Geology & Geophysics — The University of Utah

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A Logic Tree for the Subsurface Geometry of the Salt Lake City Segment of the Wasatch Fault in Light of the 2020 Magna, Utah, Earthquake

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USGS science for a changing world — Utah DNR Geological Survey

I. The 2020 Magna Earthquake

- The 2020 M_w 5.7 Magna earthquake was the largest, and most damaging, earthquake to occur in Utah since the 1992 M_w 5.5 St. George earthquake.
- Long-period regional waveform modeling, in combination with the aftershock distribution, indicates that the Magna mainshock occurred 10.5 ± 2 km below the northwestern Salt Lake Valley on an oblique-normal fault dipping 34°-39° W (Fig. 1; Table 1).
- The nearest major W-dipping active fault is the Salt Lake City segment of the Wasatch fault (SLCS), which dips 70° WSW along the nearest surface trace 15 km ENE of the epicenter (Figs. 1 and 2).

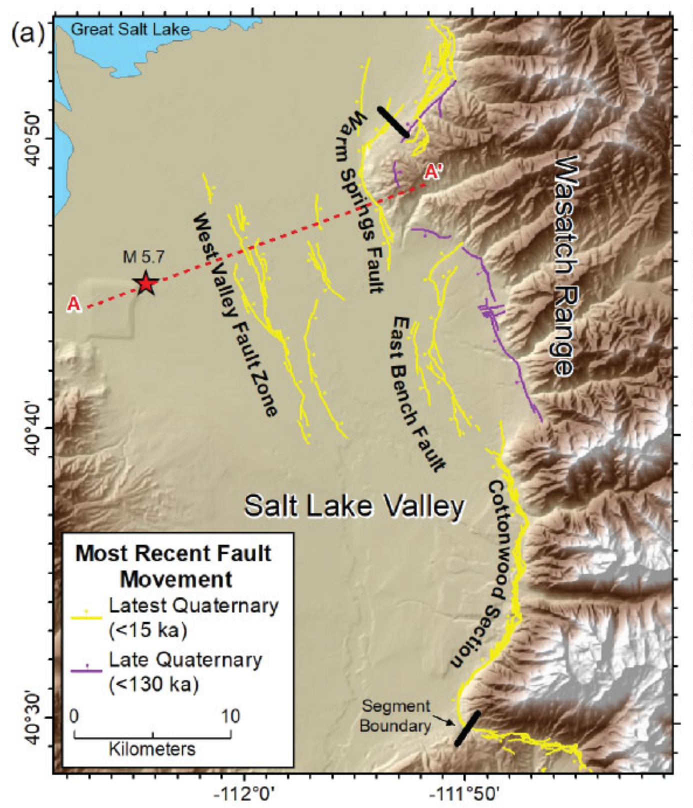

Figure 1. Map showing late Quaternary fault traces from the Utah Geological Survey, the epicenter of the M_w 5.7 Magna earthquake (red star), and the line of the cross sections in the other figures (A-A'). The bars and balls are on the downthrown sides of the faults. The SLCS consists of three left-stepping, en-echelon sections: the Warm Springs fault, the East Bench fault, and the Cottonwood section.

Table 1. Moment Tensor Solutions: 2020 Magna Earthquake

Source	Method	Centroid Depth Below Surface (km)	W-Dipping Plane		
			Strike (deg)	Dip (deg)	Rake (deg)
UUSS	TDMT	9	182	34	–52
SLU	Waveform Inversion	12	180	35	–60
USGS	Regional	9	178	38	–63
Global CMT	CMT	12	170	39	–72
Liang et al. (2022)	ISOLA	10	173	34	–65

Figure 2. Exposure of the Warm Springs fault of the SLCS in a sand and gravel quarry at 1206 Beck St. in Salt Lake City. The fault is the steeply-dipping bedrock surface in this photo, which consists of brecciated limestone of the Upper Mississippian Humbug Formation. Pavlis and Smith (1979) and Bruhn et al. (1992) report near-surface dip measurements on this fault of ~70° W.

