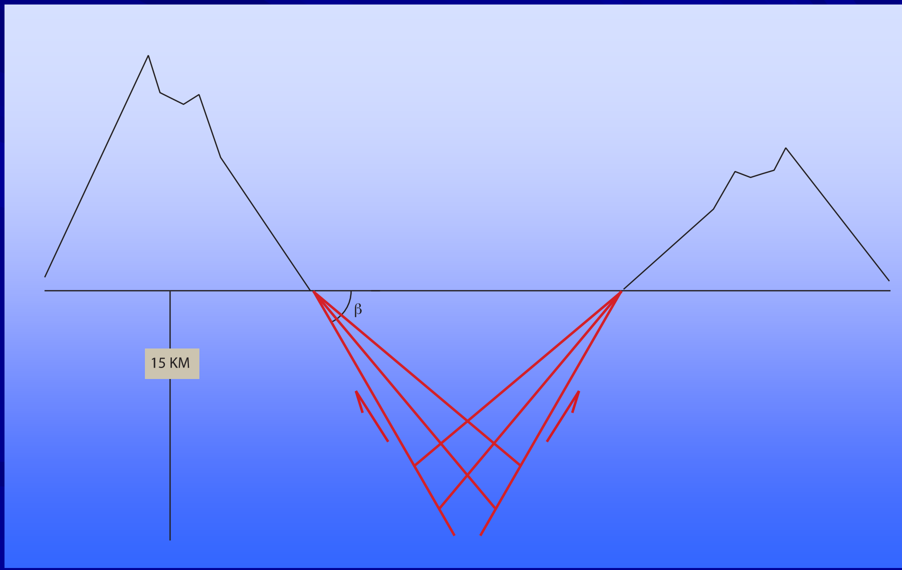
Antithetic Fault Parameters

Mike Hylland
Utah Geological Survey



Working Group on Utah Earthquake Probabilities – February 2012

How should antithetic fault pairs be modeled? (BRPEWGII issue G2)
Depending on fault dip and distance between faults, one fault likely truncates the other within seismogenic depths. But which is the master and which is the subsidiary (i.e., truncated) fault?

BRPEWGII recommendations:

Explore using metrics (such as Length, Topographic Relief, Overlap) to guide selection of master and subsidiary faults.

- Evaluate dataset for overlapping relations to select master fault based on Length
- Evaluate using aspect ratio (Length/Width) for individual fault pairs
- Where data allow, structural throw should be used rather than Topographic Relief
- Evaluate using Length x Throw as a parameter for selecting master fault

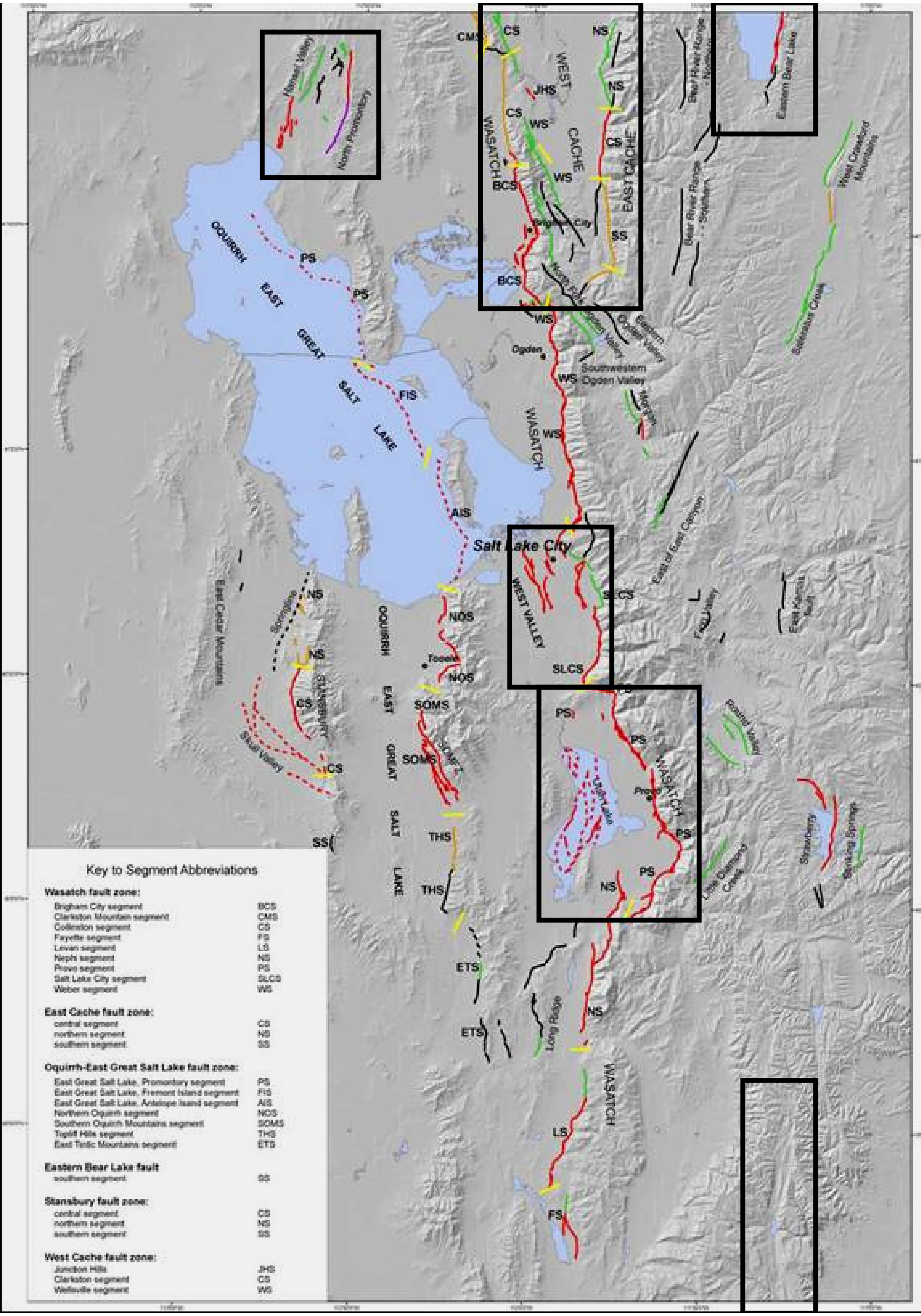
Subsurface data (e.g., seismic reflection) should be used to guide master fault selection, where available.

Where available data do not give a clear indication of master vs. subsidiary fault, model both alternatives using a logic tree approach.

How should antithetic fault pairs be modeled? (BRPEWGII issue G2) Depending on fault dip and distance between faults, one fault likely truncates the other within seismogenic depths. But which is the master and which is the subsidiary (i.e., truncated) fault?

