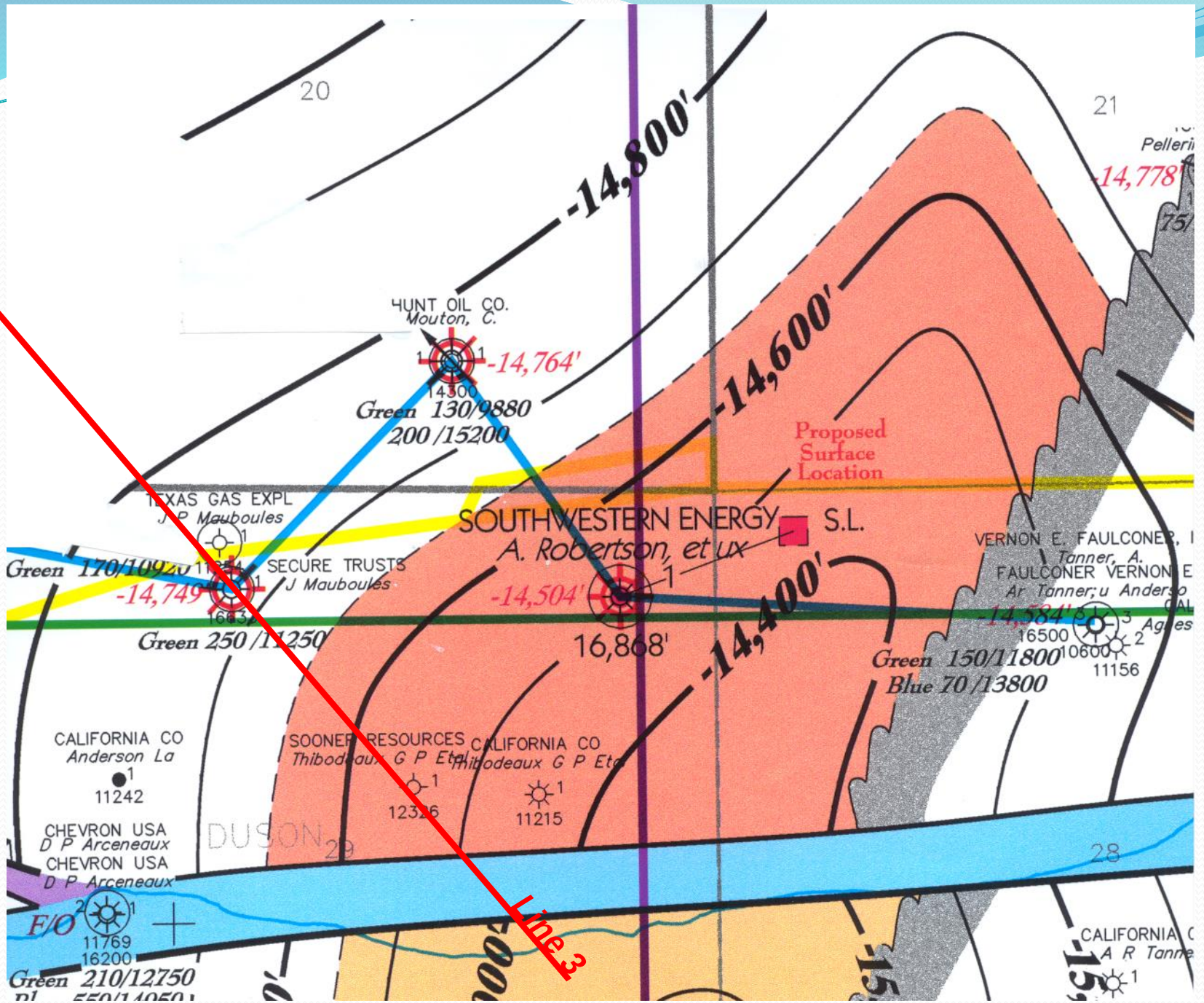
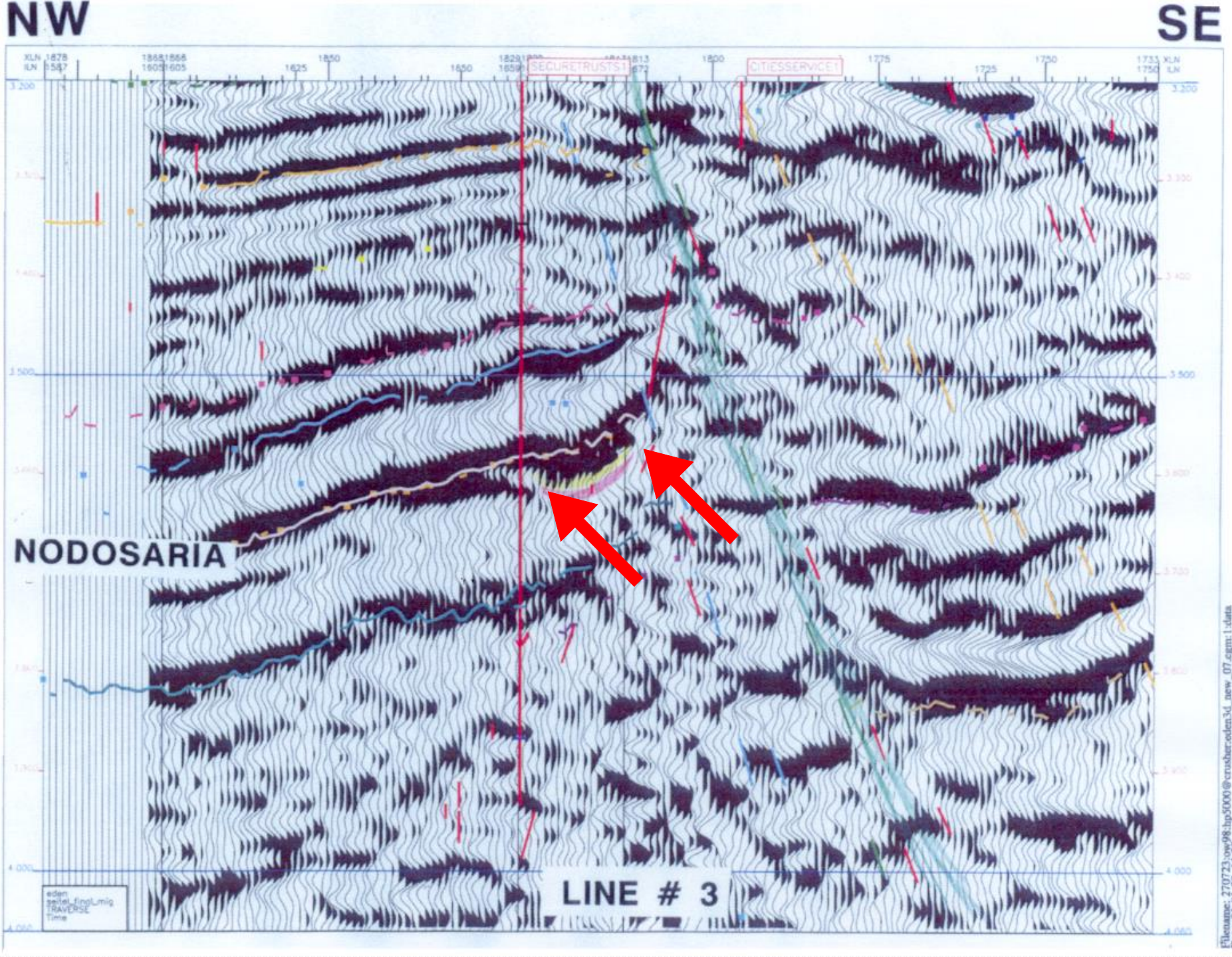