II. Prior SLCS Models

- Before 2020, most seismic hazard studies assumed that the Wasatch fault, including the SLCS, was a moderately-dipping planar fault with a dip of 50° ± 15°.
- Several published studies have interpreted the Magna mainshock rupture to be on the SLCS (e.g., Pang et al., 2020; Kleber et al., 2021).
- This interpretation implies a listric geometry for the fault, i.e., a dip that decreases downward (Fig. 3).

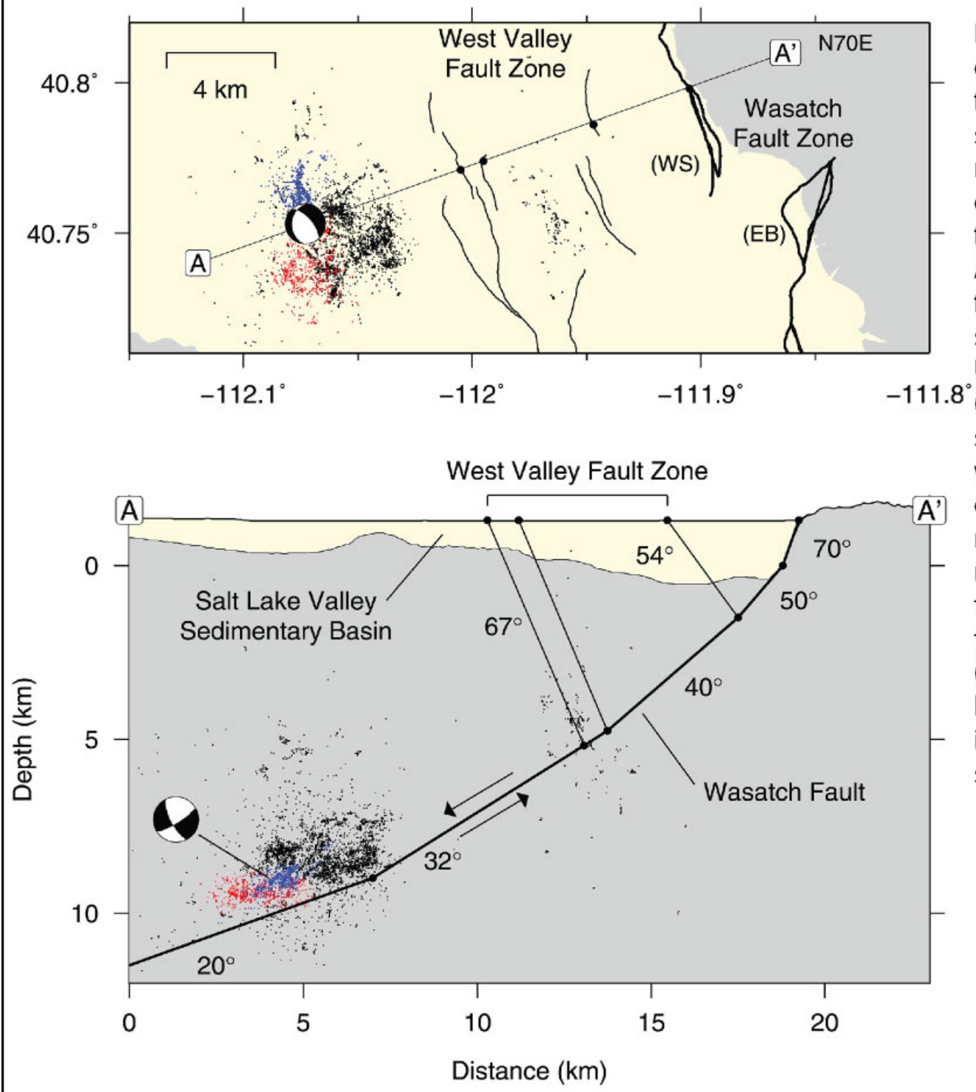

Figure 3. Map (top) and cross section (bottom) from Pang et al. (2020) showing double-difference relocations for aftershocks of the Magna earthquake from March 18 through April 30, 2020 (dots). The focal mechanism plots show the University of Utah Seismograph Stations (UUSS) moment tensor solution for the mainshock, with shaded quadrants compressional. The mainshock depth is the mean centroid depth of the first four moment tensor solutions in Table 1 (10.5 km). The solid black lines show Pang et al.'s interpretation of the subsurface fault geometry.

