SITING OF LARGE VOLCANIC CENTERS AT RELEASING FAULT STEPOVERS, WALKER LANE RIFT

with emphasis on the Central Sierra Nevada Area, to complement field guide for daytrip to Sonora Pass

Pdf version of powerpoint lecture prepared for the National Association of Geoscience Teachers
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TWO MAJOR QUESTIONS:

1. When did the Sierra Nevada microplate begin to form?

Part I - Geologic signals of transtension in the Walker Lane belt.

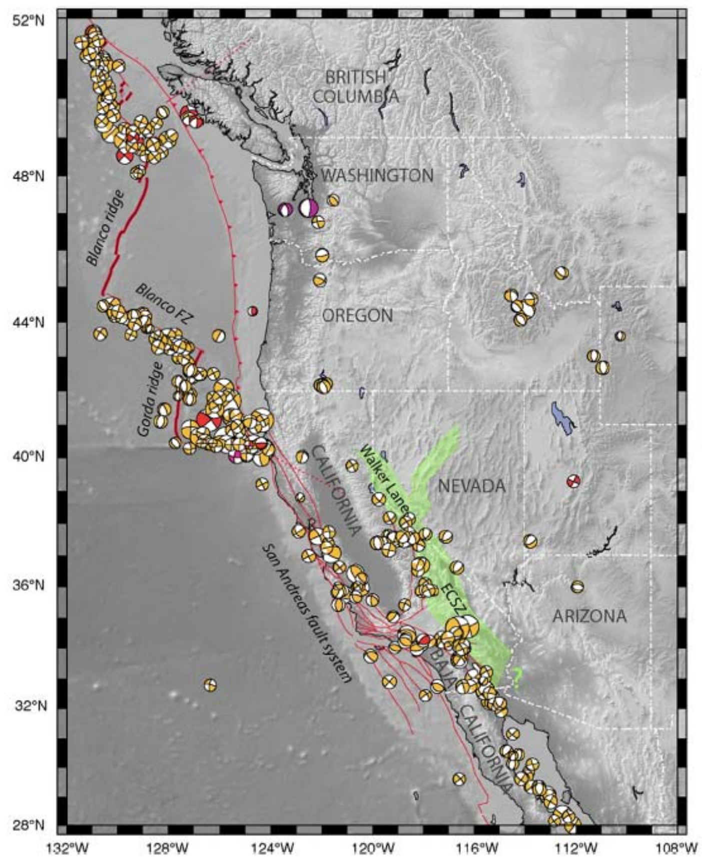
2. What is the uplift history of the Sierra Nevada?

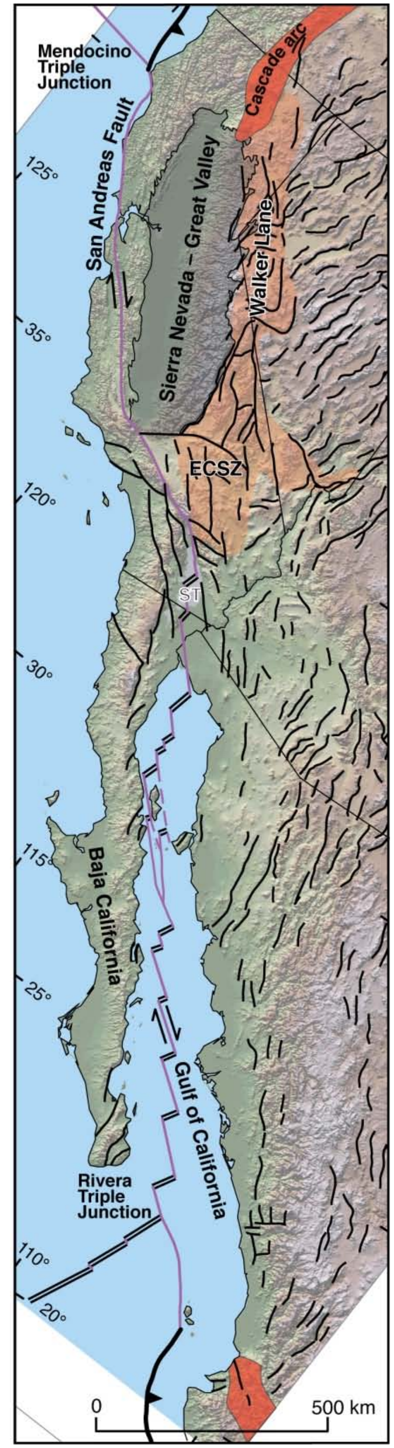
Part II - The record of Cenozoic paleo-channel fills.

What is the Walker Lane belt?

Dextral transtensional eastern boundary of the Sierran microplate, currently accommodates 20-25% of the plate motion between the Pacific and the North American plates:

INCIPIENT PLATE BOUNDARY.





Unruh et al., 2003; McCrory et al., 2009; Faulds and Henry, 2008.

Time- and space-transgressive processes can be observed from post breakup (Gulf of California in south)
to new rift (Salton Trough and its geothermal fields)
to RIFT INTIATION: Walker Lane Belt in north

Walker Lane Belt

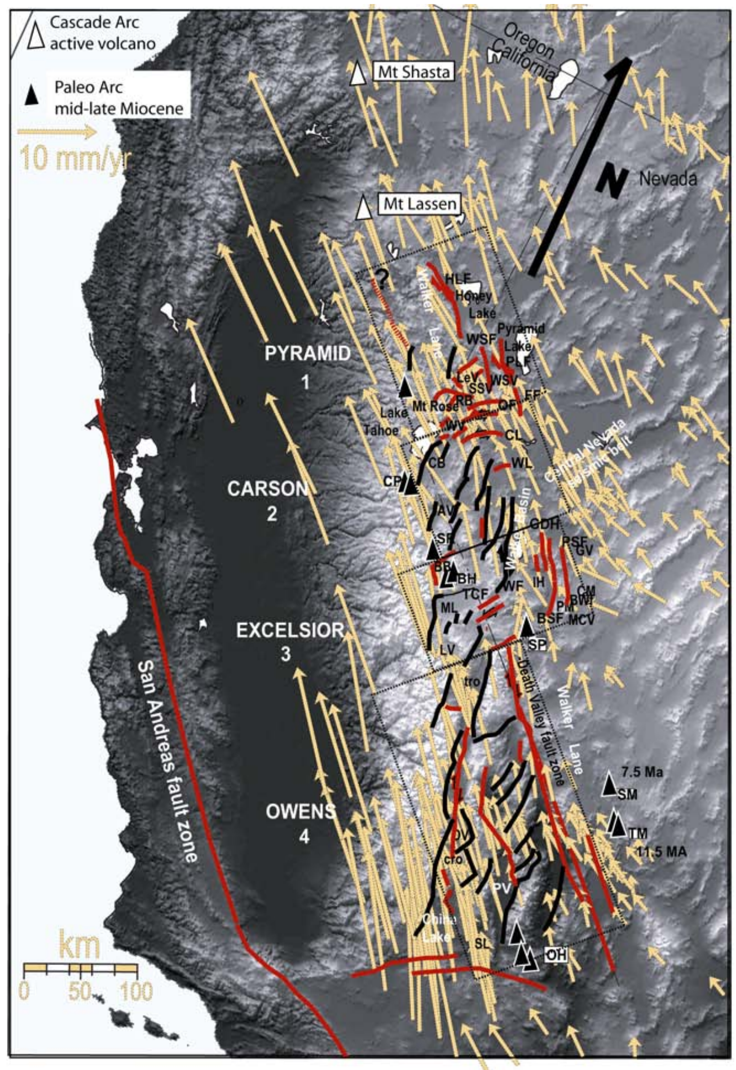
short NE oblique slip normal faults (BLACK)

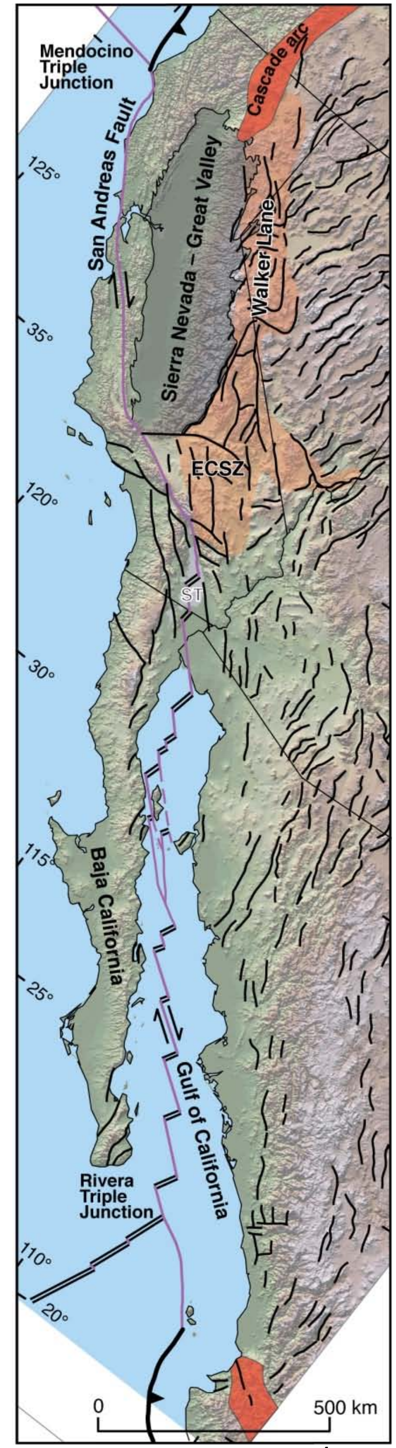
are connected by long NNW dextral faults (RED)

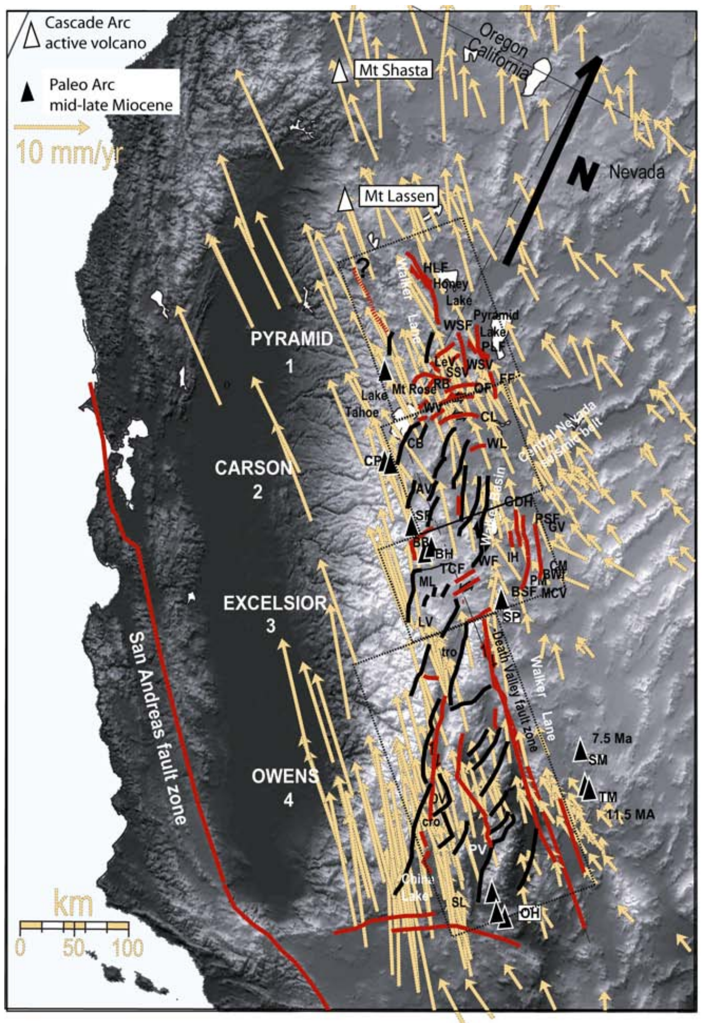
(note: yellow = GPS vectors)