Approach:
- Evaluated fault metrics for six antithetic pairs in the WGUEP study region, including length, percent overlap, maximum and "average" topographic relief, and length x relief
- Selected three master faults based on fault metrics, two master faults based on subsurface data, and used a logic tree approach for one fault pair
- Assigned preliminary 5^{th} – 95^{th} percentile dip distribution for each fault, with weights
- Assigned preliminary weights for independent vs. coseismic (vs. non-seismogenic) behavior

Questions:
- Do master fault selections seem reasonable?
- Are dip distributions and weightings appropriate?
- Are assigned weights for independent vs. coseismic (vs. non-seismogenic) behavior appropriate?
- Should the antithetic modeling approach be applied to other fault pairs in the WGUEP study region?



Fault pairs evaluated:

- West Valley fault zone – Salt Lake City segment
- Utah Lake faults – Provo segment
- Hansel Valley + Hansel Mountains (east side) + Hansel Valley (valley floor) faults – N. Promontory fault
- West Cache fault – East Cache + James Peak faults
- Western Bear Lake + Bear Lake (west side) faults – Eastern Bear Lake fault
- Joes Valley faults (east and west sides)

Should other fault pairs also be evaluated?

- East Canyon – Main Canyon faults
- Round Valley faults
- Other Wasatch Plateau faults
  - Pleasant Valley fault zone
  - Gooseberry graben
  - Snow Lake graben

Metrics for Selecting Master and Subsidiary Faults

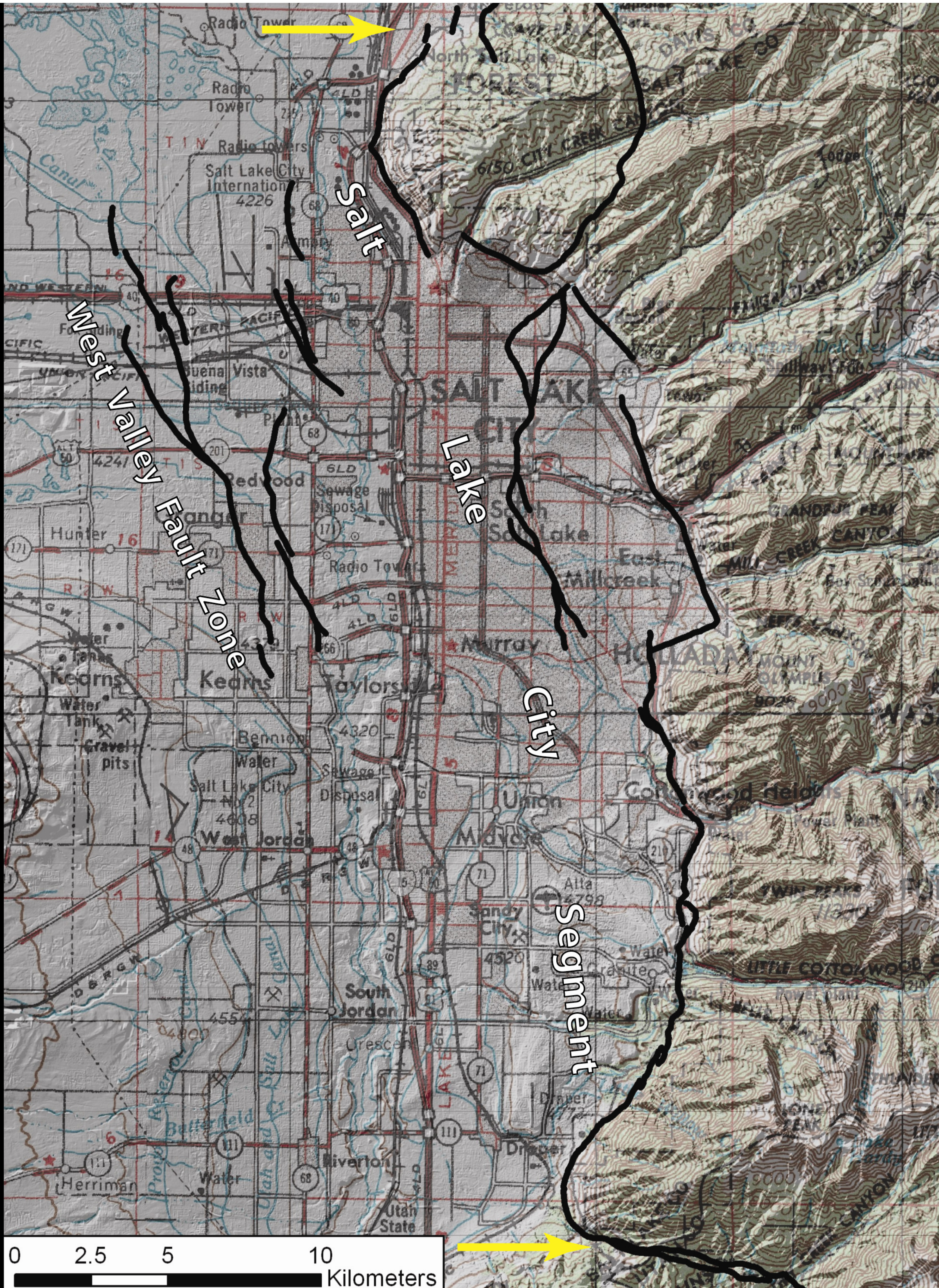
Fault Length* – proxy for fault maturity

Topographic Relief – proxy for long-term slip rate

Percent Overlap – comparative indicator of controlling structure

(Haller and Harmsen, 2011)

