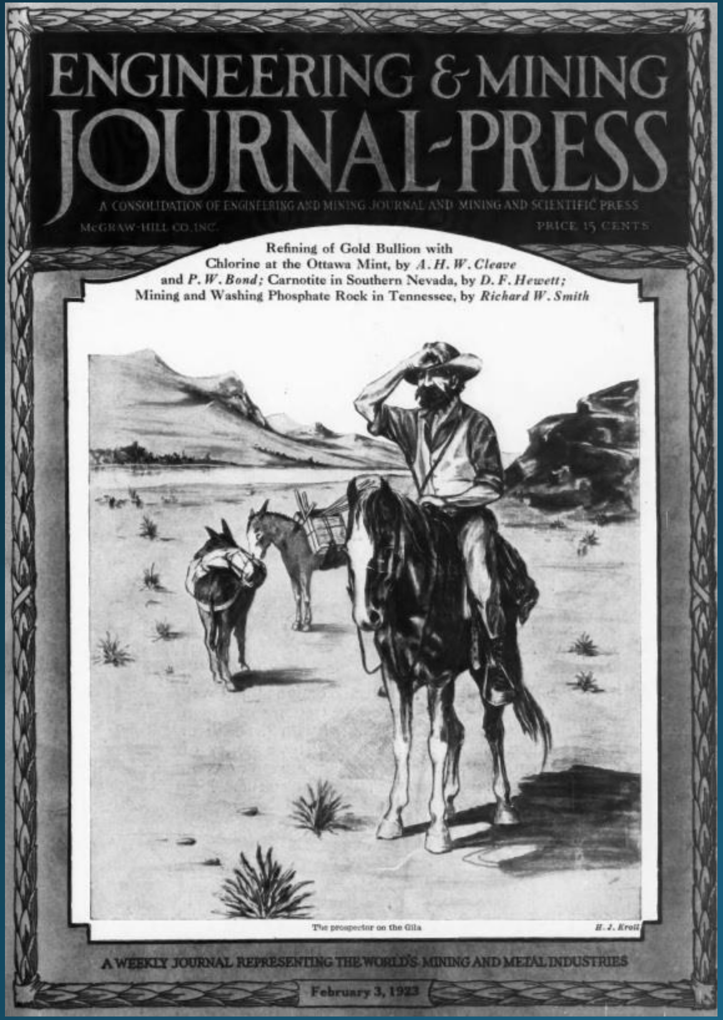
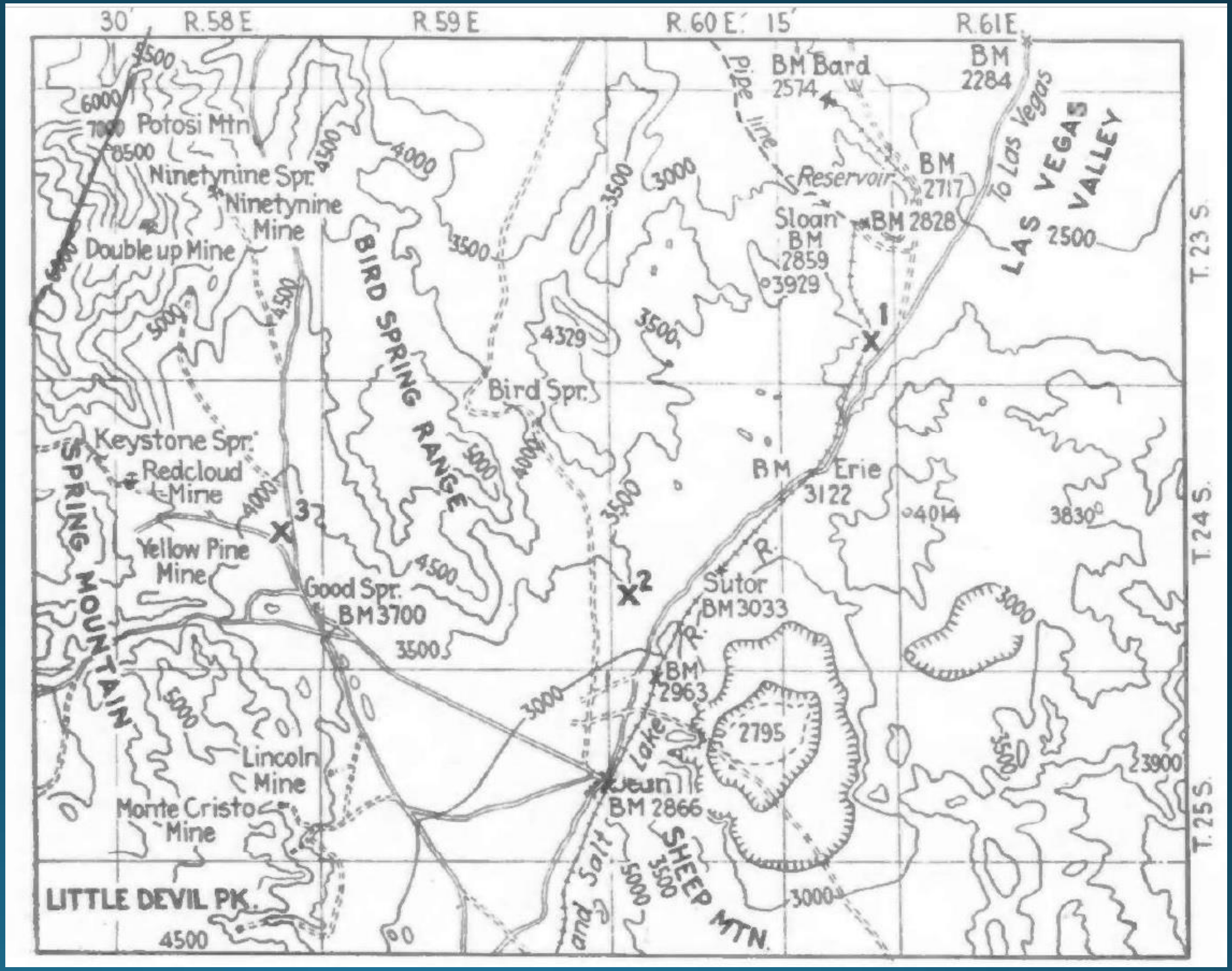
Paleo-elevation constraints from a complexly deformed pre-Colorado River geomorphic surface: Significance of carnotite occurrences in the Southern Nevada region

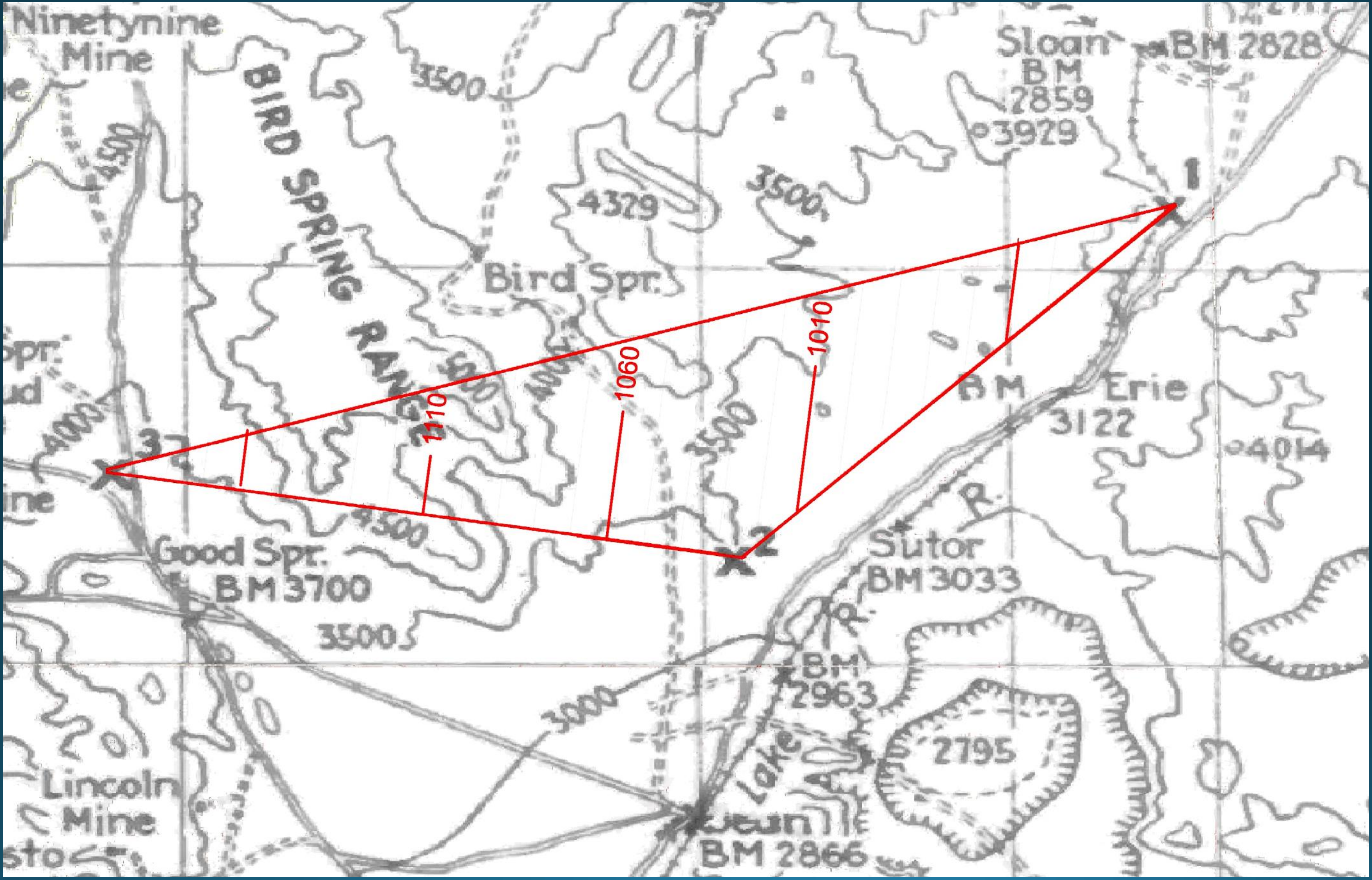
Presentation by Cady Johnson, GeoLogic VR LLC

Devils Hole Workshop, April 27, 2023

It's been 100 years since D. Foster Hewett described sparse occurrences of carnotite $[K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O]$ near Goodsprings in southern Nevada