NW
SE
ODOSARIA
LINE # 2


20
21
-14,800'
-14,600'
-14,400'
HUNT OIL CO.
Mouton, C.
-14,764'
14300
Green 130/9880
200/15200
Proposed
Surface
Location
TEXAS GAS EXPL
J P Mauboules
SECURE TRUSTS
J Mauboules
-14,749'
Green 250/11250
SOUTHWESTERN ENERGY
A. Robertson, et ux
S.L.
-14,504'
16,868'
VERNON E. FAULCONER
Tanner, A.
-14,584'
16500
10600
11156
Green 150/11800
Blue 70/13800
CALIFORNIA CO
Anderson La
11242
SOONER RESOURCES
Thibodeaux G P Etal
12326
CALIFORNIA CO
Thibodeaux G P Etal
11215
CHEVRON USA
D P Arceneaux
CHEVRON USA
D P Arceneaux
F/O
11769
16200
Green 210/12750
DUSON
29
28


20
21
-14,800'
-14,600'
-14,400'
HUNT OIL CO.
Mouton, C.
-14,764'
14300
Green 130/9880
200/15200
Proposed
Surface
Location
TEXAS GAS EXPL
J P Mauboules
SECURE TRUSTS
J Mauboules
-14,749'
Green 170/10920
Green 250/11250
SOUTHWESTERN ENERGY
A. Robertson, et ux
S.L.
-14,504'
16,868'
VERNON E. FAULCONER
Tanner, A.
-14,584'
16500
10600
11156
Green 150/11800
Blue 70/13800
CALIFORNIA CO
Anderson La
11242
SOONER RESOURCES
Thibodeaux G P Etal
12326
CALIFORNIA CO
Thibodeaux G P Etal
11215
CHEVRON USA
D P Arceneaux
CHEVRON USA
D P Arceneaux
F/O
11769
16200
Green 210/12750
DUSON
29
28
Line 3


NW
SE
NODOSARIA
LINE # 3

fed: 14,828'-831'
1965/1990
M: 6.027 BCFG
20,000 BC
-14,800'
-14,600'
-14,400'
-14,200'
-15,000'
-15,200'
-15,400'
-15,600'
Proposed Surface Location
SOUTHWESTERN ENERGY
A. Robertson, et ux
S.L.
A
A'
HUNT OIL CO.
Mouton, C.
-14,764'
Green 130/13880
200/15200
TEXAS GAS EXPL
P Mouboules
SECURE TRUSTS
J Mouboules
-14,749'
Green 250/11350
CALIFORNIA CO
Anderson La
11242
CHEVRON USA
O P Arceneaux
CHEVRON USA
Green 210/12750
Blue 550/14950
TOCE OIL
Pellerin Baltazar
15150
75/13775
GULF OIL
William Anderson
Green 140/10940
11320
LYONS PE
Paul Anders
10601
VERNON E. FAULCONER, INC.
Tonner, A.
FAULCONER VERNON E
Ar Tanner;u Anderso
16500
Agnes Rchrd Tanner
Green 150/11800
Blue 70/13800
11158
CALIFORNIA CO ETAL
A R Tanner Trst
13000
CITIES SERVICE & UNION
Petitjean
13507
TRANSCONTINENTAL
Bennett
11350
OWEN J P JR & PRESTON
Mayo Stutes Est
OWEN J P JR & PRESTON
Thomas Hutchinson
LINE # 4
LINE # 3
LINE # 2
LINE # 1