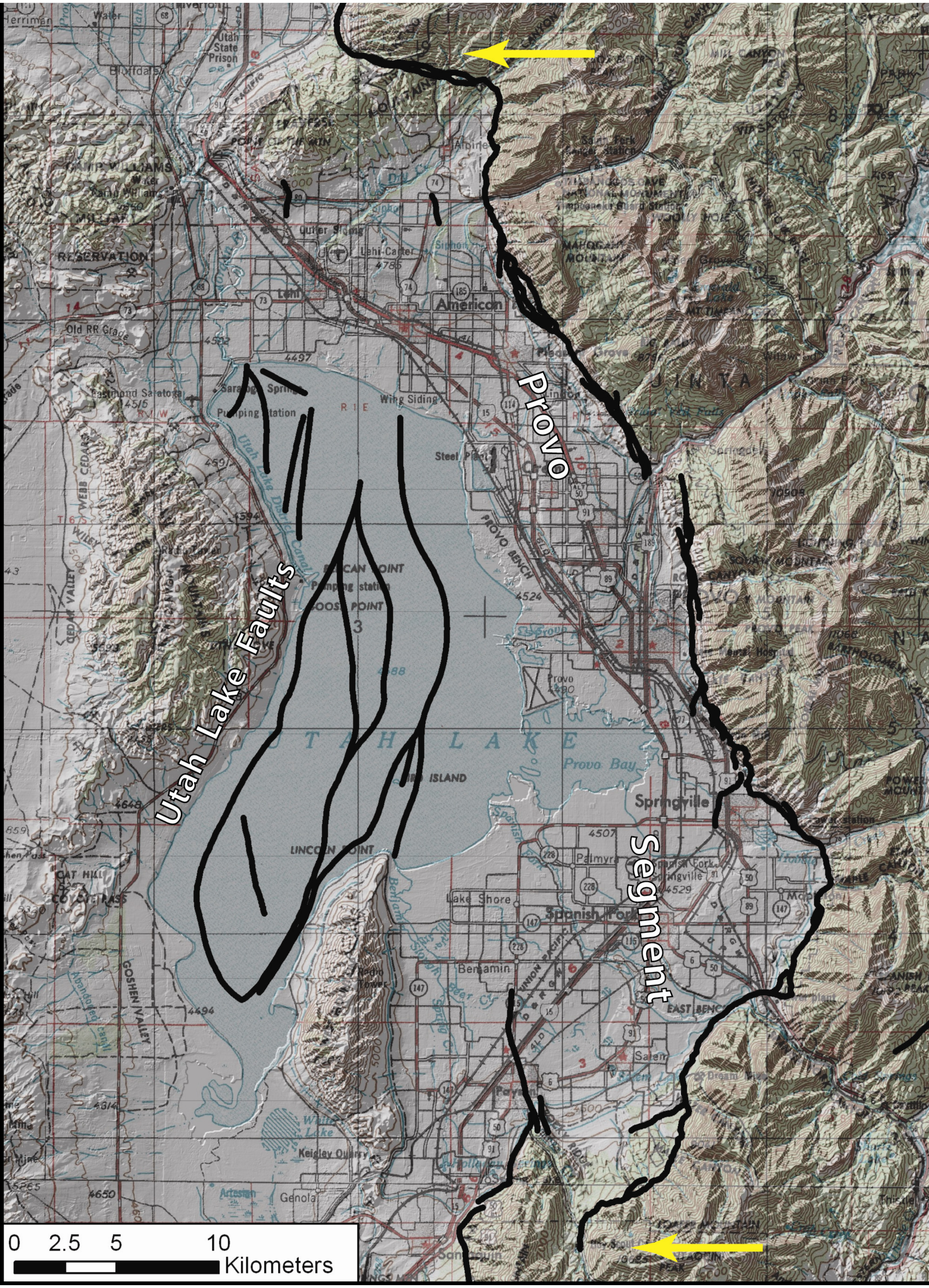
*Lengths used in this analysis may include multiple faults or fault sections, to represent a basin-bounding structure as a whole, and were measured as straight-line distances in Google Earth. Therefore, lengths used to select master vs. subsidiary faults may differ from lengths assigned as model parameters to calculate M.



West Valley Fault Zone – Salt Lake City Segment

	WVFZ	SLCS
Length (km)	16	40
Percent Overlapped	100	40
Topographic Relief (m)	6 (max.)	1950
	2 (ave.)	1070
Length x Relief (km^2)	0	43

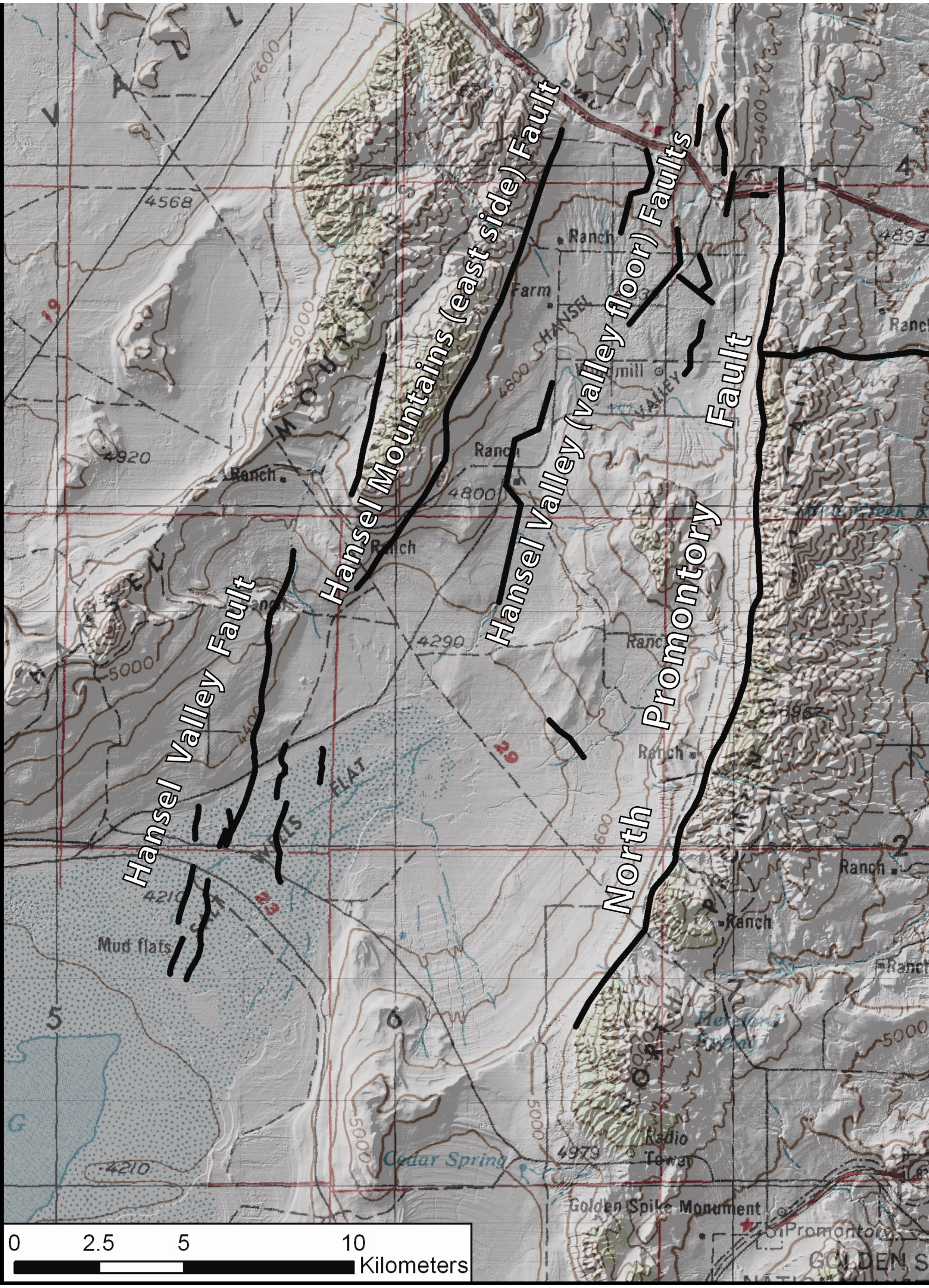
Master fault – Salt Lake City segment



Utah Lake Faults – Provo Segment

ULF	PS
<u>Length (km)</u>	
31	59
<u>Percent Overlapped</u>	
100	50
<u>Topographic Relief (m)</u>	
5 (max.)	1880
4 (ave.)	960
<u>Length x Relief (km^2)</u>	
0	57

