UTAH QUATERNARY FAULT PARAMETERS WORKING GROUP

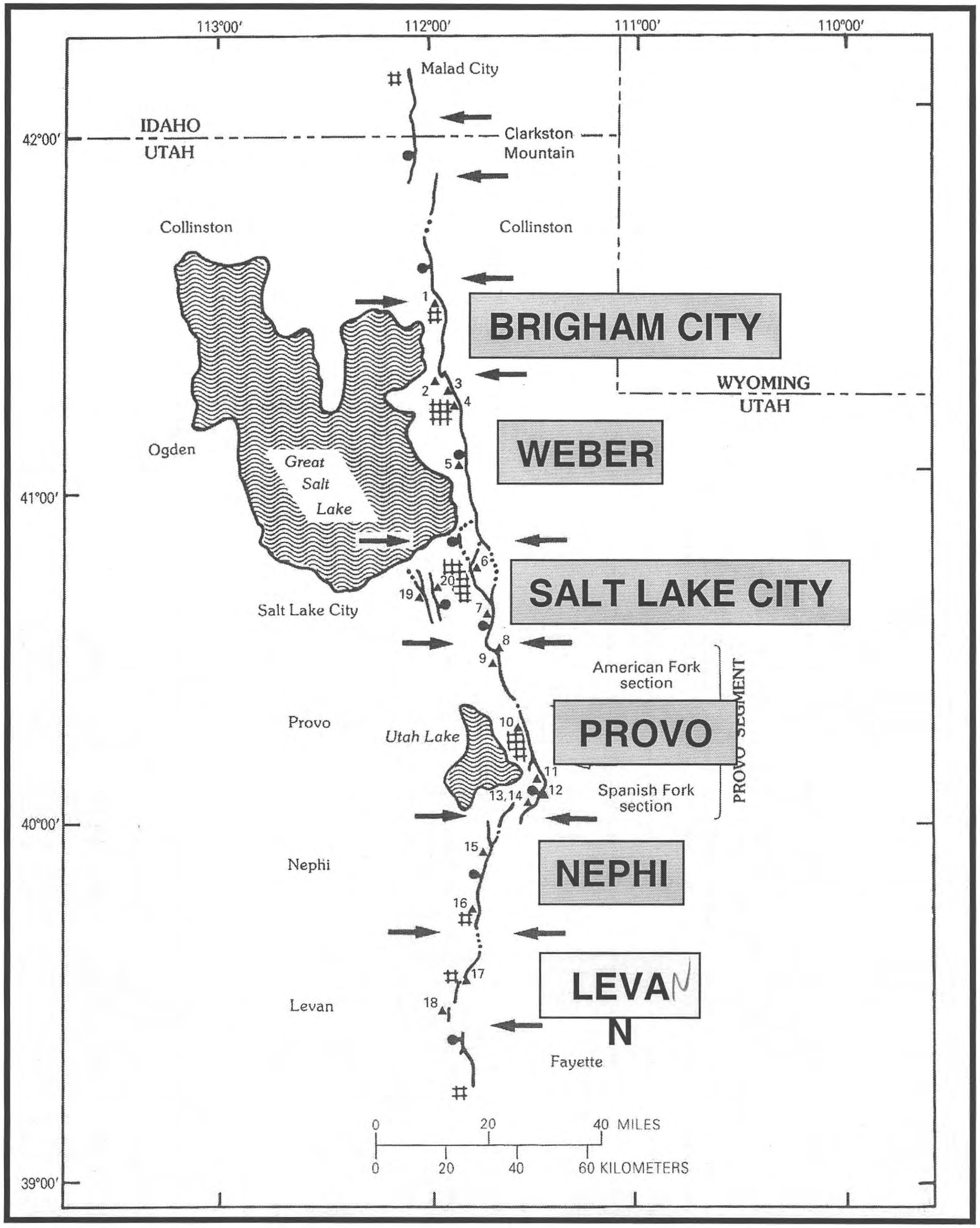
ESTABLISHING

CONSENSUS SLIP RATES and/or RECURRENCE INTERVALS

for the

SIX CENTRAL SECTIONS WASATCH FAULT ZONE

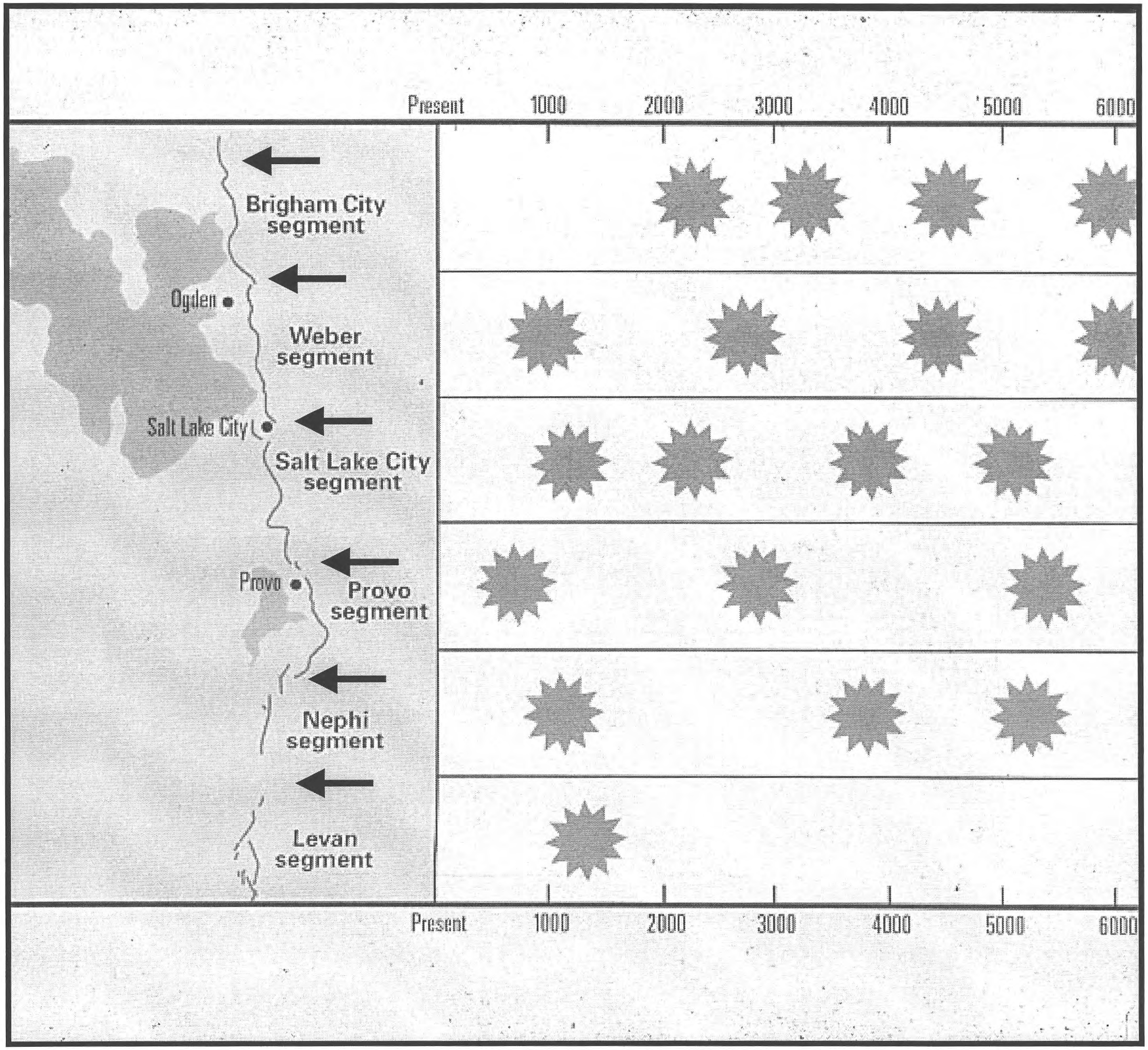
UTAH GEOLOGICAL SURVEY

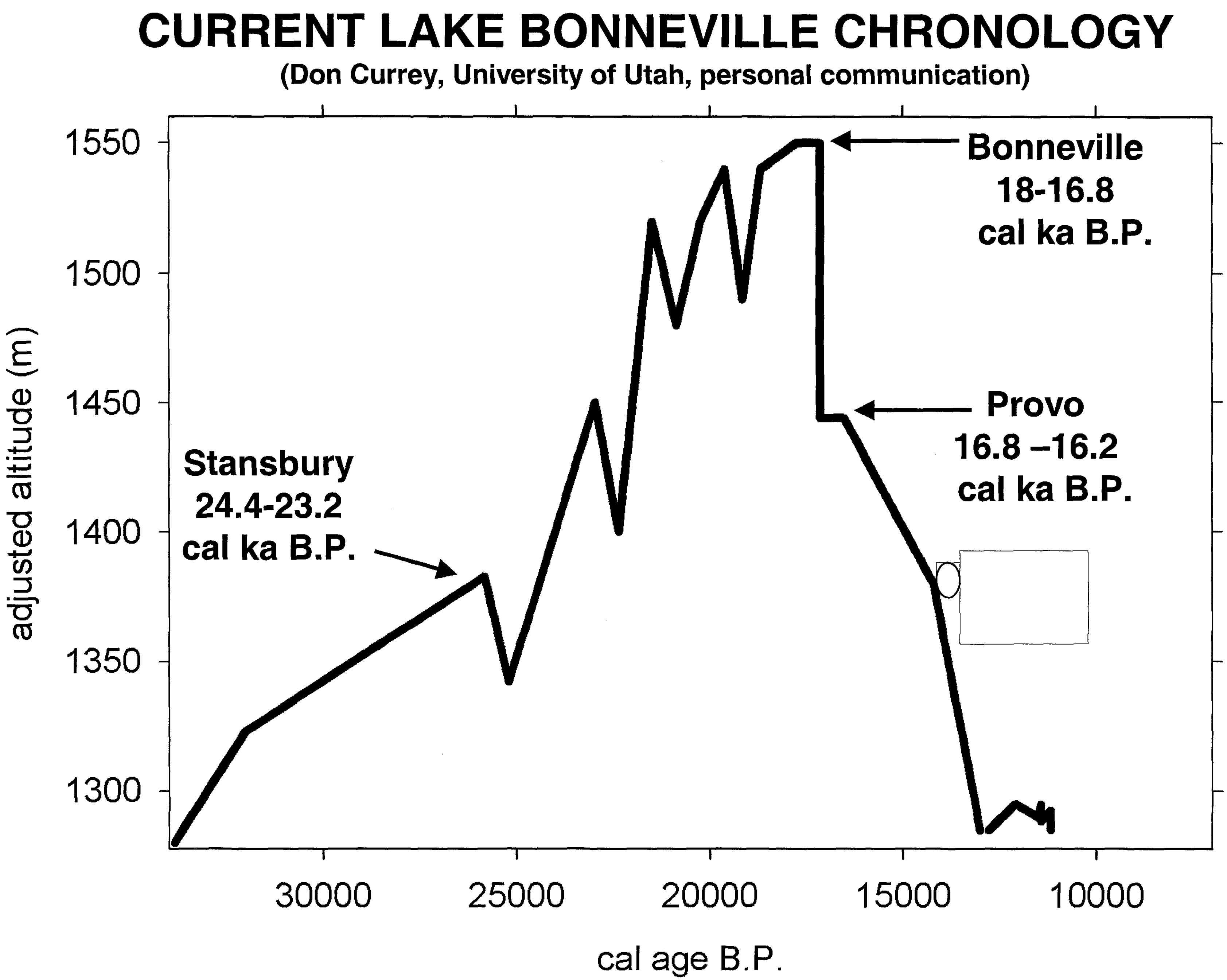


Wasatch Fault Zone Sections

(Machette and others, 1992)