fed: 14,828'-831'
1965/1990
M: 6.027 BCFG
20,000 BC
-14,800'
-14,600'
-14,400'
-14,200'
-15,000'
-15,200'
-15,400'
-15,600'
Proposed Surface Location
SOUTHWESTERN ENERGY
A. Robertson, et ux
S.L.
A
A'
HUNT OIL CO.
Mouton, C.
-14,764'
Green 130/13880
200/15200
TEXAS GAS EXPL
P Mouboules
SECURE TRUSTS
J Mouboules
-14,749'
Green 250/11350
CALIFORNIA CO
Anderson La
11242
CHEVRON USA
O P Arceneaux
CHEVRON USA
Green 210/12750
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TOCE OIL
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15150
75/13775
GULF OIL
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TRANSCONTINENTAL
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11350
OWEN J P JR & PRESTON
Mayo Stutes Est
OWEN J P JR & PRESTON
Thomas Hutchinson
LINE # 4
LINE # 3
LINE # 2
LINE # 1

fed: 14,828'-831'
1965/1990
M: 6.027 BCFG
20,000 BC
-14,800'
-14,600'
-14,400'
-15,000'
-15,200'
-15,400'
-15,600'
Proposed Surface Location
SOUTHWESTERN ENERGY
A. Robertson, et ux
S.L.
A
A'
HUNT OIL CO.
-14,764'
Green 130/13880
200/15200
Green 250/11350
Green 150/11800
Blue 70/13800
Green 140/10940
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William Anderson
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TEXAS GAS EXPL
P Mouboules
SECURE TRUSTS
J Mouboules
VERNON E. FAULCONER, INC.
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Ar Tanner;u Anderso
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11242
CHEVRON USA
O P Arceneaux
CHEVRON USA
SOONER RESOURCES
CALIFORNIA CO ETAL
A R Tanner Trst
13000
CITIES SERVICE & UNION
Petitjean
13507
TRANSCONTINENTAL
Bennett
11350
OWEN J P JR & PRESTON
Mayo Stutes Est
OWEN J P JR & PRESTON
Thomas Hutchinson
LINE # 1
LINE # 2
LINE # 3
LINE # 4

fed: 14,828'-831'
1965/1990
M: 6.027 BCFG
20,000 BC
-14,800'
-14,600'
-14,400'
-15,000'
-15,200'
-15,400'
-15,600'
Proposed Surface Location
SOUTHWESTERN ENERGY
A. Robertson, et ux
S.L.
A
A'
HUNT OIL CO.
-14,764'
Green 130/13880
200/15200
Green 250/11350
Green 150/11800
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Green 210/12750
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TOCE OIL
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Green 140/10940
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TEXAS GAS EXPL
P Mouboules
SECURE TRUSTS
J Mouboules
VERNON E. FAULCONER, INC.
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Ar Tanner;u Anderso
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16500
CALIFORNIA CO
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11242
CHEVRON USA
D P Arceneaux
CHEVRON USA
CALIFORNIA CO ETAL
A R Tanner Trst
13000
CITIES SERVICE & UNION
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TRANSCONTINENTAL
Bennett
11350
OWEN J P JR & PRESTON
Mayo Stutes Est
OWEN J P JR & PRESTON
Thomas Hutchinson
LINE # 1
LINE # 2
LINE # 3
LINE # 4

fed: 14,828'-831'
1965/1990
M: 6.027 BCFG
20,000 BC
20
21
-14,800'
-14,600'
-14,400'
-14,764'
-14,749'
-14,504'
-14,778'
-15,200'
-15,000'
-15,400'
-15,600'
HUNT OIL CO.
Mouton, C.
Green 130/9880
200/15200
TEXAS GAS EXPL
J P Mauboules
SECURE TRUSTS
J Mauboules
Green 250/11350
SOUTHWESTERN ENERGY
A. Robertson, et ux
S.L.
Proposed Surface Location
TOCE OIL
Pellerin Baltazar
15150
75/13775
GULF OIL
William Anderson
Green 140/10940
11320
LYONS PET
Paul Anders
10601
VERNON E. FAULCONER, INC.
Tanner, A.
FAULCONER VERNON E
Ar Tanner;u Anderso
CALIFORNIA CO
Agnes Rchrd Tanner
16500
Green 150/11800
Blue 70/13800
A'
CALIFORNIA CO
Anderson La
11242
CHEVRON USA
D P Arceneaux
CHEVRON USA
Green 210/12750
Blue 550/14950
CALIFORNIA CO ETAL
A R Tanner Trst
13000
CITIES SERVICE & UNION
Petitjean
13507
TRANSCONTINENTAL
Bennett
11350
OWEN J P JR & PRESTON
Mayo Stutes Est
OWEN J P JR & PRESTON
Thomas Hutchinson
LINE # 1
LINE # 2
LINE # 3
LINE # 4

fed: 14,828'-831'
1965/1990
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20,000 BC
-14,800'
-14,600'
-14,400'
-15,000'
-15,200'
-15,400'
-15,600'
Proposed Surface Location
SOUTHWESTERN ENERGY
A. Robertson, et ux
S.L.
A
A'
HUNT OIL CO.
-14,764'
Green 130/13880
200/15200
Green 250/11350
Green 150/11800
Blue 70/13800
Green 140/10940
Green 210/12750
Blue 550/14950
TEXAS GAS EXPL
SECURE TRUST
CALIFORNIA CO
Anderson La
11242
CHEVRON USA
CHEVRON USA
TOCE OIL
15150
75/13775
GULF OIL
William Anderson
11320
VERNON E. FAULCONER, INC.
FAULCONER VERNON E
Agnes Rchrd Tanner
16500
CALIFORNIA CO ETAL
A R Tanner Trst
13000
CITIES SERVICE & UNION
11350
OWEN J P JR & PRESTON
Thomas Hutchinson
LINE # 1
LINE # 2
LINE # 3
LINE # 4