Master fault – Provo segment

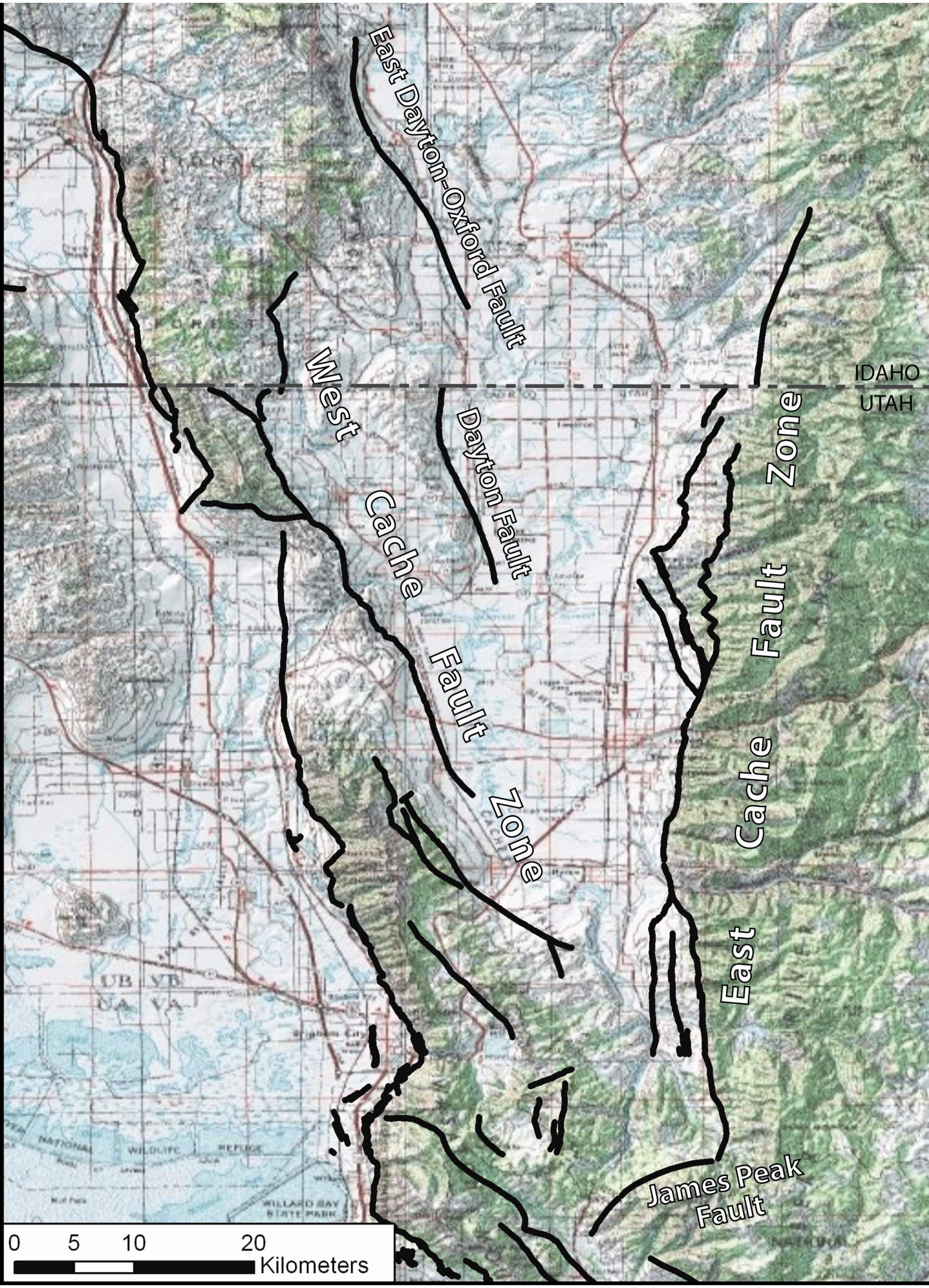


Hansel Valley Faults* – North Promontory Fault

	HVF	NPF
<u>Length (km)</u>	30	26
<u>Percent Overlapped</u>	83	100
<u>Topographic Relief (m)</u>	480 (max.)	420
	250 (ave.)	220
<u>Length x Relief (km^2)</u>	8	6

Master fault – [Hansel Valley, etc.]

*Includes Hansel Valley fault, Hansel Mountains (east side) fault, and Hansel Valley (valley floor) faults