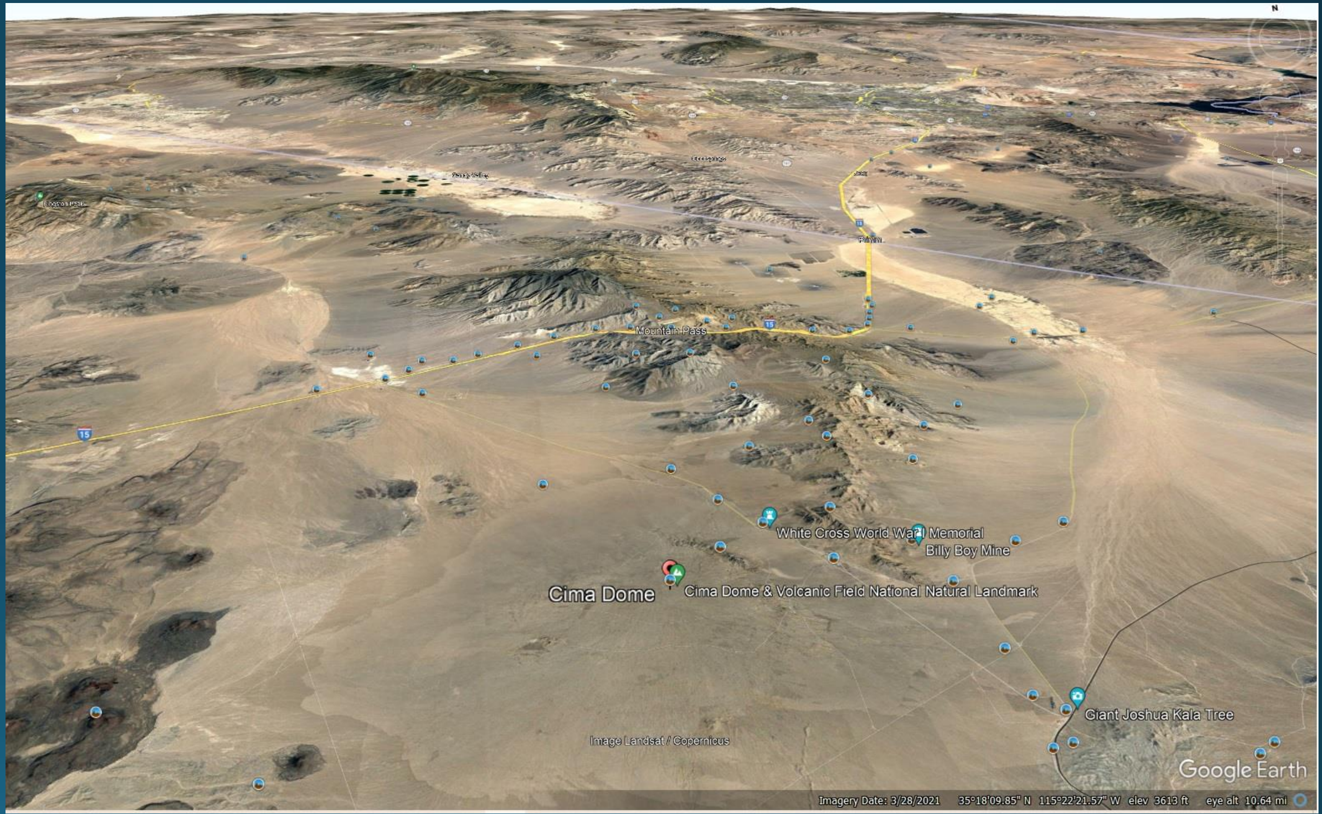




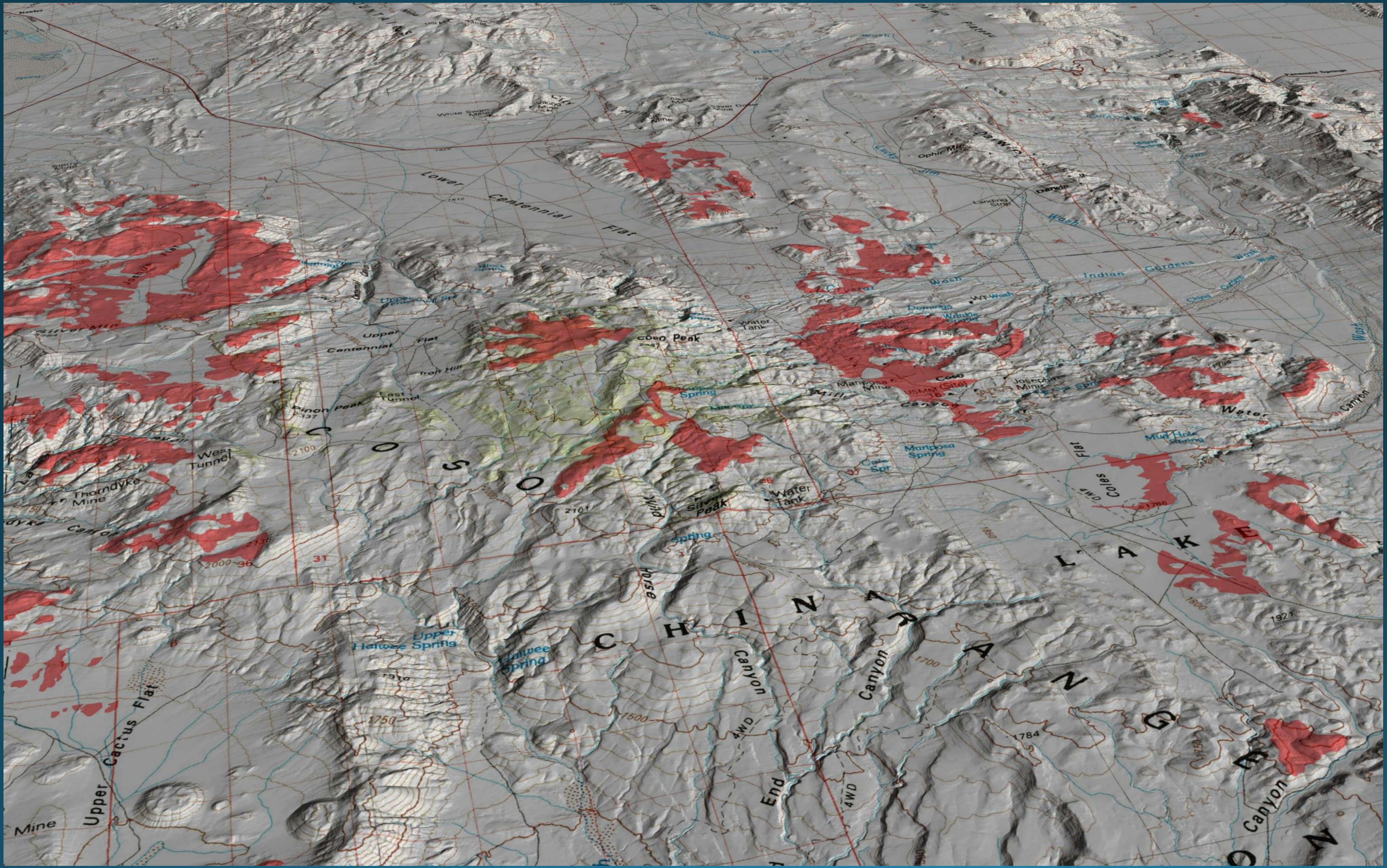


Ninetynine Mine
BIRD SPRING RANGE
3500
4500
4329
3500
Sloan BM 2859
BM 2828
3929
1
Bird Spr.
1010
1060
1110
4000
3500
BM
Erie 3122
4014
4000
3
2
4500
Good Spr. BM 3700
Sutor BM 3033
3500
BM 2963
3000
2795
Lake
Lincoln Mine
BM 2866

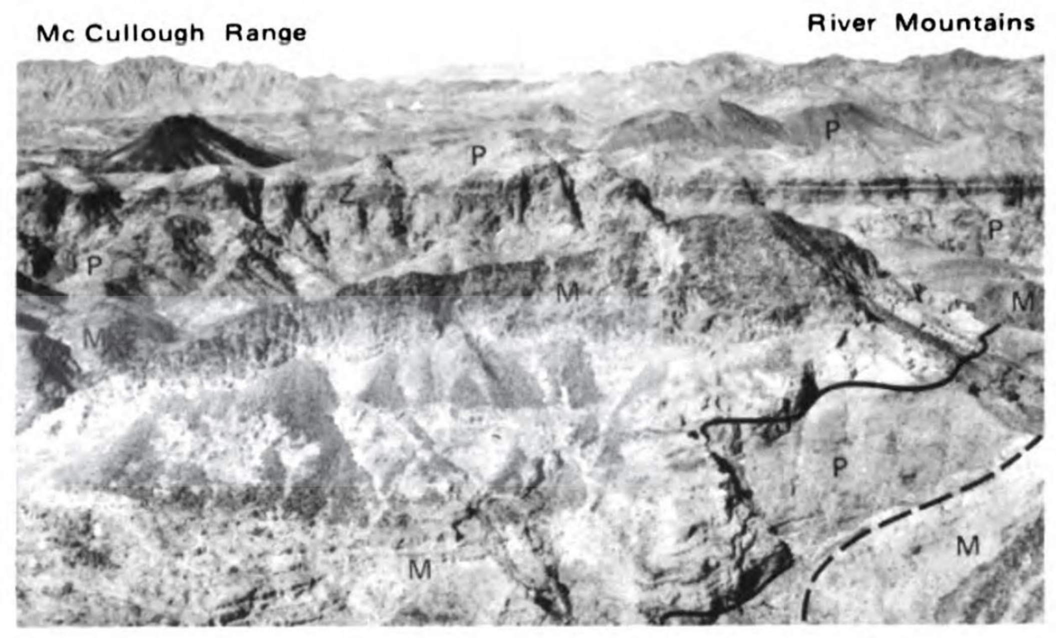
Numerous carnotite occurrences are found in the calcic "soil" profiles of the Ivanpah Upland surface, named and described by Hewett in his 1956 monograph on the Ivanpah Quadrangle. The Ivanpah Upland has been both regionally uplifted and subject to localized warping as evidenced by Cima Dome, shown here

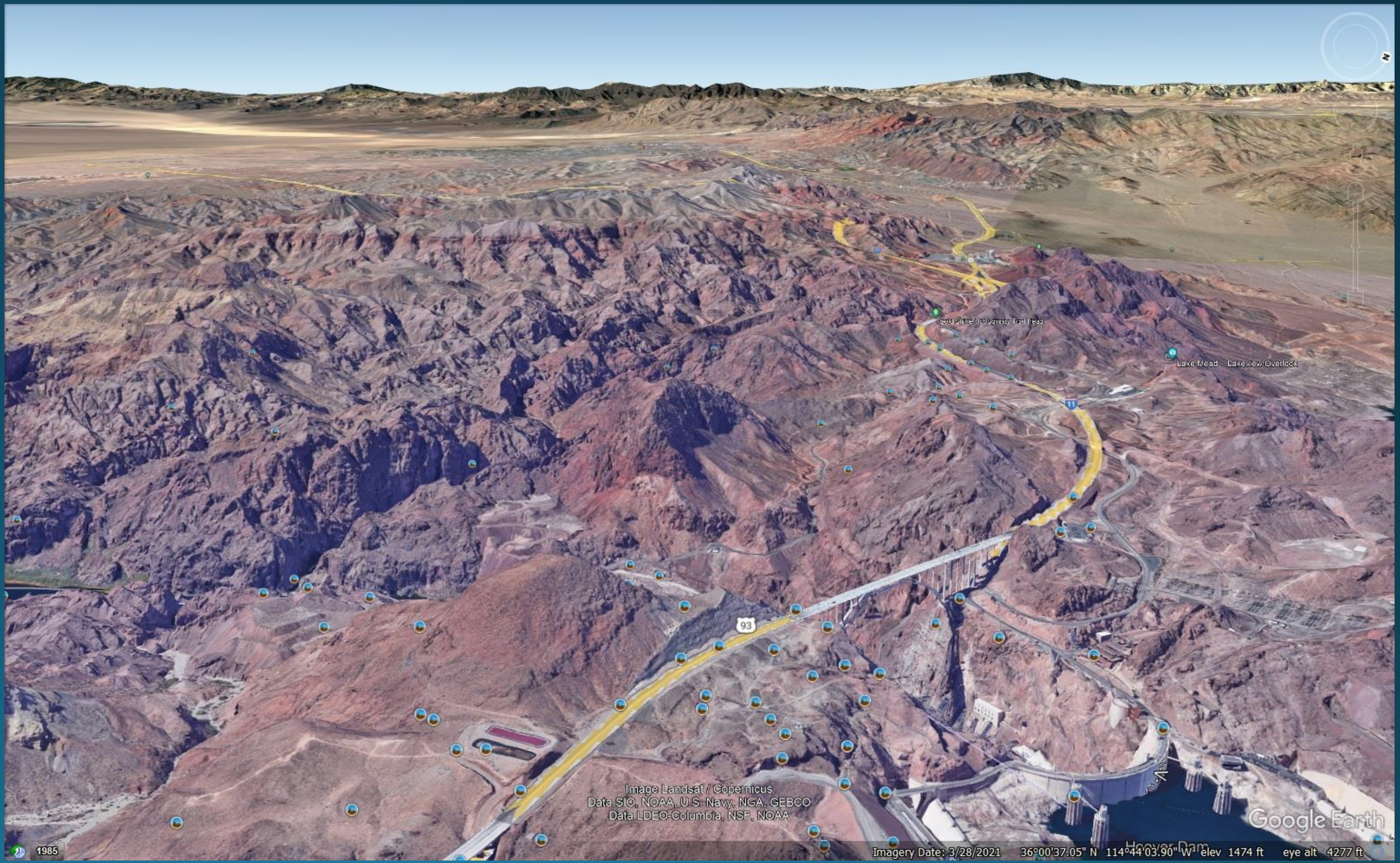


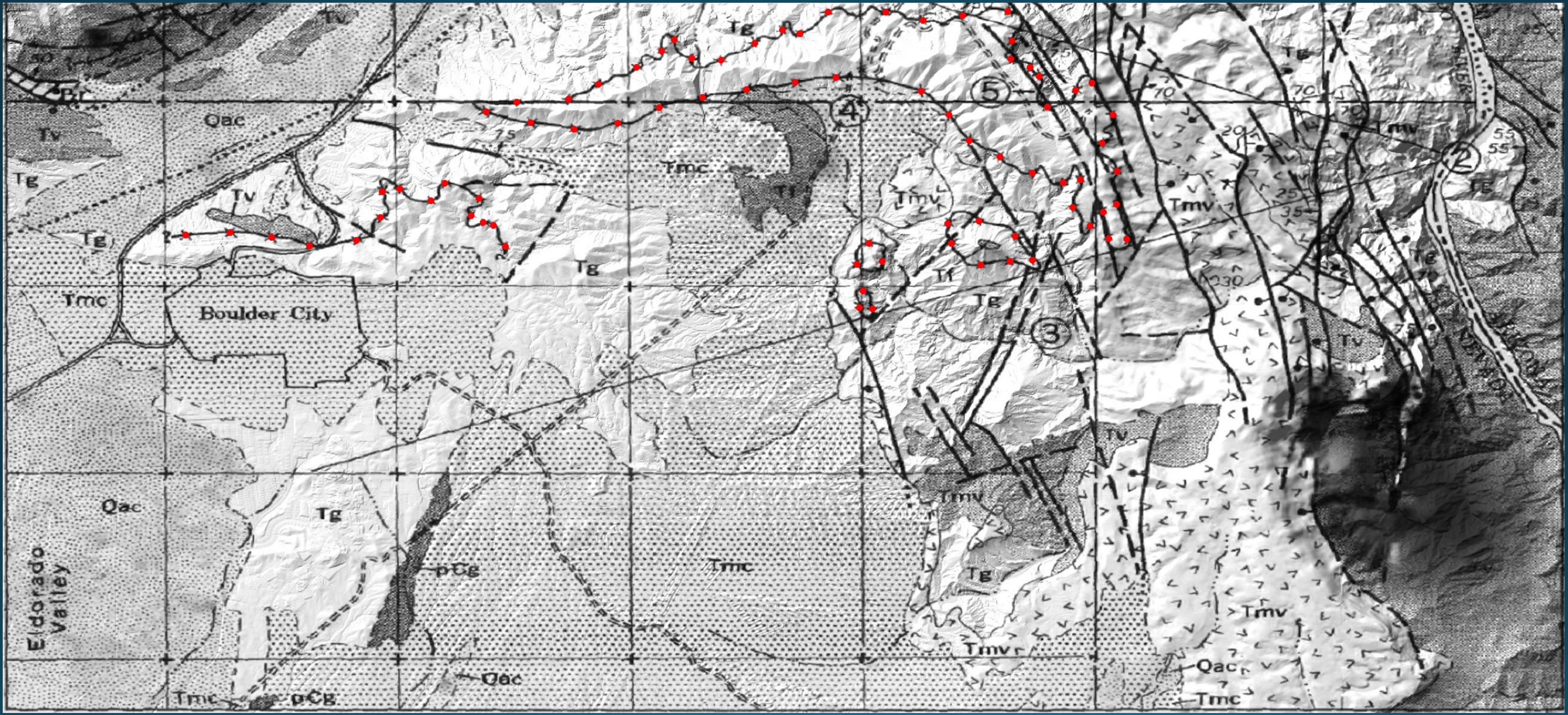
Faulted and uplifted remnants of basalts on this pre-Pliocene erosional surface are found as high as 2,350 m (7,700 feet) on the Darwin Plateau southeast of Death Valley (Jayko, 2009) with a gently curved, convex-upward geometry indicative of post-3 Ma (?) "rollover" in the hanging wall of a curved detachment fault (Burchfiel et al., 1987)



The “fossil water table” reported by Ernie Anderson in 1969 is good evidence that pre-Colorado-River groundwater in the Lake Mead area was phreatic. It turns out that there is carnotite associated with this feature streetside in Boulder City, coating gypsum (or celestite?) in steep, north-trending fractures in the Boulder City pluton