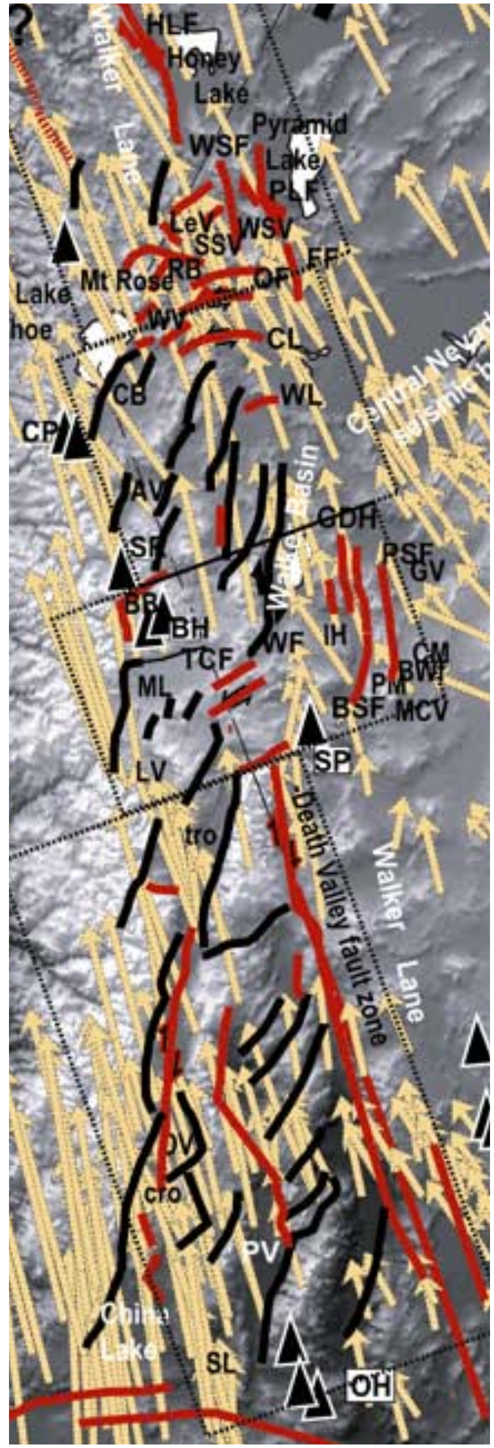
…like Gulf of California, but no sea floor spreading yet.

Jayko and Bursik, in press; Faulds and Henry, 2008)





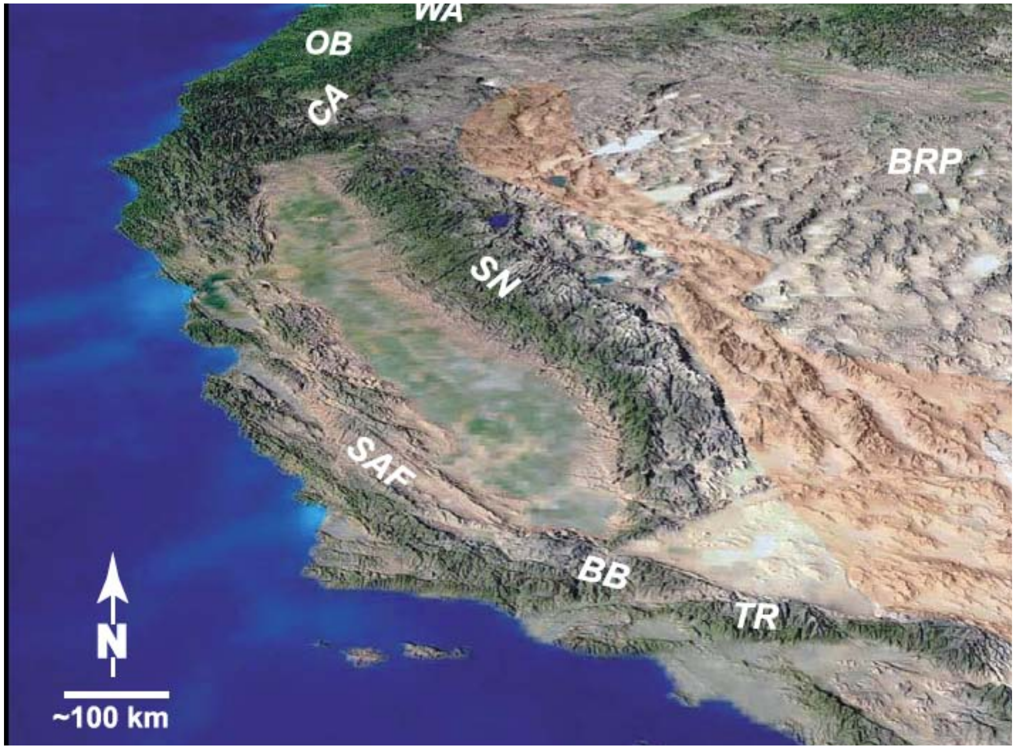




I nominate the CENTRAL part of the Walker Lane Belt "MOST LIKELY TO SUCCEED" first, because:

It has the structure that is the most similar to Gulf of California transtensional rift basins:

1. NNW strike slip motion and E-W to ESE-WNW extension are partitioned .
2. Normal faults (black) are abundant, and strike slip faults (red) are short. (Wesnousky. 2005; Surpless, 2008; Jayko and Bursik, in press



Faulds and Henry (2008) did not include central Sierra Nevada range front (gray) in Walker Lane (peach)….

but our new structural work between Mono and Tahoe basins

and work by Jayko and Bursik from Mono to Long Valley (2012)

show it is transtensional = WALKER LANE

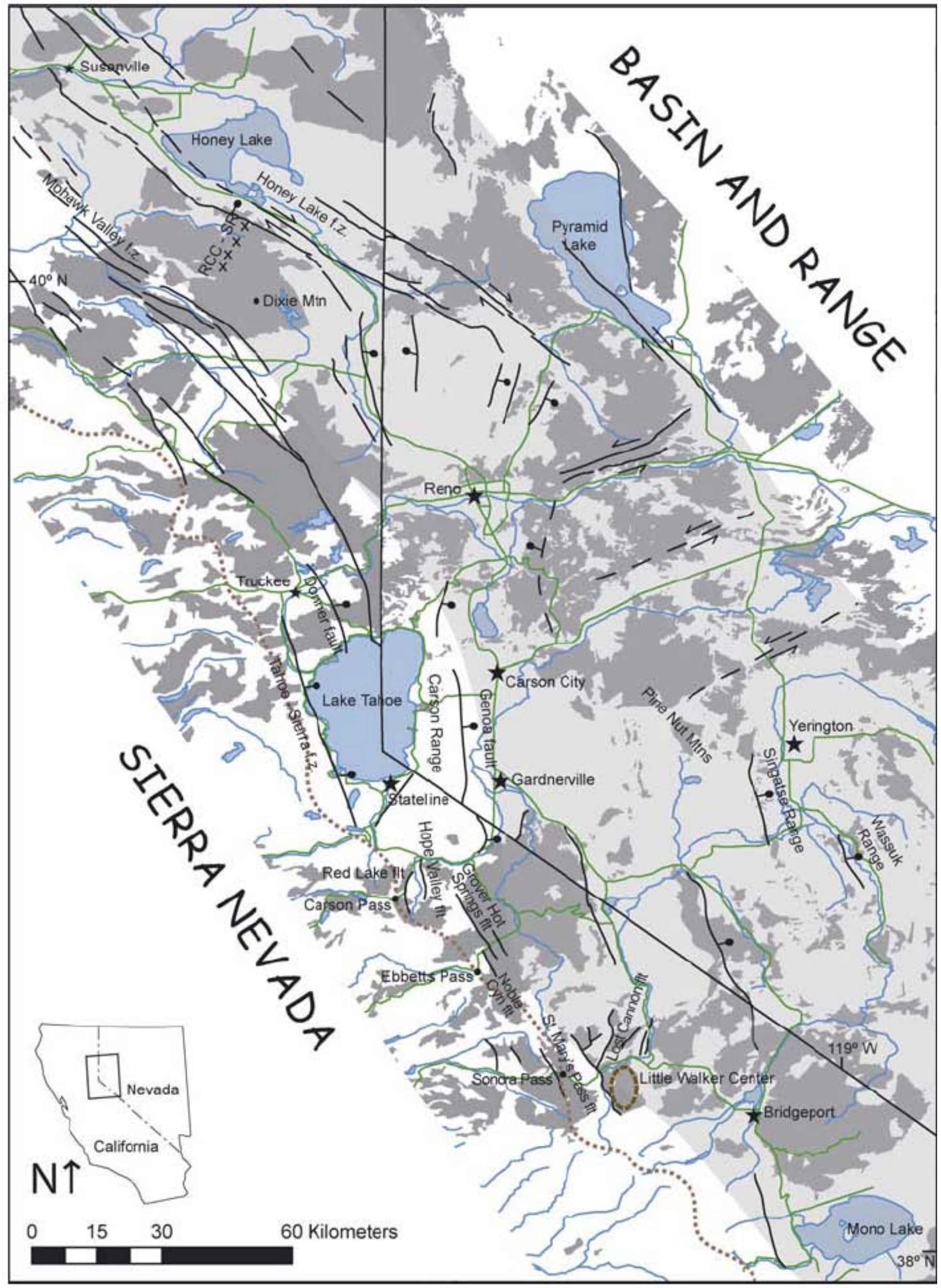
CENTRAL part of the Walker Lane Belt "MOST LIKELY TO SUCCEED" first (continued)…..

II. It has abundant Late Cenozoic to Holocene volcanic rocks (shown in gray):

A signal of rifting.

Also good for dating structures and clockwise rotations!