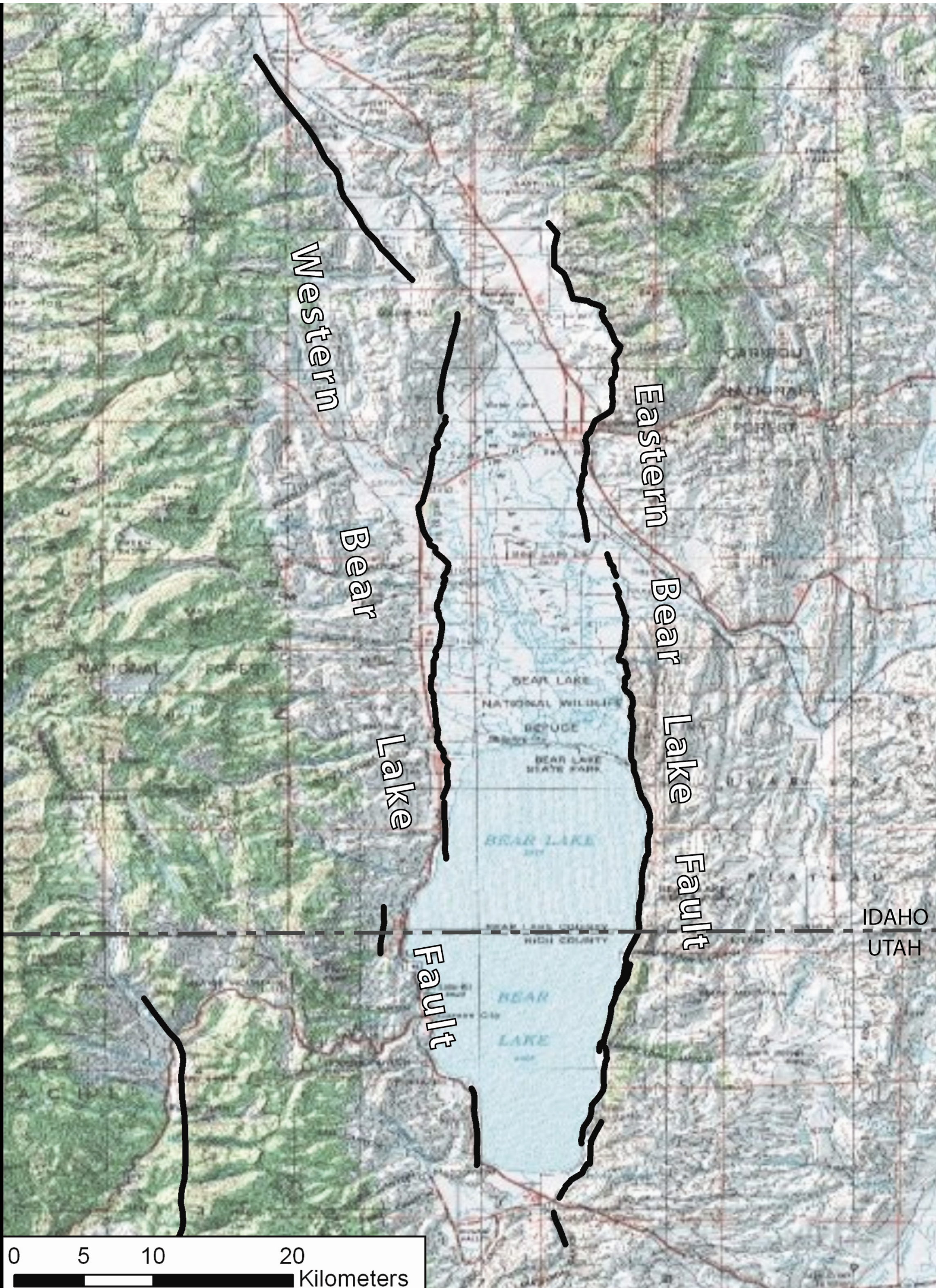


West Cache Fault – East Cache Fault*

WCF	ECF
Length (km)	
59	83
Percent Overlapped	
100	71
Topographic Relief (m)	
1250 (max.)	1440
530 (ave.)	860
Length x Relief (km^2)	
31	71

Master fault – East Cache fault

*Includes James Peak fault



Western Bear Lake Fault* – Eastern Bear Lake Fault

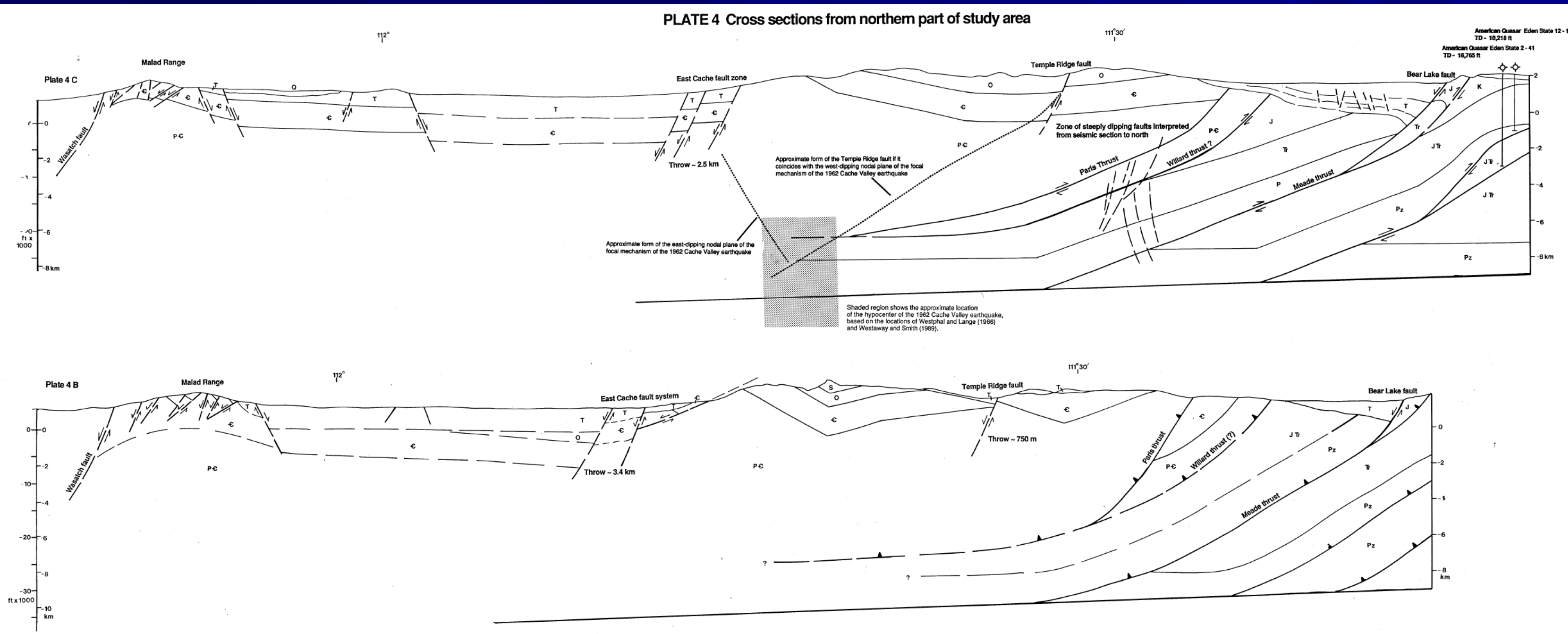
	WBLF	EBLF
Length (km)	82	73
Percent Overlapped	82	92
Topographic Relief (m)	900 (max.)	600
	740 (ave.)	370
Length x Relief (km^2)	61	27

Master fault – [Western Bear Lake fault]