Tg
Tv
Qac
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Boulder City
Tmc
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Qac
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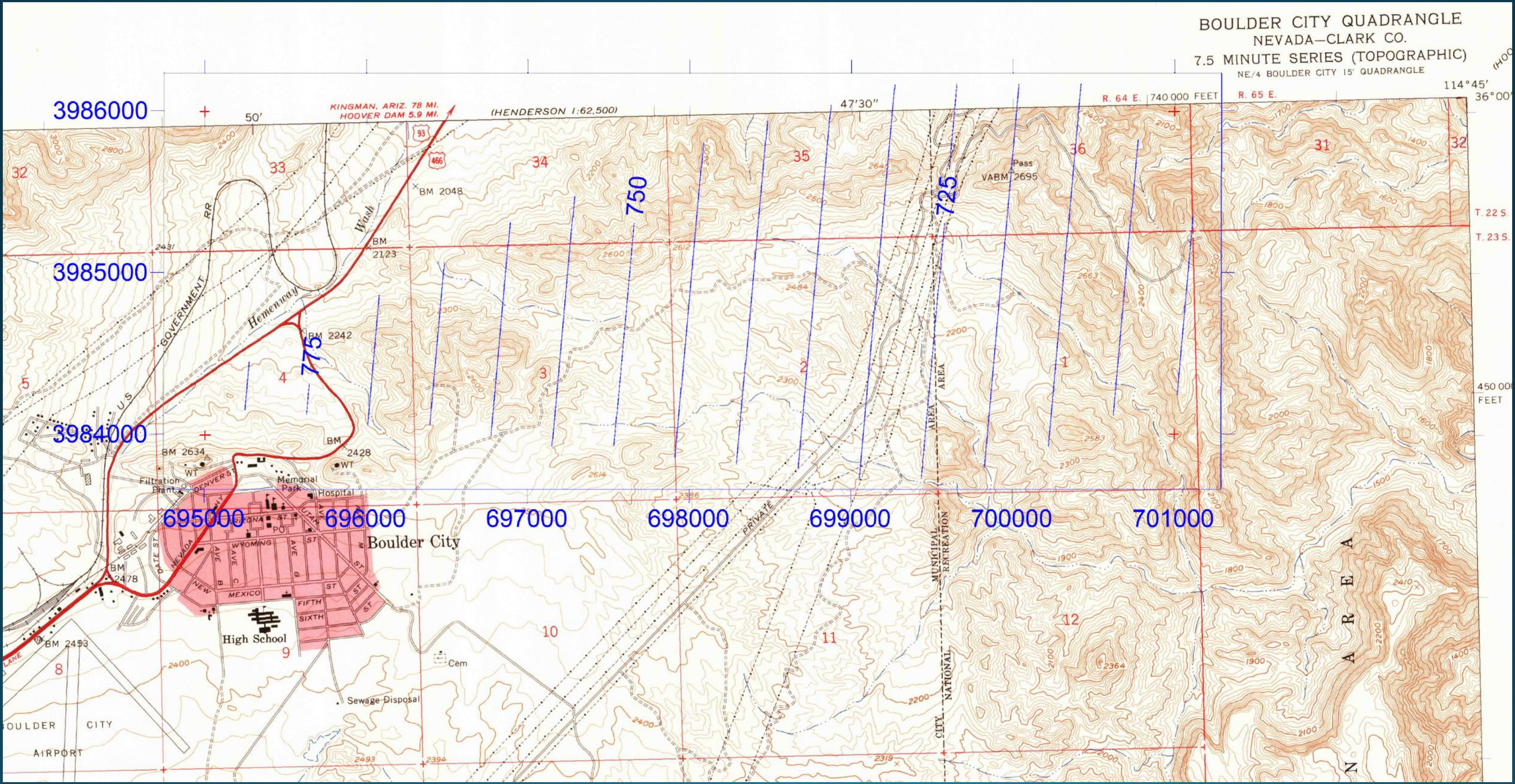
Eldorado Valley
4
5
3
2

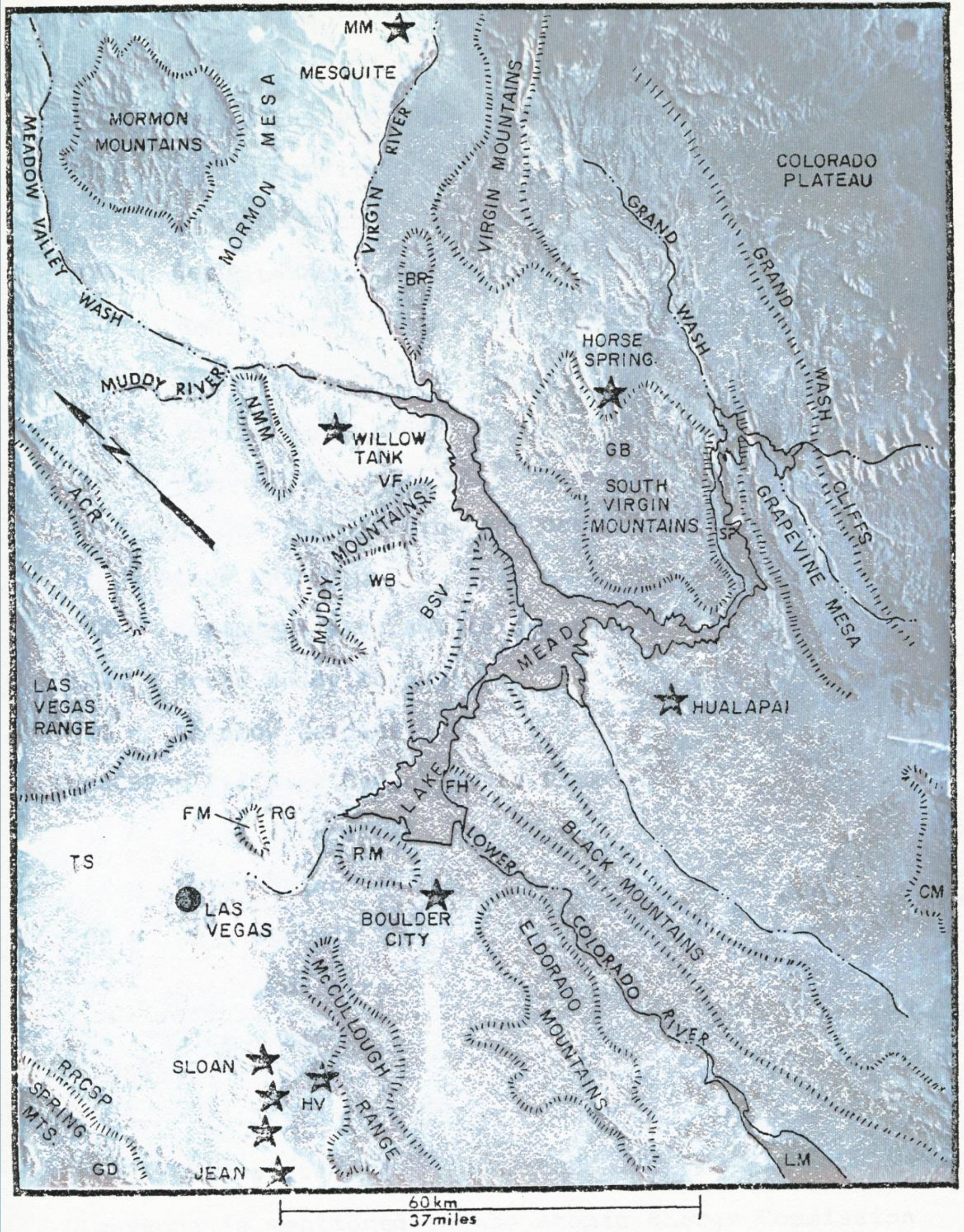


BOULDER CITY QUADRANGLE
NEVADA—CLARK CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
NE/4 BOULDER CITY 15' QUADRANGLE
3986000
3985000
3984000
695000
696000
697000
698000
699000
700000
701000
775
750
725
KINGMAN, ARIZ. 78 MI.
HOOVER DAM 5.9 MI.
(HENDERSON 1:62,500)
Boulder City
High School
Hospital
Memorial Park
Filtration Plant
Sewage Disposal
Cem
BOULDER CITY AIRPORT
Hemenway Wash
U.S. GOVERNMENT RR
MUNICIPAL RECREATION AREA
CITY NATIONAL
R. 64 E.
R. 65 E.
740 000 FEET
T. 22 S.
T. 23 S.
114°45'
47'30"
50'

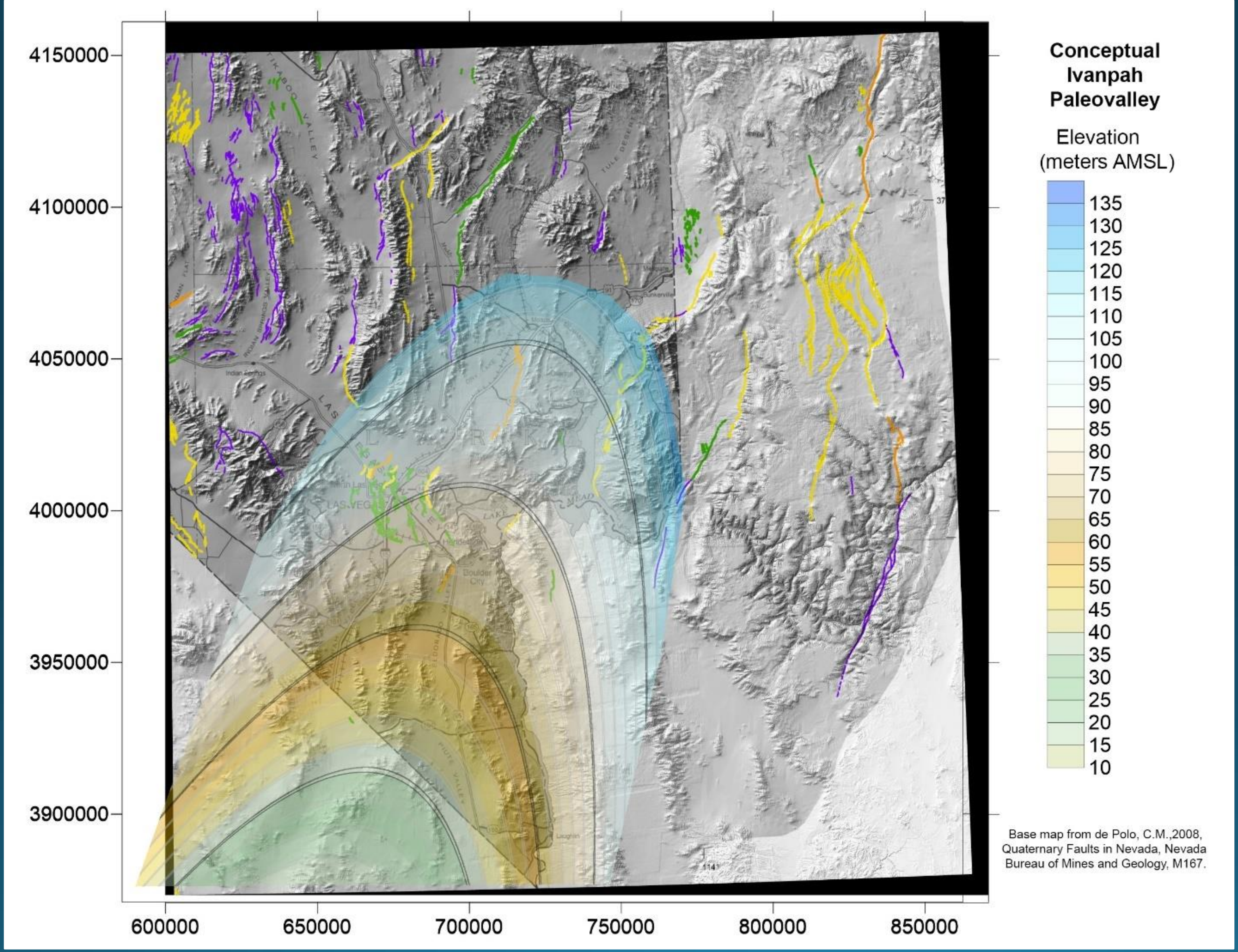
Additional carnotite locations

The Jean-Sloan, Hidden Valley, Boulder City, Hualapai, and Mormon Mesa occurrences are all associated with the Ivanpah Upland geomorphic surface (Johnson, 1982)

The Horse Spring and Willow Tank occurrences lack any evidence of association with the Mormon Mesa surface but traces of carnotite are present in calcareous/gypsiferous strata at those locations at elevations consonant with the calcrete model



Non-pedogenic carnotite occurrences near Goodsprings and elsewhere in the region support the inference of an extensive pre-Colorado-River geomorphic surface, a portion of which can be quantified for modeling and visualization purposes as a parabolic cylinder representing late Miocene surface elevations in the Lake Mead region:



An authoritative report by two eminent soil scientists appeared at a very inopportune time for a young graduate student, focused as it was on a strong pedogenic overprint but blind to the role of groundwater in establishing the subject geomorphic surface. *There is no mention of carnotite in this report, nor of more recently documented barite, palygorskite, and sepiolite in the calcrete (Brock, 2007).*

Calcic soils and calcretes in the southwestern United States

By

George O. Bachman and Michael N. Machette

Open-File Report 77-794
1977

My personal nemesis has been the impracticality of reversing this clearly-stated but mistaken opinion:

"The Mormon Mesa 'caliche' is not associated with gypsum …and based on our fieldwork is known to have a pedogenic origin."

Carnotite was discovered in association with a radiometric anomaly in the Mormon Mesa Calcrete, a geomorphic surface equivalent to the Ivanpah Upland but developed mostly on Muddy Creek Formation, here showing episodic northward tilt

These carnotite occurrences give us a powerful tool to constrain the paleo-elevation history of the Lake Mead region, *if the role of groundwater in calcrete development is interpreted correctly*

Simulated evaporation of Las Vegas Valley groundwater occasionally produces sequential precipitation gypsum and carnotite, as observed in outcrop

Brackish groundwater in eastern Las Vegas Valley can theoretically precipitate carnotite at less than 80% evaporative concentration (Johnson, 1982)

If gypsum precipitation occurs before carnotite, bicarbonate in solution is elevated by removal of calcium in the presence of calcite, depressing the carnotite saturation index and delaying the precipitation of carnotite (further enriching the fluid phase) in carnotite's constituent ions K, U, and V.