fed: 14,828'-831'
1965/1990
M: 6.027 BCFG
20,000 BC
-14,500'
-14,600'
-14,400'
-14,800'
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-15,600'
-14,764'
-14,749'
-14,504'
-14,778'
75/13775
Green 130/9880
200/15200
Green 140/10940
Green 150/11800
Blue 70/13800
Green 250/11250
Green 210/12750
Blue 550/14950
Proposed Surface Location
SOUTHWESTERN ENERGY
A. Robertson, et ux
S.L.
A'
HUNT OIL CO.
Mouton, C.
TOCE OIL
Pellerin Baltazar
GULF OIL
William Anderson
LYONS PET
Paul Anders
TEXAS GAS EXPL
J P Mauboules
SECURE TRUSTS
J Mauboules
CALIFORNIA CO
Anderson La
CHEVRON USA
D P Arceneaux
CALIFORNIA CO ETAL
A R Tanner Trst
CITIES SERVICE & UNION
TRANSCONTINENTAL
Bennett
OWEN J P JR & PRESTON
Thomas Hutchinson
LINE # 1
LINE # 2
LINE # 3
LINE # 4

fed: 14,828'-831'
1965/1990
M: 6.027 BCFG
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-14,600'
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-15,000'
-15,200'
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Proposed Surface Location
SOUTHWESTERN ENERGY
A. Robertson, et ux
S.L.
A
A'
HUNT OIL CO.
-14,764'
Green 130/13880
200/15200
Green 250/11350
Green 150/11800
Blue 70/13800
Green 210/12750
Blue 550/14950
TOCE OIL
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GULF OIL
William Anderson
Green 140/10940
11320
LYONS PE
Paul Anders
10601
TEXAS GAS EXPL
P Mouboules
SECURE TRUST
J Mouboules
-14,749'
E. FAULCONER, INC.
Tanner, A.
Agnes Rchrd Tanner
16500
11158
CALIFORNIA CO
Anderson La
11242
CHEVRON USA
D P Arceneaux
CHEVRON USA
CALIFORNIA CO ETAL
A R Tanner Trst
13000
CITIES SERVICE & UNION
Petitjean
13507
TRANSCONTINENTAL
Bennett
11350
OWEN J P JR & PRESTON
Mayo Stutes Est
OWEN J P JR & PRESTON
Thomas Hutchinson
LINE # 1
LINE # 2
LINE # 3
LINE # 4