CURRENT MODEL – MIDDLE HOLOCENE




CURRENT LAKE BONNEVILLE CHRONOLOGY
(Don Currey, University of Utah, personal communication)
1550
1500
1450
1400
1350
1300
adjusted altitude (m)
Bonneville
18-16.8
cal ka B.P.
Provo
16.8 –16.2
cal ka B.P.
Stansbury
24.4-23.2
cal ka B.P.
30000
25000
20000
15000
10000
cal age B.P.

RELEVANT ISSUES

- **DATA QUALITY – SOURCES/LEVEL OF UNCERTAINTY**
- **ADEQUACY OF THE RECORD – INFORMATION GAPS**
- **CHANGES IN SLIP RATE/RECURRENCE THROUGH TIME: CLUSTERING (THE LAKE BONNEVILLE AFFECT?)**
- **APPROPRIATE TIME INTERVAL OVER WHICH TO ESTABLISH CONSENSUS SLIP RATE AND RECURRENCE VALUES**
- **CONFIDENCE LIMITS – QUANTITATIVE vs. QUALITATIVE**

MP
- National maps use recurrance intervals for WF rather than slip rates
- Also need time-dependent hazards info (Time since MRE) + Magnitudes

- **EVOLUTION OF THE LAKE BONNEVILLE CHRONOLOGY**

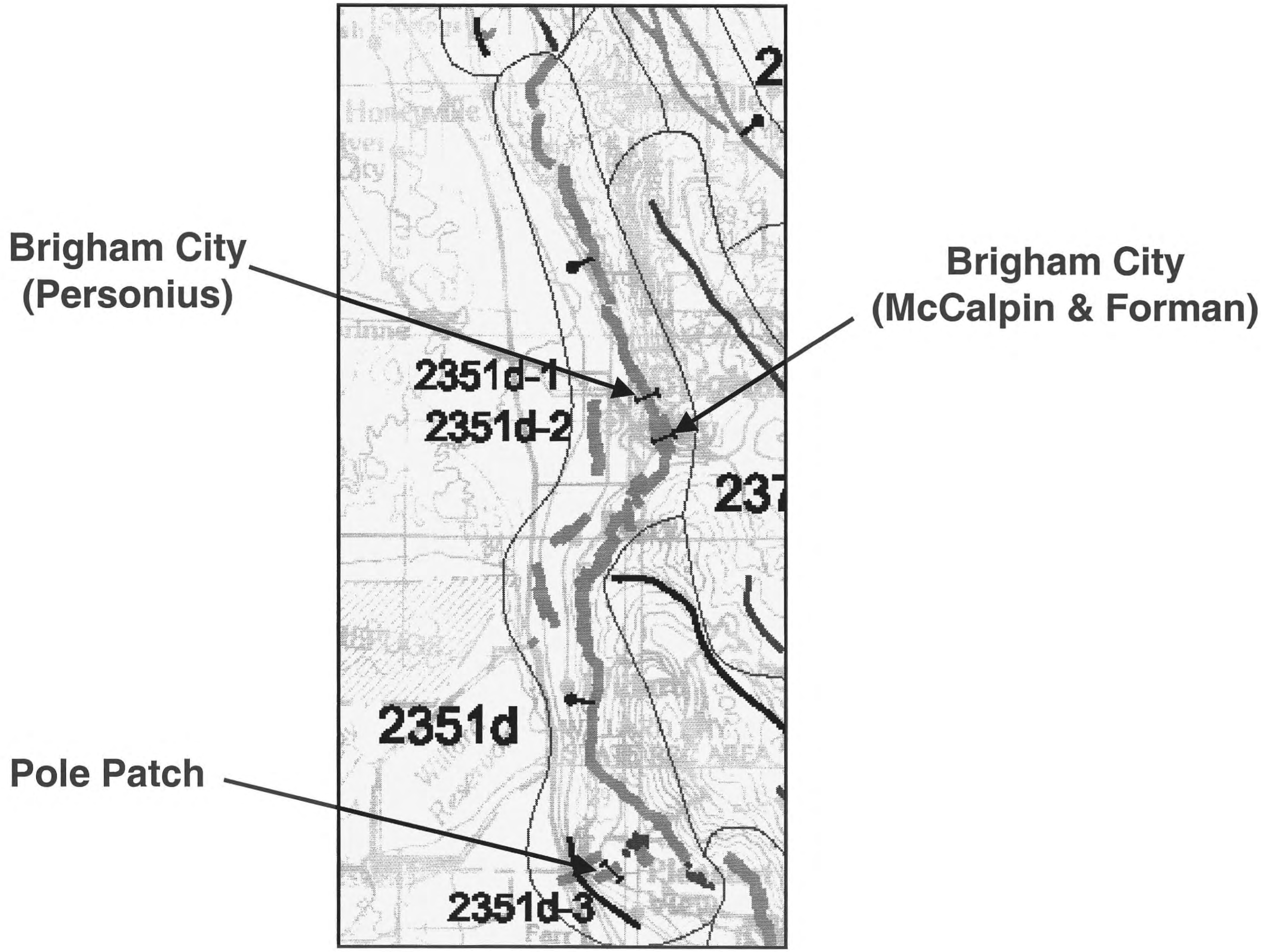
RBS
- Rates are model-dependent; must look at model uncertainty also
- How do we deal with clusters + what does it mean for return periods

Finite strain vs infinitesimal strain

- **MULTIPLE SECTION RUPTURES?**

DPS
- Fault geometry (vertical vs horizontal) - range of dips

BRIGHAM CITY SECTION



BRIGHAM CITY

Personius (1991)

- Single trench, 8-m-high scarp, Holocene alluvial fan.

- Three events: two colluvial wedges, third event equivocal.

- Event age/Net slip

  MRE: 3.6 ka/1.0 m

  PE: 4.7 ka/2.5 m

  APE: undated, estimated 5-7 ka/2.5 m

- Recurrence interval

  - Non-uniform
  - One closed interval between PE & MRE = 1100±1000 yr

- Slip rate

  0.75 mm/yr (3.5±1.0 m/4.7±0.5 ka) – open slip rate PE to present; 0.91 mm/yr (1.0 m/1.1 ka) – closed seismic cycle between PE and MRE

BRIGHAM CITY

Personius (1991)

SOURCES OF UNCERTAINTY

- Evidence for APE is equivocal
- Net-slip measurements are a combination of direct measurements and estimated displacement.
- Were all scarps at this site trenched?
- McCalpin and Forman (2002) identified a late Holocene surface-faulting event at their Brigham City site that was not recognized at this site.
- Issues related to ^{14}C AMRT ages, sampling, date inversion, etc.

BRIGHAM CITY

McCalpin & Forman (2002)

- **14 trenches, 7 sub-parallel scarps, Provo-age Lake Bonneville delta**

DPS · How continuous is record? can we say we have a complete record

- **7 (possibly 6 or 8) events since Provo delta abandoned**

DPS – older record may be incomplete
SSO – Lt. Pleistocene slip rate about equal to Lt Holocene rate. May indicate slip decreases as recurrence increases

- **Event ages**

Z: 2125±104 cal yr B.P.
Y: 3434±142 cal yr B.P.
X: 4674±108 cal yr B.P.
W: 5970±242 cal yr B.P.
V: 7500±1000 yr B.P.] TL
U: 8500±845 yr B.P.
T: >14.8±1.2 cal ka, <17.0
? at ~ 12 ka in U-T gap

- **Net slip – Not measured**

– All scarps not trenched

SP – 20 m on single scarp to south of McCalpin site
– Same general displacement at McCalpin site

DPS – 20 m (max)/Provo time

- **Recurrence**

Mean for six events (Z through U, 5 closed seismic cycles) 1275 yrs
Events U and T = 6300 yrs – Lake Bonneville effect?

• Need slip rates at each Provo delta?
• slip rates vary along segment, but recurrence shouldn't

DPS – Need to know uncertainties in Lk Bonneville chronology (are ages means? what are error bounds)
– Fewer the data, larger the uncertainty

BRIGHAM CITY

McCalpin & Forman (2002)

SOURCES OF UNCERTAINTY

- Youngest event not identified by Personius (1991)

SSO • need MRE for BC segment
long-term slip rate
Average recurrence

- Are events V and U individual surface-faulting earthquakes, or was there only one event at ~7.5–8.5 ka.

- Is the colluvium identified as evidence for event T tectonic?

- No evidence for the Personius (1991) event at ~ 4.6 ka, yet included in surface-faulting chronology.

DPS • Fault characterization by separate groups in Bay Area

- One scarp destroyed BY gravel pit, so not trenched.

DO • More uncertainty in trench dates than is represented in reports

- Uncertainties generally associated with ^{14}C AMRT dating.

• Need means in space and time, and be consistent in calculations

POLE PATCH

Personius (1991)

- Single trench across a 1.2-km-long, NE-trending fault (WFZ is NW trending) on the Pleasant View salient – boundary between Brigham City and Weber Sections.

- Three events/colluvial wedges

- Event ages
  - 4.6 ka±0.5 cal yr B.P. maximum limiting age for MRE
  - Two older events could not be dated.

-matching stratigraphy in trench to get displacement

- Slip Rate/Recurrence

  Only one dated event, published estimates are based on outdated Lake Bonneville chronology and are highly speculative.