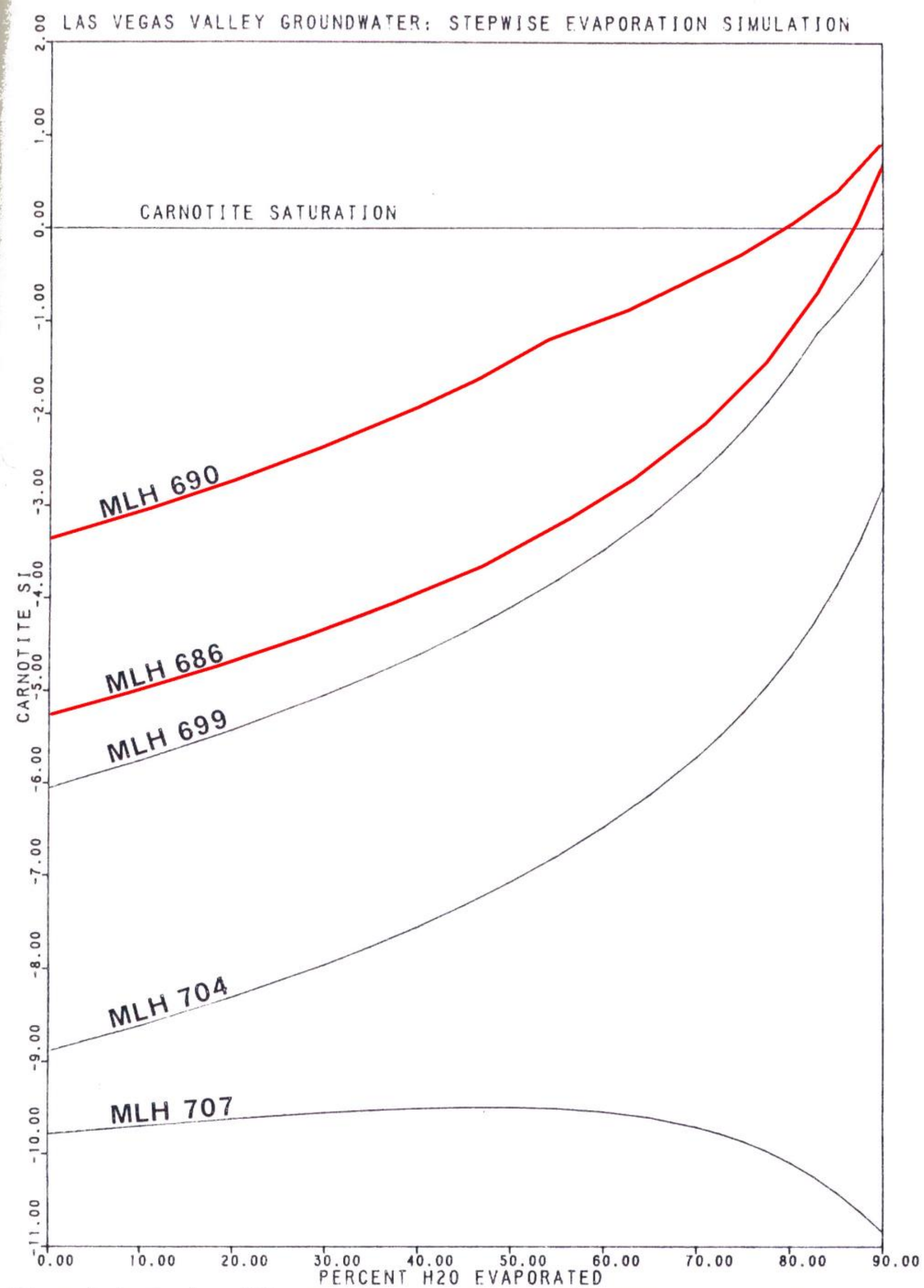


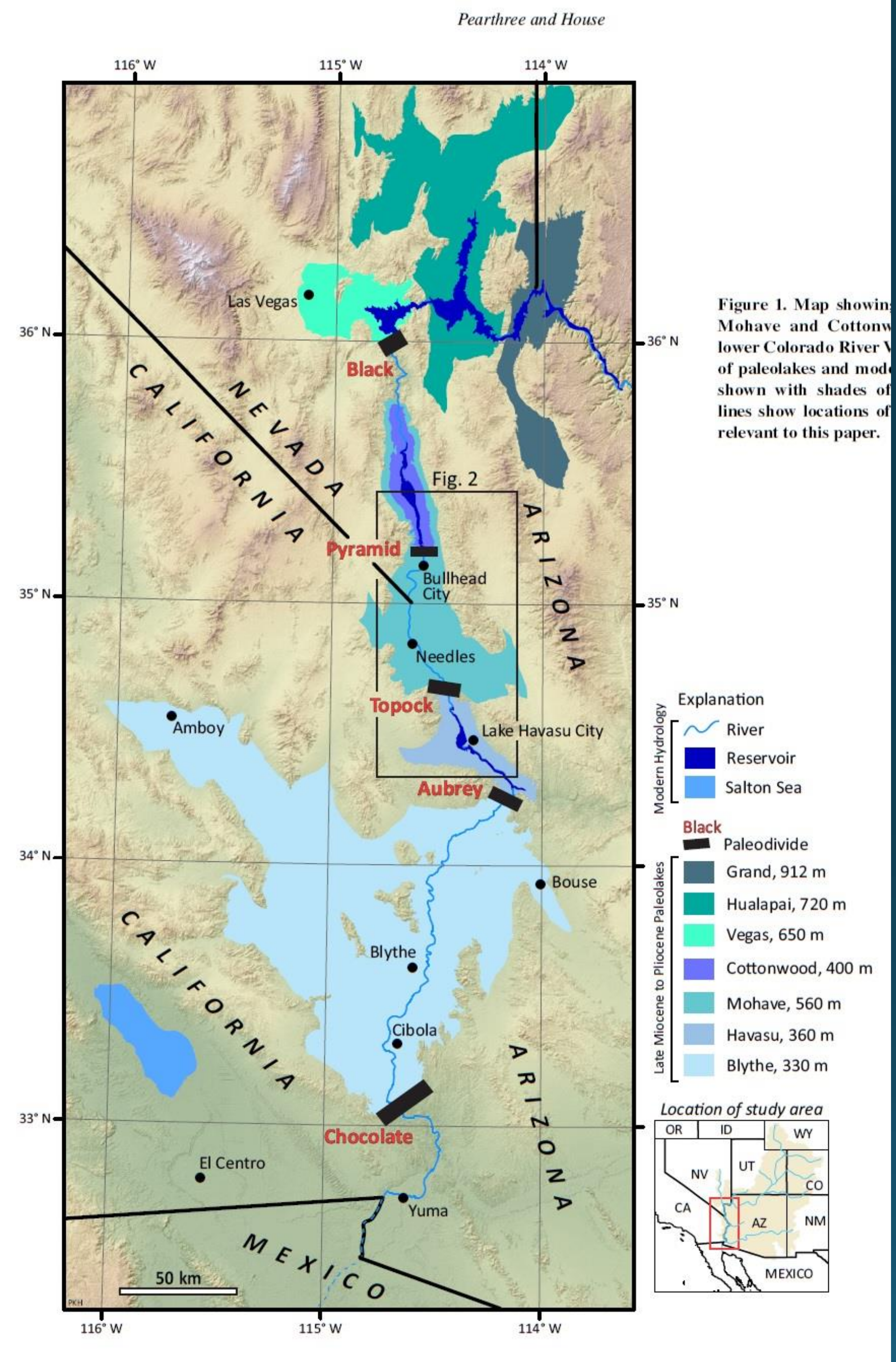
Plate 4 (color). Effects of evaporation and gypsum precipitation on the saturation index of carnotite in selected samples of southern Las Vegas Valley groundwater.

What did the paleo-flow system look like? This profusion of lakes can't be right, can it? Where is all this water coming from, and how did it arrive, since pre-Colorado River conditions in this area did not include a major stream? Regional groundwater discharge on this scale satisfies the "Muddy Creek constraint" by requiring a vanished recharge area but not necessarily a river!

The argument over the Bouse Formation significance to Colorado River history has always been polarized along estuarine vs non-marine evidence.

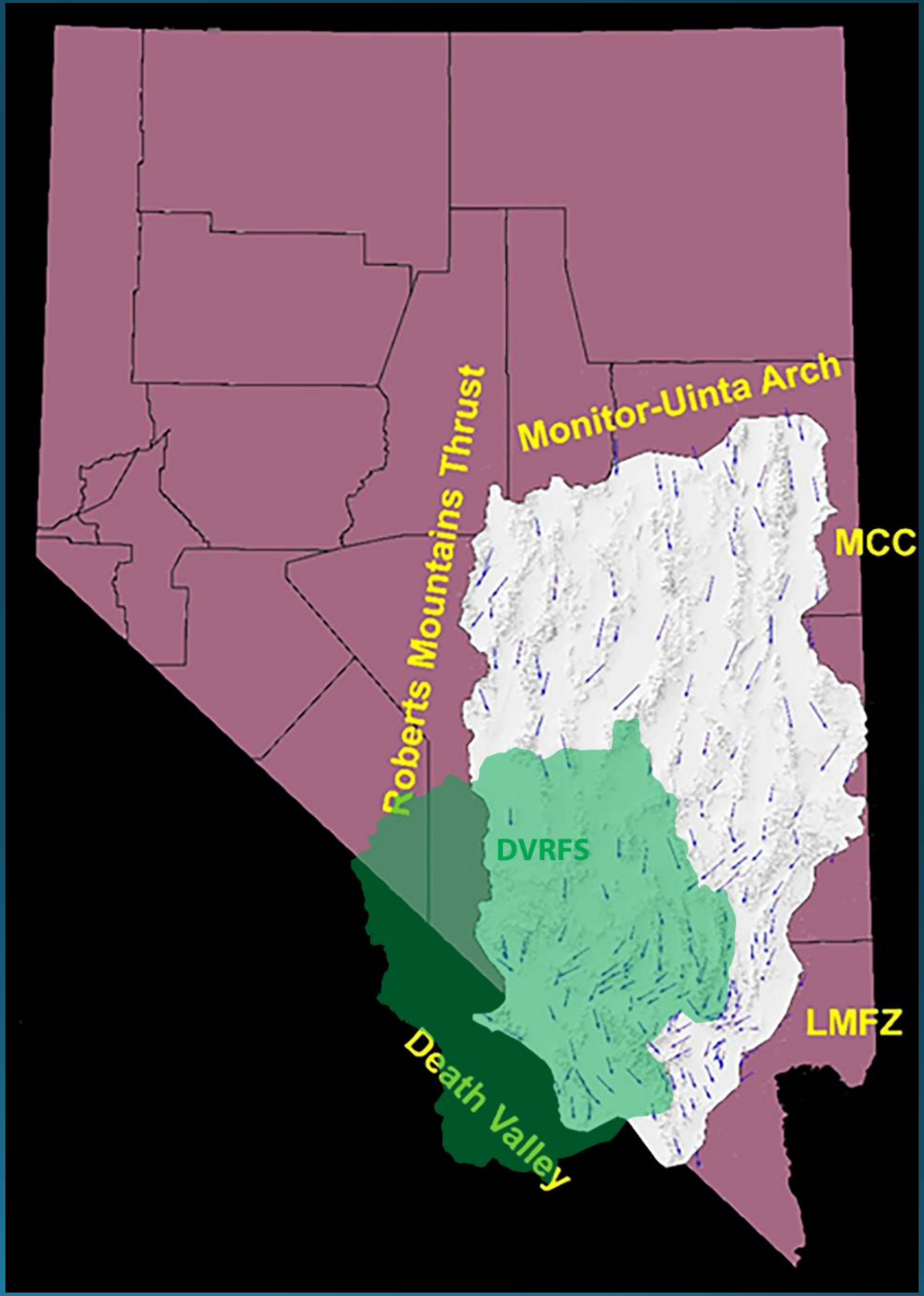
Pearthree and House (2014) cast the argument as lake vs estuary, presenting the map shown here along with careful analysis of Bouse Formation spillway elevations indicating a cascading chain of "lakes".

In my opinion, Lucchitta (1979) was instead correct in recognizing that uplifts on the big 6-5 Ma normal faults are superimposed on a non-uniform regional uplift of comparable magnitude. Latest Miocene elevations were low as would be expected around estuaries, but the depositional environment was neither lacustrine nor estuarine, it was paludal.



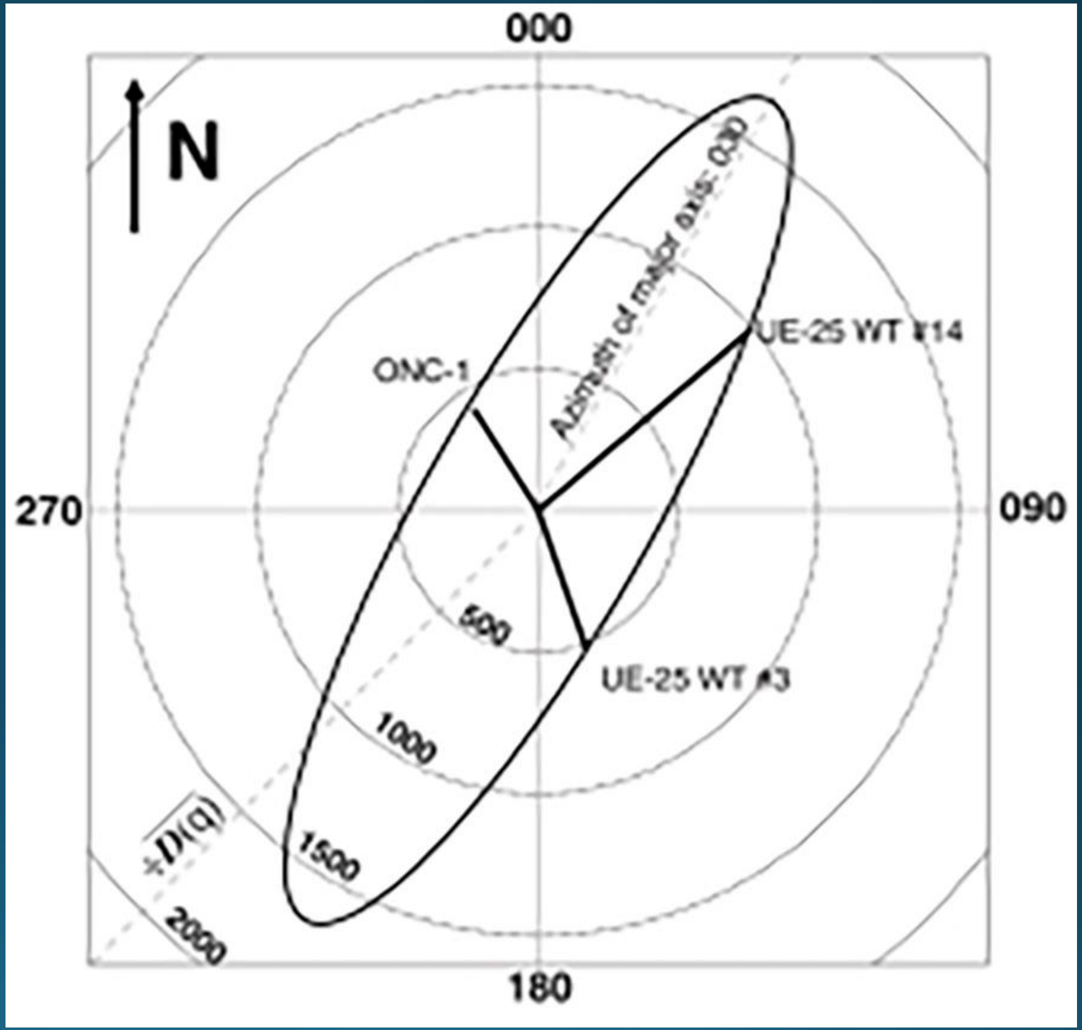
Our finite-element scoping model, described in the 2019 Devils Hole Workshop, provides scaling estimates of terrain capacity, interstitial flow velocities, and heat transport in Paleozoic carbonate-rock aquifers of the southeastern Nevada region under Recent hydraulic gradients