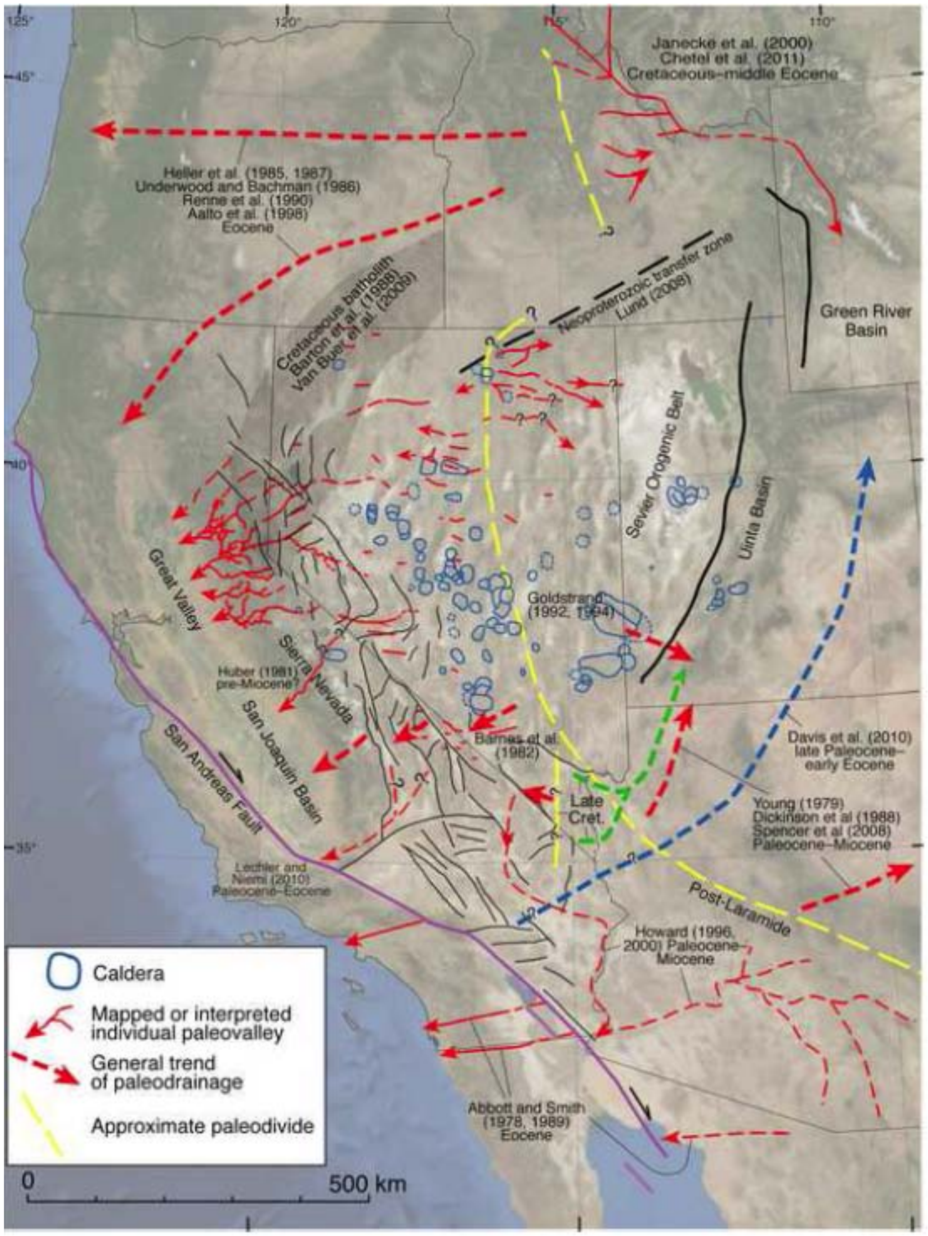
The Tahoe graben, Walker Lane belt - home of the newly discovered Polaris strike slip fault (Howle et al., 2009).



(Busby and Putirka, 2009)

The Nevadaplano

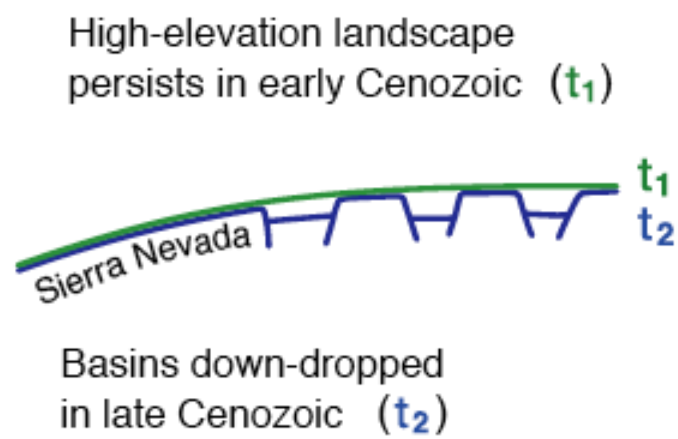
Henry et al., in press, Geosphere special issue



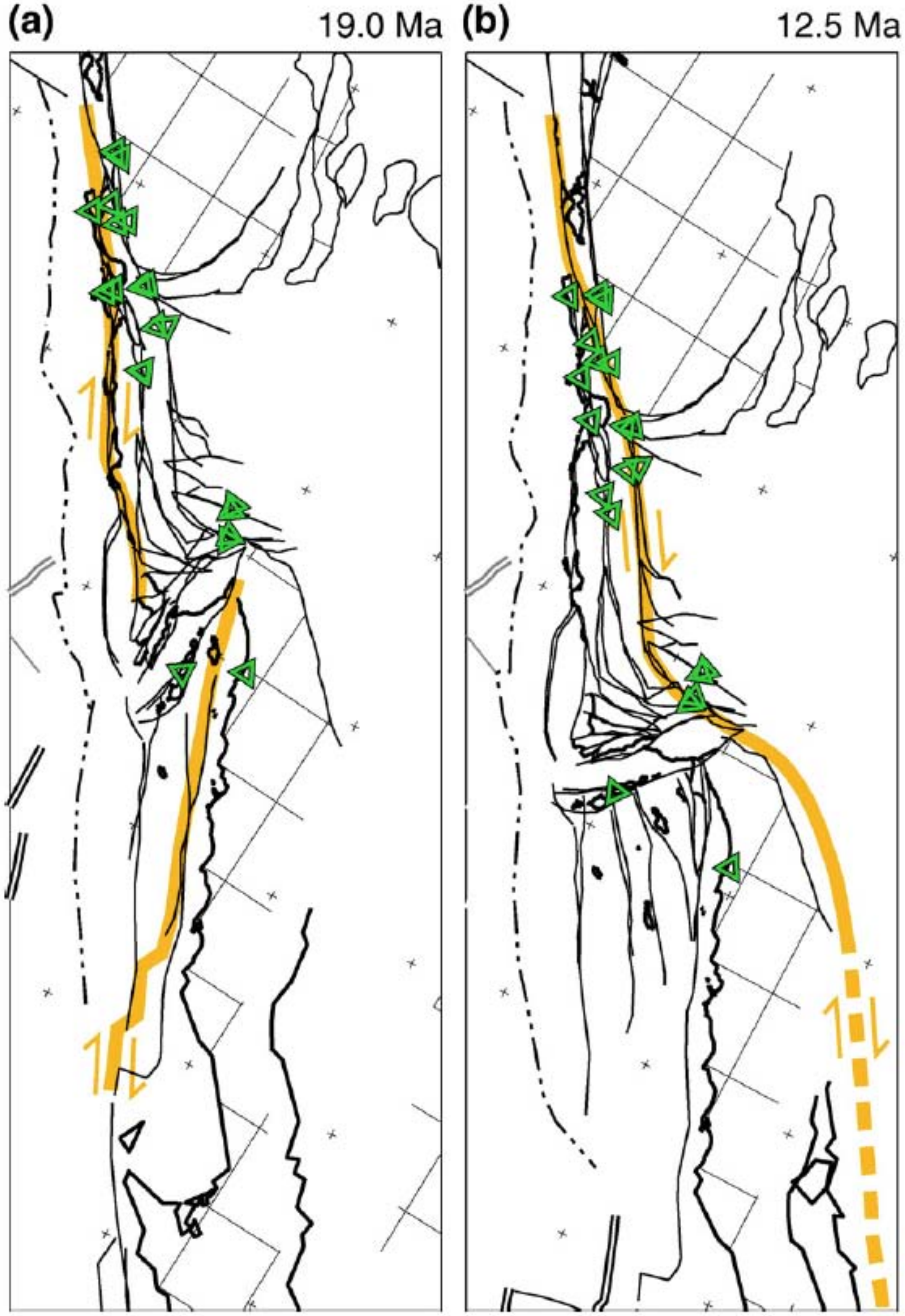
Umhoefer (November 2011 GSA Today) points out that that Gulf of California rifting was unusually FAST.

For one thing, there's no evidence of a "Nevadaplano" in Mexico, so the crust did not have to be thinned as much

….but also….



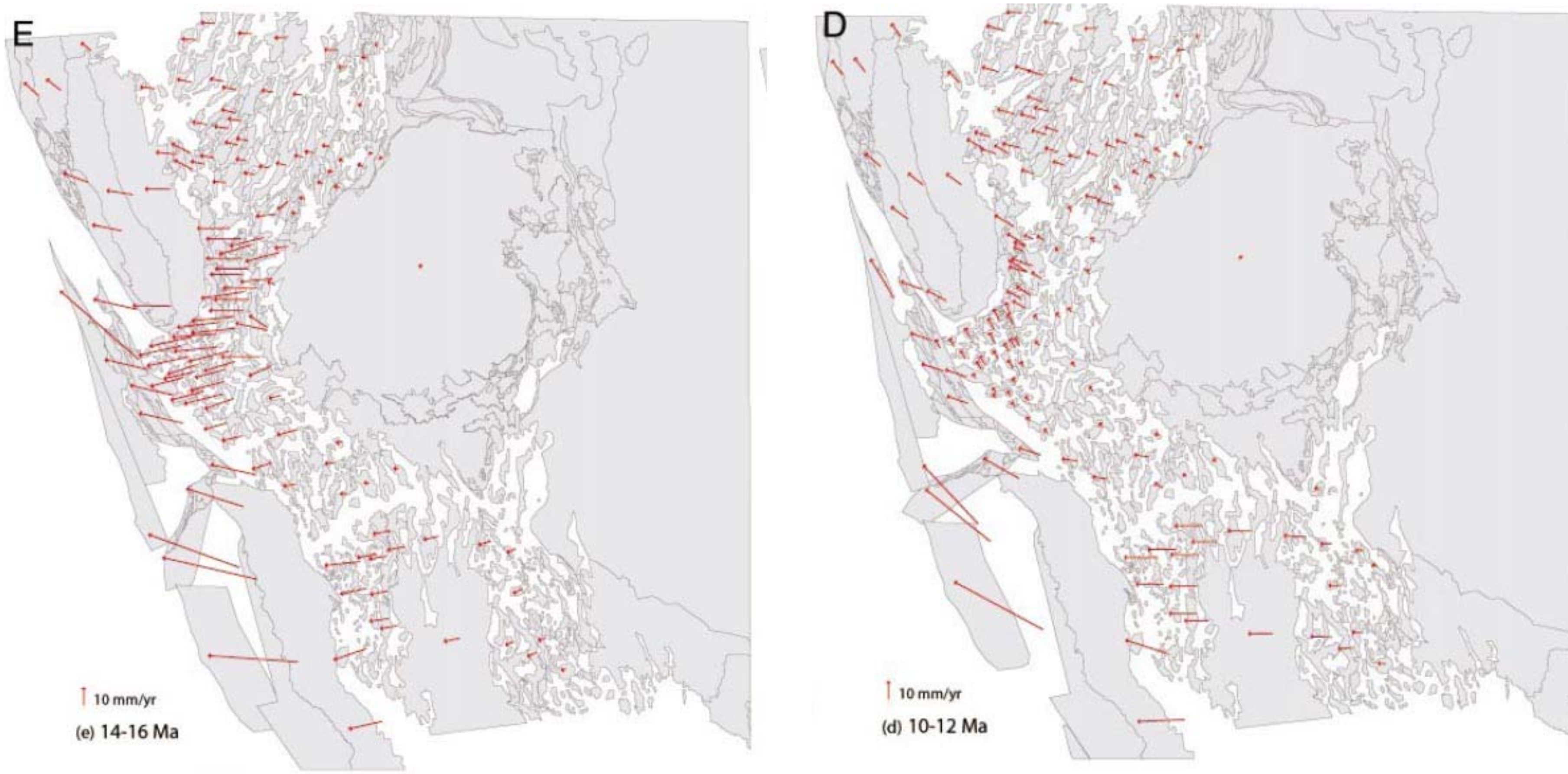
(Busby and Putirka, 2009)