POLE PATCH

Personius (1991)

SOURCES OF UNCERTAINTY

- Short fault trending nearly 90° to the WFZ on the section boundary between the Brigham City and Weber Sections.

- Only one of three events identified could be dated.

- Age ~~or~~ of MRE at Pole Patch = age of PE at Brigham City (Personius, 1991).

- The two ^{14}C AMRT ages available for the site are stratigraphically inverted.

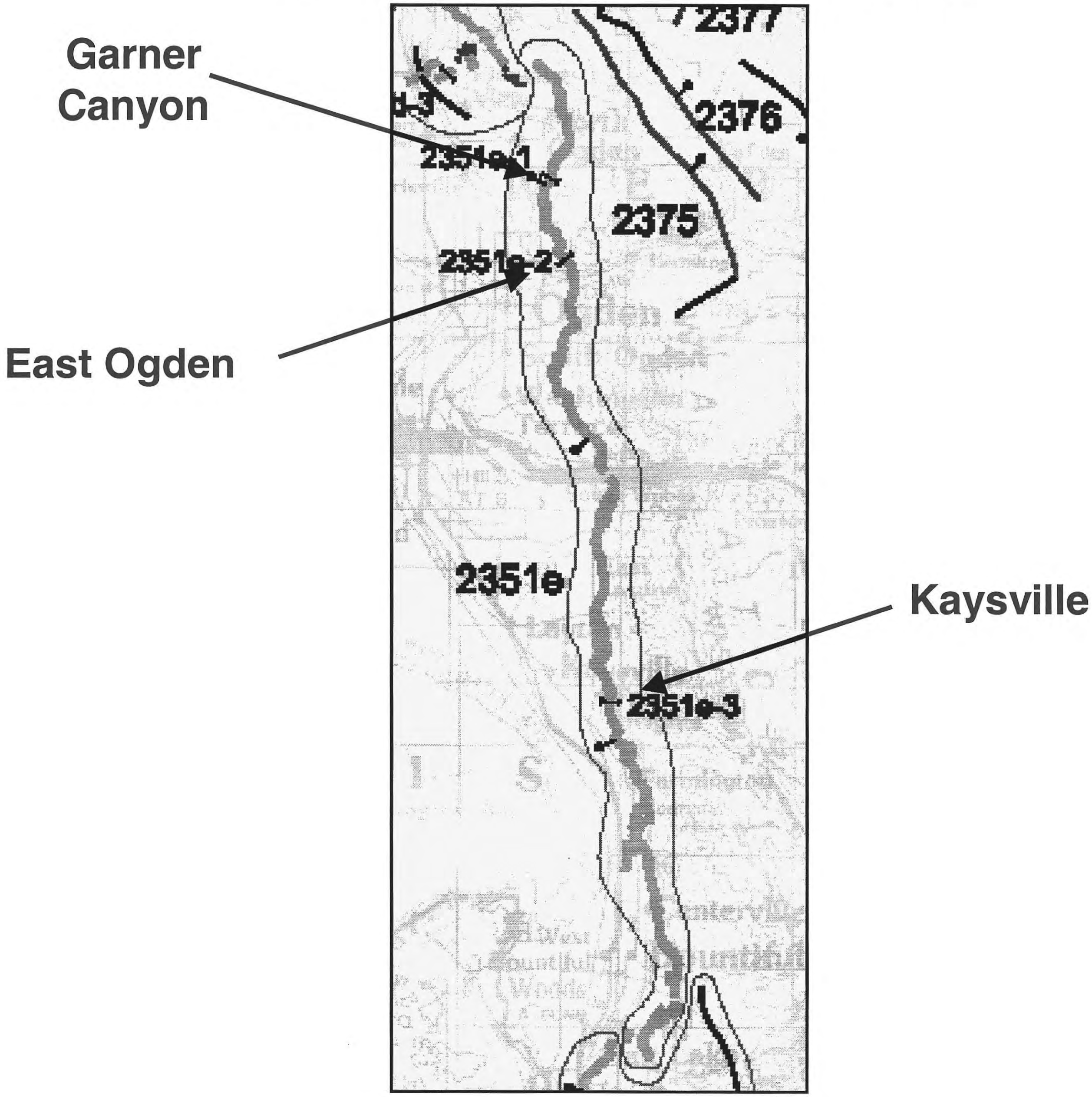
- Reported slip rate and recurrence estimates are speculative and based on an outdated Lake Bonneville chronology.

MP
- Need mean/median recurrence info
- Need 5th + 95th percentile

BRIGHAM CITY SECTION ISSUES

- **One trench site is not on the WFZ (Pole Patch).**
  - Not enough data on BC to characterize slip
- **The two sites that are on the WFZ each have at least one scarp that wasn't trenched.**
  - Uncertainty should reflect number of sites on segment - more sites should reduce uncertainty
  - stratigraphic uncertainty vs laboratory uncertainty
- **One event at each of the two WFZ sites was not recognized at the other site, even though the two sites are only a few kilometers apart.**
  - SP Comfortable with last 4 events; need to increase uncertainties or acknowledge that uncertainty is greater. Also acknowledge a possible seismic gap
- **Net slip information is limited; none from McCalpin and Forman (2002); data from Personius (1991) is partially estimated and may not include information from an untrenched scarp.**
  - Calculate # events in a time period to get average recurrence
- **Uncertainty regarding the number of older events (Events V, U, T, and a possible eighth event) at McCalpin and Forman's (2002) Brigham City site.**
  - Need to look at Steve's profiles and ages of surfaces to look at slip distribution

WEBER SECTION



KAYSVILLE

Swan and others (1980, 1981)

- 7 trenches, 2 on main scarp, 3 on antithetic scarp, 2 in graben

- Three events/colluvial-wedge deposits; additional older events likely based on cumulative net-slip measurement.

- Event ages

  MRE & PE < 1580±150 ^{14}C yr B.P.

  APE > 1580±150 ^{14}C yr B.P.

- Net slip

  MRE = 1.8 m

  PE = 1.7 m

  APE = unknown

  Cumulative slip = 10-11 m in ~6000±2000 yrs

KAYSVILLE

Swan and others (1980, 1981)

- **Recurrence interval**

  Two event in ~1.58 ka, estimate 0.5 to 1.0 ka between events. Considering 10-11 m net slip in ~ 12 ka, repeat closer to 1 ka/event.

- **Slip rate**

  1.8 (+1.0, -0.6) mm/yr 10-11 m/6000±2000 yrs (est. age of a post-Provo fan)

◦ 1580 C14 date on piece of charcoal good

KAYSVILLE

Swan and others (1980, 1981)

SOURCES OF UNCERTAINTY

- All event timing based on a single ^{14}C date.
- ^{14}C date came from graben fill not from scarp-derived colluvium or a paleosol beneath a colluvial wedge.
- Long-term recurrence estimate based on a now outdated Lake Bonneville chronology.
- Slip-rate estimate based on an estimated age for a post-Provo alluvial fan determined from soil profile development.
- Slip-rate estimate includes at least one open seismic cycle.
- McCalpin and others (1994) determined a substantially different surface-faulting chronology for this site.

KAYSVILLE

McCalpin and others (1994)

- Single trench excavated 2 meters south of Swan and others' (1980, 1981) Trench A on the main fault scarp.

- Five to six events
  - Three most recent/colluvial wedges
  - Two to three older events based on sedimentary character of geologic units, dip angles of geologic units, and number of events required to account for the cumulative net slip at the site.

° should lay logs out + overlay them to compare Swan + McCalpin

- Event ages/Net slip

Event 5 (MRE) = 0.6-0.8 ka/1.7-1.9m

Event 4 (PE) = 2.8±0.7 ka/2.3-3.4 m

Event 3 (APE) = 5.7-6.1 ka/1.4 m

Event 2 = not dated - based on presence of colluvial wedge

Event(s) 1a (1b?) <13ka, >8.5- 10.2 ka - to account for net slip.

- Cumulative slip = 10-11 m in post-Provo time

KAYSVILLE

McCalpin and others (1994)

- Recurrence interval
  - 2.7-3.6 ka for period 0.8 to 6.1/7.9 ka (events 3, 4, 5)
  - 2.2-2.6 ka if assume 5-6 paleoearthquakes in post-Provo time ($\leq$13 ka)

- Slip Rate
  - Composite slip rate of 0.8-1.1 mm/yr (10-11 m/~12 ka; (estimated age of post-Provo alluvial fan).
  - Mid-Holocene rate (events 3, 4, 5) ranges from 0.7-1.7 mm/yr to 0.9-1.2 mm/yr depending on the maximum age selected for event 3.

KAYSVILLE

McCalpin and others (1994)

SOURCES OF UNCERTAINTY

- Total number of events is an estimate based on post-Provo net slip and average slip/event.

- Post-Provo alluvial-fan deposits not dated, age estimate based on an outdated Lake Bonneville chronology – estimated age substantially different than Swan and others (1980, 1981).

- Contradictory information presented regarding unit 5, is it or isn't it a scarp derived colluvial wedge and evidence for event 2? (McCalpin, personal communication, says yes).

- No information of how age estimates for events 3, 4, and 5 were determined.

KAYSVILLE

McCalpin and others (1994)

SOURCES OF UNCERTAINTY

- Soil S2 on event 3 colluvial wedge not dated.
- Net slip/event values are estimates based chiefly on deposit geometry.
- Recurrence interval and slip-rate estimates extend to the present and each include at least one open seismic cycle.
- Slip-rate estimate based on estimated age of post-Provo alluvial fan; recurrence interval estimate based on post-Provo time, which is a longer time interval.

EAST OGDEN

Nelson and others (1987), Nelson (1988), Forman and others (1991), Machette and others (1992)

- **Five trenches: two each on 2 down-to-the-west scarps and 1 on a down-to-the-east antithetic scarp. A third major down-to-the-west scarp was not trenched.**

- **Three (possibly 4) events/colluvial-wedge stratigraphy.**

- **Event ages (as revised by Machette and others, 1992)**

  MRE = 0.8-1.2 ka 0.3-.7 - 4th event (possible), possibly smaller

  PE = 2.5-3.0 ka

  APE = 3.5-4.0 ka

  No information provided for possible 4th event

- Need to date possible 4th (MRE?) event if possible

- **Slip (Machette and others, 1992)** - scarp displacement, not net slip

  5-m scarp; 2 mid-Holocene, 2.2 m each, 1 late Holocene, 0.9 m

  8-m scarp; 2 mid-Holocene, 2.5 m and 3.5 m, 1 late Holocene, 2.2 m.