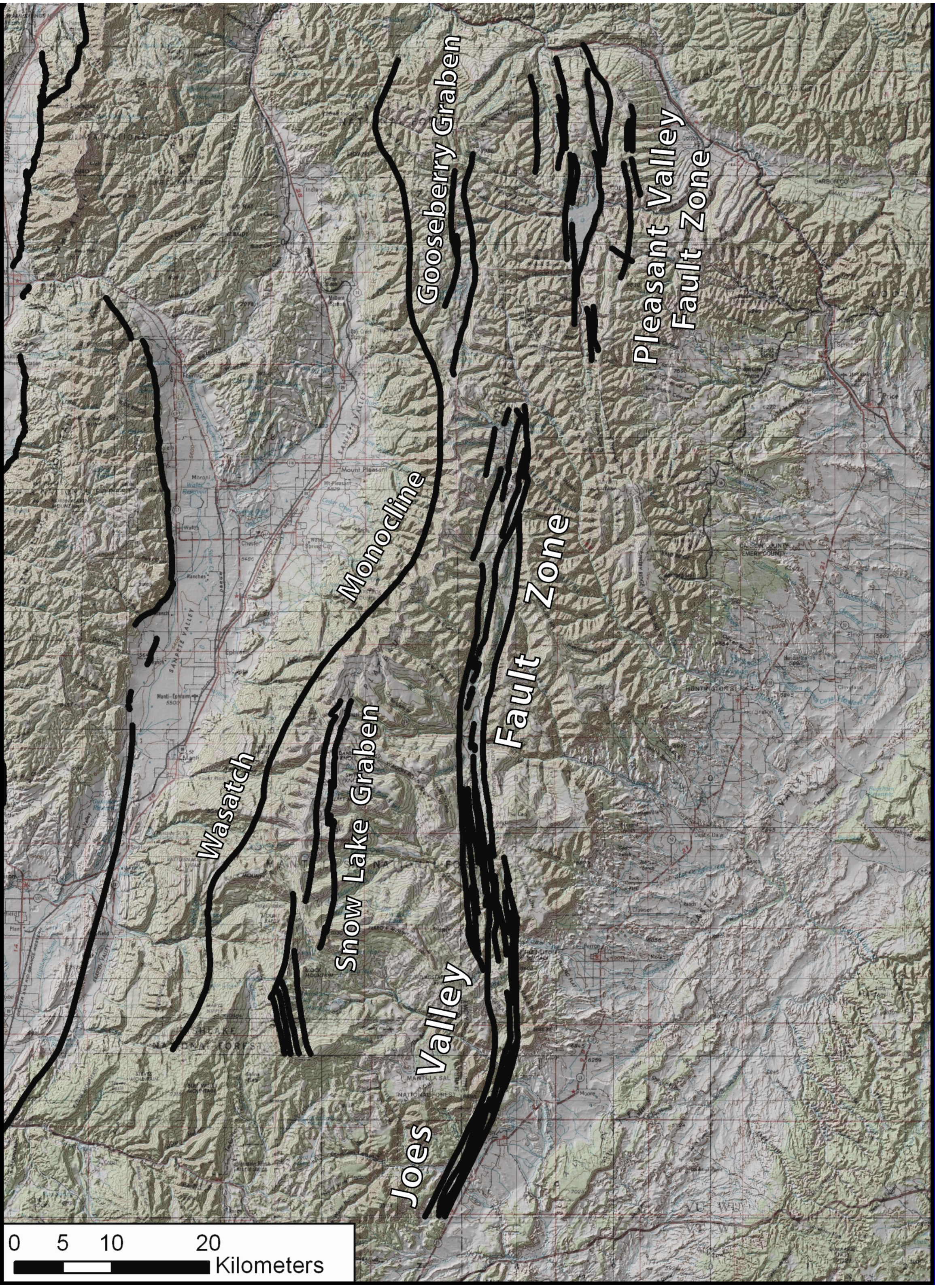
*Includes Bear Lake (west side) fault

Western Bear Lake Fault – Eastern Bear Lake Fault

Fault metrics suggest that the Western Bear Lake fault is the master fault, but interpreted seismic reflection data indicate that the Eastern Bear Lake fault is the master fault.



From Evans (1991)



Joes Valley Faults (west side) – Joes Valley Faults (east side)

WJVF	EJVF
Length (km)	
84	84
Percent Overlapped	
100	100
Topographic Relief (m)	
1000 (max.)	630
710 (ave.)	360
Length x Relief (km^2)	
60	30

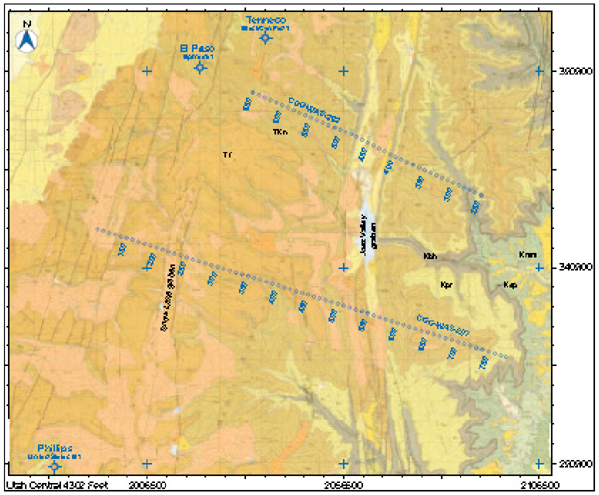
Master fault – [west side faults]

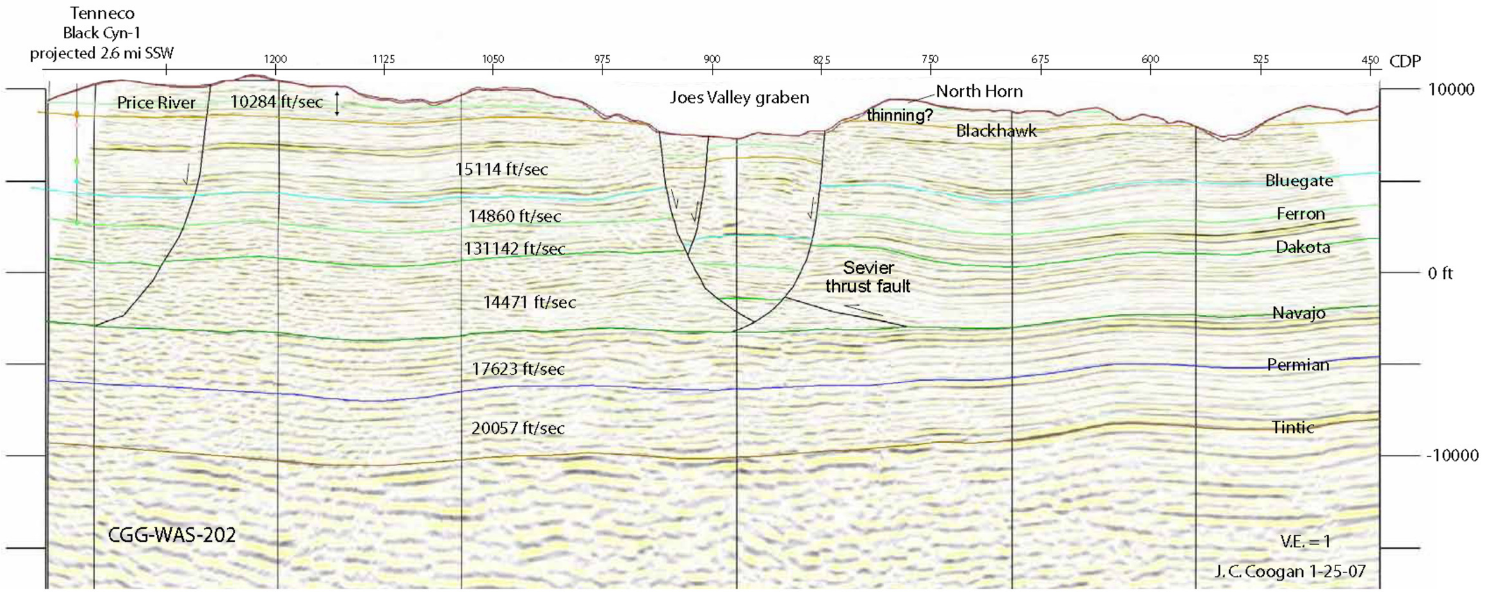
Fault metrics suggest that the western Joes Valley fault system comprises the master fault, but interpreted seismic reflection data indicate that the eastern fault system comprises the master fault.