… the capture of the much larger Guadalupe-Magdalena microplates off Baja resulted in a much bigger chunk of the margin being transferred (RIGHT) than the capture of the little Monterrey microplate did (LEFT) …

McCrory et al., 2009

Both Baja and the Sierran microplate assumed a more northward trajectory by ~12 Ma, concurrent with the same change in the motion of the Pacific plate. (McQuarrie and Wernicke, 2005)



From 12 Ma to present, this has produced LARGE VOLCANIC CENTERS IN TRANSTENSIONAL PULL-APARTS along the eastern margin of the Sierra Nevada: THE GEOLOGIC SIGNAL

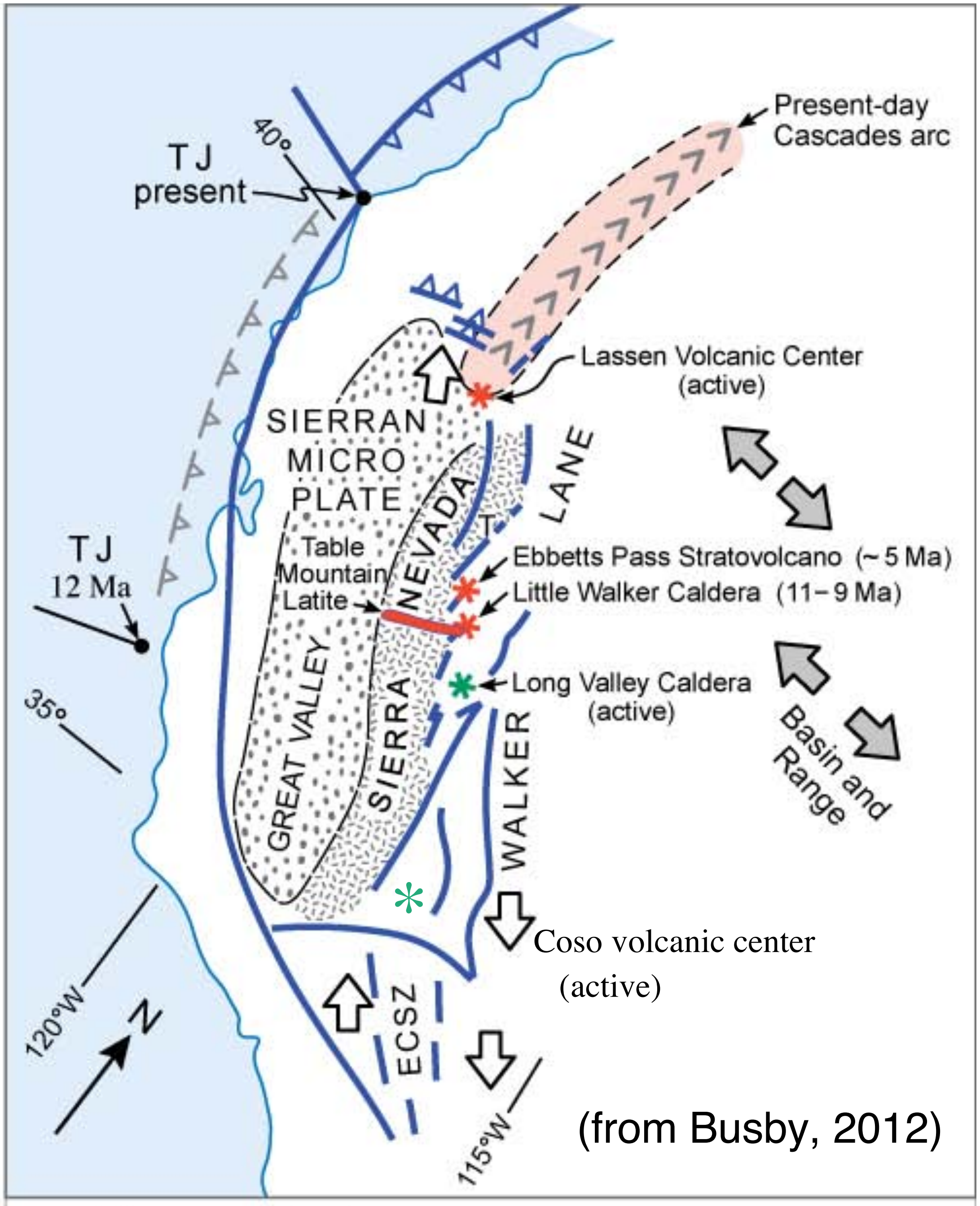
GEOLOGIC SIGNALS OF

TRANSTENSIONAL CONTINENTAL RIFTING

(1) Development of very large volcanic centers at transtensional fault stepovers along eastern margin of Sierra Nevada microplate.

Have only been identified in the past several years!

Sonora Pass

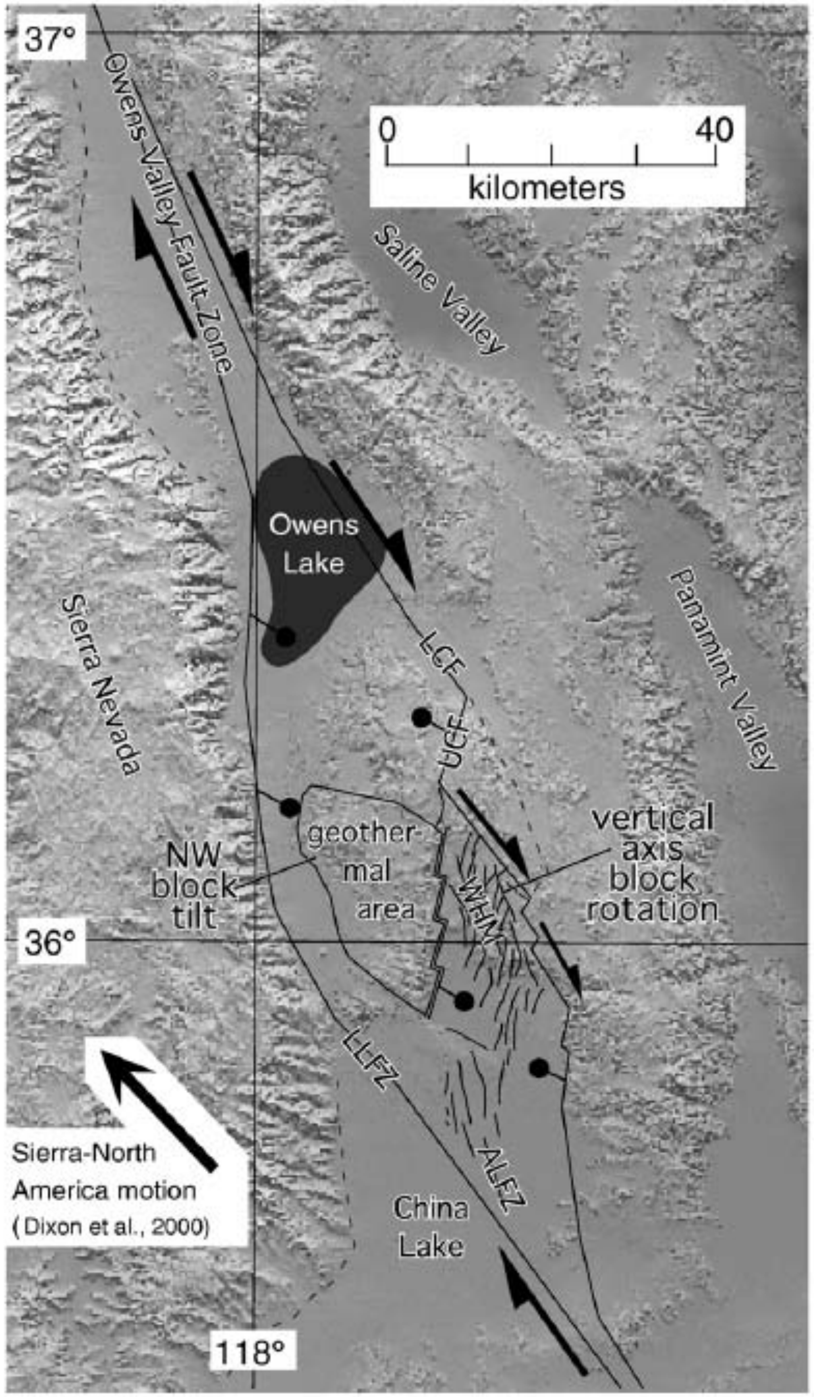


ACTIVE very large volcanic centers in trantensional settings:

- Lassen arc volcanic center (Muffler and others)
- Long Valley rift volcanic center (Bursik, 2008)
- Coso rift volcanic center (Pluhar et al., 2006)

MIOCENE AND PLIOCENE CENTERS we have discovered:

- "Little Walker volcanic center": Ancestral Cascades arc, 12 - 9 Ma
- Ebbetts Pass volcanic center: Ancestral Cascades arc/rift transition, 6 - 4 Ma



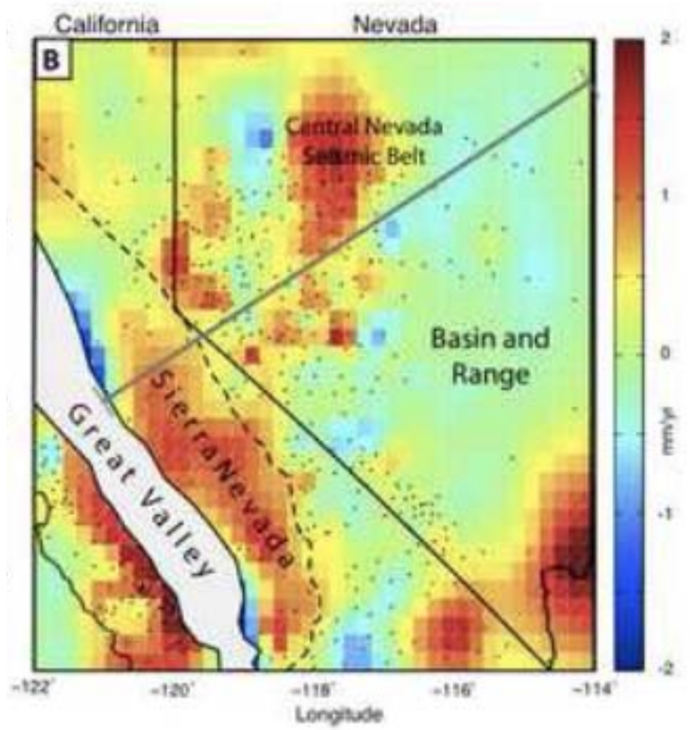
ACTIVE very large volcanic centers in trantensional settings:

Coso volcanic center:

Large-scale, transtensional, dextral releasing step over.