EAST OGDEN

Nelson and others (1987), Nelson (1988), Forman and others (1991), Machette and others (1992)

- **Recurrence interval (Nelson, 1988)**

  Surface-faulting recurrence for past 6 ka reported as ranging from 0.4-2.2 ka and averaging 1.4 ka. No recurrence interval estimates reported in other paleoseismic source documents for this site.

- **Slip rate (Nelson, 1988)**

  ~6.5 feet/1000 yrs. No slip-rate estimates reported in other paleoseismic source documents for this site.

EAST OGDEN

Nelson and others (1987), Nelson (1988), Forman and others (1991), Machette and others (1992)

SOURCES OF UNCERTAINTY

- This site lacks a final report, all available paleoseismic source documents are summaries. No trench logs are available for this site.
- At least one main, down-to-the-west scarp not trenched.
- No details regarding how ^{14}C and TL ages were used to constrain the timing of surface-faulting events.
- Numerous interpretive problems related to ^{14}C AMRT ages, contamination by "bomb" carbon and burrowing animals.

EAST OGDEN

Nelson and others (1987), Nelson (1988), Forman and others (1991), Machette and others (1992)

SOURCES OF UNCERTAINTY

- No information on how ^{14}C AMRT samples were collected or how the ages were calibrated.
- Displacements are presented on a per/scarp basis, and do not appear to be net-slip values. Displacements per event on the untrenched scarp are not known.
- The APE at this site was not recognized at Kaysville (McCalpin and others, 1994).

AN • JGR paper not as good

GARNER CANYON

<u>Nelson and others (1987), Machette and others (1992)</u>

- **Natural exposure?**

- **Three (possibly four) events based on colluvial-wedge stratigraphy and scarp height.**

- **Event ages/Net slip**

  MRE = 0.8-1.2 ka/~1.0 m

  PE = 1.5-2.0 ka/~1.0 m

  APE = >2.2 ka

  Ages based on a comparison with the timing of events at East Ogden and on ^{14}C AMRT ages from buried soil A horizons

- **Vertical displacement 4.4 m, scarp height 6 m**

- **Recurrence interval – none reported**

- **Slip rate – none reported**

GARNER CANYON

Nelson and others (1987), Machette and others (1992)

SOURCES OF UNCERTAINTY

- **Published information available for Garner Canyon is cursory; minimal information regarding site geology, geomorphology, and topography.**

- **No detailed information available regarding the characteristics of the WFZ at this location.**

- **Cumulative slip unknown; 4.4 m if there is a single scarp.**

- **Age constraints on surface-faulting depends to some extent on correlation with the nearby East Ogden site.**

- **No information available on how ^{14}C AMRT samples were collected or how the resulting numerical ages were calibrated.**

WEBER SECTION PROFILE DATA

Nelson and Personius, (1993)

- Slip rate summary for the WS based on 77 scarp profiles measured in the field and 298 profiles measured from aerial photographs using a photogrammetric plotter.

- The authors believe ~15% of the profiles are within 10% of the total net slip across the scarps and therefore provide reliable displacement data.

- Using age estimates for deposits based on geologic mapping, slip rates were estimated for the WS; the estimates showed a fairly constant slip rate near the center of the WS and a decrease toward both ends of the section, with the most rapid decrease toward the south.

WEBER SECTION PROFILE DATA

Nelson and Personius, (1993)

- **North-South slip-rate summary**

  North end WS; Holocene 0.5-1.2 mm/yr, post-Bonneville possibly as low as 0.7 mm/yr

  Coldwater Canyon/North Ogden; late Holocene 1.0-2.3 mm/yr, post-middle Holocene 1.1-1.8 mm/yr

  Garner Canyon; late Holocene 1.2±0.3 mm/yr, post-Provo 1.4±0.2 mm/yr

  East Ogden; post-middle Holocene 2.8±0.4 mm/yr (displacement source?)

- Alan may have student compile map of profile locations; for now, just plot general numbers listed here

  Taylor Canyon; late Holocene 1.1-2.8 mm/yr, latest Pleistocene 1.2-1.9 mm/yr

- Date Kaysville fan
- Are McCalpin + Nishenko "bogus" dates removed from records reported here? RMH
- Need to plot slip rates along strike

WEBER SECTION PROFILE DATA

Nelson and Personius, (1993)

- North-South slip-rate summary (cont.)

  Hobbs Reservoir; pre-late Holocene 2.7±0.8mm/yr, post-Bonneville high stand 2.0 mm/yr

  Kaysville/Shepards Creek; post-14 ka 1.6±0.1 mm/yr

  Near Farmington; latest Pleistocene 1.1-1.6 mm/yr

  Ricks Creek/Centerville; post-Provo 1.5±0.2 mm/yr

  Parish Creek; 1.1±0.2 mm/yr, time interval not specified

  Bountiful; post-Provo 0.7 mm/yr on main scarp

  North Canyon/section boundary; late Holocene 0.6 mm/yr.

WEBER SECTION PROFILE DATA

Nelson and Personius, (1993)

SOURCES OF UNCERTAINTY

- Estimated uncertainties due to calculating displacements across scarps ±10 to 30%.
- Possible errors in estimating ages of displaced deposits ±50 to 100%.
- All slip-rate estimates include at least one open seismic cycle.
- Source document presents summaries only, no original data.

WEBER SECTION ISSUES

- Only summary data are available for Garner Canyon and East Ogden, difficult to evaluate uncertainty.

- APE events not the same at East Ogden and Kaysville (McCalpin and Forman, 1994 chronology), the younger East Ogden APE apparently died out before reaching Kaysville thus implying a possible subsegment boundary between the sites.

- Small latest Holocene event identified at East Ogden not recognized at Kaysville or Garner Canyon.

- Earthquake timing data from Garner Canyon and East Ogden limited to post-middle Holocene.

WEBER SECTION ISSUES

- Earthquake timing at Kaysville extends to the latest Pleistocene, but evidence for the one or two oldest events is equivocal and a younger event is not dated.

- Not all scarps were trenched at East Ogden, unknown if all scarps were trenched at Garner Canyon; incomplete earthquake chronology?

- Quality/completeness of displacement data at East Ogden and Garner Canyon unknown.

- Net slip/event data at Kaysville are estimates from deposit geometry and are available for only the three most recent events.

- Swan and others (1980) and McCalpin and others (1994) Kaysville results are inconsistent.

WEBER SECTION ISSUES

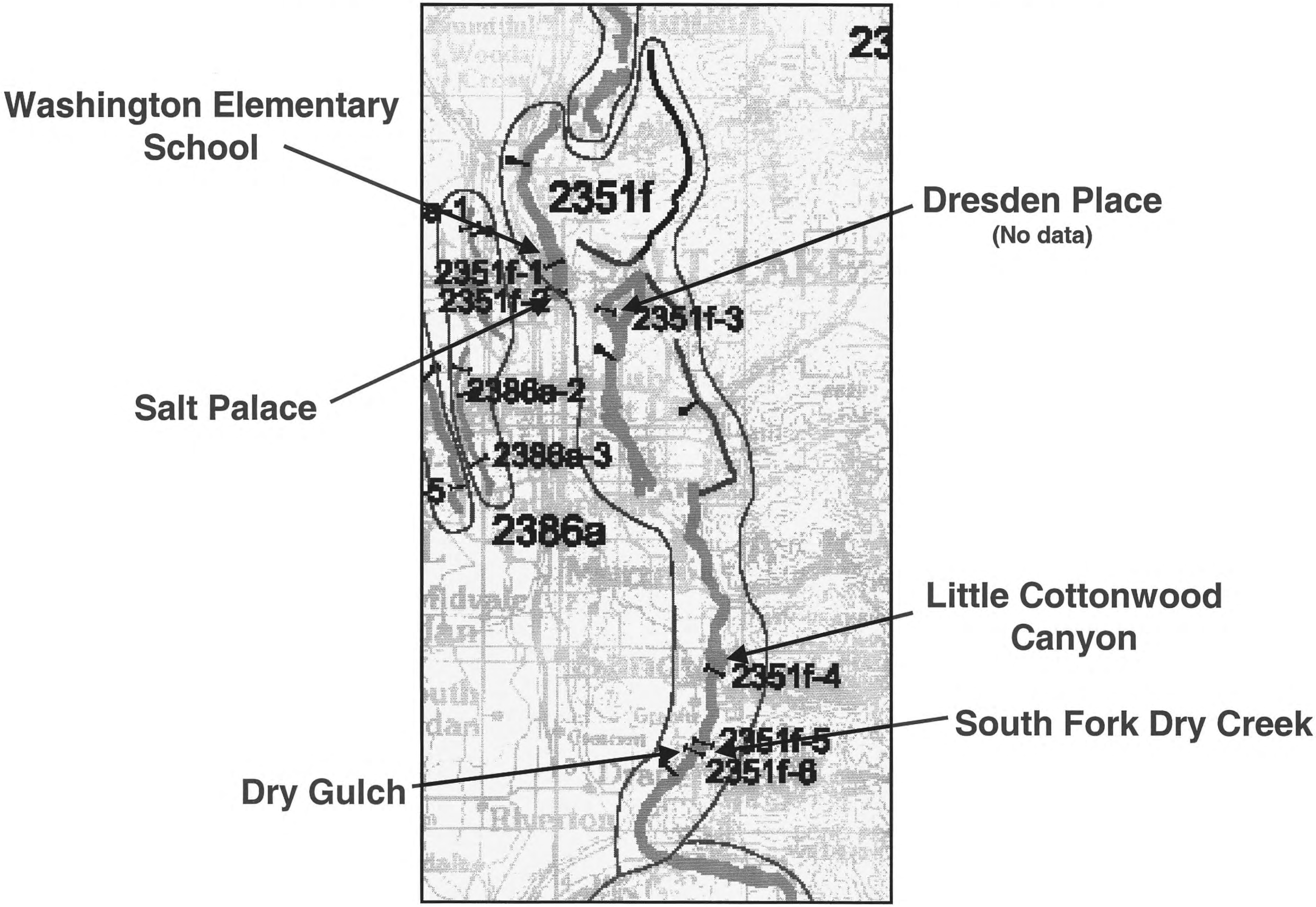
- Lake Bonneville chronology used to estimate the ages of events at Kaysville (both Swan and others [1980, 1981] & McCalpin and Forman [1994]) is now outdated.

- How do we treat the Nelson and Personius (1993) slip-rate data?