- We can't avoid highlighting contrasts and throwing some shade on the mature USGS DVRFS model
- Our alternative model, based on the FEFLOW code, utilizes heat input from the Eureka Low and transmissive anisotropy as constraints on a steady flow field feeding the regional warm springs about 200,000 acre-feet per year from the highlands
- Recharge was assumed to be uniformly distributed *to shelf carbonates only* through a north-sloping 8500-7000 ft AMSL planar recharge-cutoff surface
- The ~2 GW of heat lost from the Eureka Low (Sass and Lachenbruch, 1982) was assumed to be conserved and transported to the regional warm springs in this one-layer representation of the regional groundwater hydrology
- The complete scoping model, which requires a FEFLOW code license to explore, is archived with the Nevada State Engineer

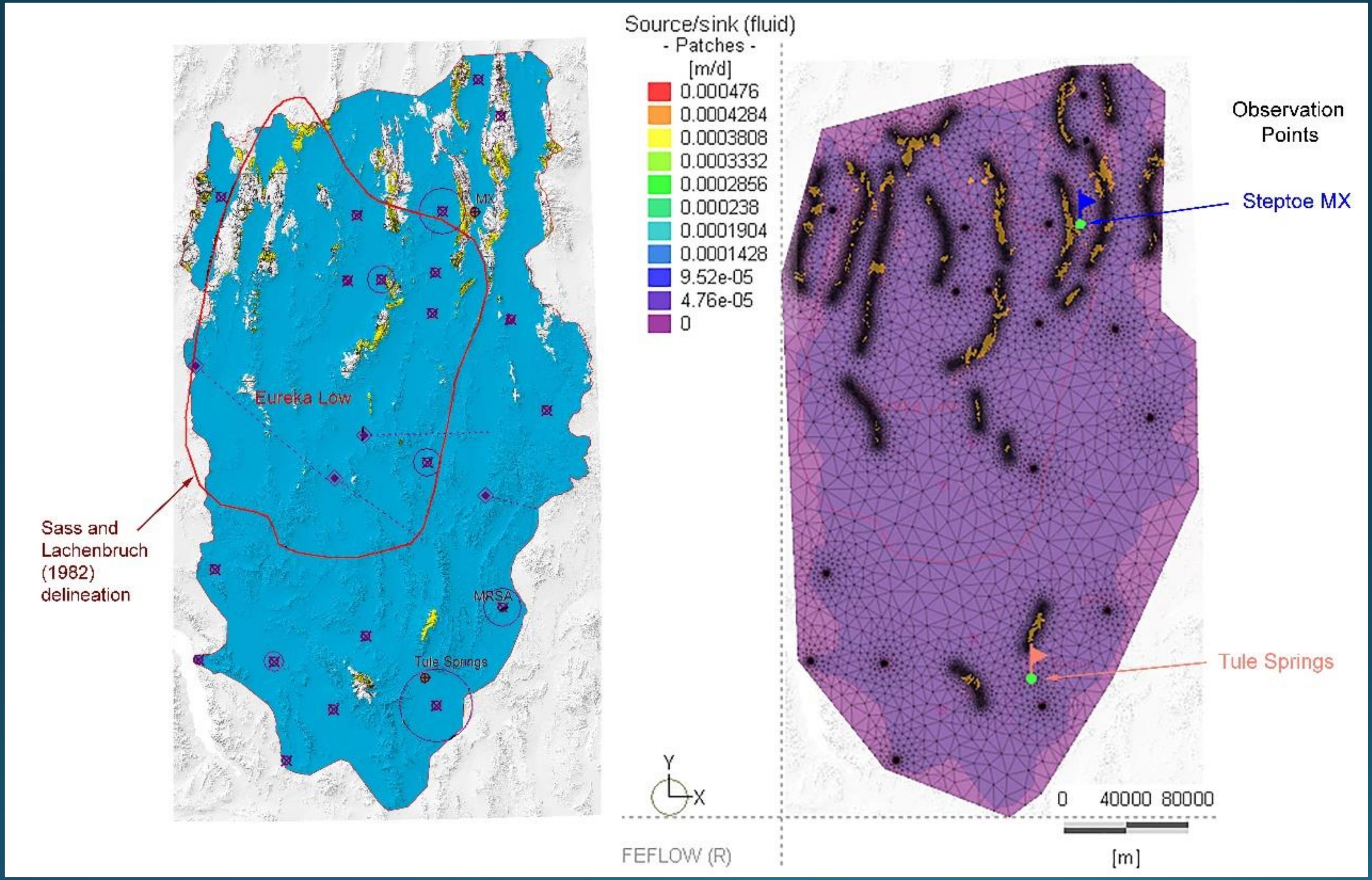


Representation of the regional flow field as anisotropic is consistent with field evidence from multi-well hydraulic tests

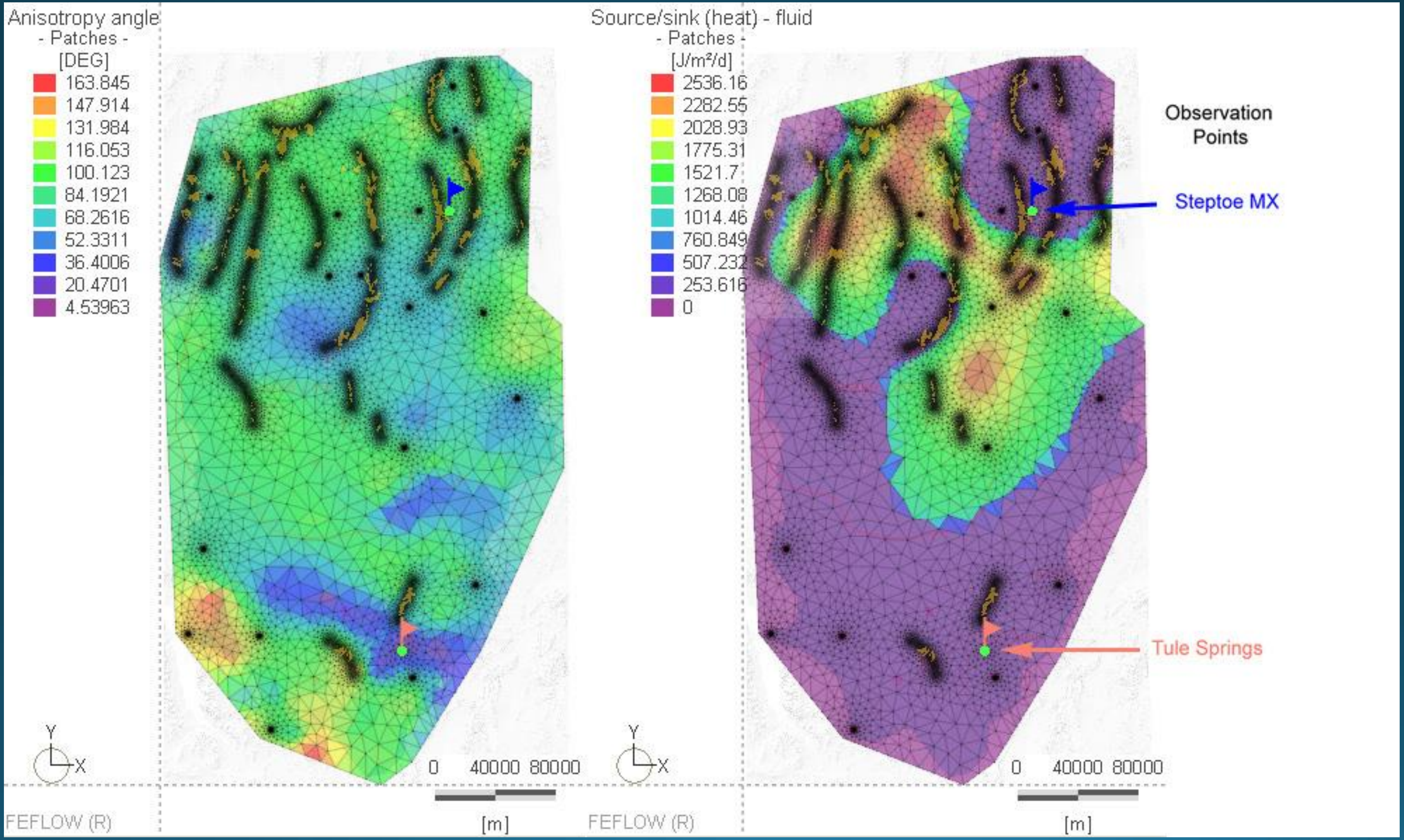
- Ferrill et al. (1999) demonstrate with field data that the assumption that regional groundwater flow is parallel to fluid-potential gradients is unwarranted
- So, why did the USGS continue with regional analyses using MODFLOW, which cannot incorporate a locally anisotropic permeability field?
- Neither can MODFLOW apply thermal constraints to the fluid-flow equations
- Consider that the 3-D geologic framework upon which DVRFS analyses are based is so complex, was so costly to develop, and so favorable to DOE's mission that a voluntary course correction with a License Application underway was not to be expected



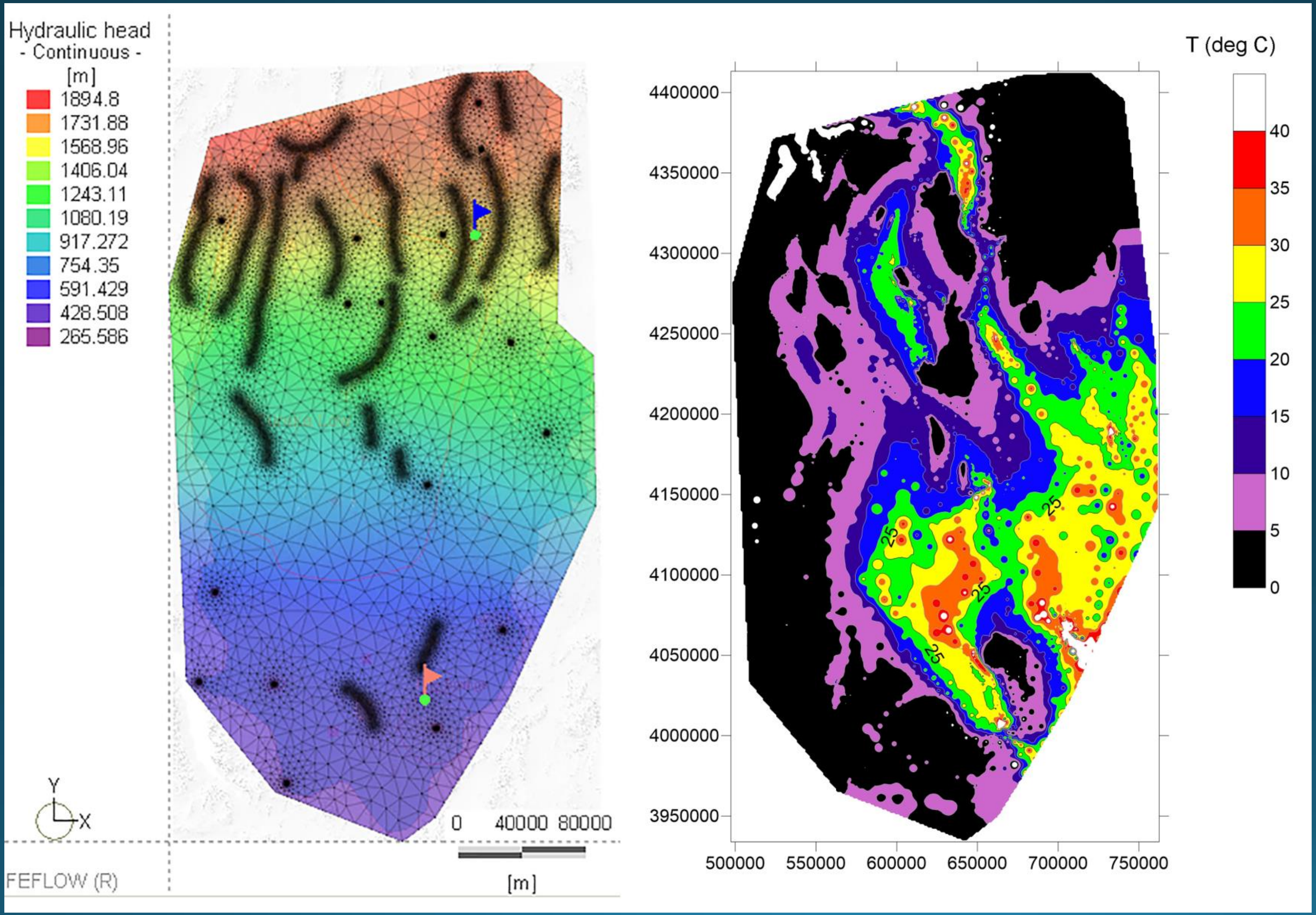
For rocks above the recharge-cutoff surface, only areas underlain by shelf carbonates were allowed to accept recharge at 0.14 m/year to balance discharge



Regional transmissivity in the base case is 300 m^2/day, porosity 0.00015. A 10:1 anisotropy ratio was assigned on an element-by-element basis to account for the tectonic fabric, and heat lost from the Eureka Low was input to the regional aquifer to emerge from regional warm springs at a system output of roughly 2 gigawatts, assuming discharging waters have been heated from 1 degree C.