III. A Simpler SLCS Model

- Fig. 4 shows that the seismic data for the Magna sequence can be fit quite well by a shallowly-dipping, nearly planar model for the SLCS which is listric only in the uppermost 1-2 km.
- The main problem with the model in Fig. 4 is that the active, E-dipping West Valley fault zone (WVFZ) cannot slip without offsetting the Wasatch fault.

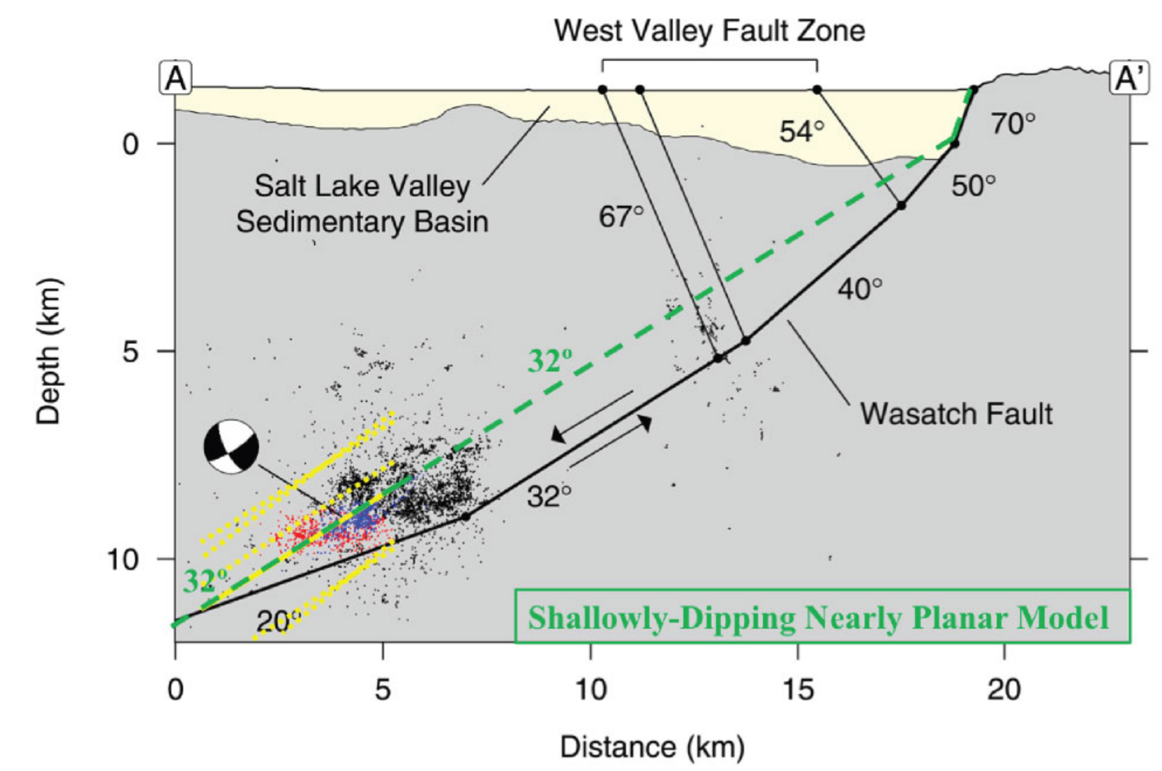

Figure 4. The Pang et al. (2020) cross section from Fig. 3, with a simple shallowly-dipping, nearly planar model for the northern SLCS superimposed as dashed green lines. The dotted yellow lines are projections of the W-dipping nodal planes from the five mainshock moment tensor solutions in Table 1. Each projection passes through the centroid depth at the mainshock epicenter and extends ~1.5 km updip and ~4 km downdip from there, consistent with source studies. The solid yellow line is the projection of the W-dipping nodal plane of the UUSS solution, shifted to 10.5 km depth at the epicenter (9 km below datum).