- Summary

  We don't have good published net slip information for the Weber section, the 10-11 m of post-Provo slip at Kaysville seems to be the most consistent number; our good understanding of earthquake recurrence only extends to the middle Holocene, and may be complicated by a subsection boundary near Weber Canyon.

SALT LAKE CITY SECTION



WASHINGTON ELEMENTARY SCHOOL

Robison and Burr (1991)

- **Three trenches; the site was heavily modified by school and playground construction prior to trenching.**

- **Estimated 4 to 6 surface-faulting earthquakes based on scarp height; no direct evidence of events in trenches.**

- **Event ages/Net slip**

  Total number and timing of events unknown, estimate 4 to 6 events in past 15 ka.

  Total displacement ~40 feet, unknown if this is net slip.

- **Recurrence interval**

  Highly speculative, 2.5-3.75 ka, based on 4-6 events in 15 ka.

- **Slip rate**

  Highly speculative, 0.8-1.0 mm/yr, based on 2 to 3 m of displacement every 2.5-3.75 ka

WASHINGTON ELEMENTARY SCHOOL

Robison and Burr (1991)

SOURCES OF UNCERTAINTY

- No evidence for individual surface-faulting events.
- No numerical ages.
- No slip/event information.
- Unclear if "total displacement" represents cumulative net slip.
- Recurrence interval and slip rate are based on a slip/event estimate taken from a site 25 kilometers to the south on a different subsection of the fault.

SALT PALACE

Simon and Shlemon (1999), Korbay and McCormick (1999)

- Foundation excavation for a major expansion of the Salt Palace Convention Center in downtown Salt Lake City.
- Discovery of a near-vertical shear plane and associated graben in the wall of a foundation excavation caused construction activities to stop.
- Two competing interpretations of the features in the foundation excavation developed: (1) fault and associated graben, (2) lateral spread liquefaction feature.
- Explanation #2 was finally accepted and construction was allowed to proceed.

LITTLE COTTONWOOD CANYON

Swan and others (1981), Schwartz and Coppersmith (1984), Schwartz and Lund (1988)

- The Little Cottonwood Canyon site has been the location of two trenching investigations: Swan and others (1981) and McCalpin (2002).

- By the time of the McCalpin (2002) study, it was clear from work conducted at the South Fork Dry Creek and Dry Gulch sites ~5 kilometers to the south that because Swan and others (1981) were unable to trench all of the scarps at Little Cottonwood Canyon, their surface-faulting chronology was incomplete.

- Neither the work at Little Cottonwood Canyon, or at South Fork Dry Creek has developed reliable slip/event or cumulative net-slip values for the WFZ.

LITTLE COTTONWOOD CANYON

Swan and others (1981), Schwartz and Coppersmith (1984), Schwartz and Lund (1988)

- **As part of the Swan and others (1981) study, a scarp profile was measured across the WFZ along the crest of the Bells Canyon lateral moraine a few hundred meters south of the Little Cottonwood Canyon trench site. The cumulative net displacement there was 14.5 (+10, -3) meters. The age of the moraine is variously estimated as 16±3 ka, 19±2 ka, and 19-20 ka. The results of this profile, remain the best estimate of cumulative slip for the Salt Lake City section. And the resulting slip rate 0.76 (+0.6, -0.2) mm/yr, the best long-term slip rate estimate for the SLC section.**

- Make 3D DEM of Moraines to reconstruct shape to do more profiles
- Uncertainty in profile due to reconstruction of moraine profiles

LITTLE COTTONWOOD CANYON

Swan and others (1981), Schwartz and Coppersmith (1984), Schwartz and Lund (1988)

SOURCES OF UNCERTAINTY

- **Not all scarps at the site were trenched – now know that events were missed.**
- **Cumulative displacement measured along the Bells Canyon moraine crest has high uncertainty limits.**
- **Age of the Bells Canyon moraine is not well constrained.**

LITTLE COTTONWOOD CANYON

McCalpin (2002)

- A single "megatrench" was excavated across two fault scarps together totaling 18 m high, which the author believes. captured all of the down-to-the-west displacement at the site. Trench and associated auger hole exposed 26 m of vertical section.

- The trench contained "stratigraphic" evidence for 7 paleoearthquakes younger than the Bonneville flood (~17 ka), and possibly an eighth, earlier event.

- Four most recent events have associated colluvial-wedge deposits, three older events are hypothesized based on the thinning or absence of deposits due to tectonic related erosion, and were identified on the basis of a retrodeformation analysis of the trench stratigraphy.

LITTLE COTTONWOOD CANYON

McCalpin (2002)

- **Surface-faulting chronology**

  Event Z (MRE): 1.3 ka
  Event Y (PE): 2.3 ka
  Event X (APE): 3.5 ka
  Event W: 5.3 ka
  Event V: 7.5 ka
  Event U: 9 ka
  Event T: 17 ka
  Event S (?): 17-20 ka

  The author had difficulty matching the surface-faulting chronology at this site with that worked out at South Fork Dry Creek/Dry Gulch by Black and others (1996) for some of the youngest four events. In those cases, the difficulties are explained and then he defaults to the Black and others (1996) age estimates.

- **Slip – did not trench across the entire fault zone, no information on antithetic fault displacement.**

LITTLE COTTONWOOD CANYON

McCalpin (2002)

- Recurrence
  - Four most-recent events: 1150-1500 yrs – preferred 1350±200 yrs. (after Black and others, 1996)
  - Events U/V and V/W: roughly 2000 yrs.
  - Events T/U: 7100-9600 yrs, mean value 8350 yrs.

- Slip rate – Not reported, no slip/event or cumulative slip information available.

LITTLE COTTONWOOD CANYON

McCalpin (2002)

SOURCES OF UNCERTAINTY

- Interpretations for Events V, U, and T are based on retrodeformation analysis of the trench stratigraphy and rely on negative evidence – the absence or thinning of deposits , rather than the presence of scarp-derived colluvium.

- There are some problems with the correlation of the timing of the four younger surface-faulting events between Little Cottonwood Canyon and South Fork Dry Creek.

- No net slip values available for slip rate estimates

SOUTH FORK DRY CREEK/DRY GULCH

Schwartz and Lund (1988), Lund (1992), Black and others (1996)

- Nine trenches excavated across 6 west-facing scarps over the course of two trenching campaigns (1988 and 1994). Scarps are formed on Holocene alluvial-fan deposits above the Lake Bonneville high stand.

- Four surface-faulting events/colluvial-wedge stratigraphy

- Event ages

  Event Z (MRE): 1300 (+250, -200) cal yr B.P.

  Event Y (PE): 2450±350 cal yr B.P.

  Event X (APE): 3950 (+550, -450) cal yr B.P.

  Event W: 5300 (+450, -350) cal yr B.P.

SOUTH FORK DRY CREEK/DRY GULCH

Schwartz and Lund (1988), Lund (1992), Black and others (1996)

- **Net slip – none reported, possible untrenched antithetic faults.**

only represents uncertainty in means; need a number that represents total uncertainty

- **Recurrence**

  1350±200 yrs for the past 6 ka, calculated using the three closed seismic cycles provided by the four well--dated Holocene events.

- **Slip rate**

  None reported, study did not produce slip/event or cumulative net-slip information.

SOUTH FORK DRY CREEK/DRY GULCH

<u>Schwartz and Lund (1988), Lund (1992), Black and others (1996)</u>

SOURCES OF UNCERTAINTY

- **The timing of Event X hinges on a single ^{14}C AMRT age on a paleosol buried by a scarp-derived colluvial wedge, but the age obtained and the stratigraphic evidence relating it to a surface-faulting event are both considered to be good. However, this is the event that McCalpin (2002) had trouble correlating at Little Cottonwood Canyon.**

- Where are we in the cycle? Are we in a stress shadow from MRE? (1906 SF?)

Next

- look at uncertainties in recurrance on Black + others
- Use age ranges for events
- Comment on gap in recurrance in early Holocene - Late Pleistocene
- Need to identify "slip rates" as "vertical slip rates."

List of uncertainties

- Subsegments may increase hazard
- Longer recurrance may decrease hazard

SALT LAKE CITY SECTION ISSUES

- The Salt Lake City section consists of three well defined subsections: Warm Springs, East Bench, and Cottonwood.

Paleoseismic information for the Warm Springs subsection comes from two "sites of opportunity," is incomplete, and provides little or no information suitable for determining a recurrence interval or slip rate.

There is no paleoseismic information available for the East Bench subsection.

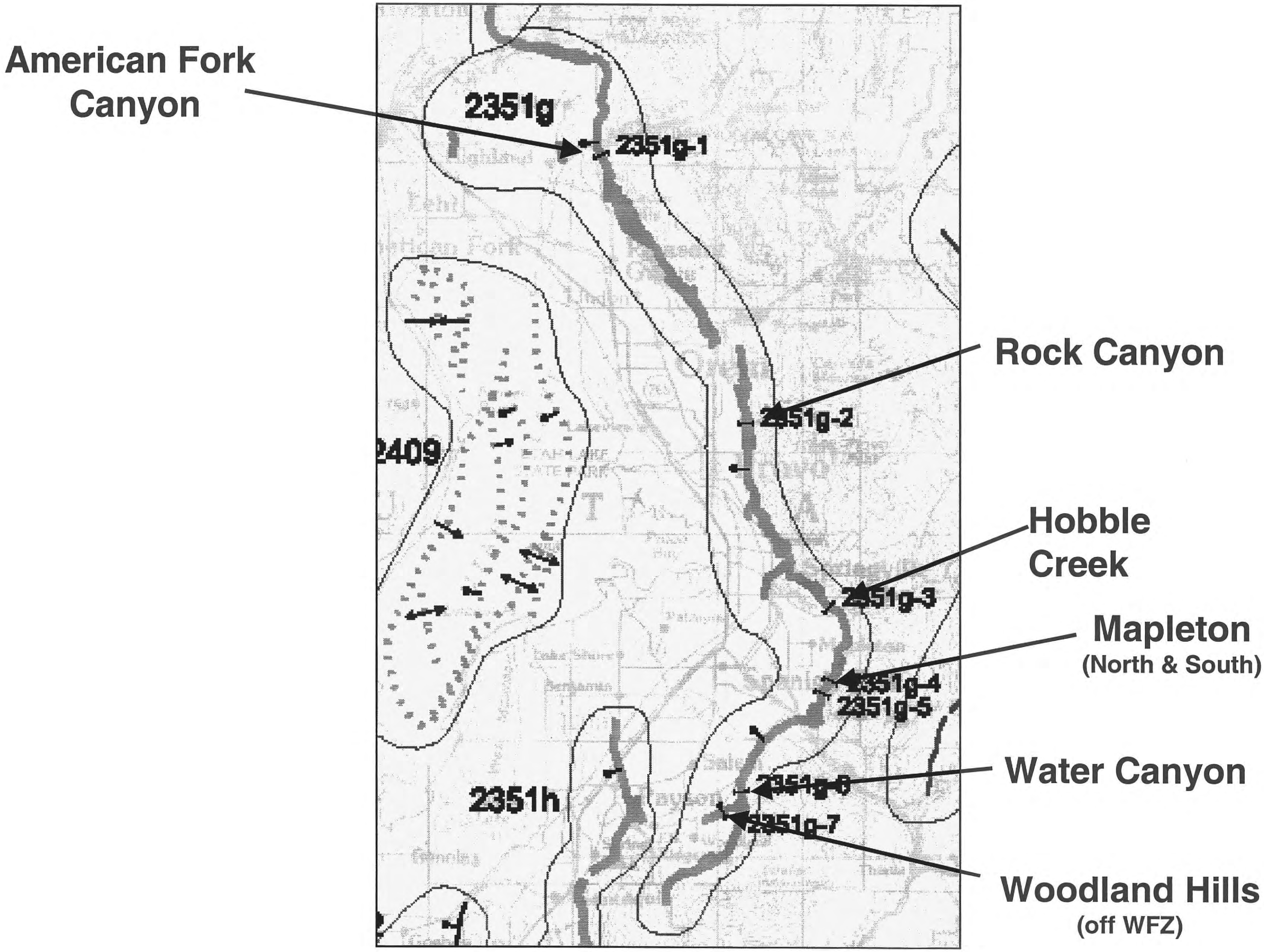
All that is presently known about the surface-faulting chronology of the Salt Lake City section comes from two sites on the Cottonwood subsection (Little Cottonwood Canyon and South Fork Dry Creek/Dry Gulch) in the extreme southeast corner of the Salt Lake Valley. Is that information relevant to the other two fault subsections?