Paleomagnetics of Pliocene lava and sediments show clockwise vertical axis rotations, plus 13-25% extension.

Pluhar et al., 2006, EPSL



NOTE BLUE BLOB AT COSO: it's going DOWN.

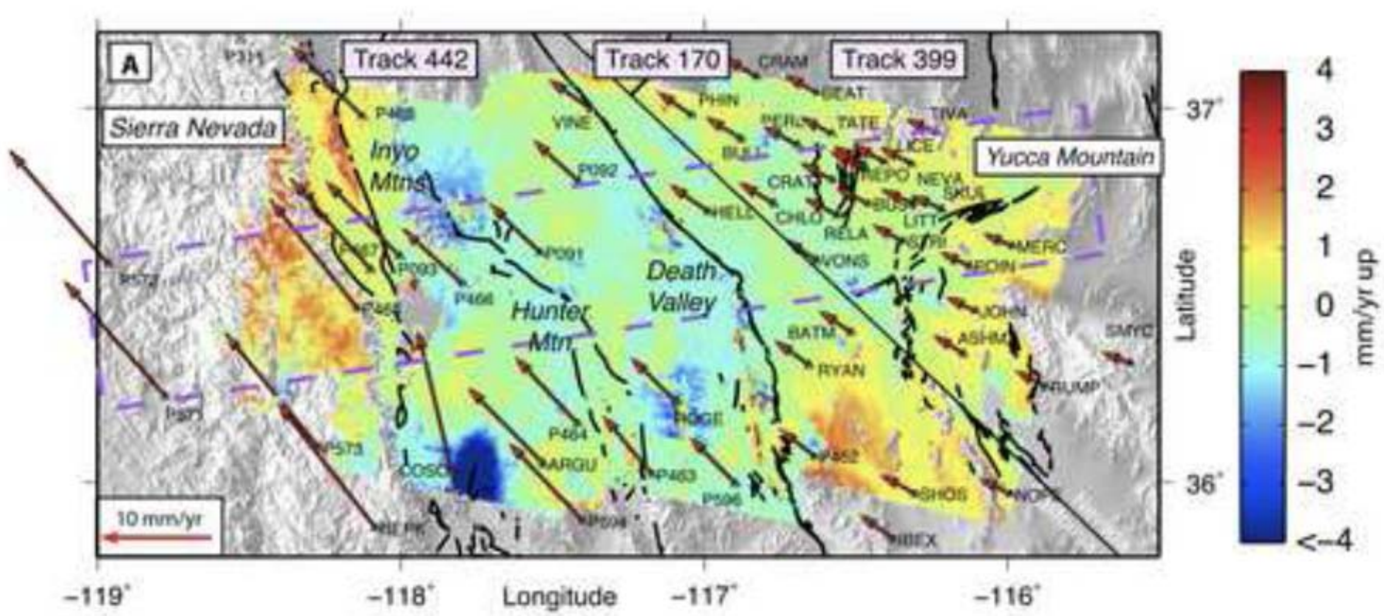
Vertical GPS velocity (top).

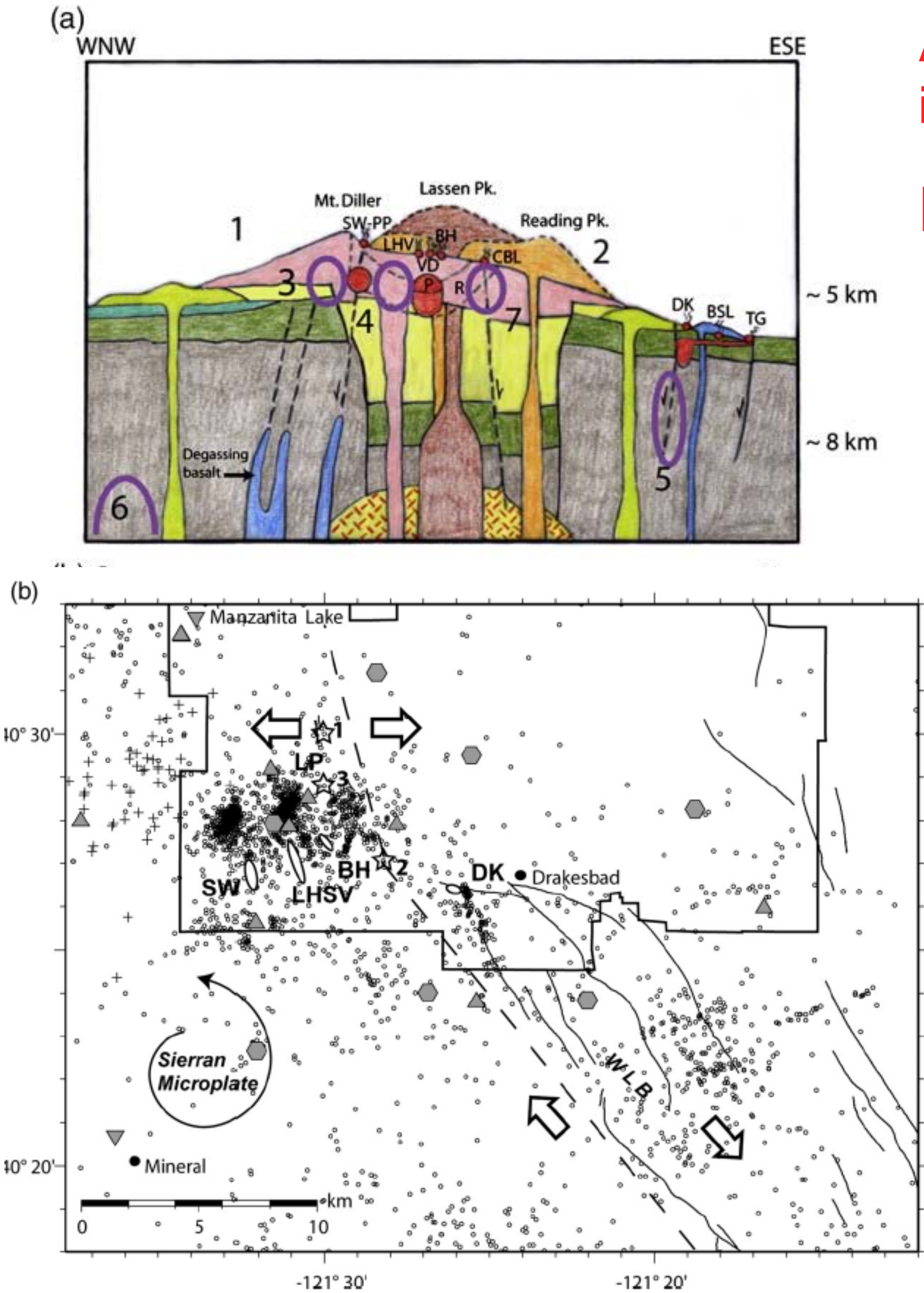
Vertical velocity from InSAR (below).

Hammond et al., Contemporary uplift of the Sierra Nevada, western U.S., from InSAR and GPS measurements: Geology, 2012.

We'll get back to the RED over the Sierra later.

Arrows show horizontal velocity from GPS.





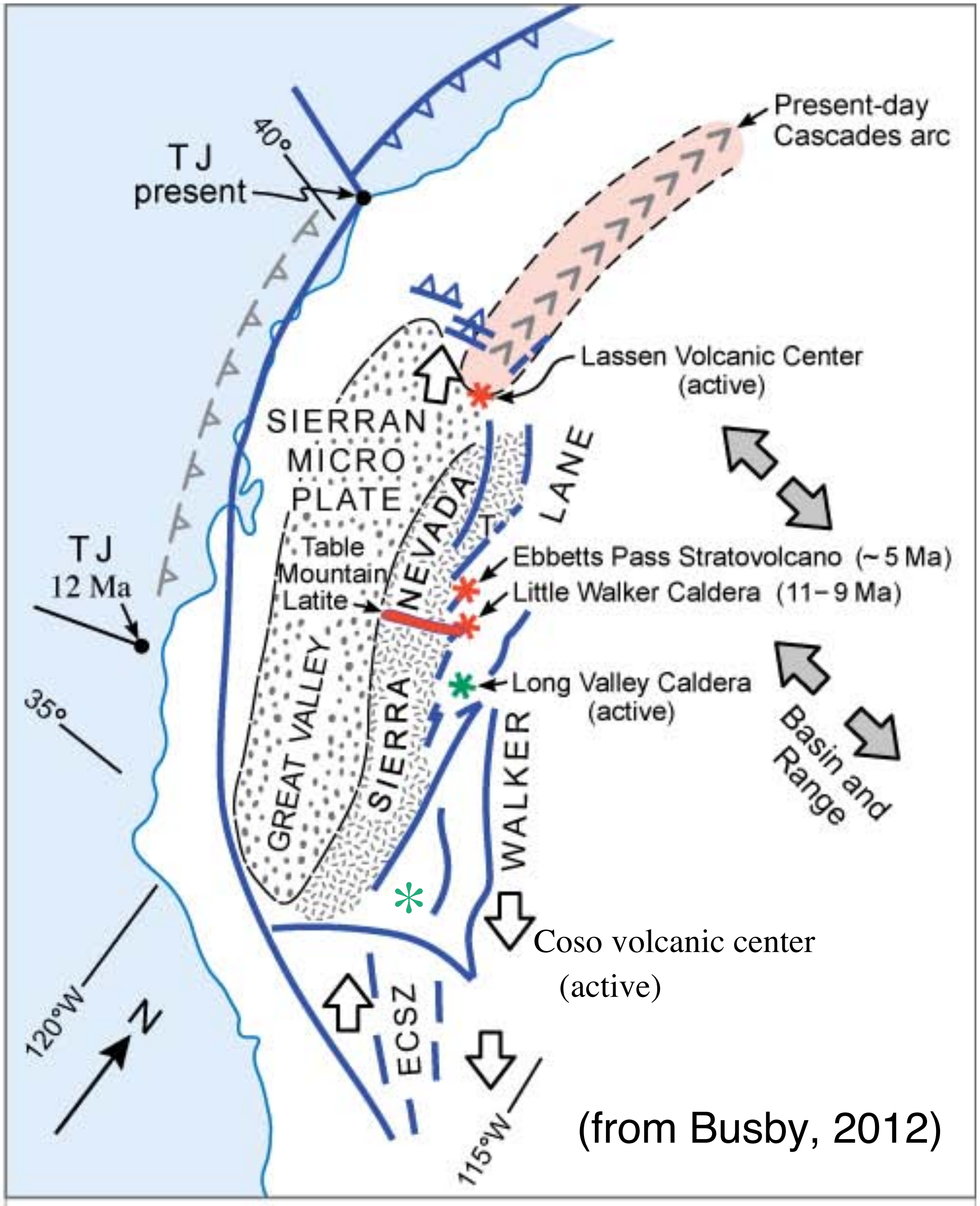
ACTIVE very large volcanic centers in trantensional settings:

LASSEN

"Beginning at 3.5 Ma, the northern Walker Lane increasingly interacted with the Cascade subduction zone to produce transtensional environments favorable to the development of major volcanic centers"

(Muffler, Blakely and Clynne, 2008 and in prep).