IV. The WVFZ Constraint

- The existence of the E-dipping WVFZ, located 3-10 km W of the northern half of the SLCS, provides independent evidence of a listric geometry for this part of the SLCS (Fig. 1).
- A decrease in dip on the SLCS below where it intersects the WVFZ would permit both of these faults to slip without offsetting each other, forming a large-scale backtilt graben system (Fig. 5).
- The estimated ratio between the vertical slip rates on the WVFZ and the SLCS is 0.09-0.42, which provides a weak model-dependent constraint on the dip change of the SLCS (Fig. 5).

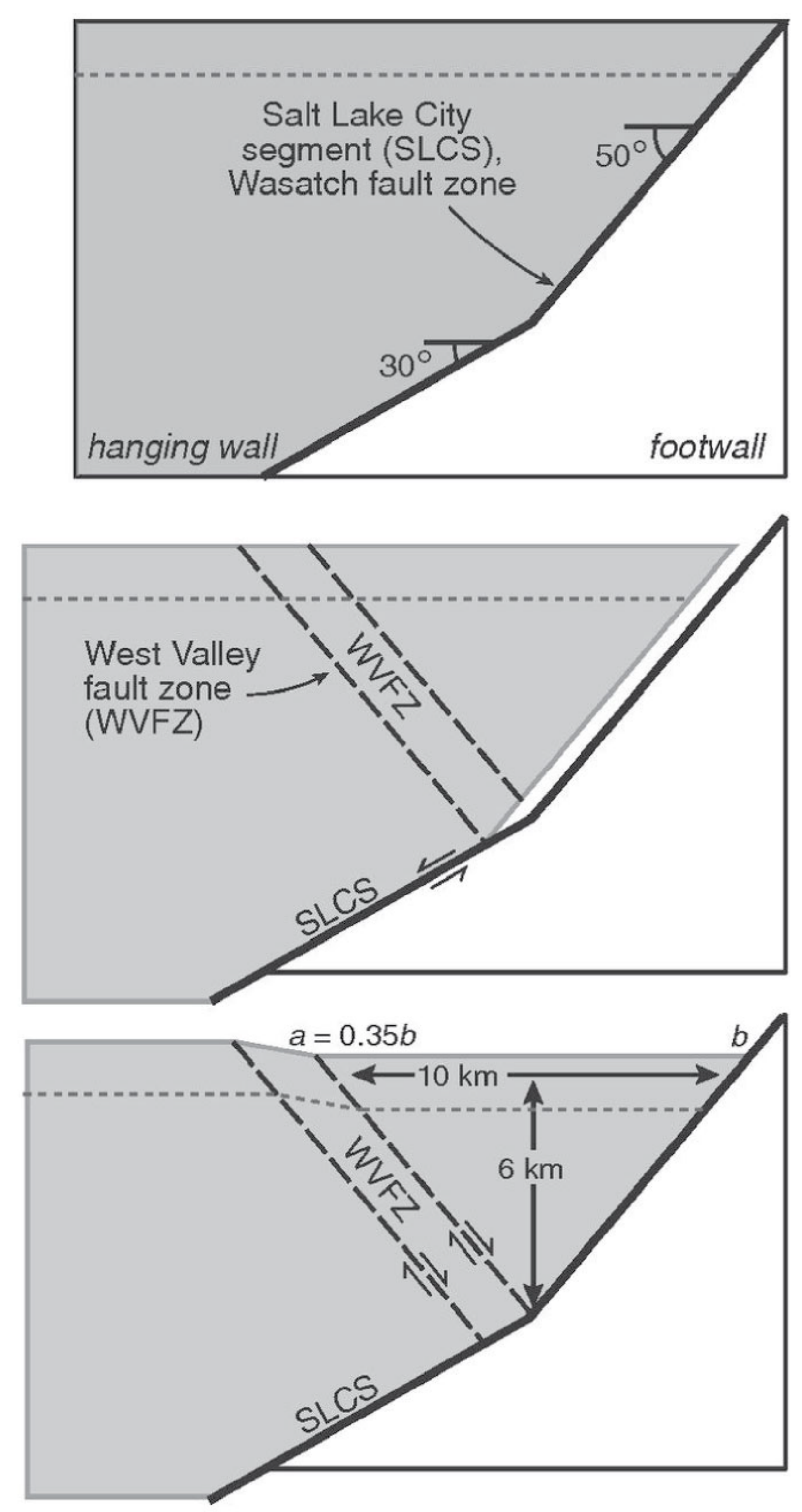

Figure 5. Block diagrams illustrating the backtilt graben model for the WVFZ (from DuRoss and Hylland, 2015; after Xiao and Suppe, 1992). The text box below summarizes the paleoseismic constraints on the ratio between the vertical slip rates on the WVFZ and the SLCS.

Paleoseismic Constraints on the WVFZ-SLCS Vertical Slip Rate Ratio
(DuRoss and Hylland, 2015)

(1) "Mean WVFZ per-event vertical displacement (~0.5 m) is 26% – 42% of that for the SLCS (~1.2 – 1.9 m)."
(2) "WVFZ earthquakes occur with every one to three SLCS earthquakes."

(1), (2) ===>

$$\frac{\textit{WVFZ vertical slip rate}}{\textit{SLCS vertical slip rate}} = 0.09 \text{ to } 0.42$$

V. Logic Tree of SLCS Models

- Alternative models for the subsurface geometry of the SLCS are needed to quantify the uncertainties in this geometry for probabilistic seismic hazard analyses.
- Our logic tree for modeling the geometry of the SLCS has four primary branches, each combining different models for (A) the northern half of the SLCS (the Warm Springs and East Bench faults), where the WVFZ is present, and (B) the southern half (the Cottonwood section) (see Fig. 1).
- In all four branches the southern half of the SLCS has a planar geometry with an asymmetrically weighted dip distribution of 35°(0.3)–50°(0.5)–65°(0.2), as illustrated in Figure 6a.
- For the northern half of the SLCS, each branch of the logic tree has one of the four models shown in Figures 6a to 6d.
- The Magna earthquake is on or near the SLCS in the 35°-dipping branch of Model 1 and in Models 2 and 3, which have a combined weight of 0.66; in Model 4 and in the other branches of Model 1, this earthquake is on a subsidiary fault in the SLCS hanging wall (Fig. 6).
- The models in our new logic tree are consistent with the data from the Magna earthquake and the WVFZ, and incorporate a plausible range of uncertainties in the subsurface geometry of the SLCS.
- Using this logic tree for probabilistic seismic hazard analyses, instead of the previously-favored planar models with dips of 50° ± 15°, will increase the predicted ground shaking hazard in the NW Salt Lake Valley because of the shorter average distances to the SLCS (Wong et al., 2023).