SALT LAKE CITY SECTION ISSUES

- With the exception of the scarp profile (Swan and others, 1981) measured along the crest of the Bells Canyon lateral moraine, there are no reliable slip/event or cumulative net slip measurements available for the Salt Lake City Section.

- Events older than middle Holocene identified on the Salt Lake City section are based on a retrodeformation analysis of trench stratigraphy (McCalpin, 2002), and rely on negative evidence, the absence or thinning of deposits, rather than on the presence of scarp-derived tectonic deposits or other direct tectonic indicators.

PROVO SECTION



AMERICAN FORK CANYON

Machette (1988), Machette and others (1992)

- **Three trenches, one on the main fault, one on an antithetic fault, and the third on a small synthetic, en echelon fault; scarps formed on Holocene alluvial-fan deposits.**

- **Four surface-faulting earthquakes/evidence for the three most recent events consists of colluvial-wedge deposits, evidence for the fourth, oldest event is unclear – possibly a colluvial wedge.**

- **Event ages** Uncertainty includes geological uncertainty as well as analytical ; error from 2x lab multiplier

  charcoal dates in main trench

  MRE = 500±200 cal yr B.P.; (after Machette and others, 1992)

  PE = 2650±250 cal yr B.P.; " "

  charcoal

  APE = 5300±300 cal yr B.P. ; " "

  Event 4 = >5.4 ka, <8.1 ka; (after Machette, 1988)

AMERICAN FORK CANYON

Machette (1988), Machette and others (1992)

- **Net slip**
  - The PE and APE events combined to produce 5-6 m of net slip
  - Estimated 2.2-2.7 m/event based on colluvial-wedge geometry — maybe add 0.5 m for untrenched strand nearby
  - Net slip measured on the Bonneville shoreline = 15-26 m

- **Recurrence (after Machette and others, 1992)**

  MRE – PE = 2150±450 yrs
  PE – APE = 2650±450 yrs
  } error limits and dates included

  • Colluvial wedge thicknesses for single-event scarps may be 0.5X displacement, but later wedges vary + have no consistent relation to wedge thickness

- **Slip rate**
  - Middle Holocene (two closed seismic cycles) = 1.0-1.4 mm/yr
  - Post-Bonneville lake cycle = 1.0-1.7 mm/yr (outdated Lake Bonneville chronology)

    correct for new chronology

    – may be best post-Bonneville slip rate ?

AMERICAN FORK CANYON

Machette (1988), Machette and others (1992)

SOURCES OF UNCERTAINTY

- Reports are summaries only, no trench logs or other detailed information, difficult to evaluate uncertainty.

- Per event net slip estimated from colluvial-wedge geometry, displacement on Bonneville cycle shoreline has high associated uncertainty.

- Details lacking concerning ^{14}C date sampling and calibration.

- Pleistocene slip-rate calculation based on a now outdated Lake Bonneville chronology.

ROCK CANYON

Lund and Black (1998)

- **One trench across a 5-m-high scarp, and a natural stream-cut exposure.**

- **One surface-faulting event/colluvial-wedge stratigraphy**

- **Event age**

  =cal. calibration only

  - **Trench: 550 (+50, -50) cal yr. B.P.; minimum limiting age**
  - **Stream cut: 650 (+50, -100) cal yr. B.P.; closely limiting minimum age**

- **Net slip**

  slip rate = 3.3 m / 2150

  MRE = 3.3 m, measured directly from displaced stratigraphy

- **Recurrence interval & slip rate – None reported, only one event**

ROCK CANYON

Lund and Black (1998)

SOURCES OF UNCERTAINTY

- All ^{14}C ages were AMRT dates on buried soil organics.

- Key ^{14}C AMRT age on soil 11s in the trench came from beneath graben-fill deposits not the MRE colluvial wedge, and therefore represents a minimum limiting age. The event could be tens to a few hundred years older.

- Samples from buried soils in the trench for ^{14}C dating were all channel samples across the full width of the soil horizon

- Unable to resample the 6s soil at the west fault zone in the stream cut exposure to refine the time of faulting at that location.

HOBBLE CREEK

Swan and others (1980), Machette and others (1992)

- **Three trenches excavated across the main fault and an associated graben formed on a Holocene alluvial fan. Three paired strath terraces and one unpaired terrace have formed along Hobble Creek on the fault footwall.**

- **Six or possibly seven surface-faulting earthquakes in post-Provo time. Evidence for the three most recent events consists of scarp-derived, colluvial-wedge deposits in the trenches, the strath terraces are interpreted as evidence for at least three and possibly four older events.**

- **There were no numerical age dates available for this study so all event ages are estimates. The three most recent events are estimated as <6 ka. The three to four older events are estimated as >6 ka and < 12 ka, based on the stratigraphic position of the terraces and the Lake Bonneville chronology current at that time.**

HOBBLE CREEK

Swan and others (1980), Machette and others (1992)

- **Net Slip – from scarp profiles**
  - Provo fan-delta surface = 11.5-13.5 meters ← single most important info from site
  - Post-Provo/pre-Utah Lake terrace = 7-8.5 meters
  - Cumulative displacement of Bonneville cycle deposits estimated at 30±5 meters (later revised by Machette and others [1992] to 40-45 m).

- future work – Date mid-Holocene fan deposits

- **Recurrence**

  Estimate 6 to 7 events in ~12-13 ka, therefore estimate recurrence as 1500-2600 yrs.

- **Slip rate**
  - post-Provo: 1.0±0.1 mm/yr
  - post Bonneville 3.9 (+7.9, -1.4) mm/yr (revised by Machette and others, 1992 to 1.8-2.5 mm/yr). Note large difference in slip rate values in deposits only a few thousand years different in age – and also the sense of change, i.e. older faster.

- datum may ~~not~~ be same on either side of faults (uplifted shoreline during lake?)

- DPS doesn't believe this slip rate is very good

HOBBLE CREEK

Swan and others (1980), Machette and others (1992)

SOURCES OF UNCERTAINTY

- No numerical age estimates available for this site.
- Evidence for three to four older events is geomorphic, no stratigraphic record in trenches.
- Ages of individual surface-faulting events not determined.
- Net slip/event not known and cumulative slip values, especially for Bonneville-cycle deposits, have high uncertainties associated with them.
- Both recurrence and slip-rate estimates rely on an estimated number of events and an outdated Lake Bonneville chronology.

MAPLETON

Lund and others (1991)

- **Three trenches, two at Mapleton North and one at Mapleton South**

- **Two surface-faulting events/colluvial-wedge stratigraphy**

- **Event ages**

  - Mapleton North MRE = 600±80 cal yr B.P. (best estimate); alternative age = 560±130 cal yr B.P. (second trench).

  - Mapleton South PE = shortly before 2820 (+150, -130) cal yr B.P.

- **Net slip**

  - Mapleton North MRE = 1.4-3.0 meters, estimated from colluvial-wedge thickness.

  - Unable to estimate cumulative slip from scarp profiles due to problems projecting surfaces on either side of the fault.

MAPLETON

Lund and others (1991)

- **Recurrence interval**

  ME - PE = 2200 to 2700 yrs

- **Slip rate**

  Considering uncertainties associated with both the length of the recurrence interval and event net slip, the slip rate for the PE – MRE closed seismic cycle ranges from 0.52-1.36 mm/yr.

  Using mean values for recurrence (2450 yr) and slip (2.2 m) results in a slip rate for a single seismic cycle of 0.9 mm/yr.

MAPLETON

Lund and others (1991)

SOURCES OF UNCERTAINTY

- Key ^{14}C AMRT and TL ages on a buried soil in the MS trench came from beneath graben-fill deposits not the PE colluvial wedge, and therefore represents a minimum limiting age for the event. The PE could be tens to a few hundred years older.

- Neither cumulative slip or slip/event could be directly measured. MRE slip estimated from colluvial-wedge thickness.

- The ^{14}C AMRT age on the buried paleosol in the Mapleton South trench was from a channel sample taken across the full width of the buried soil.

WATER CANYON

Ostenaa (1990)

- **Two trenches in alluvial-fan deposits.**

- **Three (+) Holocene surface-faulting events.**

- **Event ages**

  MRE = 0.54-0.28 or 0.23-0.15 ka } charcoal dates

  PE = 0.94-0.70 ka

  ~3.5-5.5 ka

  One or two events >4.0-3.5 ka, but considerably <5.5-5.0 ka

  Additional faulting <9425±105 ^{14}C yr B.P.

- **Net slip**

  Two most recent events produced 1- to 2-m-thick colluvial-wedge deposits.