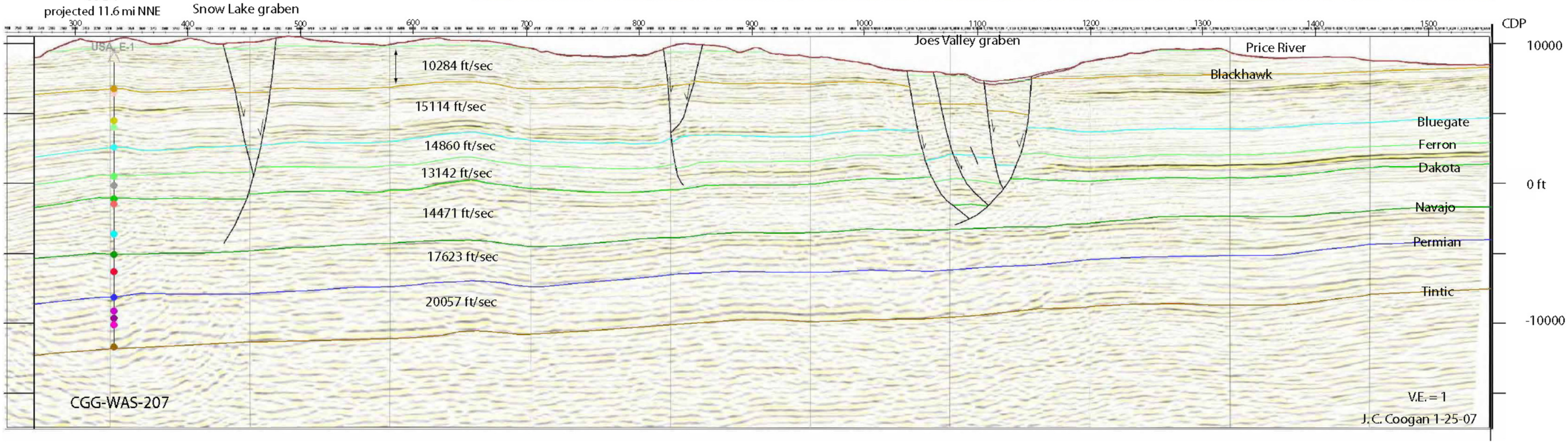
Joes Valley Faults

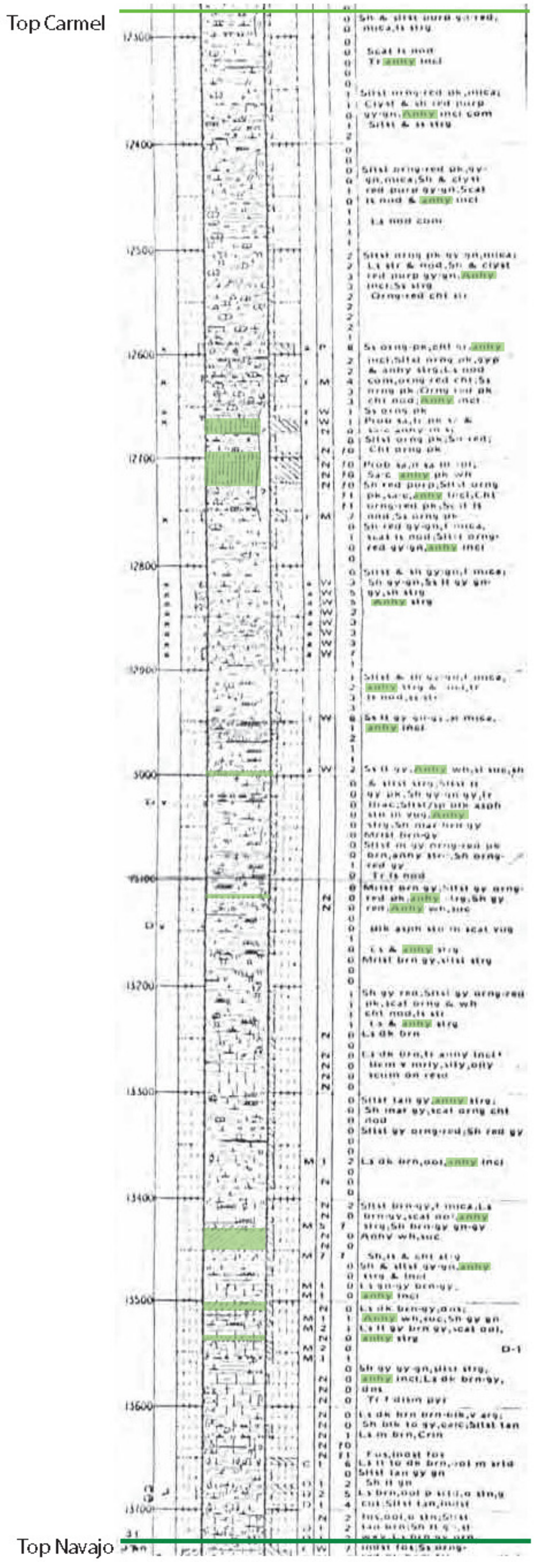
Vert. displacement of lower T and Upper K strata across main graben-bounding faults is 600–900 m.

Depth-migrated seismic reflection profiles (Coogan, 2008, *in* Anderson, 2008)