fed: 14,828'-831'
1965/1990
M: 6.027 BCFG
20,000 BC
-14,800'
-14,600'
-14,400'
-14,200'
-15,000'
-15,200'
-15,400'
-15,600'
Proposed Surface Location
SOUTHWESTERN ENERGY
A. Robertson, et ux
S.L.
A
A'
HUNT OIL CO.
-14,764'
Green 130/13880
200/15200
Green 250/11350
Green 150/11800
Blue 70/13800
Green 140/10940
Green 210/12750
Blue 550/14950
CALIFORNIA CO
Anderson Lo
11242
CHEVRON USA
O P Arceneaux
CHEVRON USA
TOCE OIL
Pellerin Baltazar
15150
75/13775
GULF OIL
William Anderson
11320
LYONS PE
Paul Anders
10601
E. FAULCONER, INC.
Tanner, A.
Agnes Rchrd Tanner
16500
11158
CALIFORNIA CO ETAL
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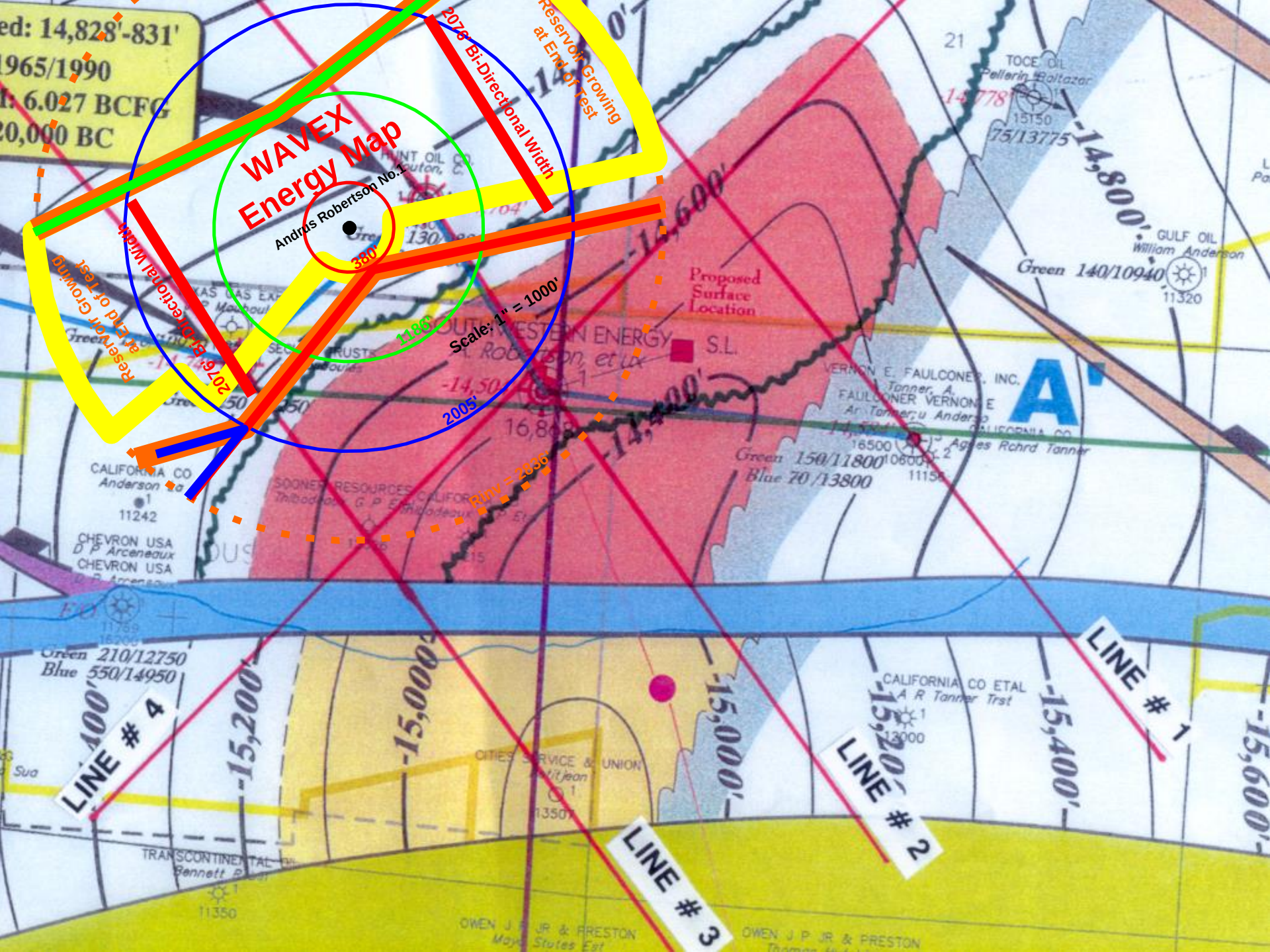
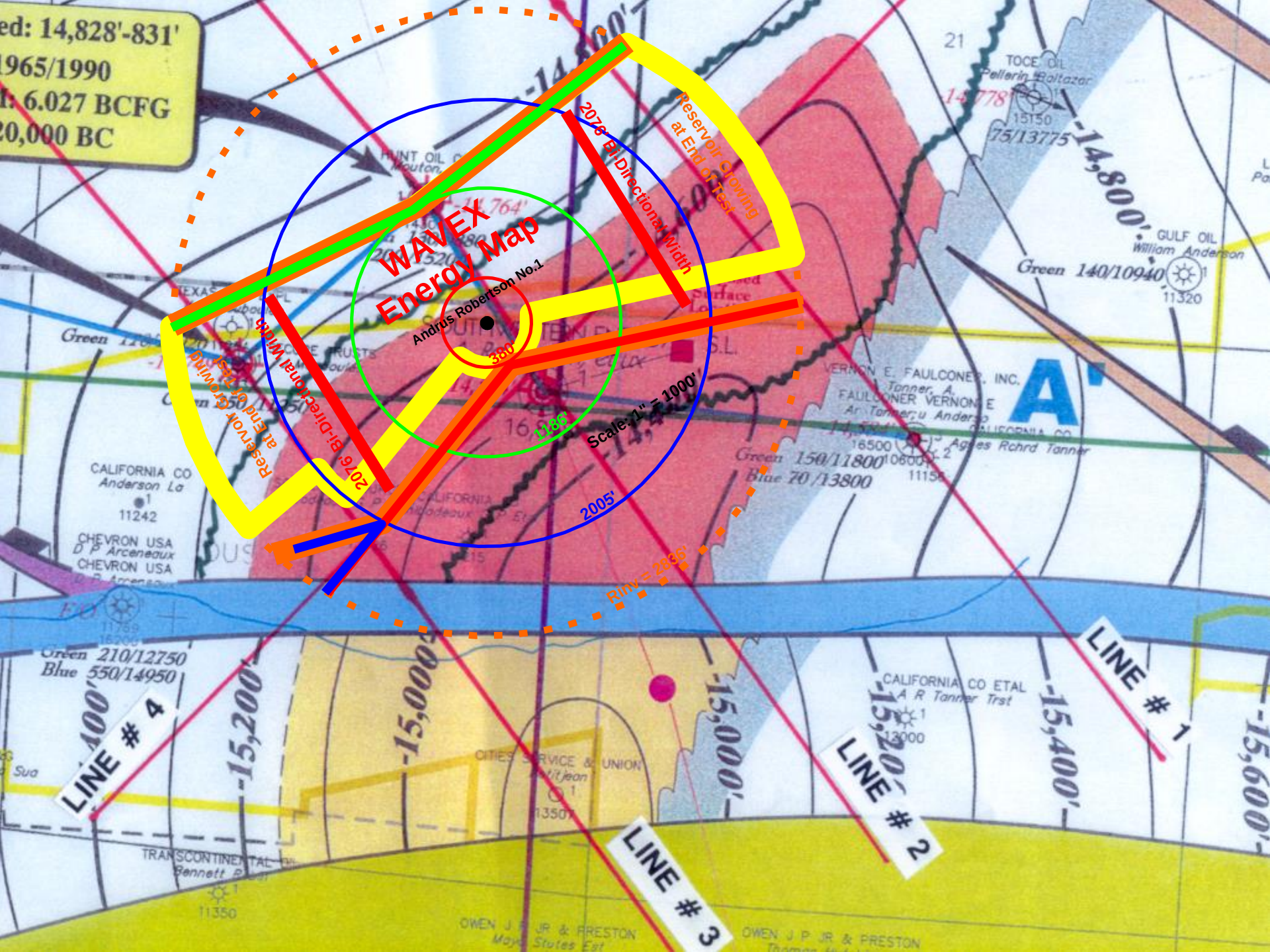
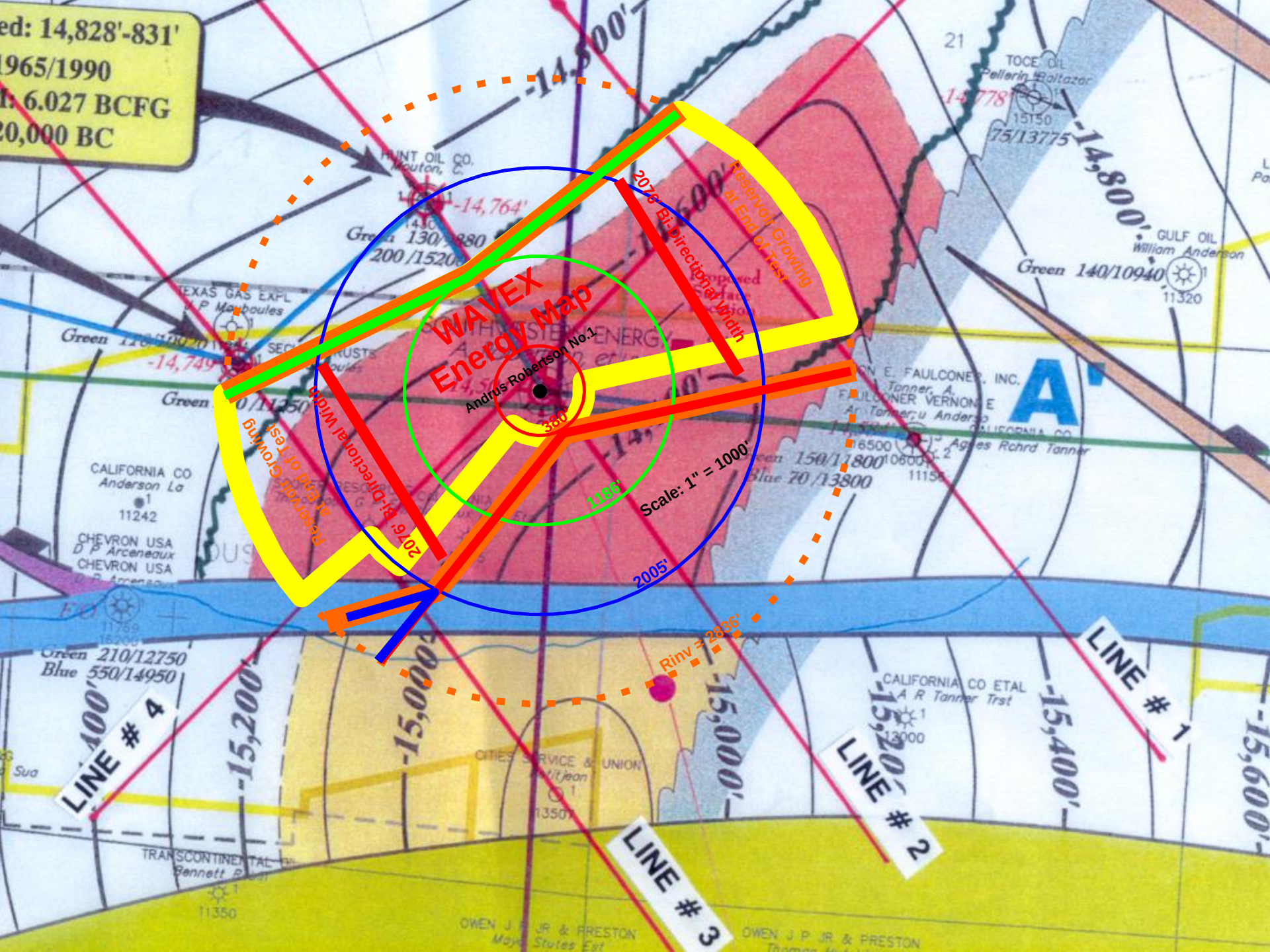
13000
CITIES SERVICE & UNION
Petitjean
13507
TRANSCONTINENTAL
Bennett
11350
OWEN J P JR & PRESTON
Mayo Stutes Est
OWEN J P JR & PRESTON
Thomas Hutchinson
LINE # 1
LINE # 2
LINE # 3
LINE # 4