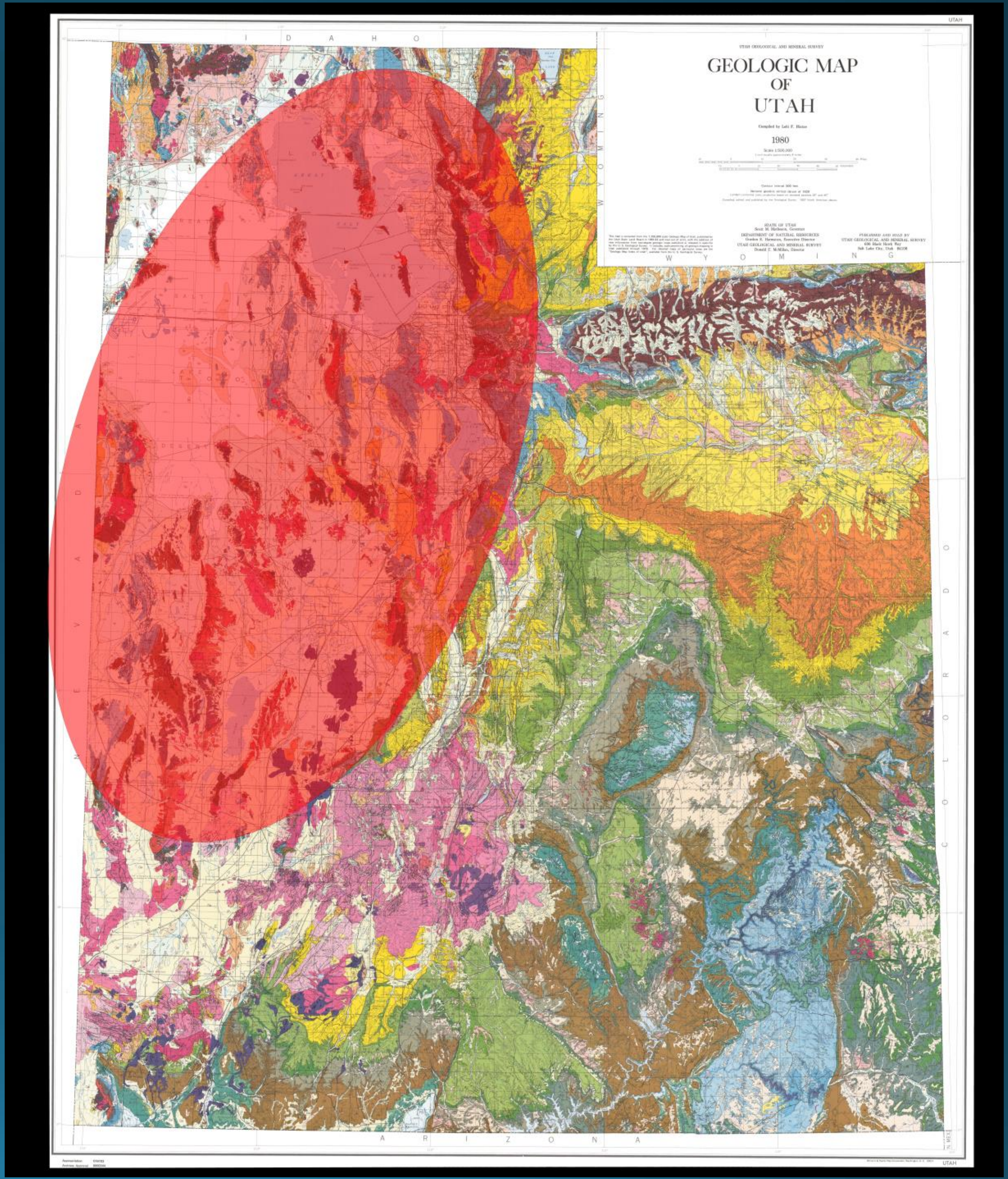
Computed head and temperature fields in this regional scenario of recharge and discharge are reasonable in the eastern part of the model, but a noteworthy failure is evident in the Tecopa area, where modeled waters are too cool. The strength of the Eureka Low was therefore underestimated locally. Groundwater flux to Las Vegas Valley is about 59,000 acre-ft/yr, the largest sink in the model, and recharge 140 mm/yr



As we collectively awaken to the role of regional groundwater flow systems in forming deposits long thought to be lacustrine, the **streetlight effect** may be in play when "Colorado Plateau waters" are invoked to explain the provenance of the Hualapai Limestone, or the Spring Mountains as the source of recharge for Tecopa Hot Springs

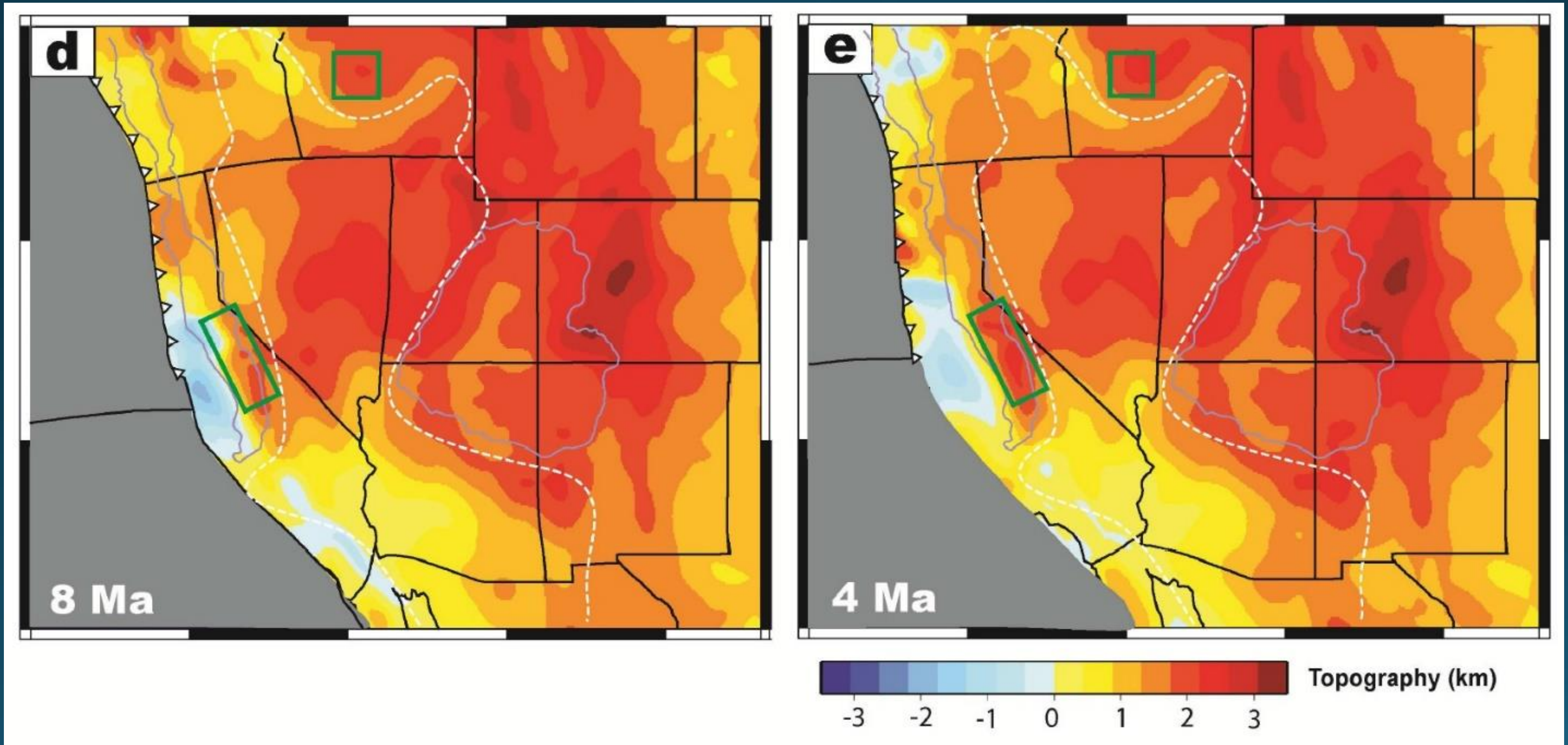
What is more realistic than the Colorado Plateau in terms of a recharge area for Bouse groundwater-discharge deposits?

- The Bouse wetted area from Pearthree and House is about 20,000 sq km
- The West Desert as indicated by red shading on the Utah map is about 63,000 sq km
- ET of 50 mm/yr from Bouse domains based on minimal Armagosa Desert rates requires about 31.7 cubic meters per second (800,000 acre-ft/yr) of groundwater discharge
- For comparison, groundwater discharge to Las Vegas Valley today is about 59,000 acre-ft/year
- For context, the ancestral Bouse groundwater discharge rate is roughly half the average annual discharge of the Yampa River at its confluence with the Green River
- Recharge of 0.14 m/yr analogous to the modern system in eastern Nevada would meet the discharge requirement with only about 11% of the Mio-Pliocene upland area contributing recharge to the regional system

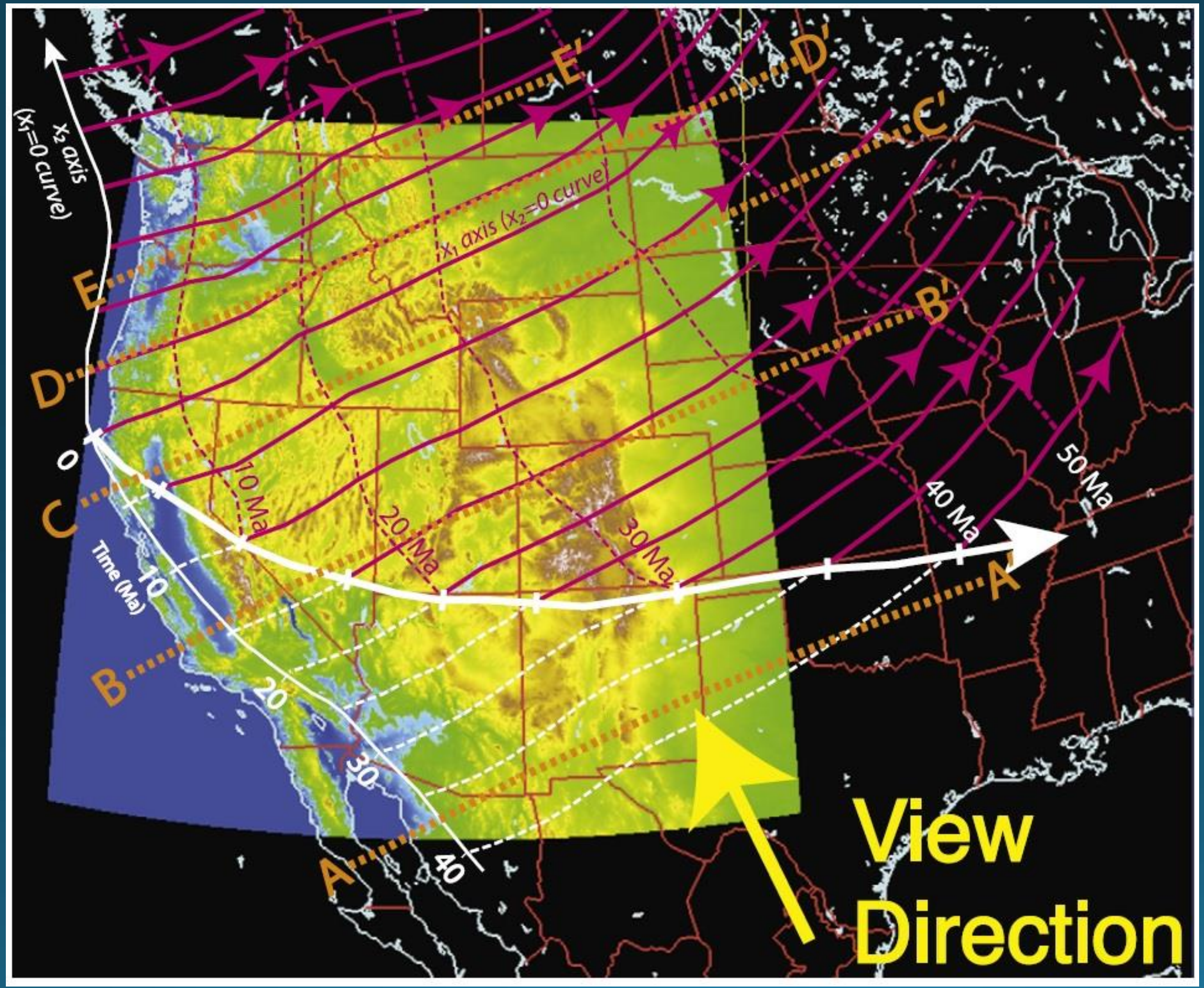


Seismic tomography explains some observations about how the groundwater hydrology of this region has evolved, in particular the collapse of the West Desert of Utah:

A prominent feature in the estimated topographic evolution of the western U.S. since 20 Ma is the monotonic subsidence of ~1.5 km within the central-eastern B&R since the middle Miocene …Zhou and Liu (2019)



Neogene collapse of the West Desert of Utah, a region underlain by shelf carbonates, removed an important recharge area, analogous to but larger than present-day high country in east-central Nevada. Mantle processes modeled by Pavlis et al. (2012) implicitly reconcile the collapse of the West Desert of Utah with sinking of the subducted Farallon slab or slab fragment. The Cape Mendocino Slab Window Edge (white arrow) separates the late Miocene regional recharge area in the West Desert from the former regional discharge area, the Ivanpah paleovalley proposed here. Supplements to the Pavlis report are an adventure with 3-D glasses!



Along the edge of the subducting Farallon Plate there would need to be an expulsion of hot fluids with marine affinities, derived from metamorphism of subducted oceanic crust; consider hydrothermal manganese at Three Kids mine in the River Mountains (Van Gilder, 1963) and Ca-Cl-facies groundwater from southern Death Valley (Lowenstein and Risacher, 2009) as examples.