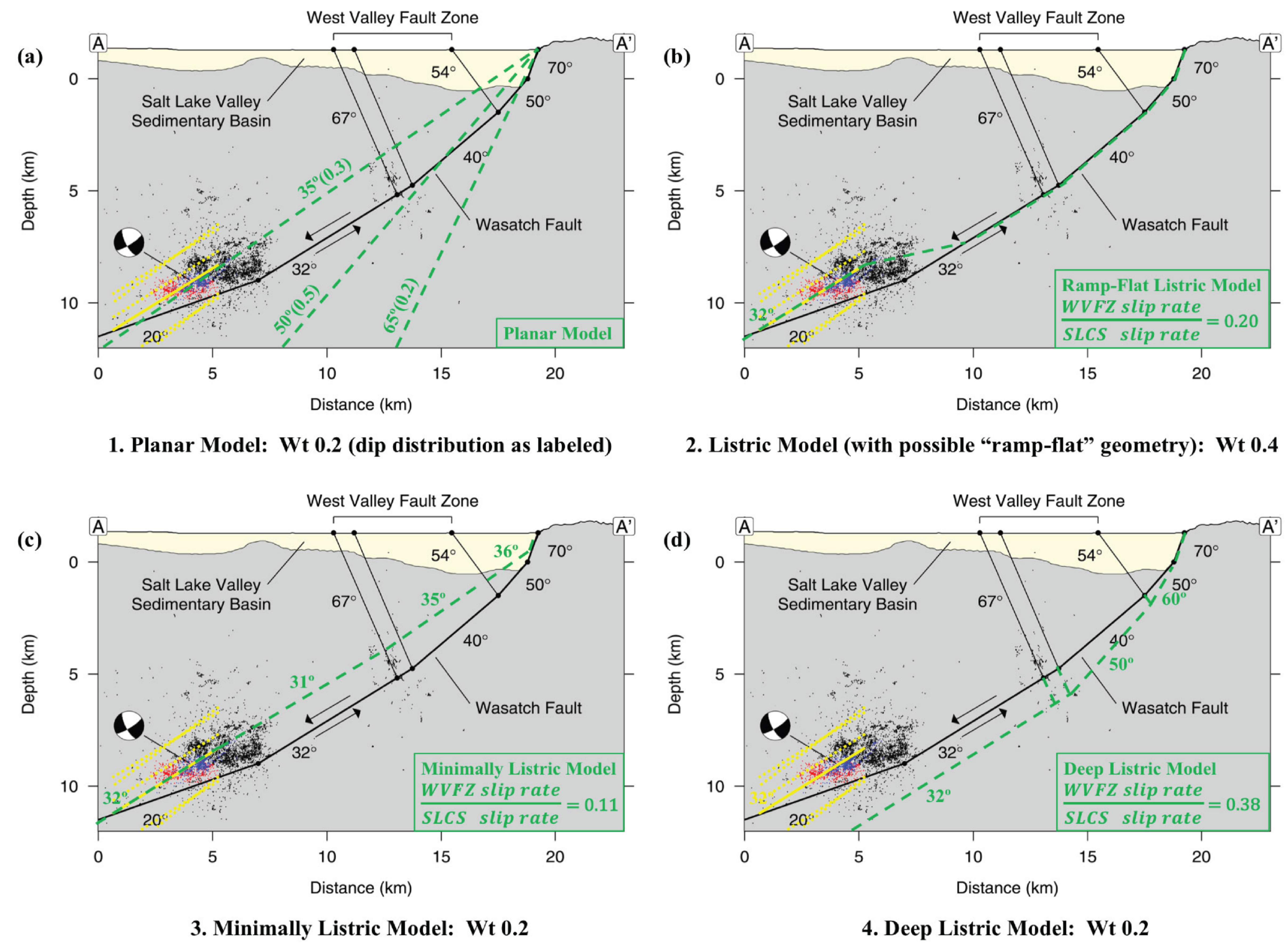

Figure 6 (a-d). Alternative models for the subsurface geometry of the Wasatch fault's northern SLCS, superimposed as dashed green lines on the Pang et al. (2020) cross section from Fig. 3. The model numbers, names and weights are at the bottom of each panel.

The green boxes in panels b-d show the slip rate ratio between the WVFZ and the SLCS that is predicted by the backtilt graben model for the dashed green fault model shown and a WVFZ dip of 67°. See the Fig. 4 caption for an explanation of the yellow lines.

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