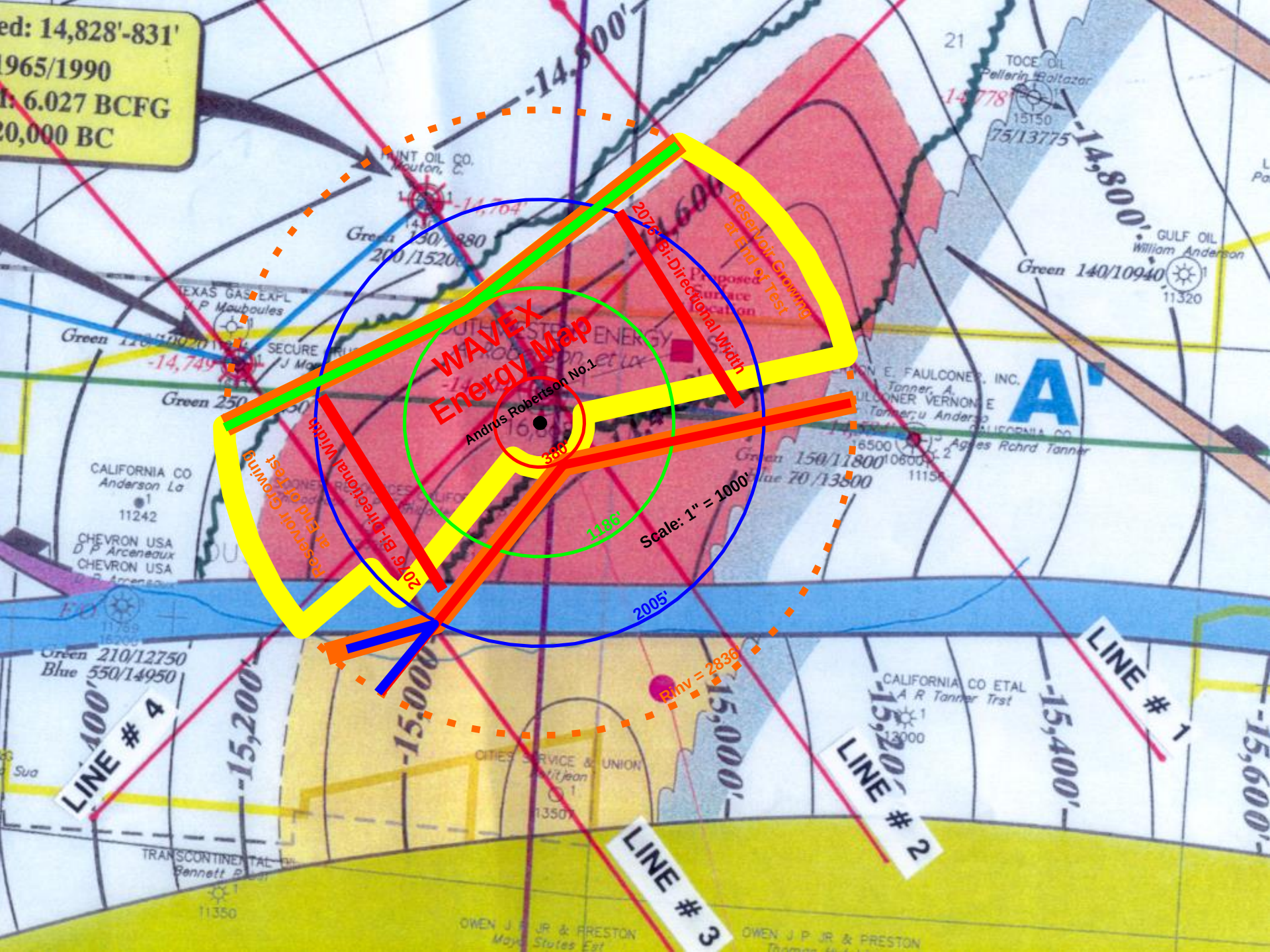


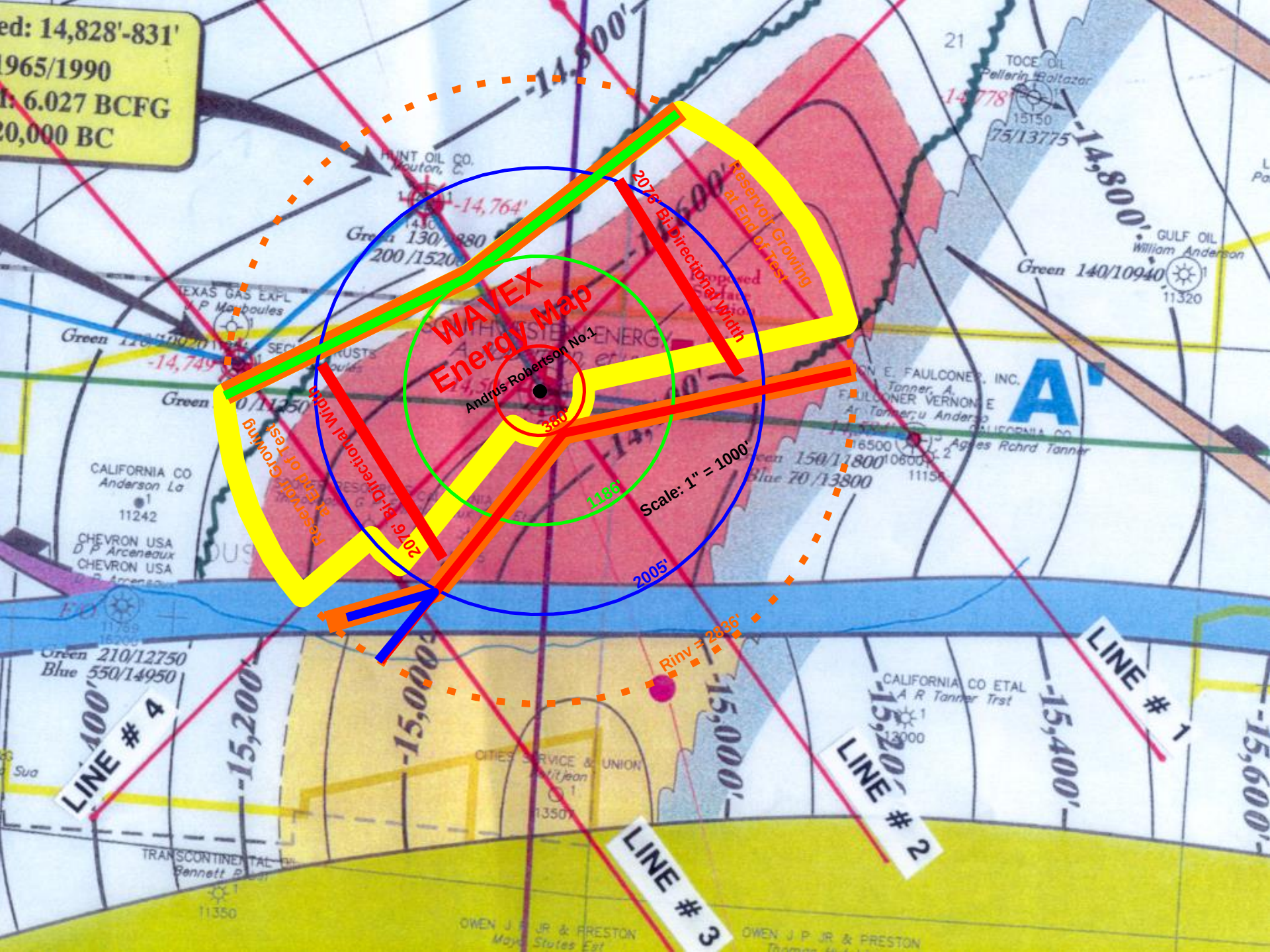
WAVEX
Energy Map
Andrus Robertson No.1
380'
2076' Bi-Directional Width
Reservoir Growing at End of Test
2076' Bi-Directional Width
Reservoir Growing at End of Test
Scale: 1" = 1000'
2005'
Run = 2036
Proposed Surface Location
SOUTHWESTERN ENERGY
S.L.
A'
LINE # 1
LINE # 2
LINE # 3
LINE # 4
-14,600'
-14,800'
-14,400'
-15,200'
-15,000'
-15,400'
-15,600'
TOCE OIL
Pellerin Baltazar
GULF OIL
William Anderson
Green 140/10940
VERNON E. FAULCONER, INC.
Tanner, A.
FAULCONER VERNON E
Green 150/11800
Blue 70/13800
CALIFORNIA CO
Anderson La
CHEVRON USA
D P Arceneaux
Green 210/12750
Blue 550/14950
CALIFORNIA CO ETAL
A R Tanner Trst
CITIES SERVICE & UNION
TRANSCONTINENTAL
OWEN J P JR & PRESTON