Diagram from Zandt and Humphreys (2008)

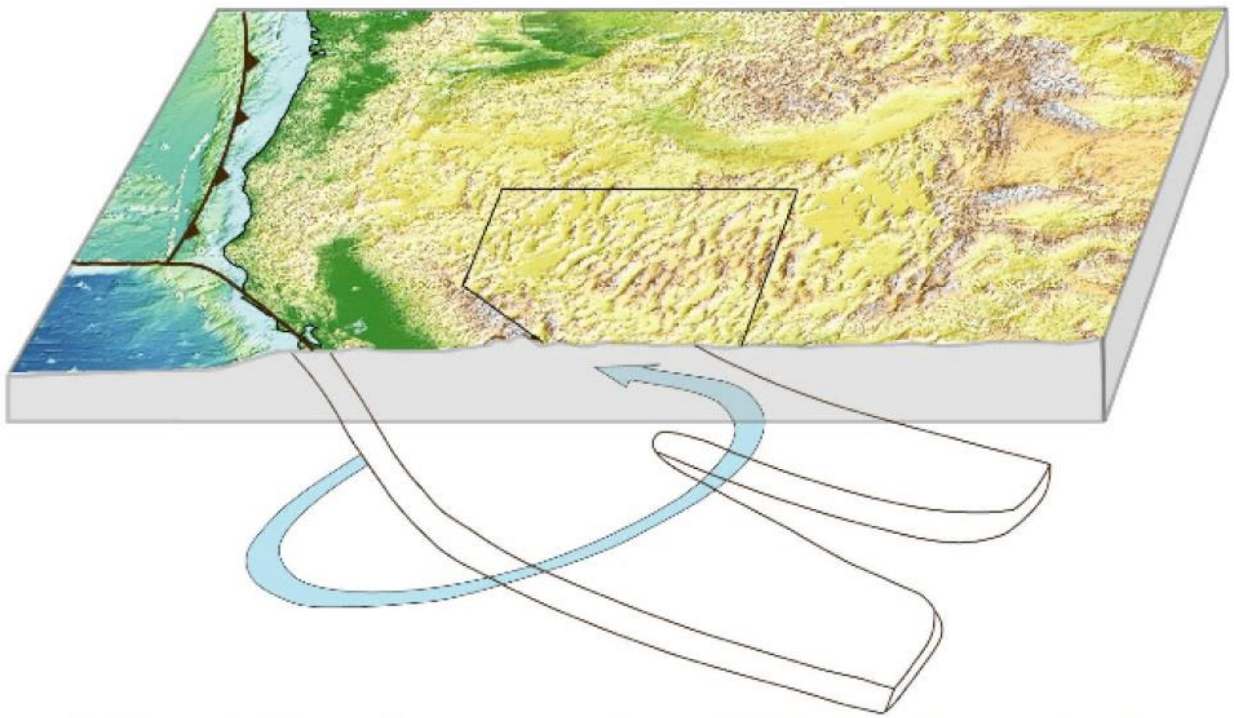
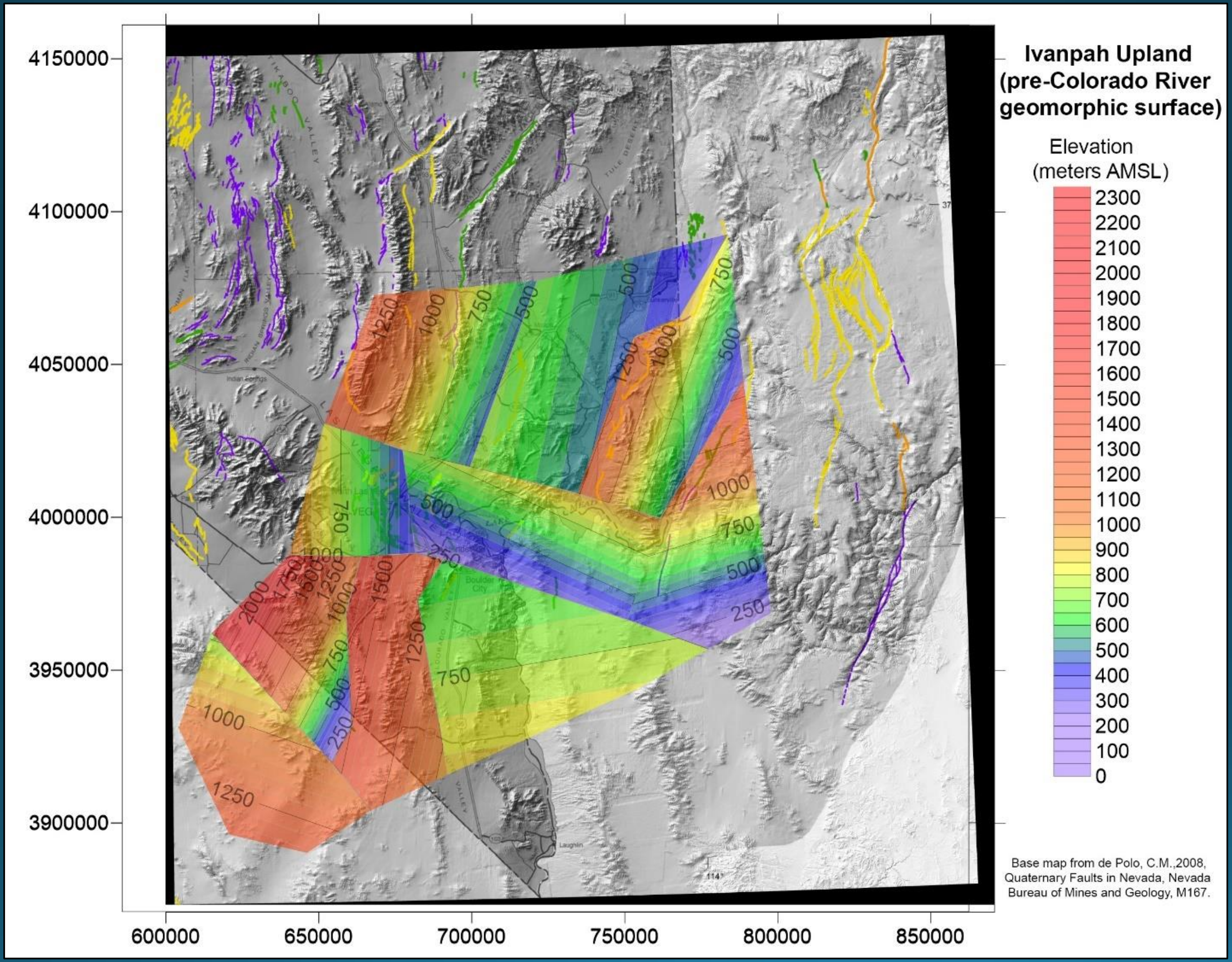
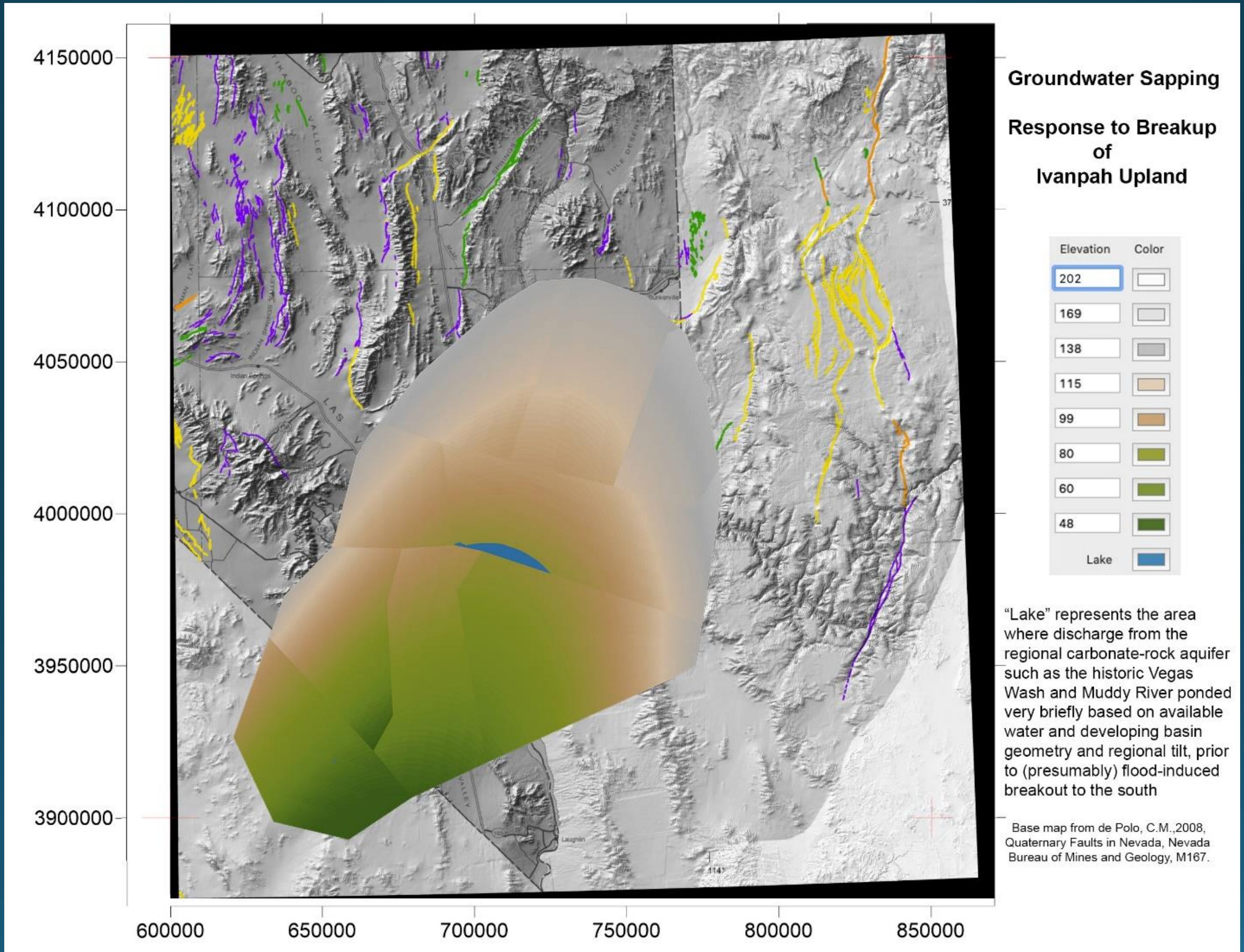


Figure 2. Schematic diagram showing an ascending toroidal flow beneath the western North American plate around the edge of the Gorda-Juan de Fuca slab. This flow results in a loss of dynamic slab support, causing rapid slab roll back and steepening in the mid-upper mantle. Slab geometry represents seismically imaged slab (Bijwaard et al., 1998, Bostock and Vandecar, 1995). The toroidal flow creates an anisotropy field that results in a circular pattern of fast split directions, as observed in Fig. 1. Outline of Nevada is shown for comparative location with Figure 1. Abbreviations: CP = Colorado Plateau, JdF = Juan deFuca, NA = North America, Pac = Pacific, SAF = San Andreas Fault, SN = Sierra Nevada, SP = Snake River Plain, NHT = Newberry Hotspot Track, Y = Yellowstone.

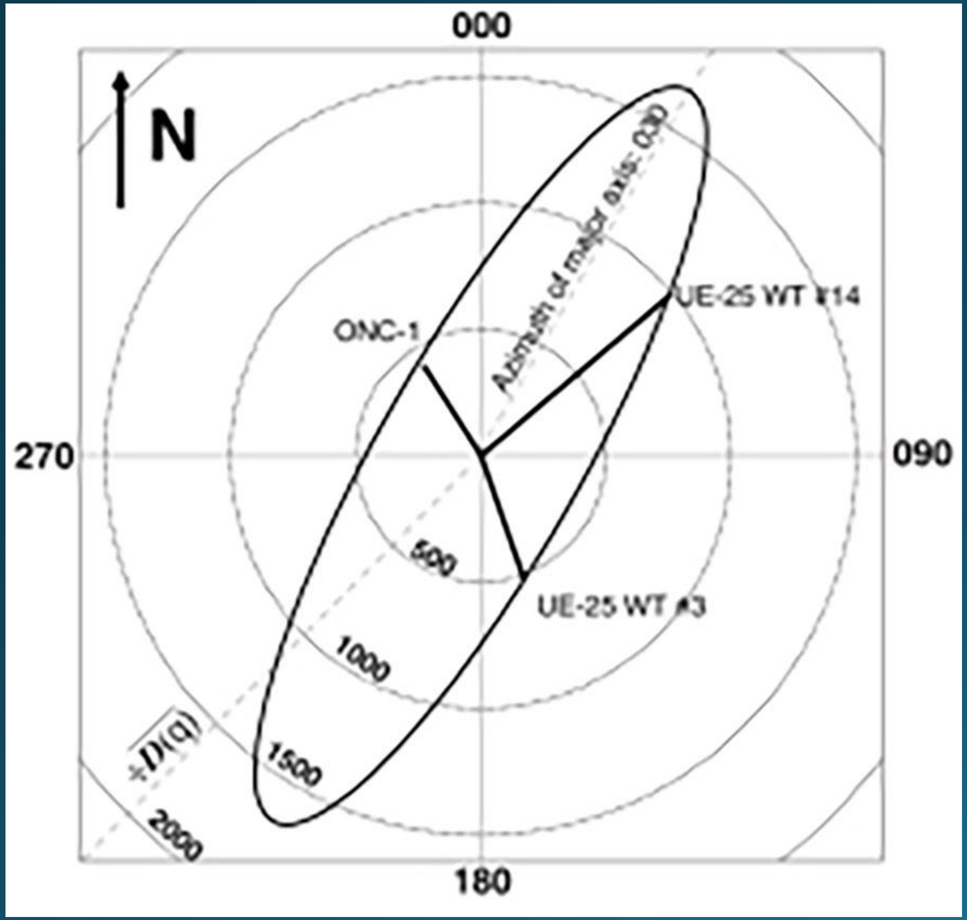
Keeping in mind the parabolic-cylinder shape of the estimated pre-Colorado-River geomorphic surface, we can quantitatively explore (with grid math) how intermediate steps toward net displacement modified the drainage geometry

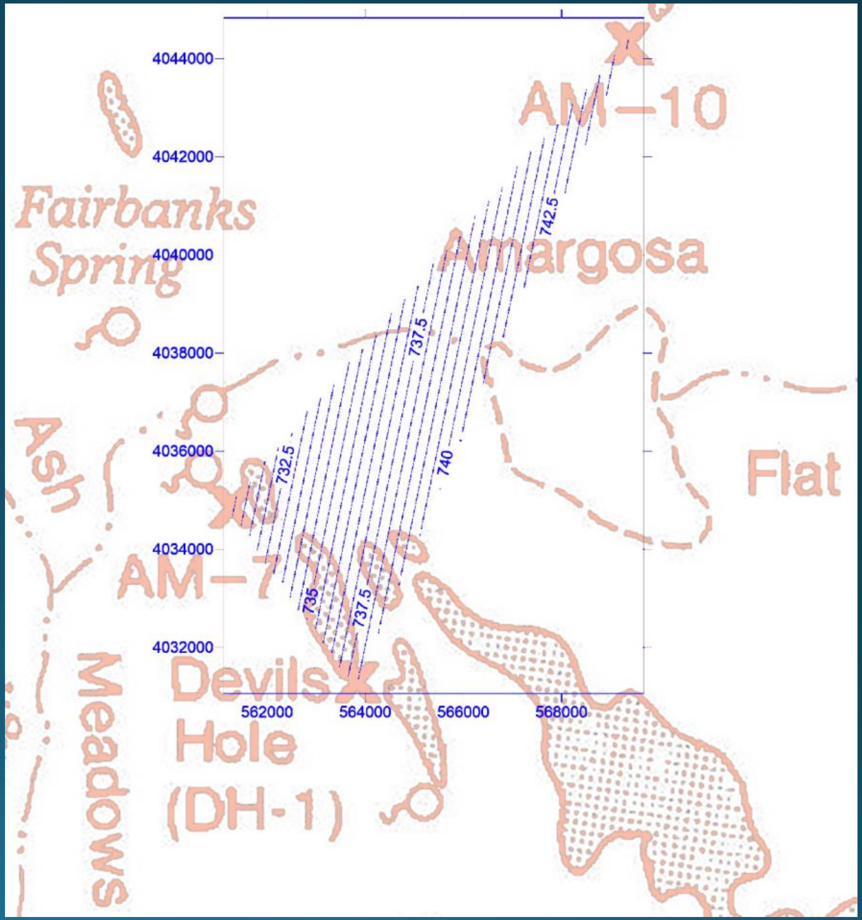


If we add <u>one percent</u> of the difference between these surfaces to the parabolic cylinder model elevations, we get a closed depression that straddles the location of the lower Colorado River:

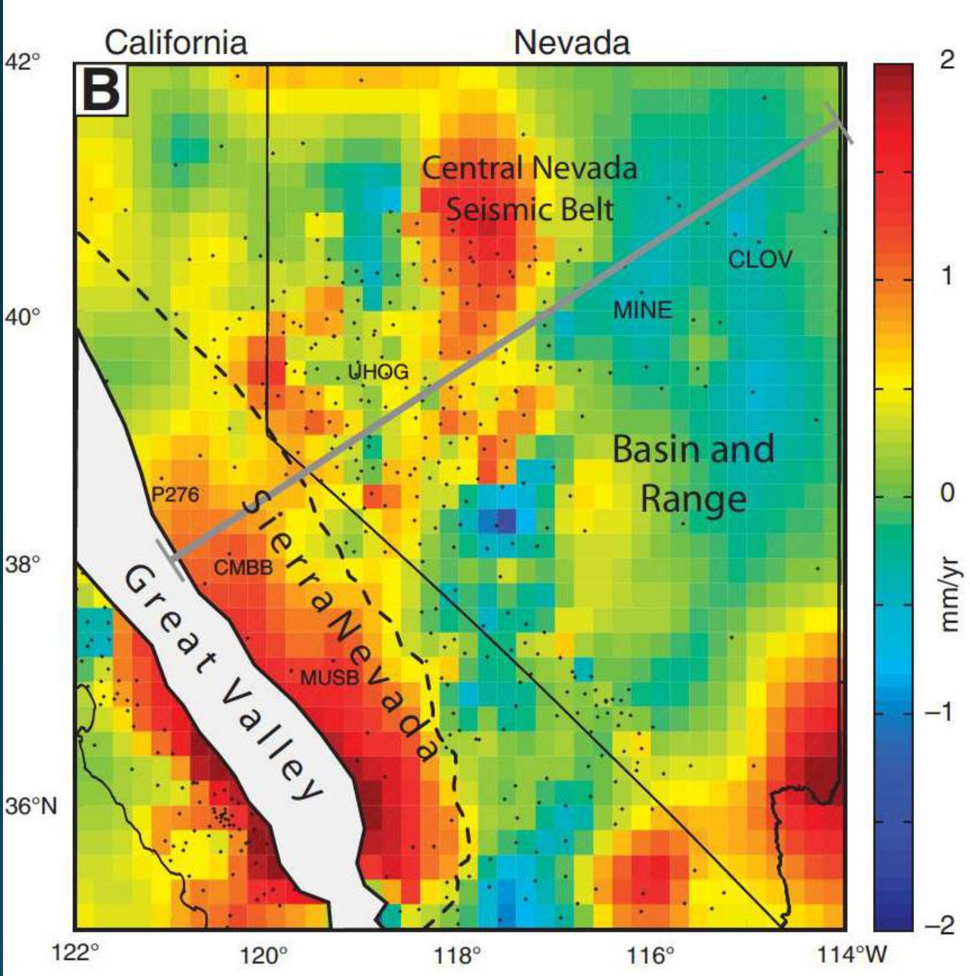


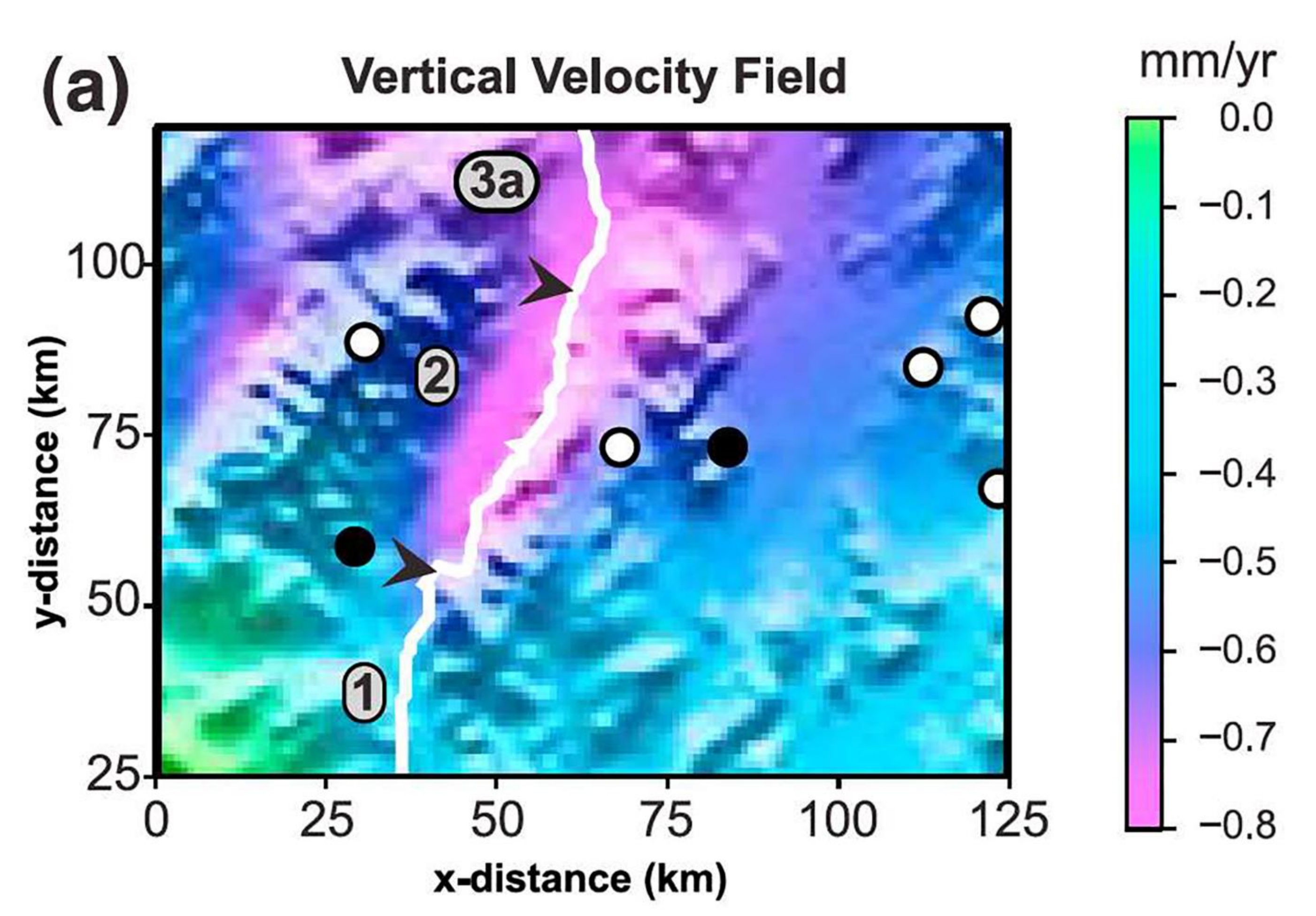
The anisotropy ellipse of Ferrill et al. (1999) is consistent with the regional flow conceptualization herein, while the elevations of the calcite veins of Winograd and Szabo (1988) are suggestive of uplift to the southeast since Pliocene recharge from the southeast can be unequivocally ruled out



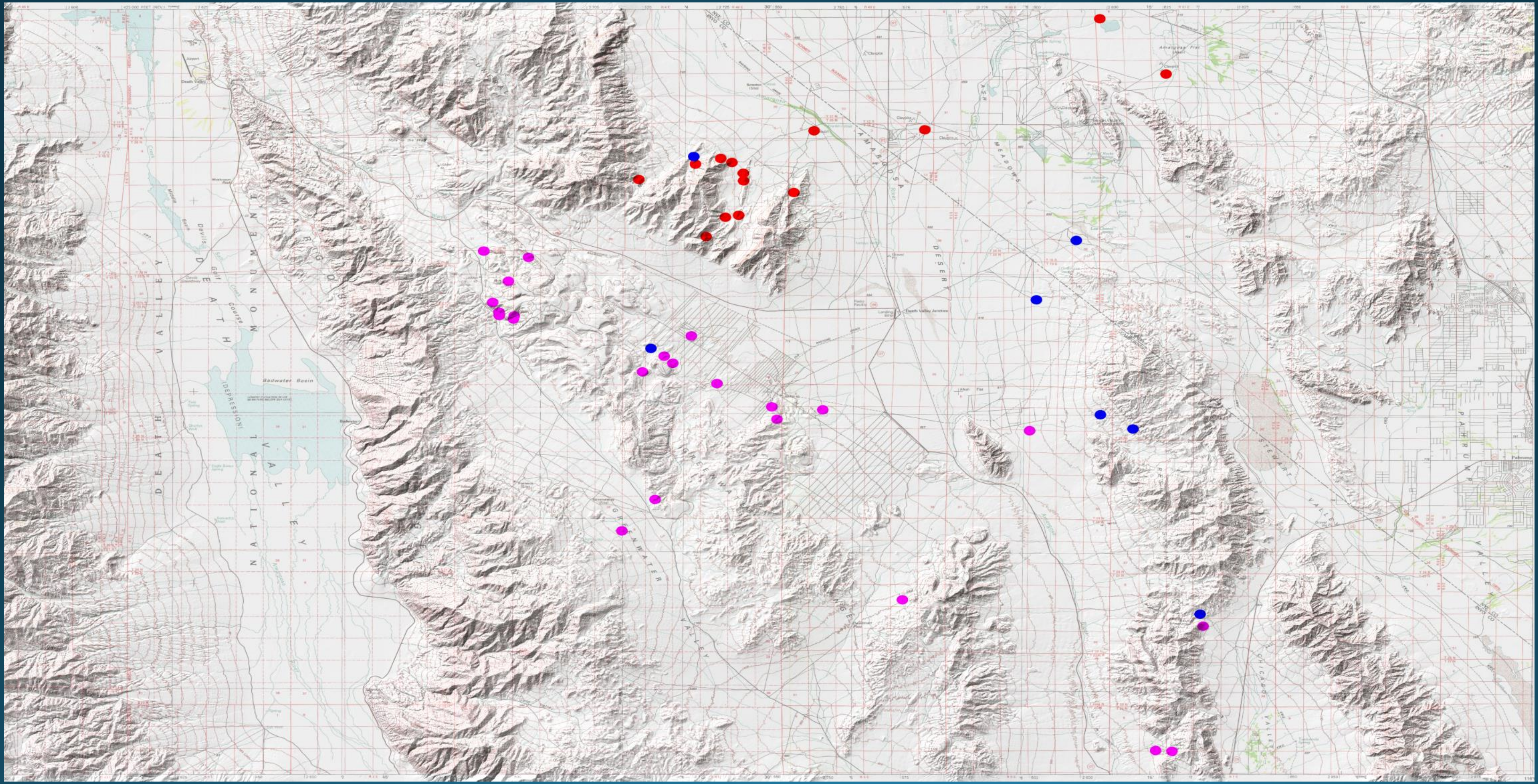


Regional GPS monitoring by Hammond et al. (2012) and geodynamic analyses of Death Valley by Del Pardo et al. (2012) are consistent with ongoing NW tilting of the Amargosa Flats – Ivanpah Upland region (but why no NTS data points?)





I suggest that two regional, Pliocene groundwater flow systems find expression here: evaporation of northeasterly waters evolved though dedolomitization (Back et al., 1983) produced Mg-clays (red dots) while evaporation of high-pCO2 magmatic/hydrothermal waters driven by and mixed with westerly high-terrain recharge produced borates (cyan dots)



To conclude, ponding of groundwater discharge in an embryonic Lake Mead Basin occurred after 6 Ma. Release of energy stored by this natural impoundment was sufficient to excavate Black Canyon as it was uplifted 550 m (1800 ft) from near sea level by 4.4 Ma.

This result begs the question: Can the deformed Ivanpah Upland be recognized in the Ash Meadows / Amargosa Flat area and on the Darwin Plateau beyond to reveal differing tectonic modifications of the same Mio-Pliocene land-surface datum?

- The idea that an anisotropic regional groundwater system analogous to but substantially larger than the vestigial eastern Nevada flow system was instrumental establishing low-elevation paludal deposits in the present-day Ivanpah Upland – Lower Colorado region has yet to gain traction, notwithstanding clear mineralogical evidence, but these paleo-elevation constraints along the Lower Colorado River serve to clarify relations in surrounding areas.
- The Mg-clay beds and surrounding calcite veins at Amargosa Flat are here interpreted to be associated with a remnant of the Ivanpah Upland, clearly owe their origins in large part to evaporation of groundwater discharge, with dedolomitization of the up-gradient carbonate aquifer driven by gypsum dissolution (Back et al., 1983; Plummer et al., 1990) the cause of dissolved Mg enrichment, a necessary precursor to palygorskite and sepiolite precipitation.
- Based on the maximum ages of ash beds in Lake Tecopa and occurrence of sepiolite low in the Tecopa lake beds, precipitation of Mg-clays in Amargosa Flat appears to have ended at about the time the spring-fed, Pleistocene Amargosa River was born
- Neogene groundwater discharge has shifted progressively westward. Extension east of the Spring Mountains had largely ceased by 6 Ma (Wernicke, 1988) and the course of the Lower Colorado River was established by 4.4 Ma.
- A challenge for the future is characterization of the transition from two geochemically distinct Pliocene flow fields, both discharging to the un-extended proto-Furnace Creek Wash area, to the Pleistocene-Recent case where regional groundwater with exclusively northeasterly origins in dolomitic aquifers discharges to the collapsing East California Shear Zone, leaving the paleohydrology of the Death Valley borate beds indeterminate, for now, due to tectonic disruption of candidate recharge areas to the west.

"I told Dallas (Peck) we'd be dancing around in pink tutus if we took that (DOE Yucca Mountain) project"

...Bruce Hanshaw, personal communication to Cady Johnson, Orlando, FL, October 14, 1985

And what a dance it was. *Importantly*, we still suffer the consequences of biased work products that were developed to support this mission-oriented charade: **no recharge area, no heat, no anisotropy, and no alternative, detachment-dominated framework (!)**

Best science? DOE's utilization of the DVRFS conceptualization for Repository licensing is sufficient basis to consider disqualification of this deliberately unconstrained and over-prescribed model for any science-based water-resource study of the region.

Nevada State Engineer take note!