Pronounced linear alignments of volcanic vents, seismicity, and a gravity low (Janik and MacLaren, 2010).



ACTIVE very large volcanic centers in trantensional settings:

We'll talk about

* Long Valley rift volcanic center (Bursik, 2008)

to compare to a

MIOCENE CENTER we have discovered:

* "Little Walker volcanic center": Ancestral Cascades arc, 12 - 9 Ma

INCLUDES SONORA PASS AREA

GEOLOGIC SIGNALS OF

TRANSTENSIONAL CONTINENTAL RIFTING

(1) Development of large volcanic centers at sites of maximum displacement on releasing transtensional stepover faults.

(2) Extreme effusive eruptions along fault-controlled fissures, including *intermediate-composition* fissure eruptions of “flood lava”.

The 12 Ma BIRTH OF THE PLATE BOUNDARY

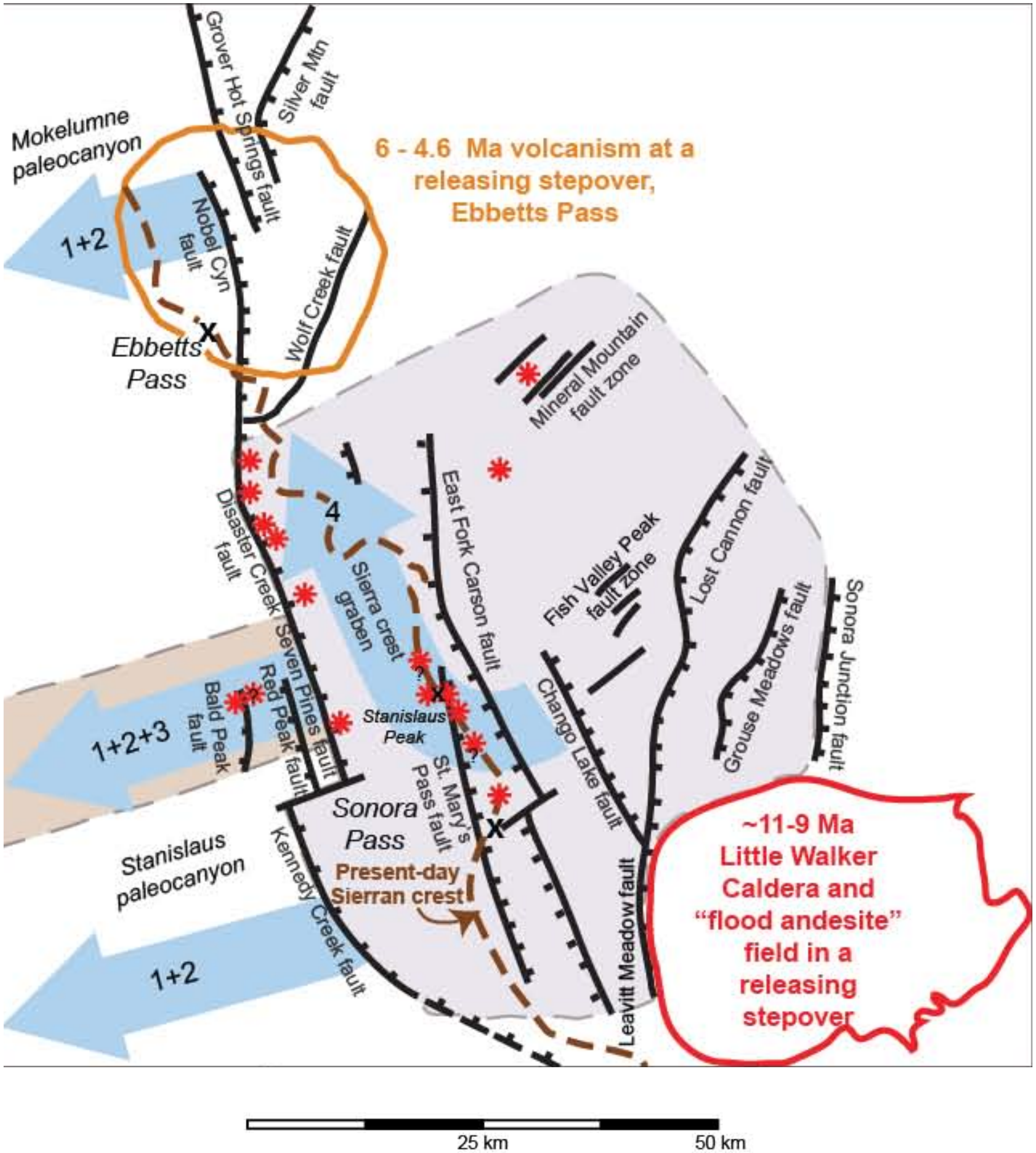
was signaled by development of the

HUGE, newly recognized

“LITTLE WALKER VOLCANIC CENTER”

in a Walker Lane pull-apart system

within the Ancestral Cascades arc



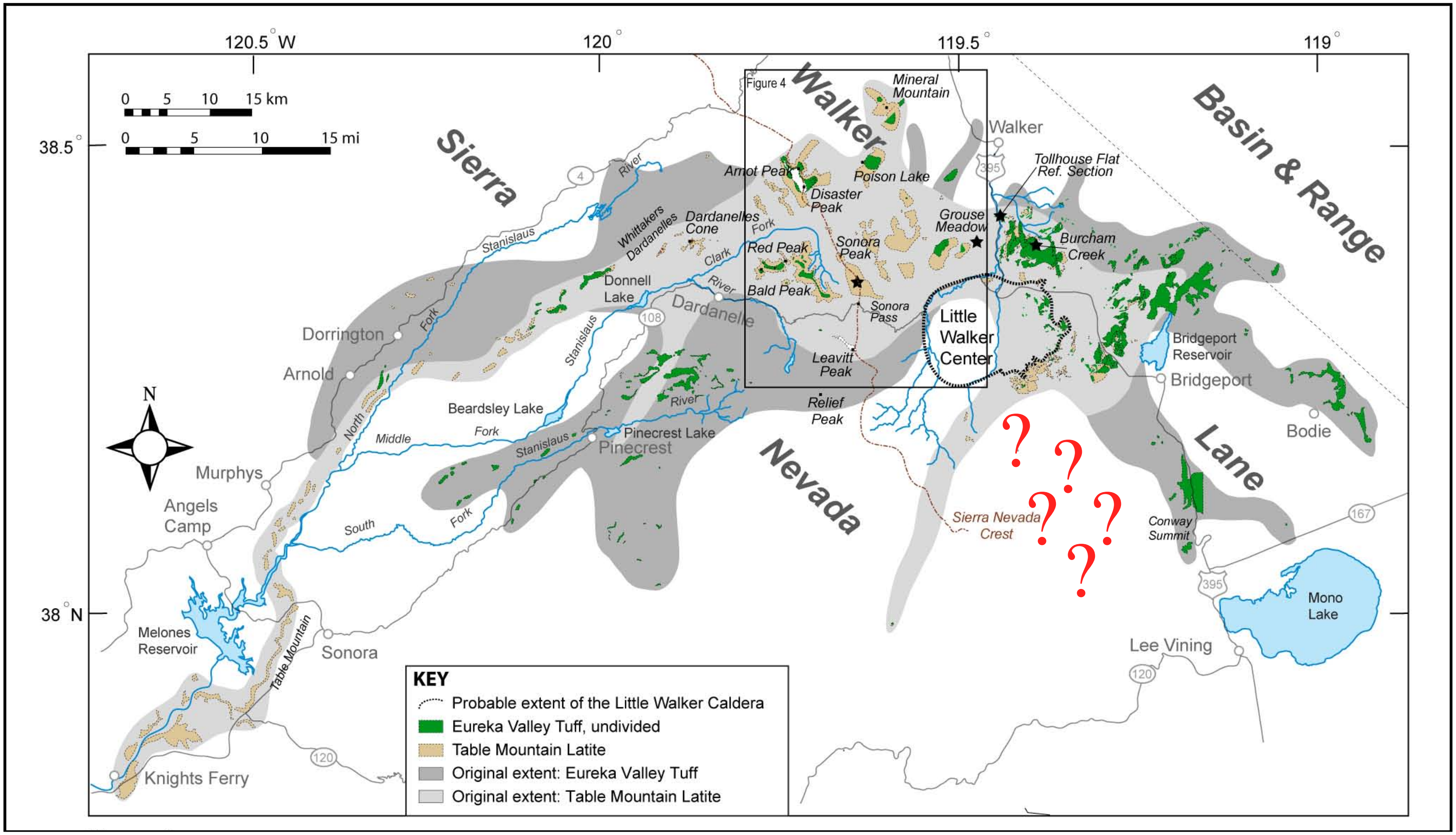
Newly-recognized "Little Walker volcanic center"

The Little Walker caldera has long been known (Priest, 1979)

but our new mapping, dating and geochemical work shows that it forms a SMALL part of a MUCH MUCH LARGER

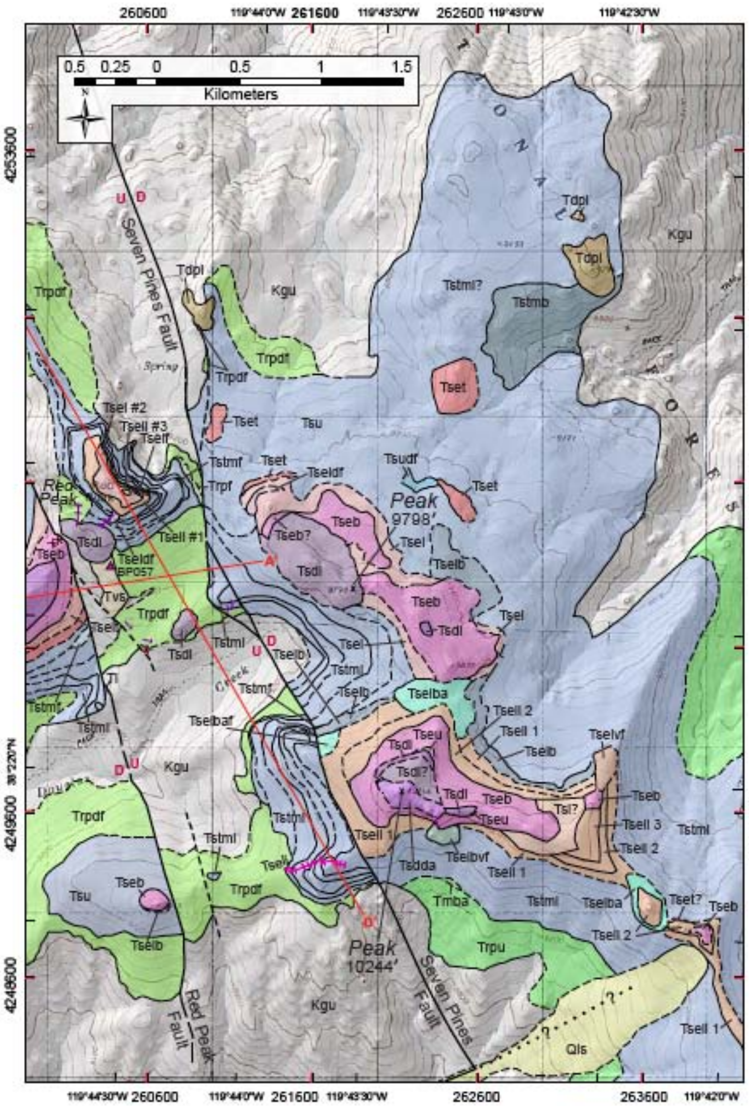
Vents for this COMPOSITIONALLY DISTINCTIVE HIGH K VOLCANIC FIELD cover an area of at least 250 km (shown at left), and probably double that……..