ed: 14,828'-831'
1965/1990
h: 6.027 BCFG
20,000 BC
WAVEX
Energy Map
Andrus Robertson No.1
2076' Bi-Directional Width
Reservoir Clowning at End of Test
2076' Bi-Directional Width
Reservoir Clowning at End of Test
380
1186'
2005'
Scale: 1" = 1000'
Rinv = 2836'
LINE # 1
LINE # 2
LINE # 3
LINE # 4
CALIFORNIA CO
Anderson La
11242
CHEVRON USA
D P Arceneaux
CHEVRON USA
Green 210/12750
Blue 550/14950
Green 150/11800
Blue 70/13800
Green 140/10940
11320
GULF OIL
William Anderson
TOCE OIL
Pellerin Baltazar
15150
75/13775
VERNON E. FAULCONER, INC.
CALIFORNIA CO ETAL
A R Tanner Trst
13000
CITIES SERVICE & UNION
11507
TRANSCONTINENTAL
Bennett
11350
OWEN J P JR & PRESTON
OWEN J P JR & PRESTON
-14,800'
-15,000'
-15,200'
-15,400'
-15,600'



ed: 14,828'-831'
1965/1990
M: 6.027 BCFG
20,000 BC
WAVEX
Energy Map
Andrus Robertson No.1
380'
1100'
2005'
Scale: 1" = 1000'
Rinv = 2886'
2076' Bi-Directional Width
Reservoir Growing at End of Test
LINE # 1
LINE # 2
LINE # 3
LINE # 4
A'
-14,800'
-15,000'
-15,200'
-15,400'
-15,600'
HUNT OIL CO.
Mouton, C.
-14,764'
TEXAS GAS EXPL
J P Mayboules
-14,749'
CALIFORNIA CO
Anderson La
11242
CHEVRON USA
D P Arceneaux
Green 210/12750
Blue 550/14950
TOCE OIL
Pellerin Baltazar
-14,778'
75/13775
GULF OIL
William Anderson
Green 140/10940
11320
FAULCONER, INC.
Tanner, A.
FAULCONER VERNON E
Agnes Rchrd Tanner
Green 150/11800
Blue 70/13800
CALIFORNIA CO ETAL
A R Tanner Trst
13000
CITIES SERVICE & UNION
TRANSCONTINENTAL
Bennett
11350
OWEN J P JR & PRESTON
Mayo Stutes Est


ed: 14,828'-831'
1965/1990
I: 6.027 BCFG
20,000 BC
WAVEX Energy Map
Andrus Robertson No.1
2075' Bi-Directional Width
Reservoir Growing at End of Test
Reservoir Growing at End of Test
20% Bi-directional Width
380'
1186'
2005'
Scale: 1" = 1000'
Rinv = 2836'
LINE # 1
LINE # 2
LINE # 3
LINE # 4
-14,800'
-15,000'
-15,200'
-15,400'
-15,600'
HUNT OIL CO.
TOCE OIL
GULF OIL
TEXAS GAS EXPL
SECURE
CALIFORNIA CO
CHEVRON USA
CALIFORNIA CO ETAL
CITIES SERVICE & UNION
TRANSCONTINENTAL
OWEN J P JR & PRESTON



ed: 14,828'-831'
1965/1990
M: 6.027 BCFG
20,000 BC
WAVEX
Energy Map
Andrus Robertson No.1
Scale: 1" = 1000'
2005'
2076' Bi-Directional Width
Reservoir Growing at End of Test
Reservoir Growing at End of Test
2076' Bi-Directional Width
Rinv = 2886'
LINE # 1
LINE # 2
LINE # 3
LINE # 4
A'
-14,800'
-14,764'
-14,749'
-15,000'
-15,200'
-15,400'
-15,600'
HUNT OIL CO.
TOCE OIL
Pellerin Baltazar
GULF OIL
William Anderson
TEXAS GAS EXPL
CALIFORNIA CO
Anderson La
CHEVRON USA
D P Arceneaux
CALIFORNIA CO ETAL
A R Tanner Trst
CITIES SERVICE & UNION
TRANSCONTINENTAL
OWEN J P JR & PRESTON
Green 210/12750
Blue 550/14950
Green 140/10940
Blue 70/13800

Conclusions…

- Well Testing generates fairly consistent values for skin & perm…and mostly arguments about everything else
- If done independently (without seeing the geologic image first), the credibility of the well test analysis can be improved
- Well Test Analysis can initiate a re-evaluation of the geologic interpretation & Vice Versa
- Best practice: Work separately until the G&G team and the Well Testers have independent models/maps; then work as a team with both sides being willing to change