WATER CANYON

Ostenaa (1990)

- Recurrence – highly variable
  - 300-500 years for the MRE/PE
  - Preceding events >2600 yrs to <4500 yrs

- Slip rate – none reported

WATER CANYON

Ostenaa (1990)

<u>SOURCES OF UNCERTAINTY</u>

- **Abstract only, no trench logs, difficult to evaluate uncertainty.**
- **The number and timing of events prior to the PE are poorly constrained.**
- **No net-slip data reported.**
- **The timing of surface-faulting events at this site does not correlate well with the timing of events at sites farther north on the Provo section.**

PROVO SECTION ISSUES

- **Reasonably good correlation between the timing of events at American Fork (3+), Rock Canyon (1), and Mapleton (2) – but not perfect.**

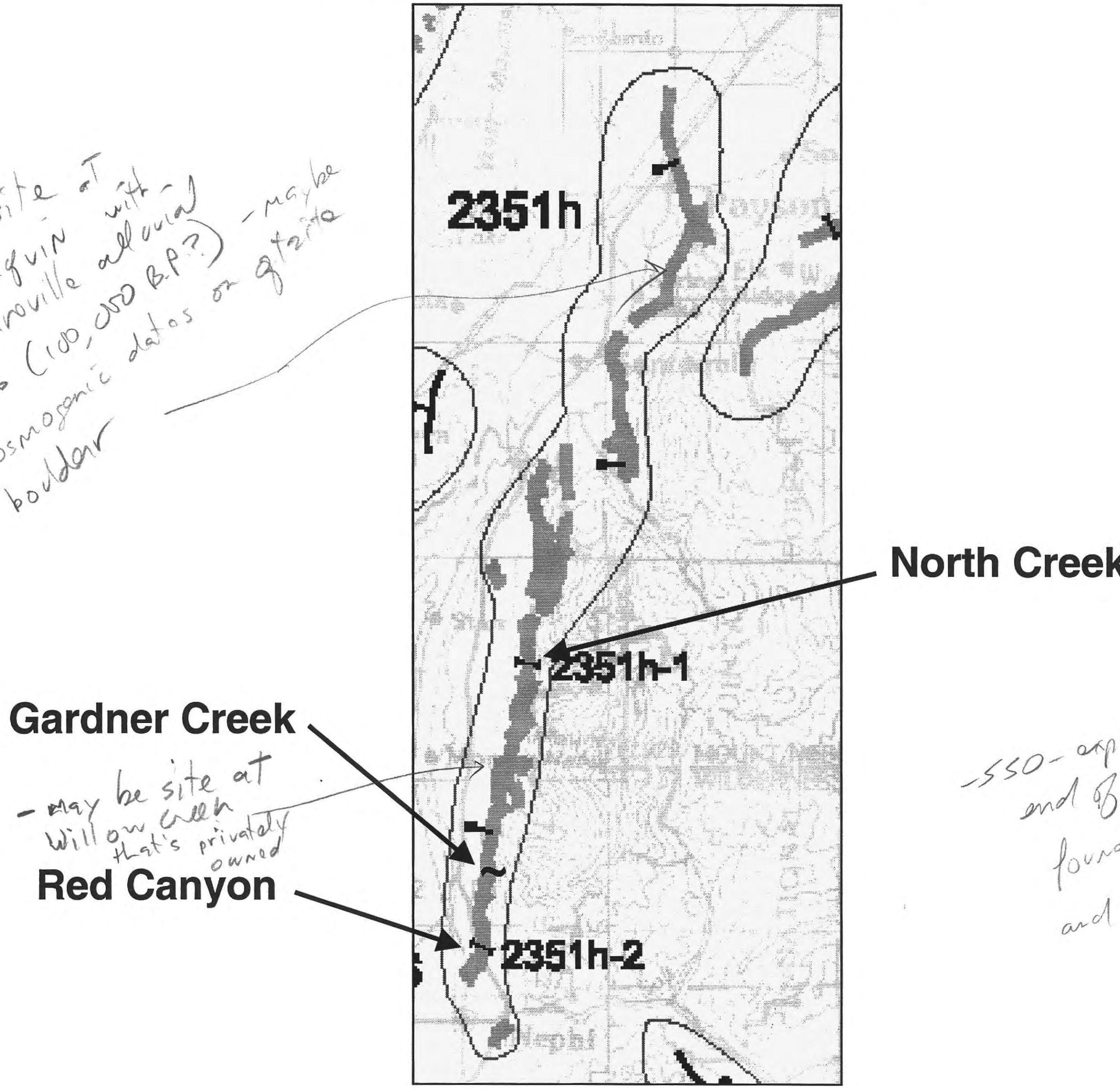
- **Water Canyon has two late Holocene events, unlike sites farther north and the PE identified to the north is apparently missing at Water Canyon. The APE may correlate, but the timing of that event is poorly constrained at Water Canyon.**

- **Slip/event and net slip values are poorly constrained all along the section except for the MRE at Rock Canyon.**

- **The number and timing of events older than the middle Holocene are poorly constrained and not well supported with evidence from trenches.**

◦ In hazard analysis, should include a possibility of smaller ruptures/earthquakes on part of segment

NEPHI SECTION



- Trench site at Santaquin with pre-Bonneville alluvial fans (100,000 B.P.?) - maybe cosmogenic dates on qtzite boulder

MM - may be site at Willow Creek that's privately owned

-550- exposure at Northern end of Nephi segment found by DuRoss, UGS and displaced debris flow

NORTH CREEK

Hanson and others (1981), Machette and others (1992)

- **Three trenches excavated across the main fault scarp.**

- **Three surface-faulting events, colluvial-wedge deposits provide evidence for the two most recent events, a third, older event is indicated by an unpaired terrace along North Creek in the fault footwall.**

- 2 events in trench, one in terrace; 3 events post 5.3 my (charcoal date just below surface)

- **Event ages (calendar calibrated by Machette and others, 1992)**

    - MRE: < 975 or 1028 cal yr B.P.; Hanson and others (1981) feel this event may be as young as 300-500 years.

    - PE: prior to 4.2±0.2 ka; however, this is an AMRT date on a paleosol for which no MRE has been applied (date is too old).

    - APE: >4.2±0.2 ka, <5.3 ka (~age of alluvial fan)

- Dave Schwartz will look at log and determine why the ~~those~~ older dates

NORTH CREEK

Hanson and others (1981), Machette and others (1992)

- **Net slip**

  - MRE: 2.0-2.2 m, estimated based on fault geometry, wedge thickness, antithetic faulting, and scarp profiles.

  - PE/APE: less well constrained; APE = ~2.6 m based on height of terrace riser adjacent to fault; PE = 2.0-2.5 m, remainder between MRE + APE total, and cumulative net slip of 7.0±0.5 m measured by scarp profile.

- **Recurrence – appears non-uniform**

  MRE/PE: >2900 yrs, possibly as long as 4000 yrs

  PE/APE: ≤1600 yrs

- **Slip rate**

  1.3±0.1 mm/yr based on a cumulative slip of 7.0+0.5 m in the past 4580 ^{14}C yr B.P. This slip rate estimate extends to the present and is open across at least one seismic cycle. The time interval selected dates the fan and is a broad maximum for the time of faulting (calendar calibrates to 5.3 ka).

NORTH CREEK

Hanson and others (1981), Machette and others (1992)

<u>SOURCES OF UNCERTAINTY</u>

- Surface-faulting ages are loosely constrained.

- Conflicting sets of ^{14}C ages allows alternate interpretation of surface-faulting chronology.

- This study was conducted early on in the history of normal fault paleoseismic studies. Some questions regarding how the available ^{14}C ages were interpreted.

- Evidence for the APE is geomorphic and consists of an unpaired strath terrace in the fault footwall.

NORTH CREEK

Hanson and others (1981), Machette and others (1992)

SOURCES OF UNCERTAINTY

- No information available on how the buried soils were sampled for dating, assume channel samples, and no mean residence correction was applied to the AMRT ages.
- Except for the MRE, slip/event values are poorly constrained.
- The published slip rate extends to the present and is open over at least once seismic cycle, the time interval selected provides only a broadly limiting maximum age on the time of faulting and is not calendar calibrated.

RED CANYON

Jackson (1991)

- **One trench excavated across a scarp formed on a Holocene alluvial fan.**

- **Three surface-faulting events/stacked colluvial-wedge deposits.**

- **Event ages – as reported**

  MRE: 1.0 to 1.2 ka
  PE: 3.0-3.5 ka
  APE: after 4.0-4.5 ka

- **Net slip**

  MRE: 1.4±0.3 m; based on colluvial-wedge thickness
  PE: 1.5±0.2 m; " "
  APE: 1.7±0.3 m; " "
  Cumulative slip from displaced stratigraphy = 5.4±0.3 m

RED CANYON

Jackson (1991)

- Recurrence

  MRE/PE: minimum 1500 years, maximum 3350 years

  PE/APE: minimum 1700 years, maximum 2200 years

- Slip rate – none reported

RED CANYON

Jackson (1991)

SOURCES OF UNCERTAINTY

- **Conflicting sets of TL and ^{14}C ages forced the author to choose preferred ages to date events – in all cases the dates that would cause the results to most closely conform to the event ages at North Creek were selected. Had the other sets of dates been chosen, a significantly different surface-faulting chronology would have resulted for the Nephi segment.**

- DPS - may not be 3 events in this trench

- **The author confused the concept of "maximum" and "minimum" limiting ages with regard to buried paleosols, as a result, the MRE and PE age estimates are too young by a matter of a few hundreds of years.**

REVISED AGE ESTIMATES

MRE: shortly before 1.4 ka

PE: shortly before 3.9 (+0.5, -0.4) ka

APE: > 3.9 (+0.5, -0.4) ka, likely <5.3 ka

RED CANYON

Jackson (1991)

SOURCES OF UNCERTAINTY

- Cumulative net slip measurement is based on displaced stratigraphy in the trench, but the unit used for the measurement dips 3° in the footwall and 7° in the hanging wall, indicating the effects of near fault warping in the downthrown block.

- No information on how the buried soils were sampled for dating.

GARDNER CREEK

Machette and others (1992)

At Gardner Creek, 150 to 250 ka alluvial-fan deposits that have well-developed calcic soils are displaced about 30 meters across the WFZ. Based on those relations, the WFZ has had a slip rate of 0.12 to 0.20 mm/yr during the past 150 to 250 ka. At the same site, middle-Holocene sediments are displaced 3.9 meters, indicating an average slip rate of 0.8 to 1.0 mm/yr for the past 4 to 5 ka. The authors state that these average slip rates, which reflect an approximate fivefold increase in slip rate during the latest Quaternary, are typical for the central parts of the WFZ, and that similar large temporal changes in slip have been observed at sites on the Provo, Salt Lake City, and Brigham City sections of the fault.