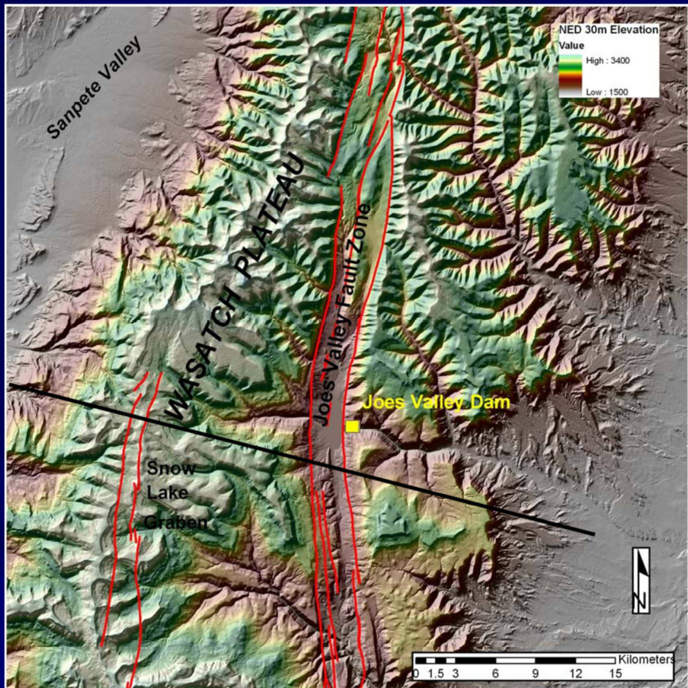
Joes Valley Faults

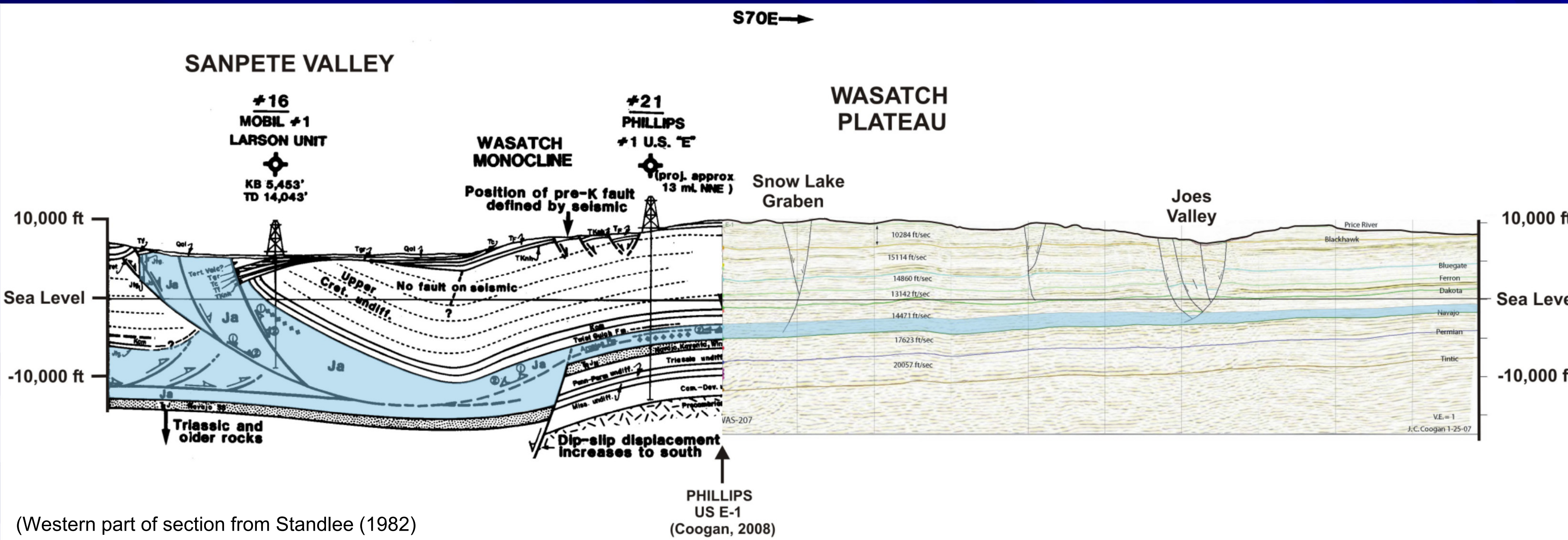
Phillips US E-1 Well

- Carmel Formation 1456 ft (444 m) thick
- Contains anhydrite throughout (highlighted in green)
- 5–40 ft thick (1.5–12 m) beds in middle 900 ft (275 m) of formation

(Coogan, 2008, *in* Anderson, 2008)

Joes Valley Faults





(Western part of section from Standlee (1982)

From Anderson (2008)

Master/Subsidiary Fault Classification

Master/Subsidiary Fault Classification for Antithetic Fault Pairs in the WGUEP Study Area.

Fault	Length	Overlap	Relief	Length X Relief	Classification
West Valley fault zone	S	S	S	S	**S**
Salt Lake City segment	M	M	M	M	**M**
Utah Lake faults	S	S	S	S	**S**
Provo segment	M	M	M	M	**M**
Hansel Valley–Hansel Mtns (east side) faults	[M]	[M]	M	M	**M** (0.25)
North Promontory fault	[S]	[S]	S	S	**M**[1] (0.75)
West Cache fault	S	S	S	S	**S**
East Cache fault (incl. James Peak fault)	M	M	M	M	**M**
Western Bear Lake fault	S	[S]	M	M	**S**
Eastern Bear Lake fault	M	[M]	S	S	**M**[2]
Joes Valley faults (west side)	—	—	M	M	**S**
Joes Valley faults (east side)	—	—	S	S	**M**[3]

M, master fault; S, subsidiary fault.
Brackets indicate <10% difference in parameter values.
[1] *Likelihood for master fault based on regional pattern of half-graben structure.*
[2] *Master fault based on interpreted seismic reflection data (Evans, 1991).*
[3] *Master fault based on interpreted seismic reflection data (Anderson, 2008); neither fault penetrates deeper than about 3.4 km.*

Several examples where fault metrics provide clear indication of master fault
- Salt Lake City segment, Provo segment, East Cache fault zone

Several examples where fault metrics provide somewhat ambiguous results
- Hansel Valley – North Promontory, Western – Eastern Bear Lake faults, Joes Valley faults

Strawman Model Parameters for Antithetic Fault Pairs in the WGUEP Wasatch Front Study Region

Fault	Classification[1]	Dip[2] (degrees) (5th, 50th, 95th) (0.3–0.4–0.3)	Independent vs. Coseismic (vs. non-seismogenic)[3]
West Valley fault zone	S	35–50–65	0.55, 0.45
Salt Lake City segment	M	35–50–65	0.55, 0.45
Utah Lake faults	S	35–50–65	0.4, 0.3 (0.3)[4]
Provo segment	M	35–50–65	0.55, 0.45
Hansel Valley + Hansel Mtns (east side) faults	M (0.25)	35–50–90[5]	0.55, 0.45
North Promontory fault	M (0.75)	35–50–65	0.55, 0.45
West Cache fault	S	35–50–65	0.7, 0.3[6]
East Cache fault + James Peak fault	M	35–50–65	0.8, 0.2[6]
Western Bear Lake fault	S	35–50–65	0.55, 0.45
Eastern Bear Lake fault	M	35–50–65	0.55, 0.45
Joes Valley faults (west side)	S	55–70–85[7]	0.3, 0.4 (0.3)[8]
Joes Valley faults (east side)	M	55–70–85[7]	0.4, 0.3 (0.3)[8]

[1] *M, master fault; S, subsidiary fault (truncated at depth by master fault).*
[2] *Default WGUEP dip distribution (50° ± 15°) except where noted.*
[3] *Preliminary WGUEP recommended range except where noted.*
[4] *Potential non-seismogenic character of the fault weighted 0.3 after S. Olig (p[a] = 0.7; written communication).*
[5] *Preliminary WGUEP recommended range.*
[6] *Higher weights for independent behavior relative to other fault pairs based on greater average separation distance between the West and East Cache fault; higher weight for East Cache fault being independent relative to West Cache fault based on higher likelihood of East Cache fault being the master fault.*
[7] *Range based on interpreted seismic reflection data (Anderson, 2008).*
[8] *Potential non-seismogenic character of the faults weighted 0.3 after S. Olig (p[a] = 0.7; written communication); higher weight for east side fault being independent relative to west side fault based on higher likelihood of east side fault being the master fault.*