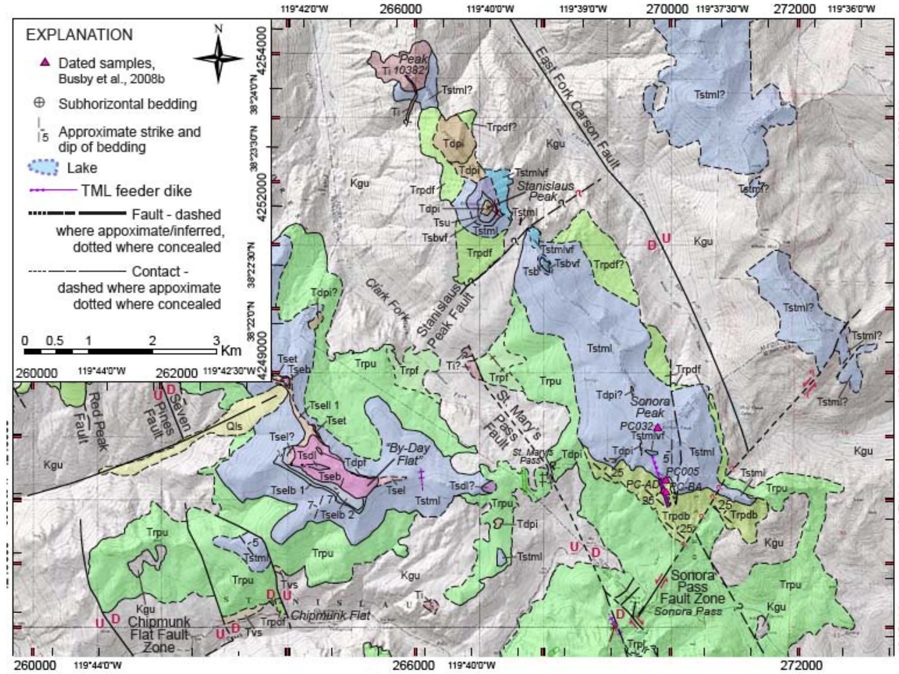
.....because the southern half now is now buried under Bridgeport basin.

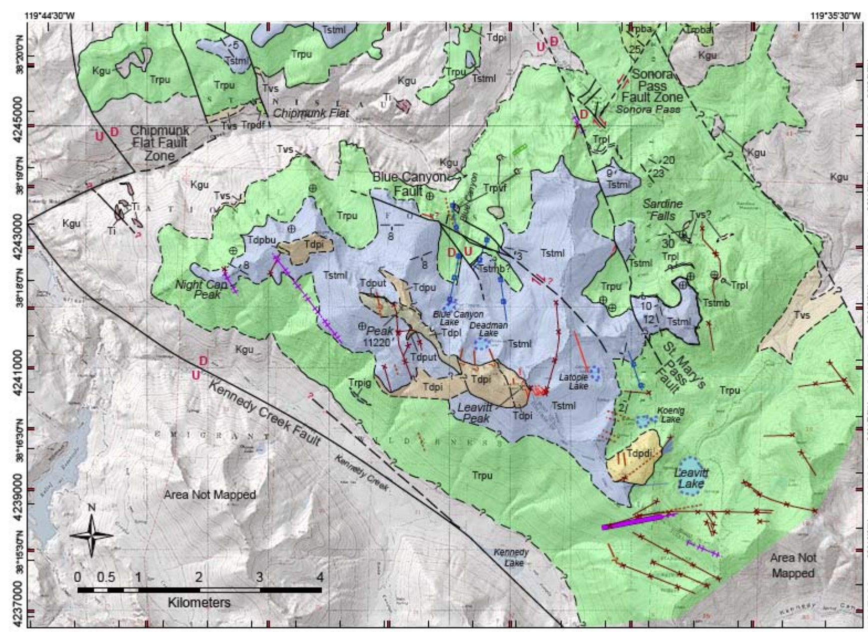


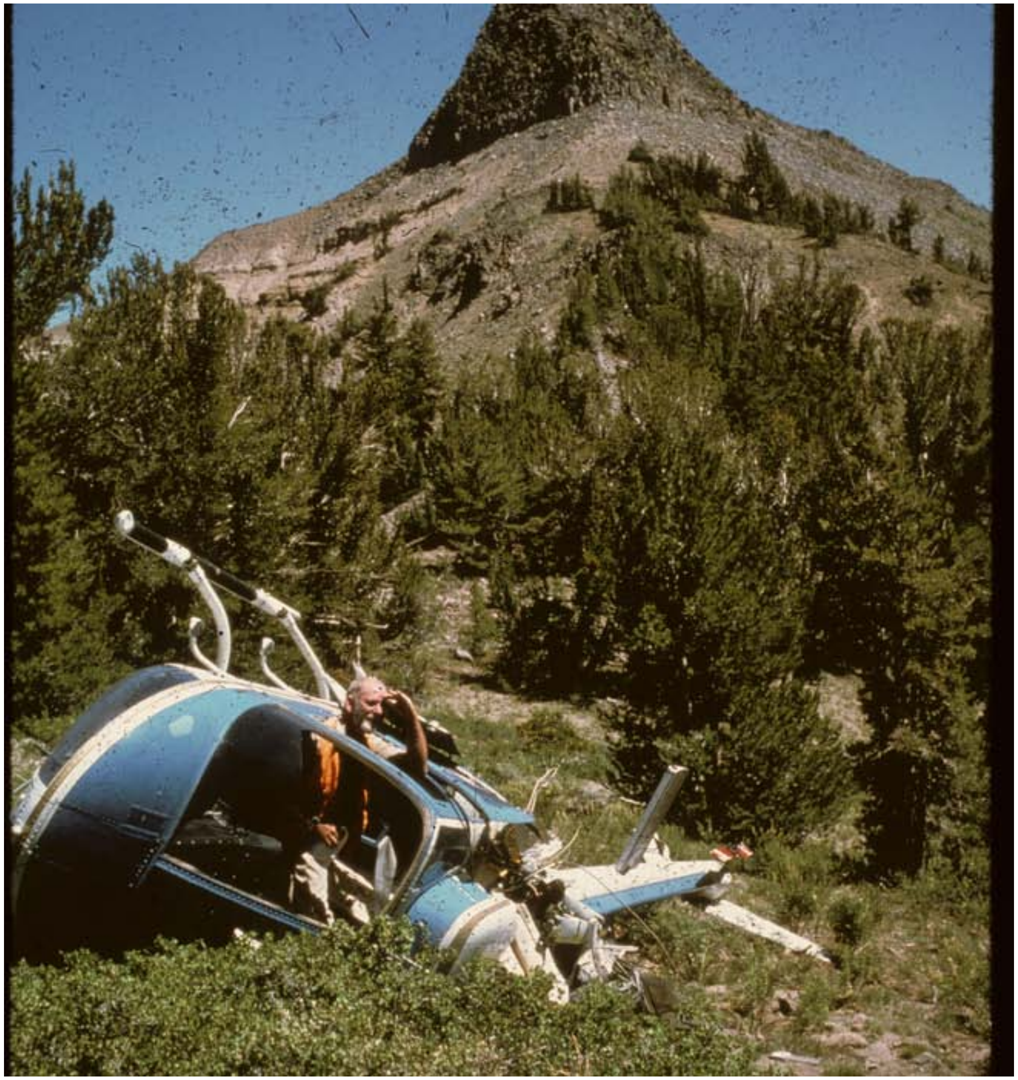
Boxed in area: our new detailed maps of the Carson-Iceberg Wilderness and adjoining areas, being published in a series of papers.

This work is based on 10 years of geologic mapping with my students……







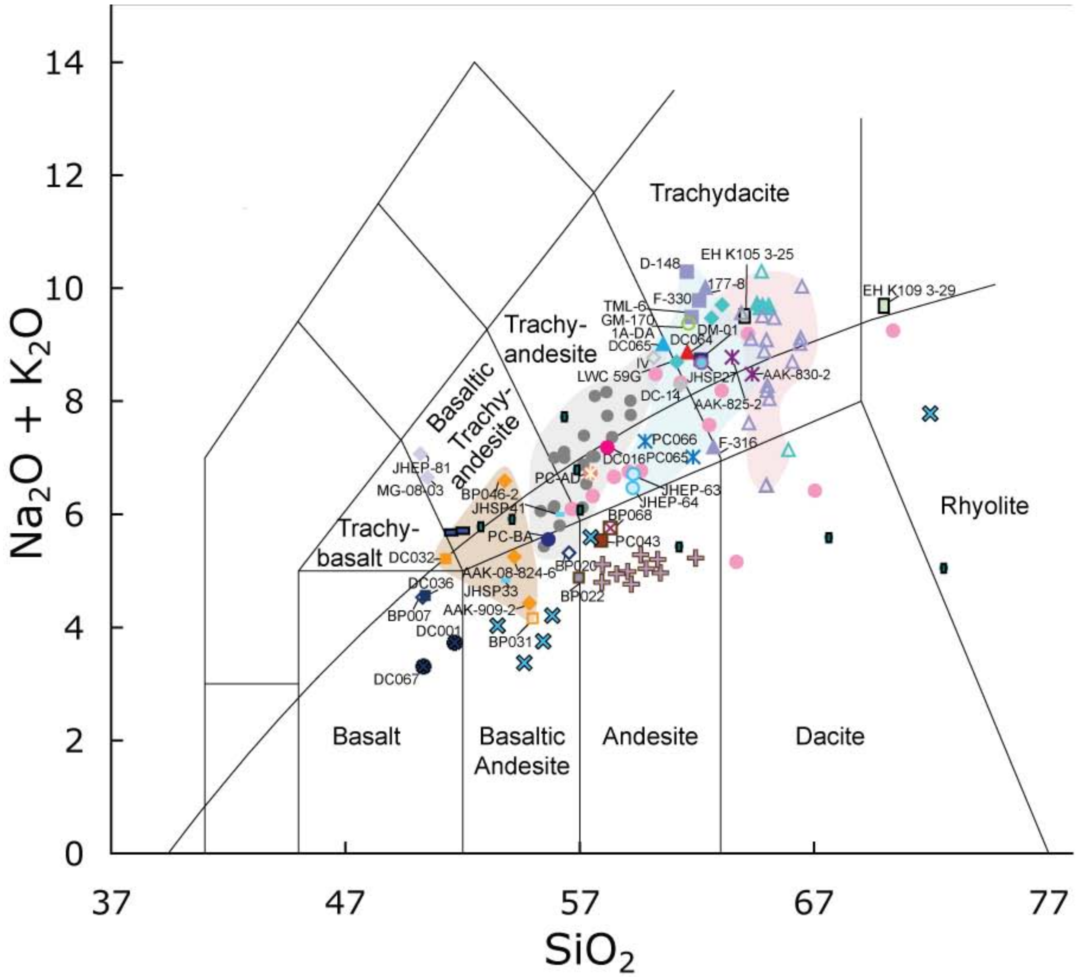


Previous mapping of the Carson Iceberg Wilderness(in 1970’s) was done by helicopter day trips (photo courtesy of George Bergantz).