MM - No dates

- Phil Armstrong - denudation rates; long-term; zircon, etc.

NEPHI SECTION ISSUES

- Trench sites are not evenly distributed on the Nephi section, in particular the northern subsection of the fault (Benjamin fault), which is physically separate from the southern subsection, has no available paleoseismic data. Relation to Water Canyon dates?

- Both trench sites on the Nephi section experienced problems with conflicting sets of ^{14}C and/or TL ages obtained for the same materials. In both studies the authors were forced to choose a preferred set of ages, and in both instances if the alternative set of dates had been selected, the resulting surface-faulting chronology would have been significantly different.

- 2-3 events in 5.3 k; good scarp height of 7 m at North Creek.

- In the case of the Red Canyon site, the selection of "preferred dates" caused the Red Canyon results conform to the results obtained at North Creek a decade earlier.

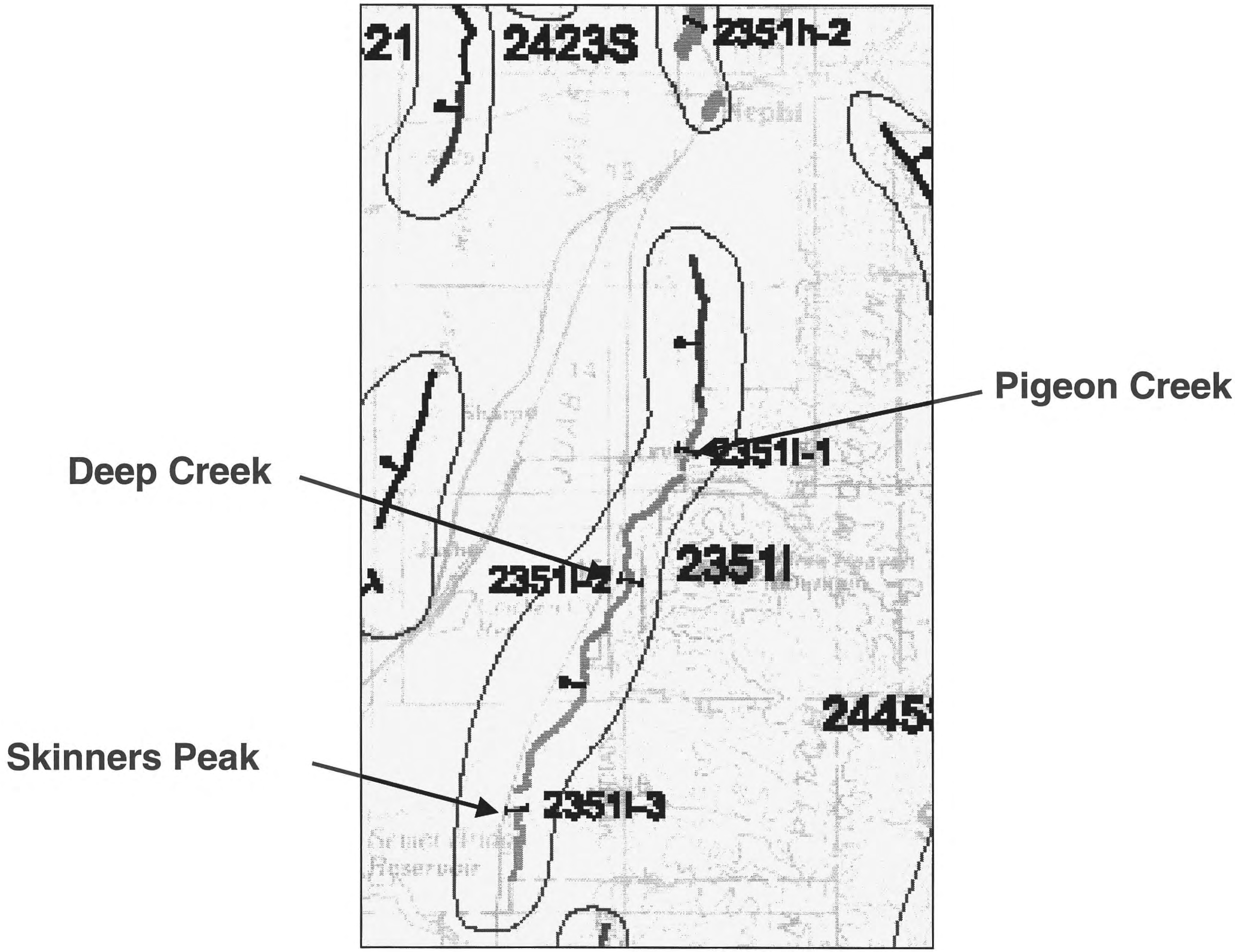
NEPHI SECTION ISSUES

- At North Creek, decisions were made regarding the significance of ^{14}C dates that likely resulted in an under estimation of the age of the MRE.

- At Red Canyon, the author was confused regarding "maximum" and "minimum" limiting ages as they apply to colluvial-wedge buried paleosols. As a result, the ages reported for the MRE and PE are systematically too young.

- Presently, considerable uncertainty exists regarding the timing of surface-faulting earthquakes on the Nephi section.

LEVAN SECTION



DEEP CREEK

Schwartz and Coppersmith (1984), Jackson (1991)

- The investigation at Deep Creek reported in Schwartz and Coppersmith (1984) was of a reconnaissance nature and consisted of dating charcoal from an alluvial-fan deposit (7300±1000 ^{14}C yr B.P.) displaced by a 2.5-m-high scarp. They believe the scarp represents a single surface-faulting earthquake and therefore the MRE post-dates the ^{14}C age.

- Jackson (1991) performed a more detailed investigation at North Creek and recognized a scarp-derived colluvial wedge and buried paleosol in a natural stream-cut exposure.
  - Number of events; one/colluvial-wedge deposit
  - Event age; >1000±100 yr B.P. , < 7300±1000 ^{14}C yr B.P.
  - Net slip; reported as 1.8 m, but I was unable to reproduce this measurement from the log of the stream cut.
  - Recurrence; none, single event
  - Slip rate; none, single event.

DEEP CREEK

Schwartz and Coppersmith (1984), Jackson (1991)

SOURCES OF UNCERTAINTY

- TL age estimate on buried soil not confirmed with a ^{14}C date.
- Unable to duplicate net slip/event measurement.

PIGEON CREEK

Schwartz and Coppersmith (1984), Jackson (1991)

- **The investigation at Pigeon Creek reported in Schwartz and Coppersmith (1984) was also of a reconnaissance nature and consisted of dating charcoal from an alluvial-fan deposit (1750±350 ^{14}C yr B.P.) displaced by the "same scarp" as at Deep Creek 2 km to the south. The authors believe the scarp represents a single surface-faulting earthquake and therefore the MRE post-dates the ^{14}C age, thus better constraining the time of the MRE on the Levan section.**

- **Jackson (1991) calendar calibrated the Schwartz and Coppersmith (1984) Pigeon Creek date (1600 [+500, -300] cal yr B.P.) and used that age along with his TL date from Deep Creek to constrain the timing of the MRE on the Levan segment to a approximate 600 year window between 1000±100 yr B.P, and 1600 [+500, -300] cal yr B.P.**

PIGEON CREEK

Schwartz and Coppersmith (1984), Jackson (1991)

SOURCES OF UNCERTAINTY

- No details are available regarding the source or characteristics of the charcoal dated at Pigeon Creek.
- Arriving at an age for the the MRE requires using ^{14}C and TL ages from two different sites and assuming that the history of surface faulting is the same at both locations.
- No trenches were excavated at either the Pigeon Creek or Deep Creek sites, so the interpretation of a single event since at least the middle Holocene relies on a single stream cut exposure at Deep Creek.

SKINNERS PEAK

Jackson (1991)

- **Single trench excavated across a 3.3-m-high scarp on a Holocene alluvial fan.**

- **Number of events is uncertain, the trench exposed a single scarp-derived colluvial wedge, but the author feels that a single event cannot account for a 3.3-m-high scarp and the thickness of alluvial deposits on the downthrown block, and therefore postulates a second event, the evidence for which was likely removed by erosion.**

- Event ages

  TL and ^{14}C ages from an in situ burn layer in alluvial fan sediments of 2000±300 yr B.P. and 1700±200 cal yr B.P. place a maximum constraint on the time of faulting. How much younger the faulting may be is not known, but the author believes 300-800 yrs and estimates the age of the MRE as 1.0-1.5 ka.

SKINNERS PEAK

Jackson (1991)

- Event ages (cont.)

  TL and ^{14}C ages from a buried soil A horizon formed on a debris-flow deposit a meter below the MRE colluvial wedge of 3100±300 yr B.P. and 3900±300 cal yr B.P. place broad minimum age constraints on the timing of a possible PE earthquake.

- Net slip – problematic, but estimated as 2.0-2.8 m for the MRE.

- Recurrence – none reported, only a single verifiable event.

- Slip rate - none reported, only a single verifiable event.

SKINNERS PEAK

Jackson (1991)

SOURCES OF UNCERTAINTY

- Age of MRE is <2000±300 yr B.P. (TL age) and/or 1700+200 cal yr B.P. (^{14}C AMRT age). Reported age of 1.0-1.5 ka based on an estimate of the time for additional sediments to accumulate and a soil to form – appears to rely heavily on the results from the Deep Creek and Pigeon Creek sites.

- Ages constraining the timing of the MRE are from non-tectonic deposits in the fault footwall.

- Age of PE is >3100±300 yr B.P. (TL) and/or 3900±300 cal yr B.P., but how much older is unknown; possibly > 7300±1000 ^{14}C yr B.P., if the date from Deep Creek applies to Skinners Peak as well.

LEVAN SECTION ISSUES

- **It is only possible to verify a single surface-faulting earthquake on the Levan section since middle Holocene time (assuming the scarps observed there are all single-event features).**

- **No evidence has been discovered for an event older than the middle-Holocene and information from Deep Creek and Skinners Peak suggest that there may not have been an older event since the late Pleistocene.**

- **The Levan section, along with the Nephi section, ranks as the least studied and least well understood of the six central sections of the WFZ.**

- what are oldest surfaces that have small scarps?
- Previous event may be early Holocene - Lt Pleistocene