Before that, it was done by day hikes in the 1950’s, by Berkeley PhD candidates Garniss Curtis and Burt Slemmons (shown here on a 2005 field trip I ran).

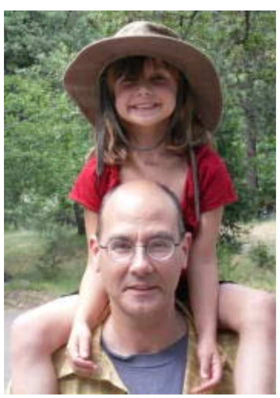
Our detailed mapping was done by backpacking or by establishing back-country camps with pack animals.

Jeanette Hagan, B.S., Cal Tech 2002, who got her PhD with me in 2010; currently at Exxon Mobil, Houston.

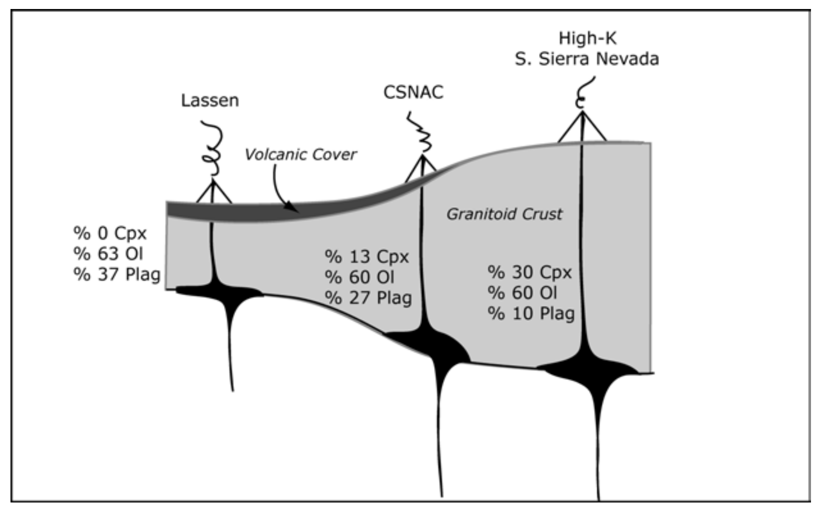


This work is also based on over a decade of collection of geochemical and petrographic data, with Keith Putirka (CSU Fresno).

“Typical” calc-alkaline arc volcanic rocks were erupted before and after growth of the HIGH-K “Little Walker Volcanic Center” ….



…produced by eruption of low-F melts trapped by a thick crustal column and unleashed by transtension at ~12 - 9 Ma.



(Putirka and Busby, Geology, 2007)

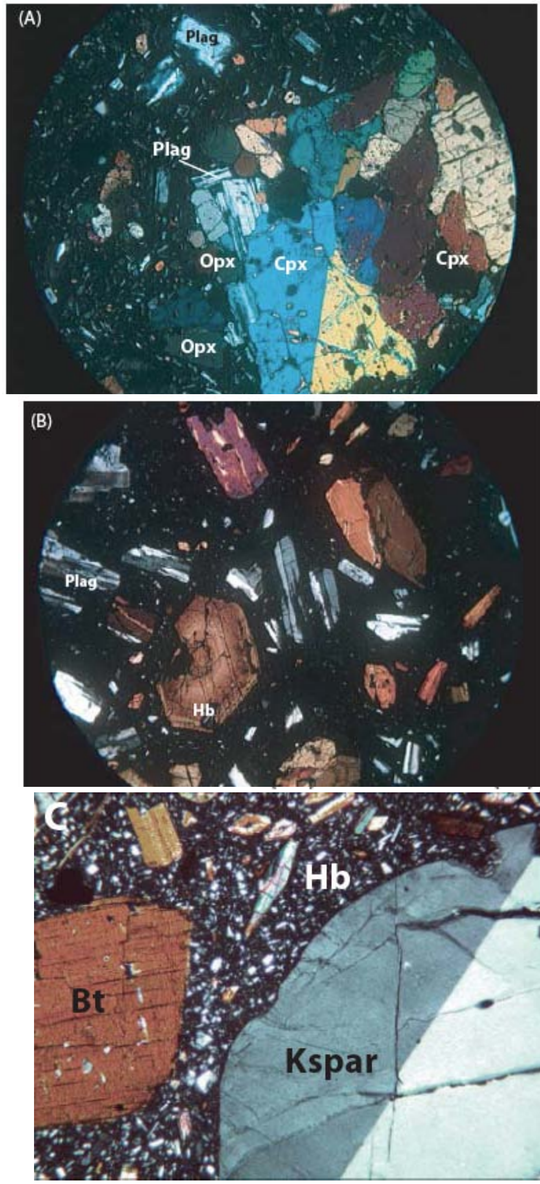
Typical Ancestral Cascades arc: andesites, basaltic andesites, and lesser dacites

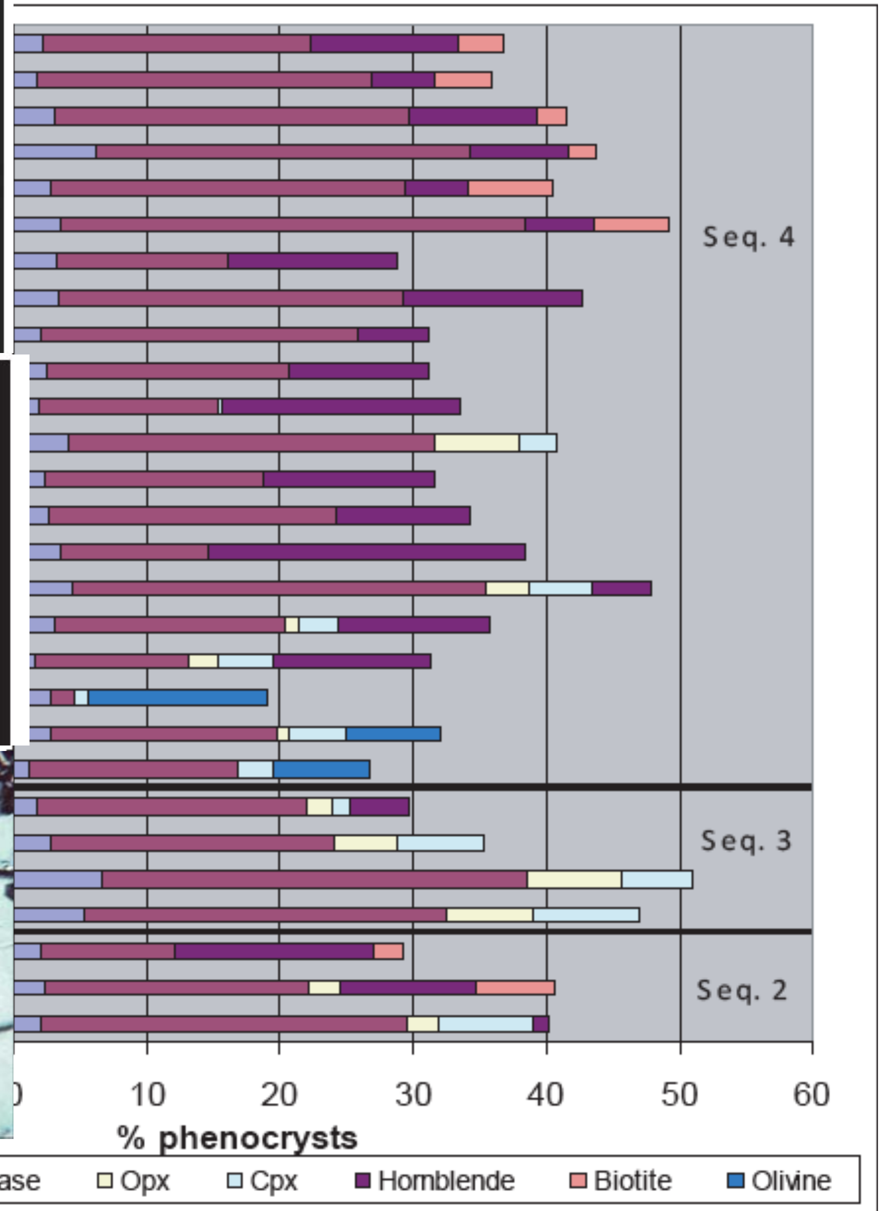
with Hb, Px, Bi

minor Ol Px basalts

and rare sanidine rhyolites.

NUMEROUS SMALL CENTERS





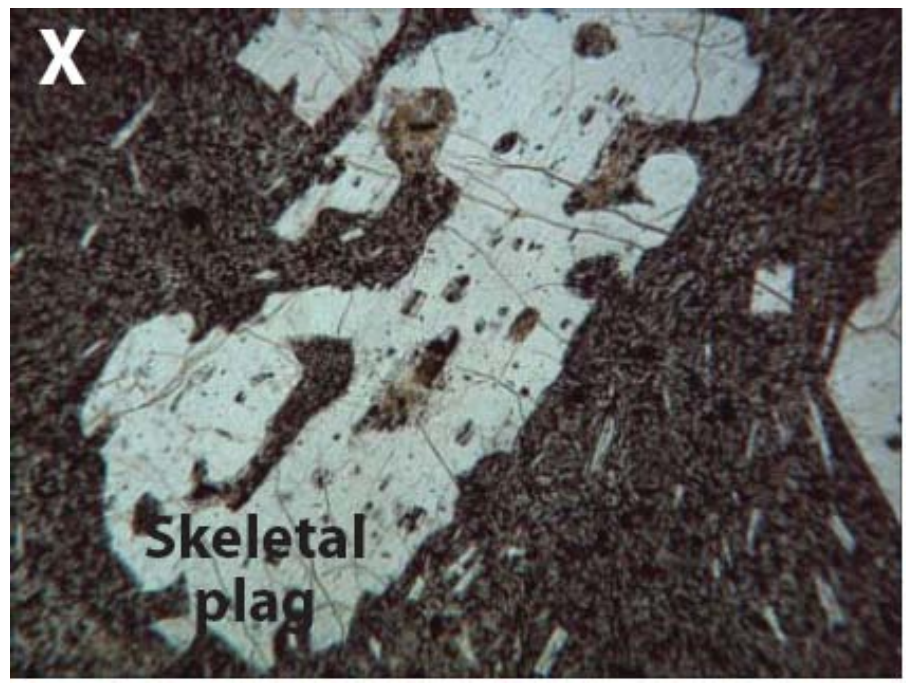
VOLUMINOUS HIGH-K

VOLCANIC ROCKS

(Stanislaus Group) -

Trademark large sieve/skeletal

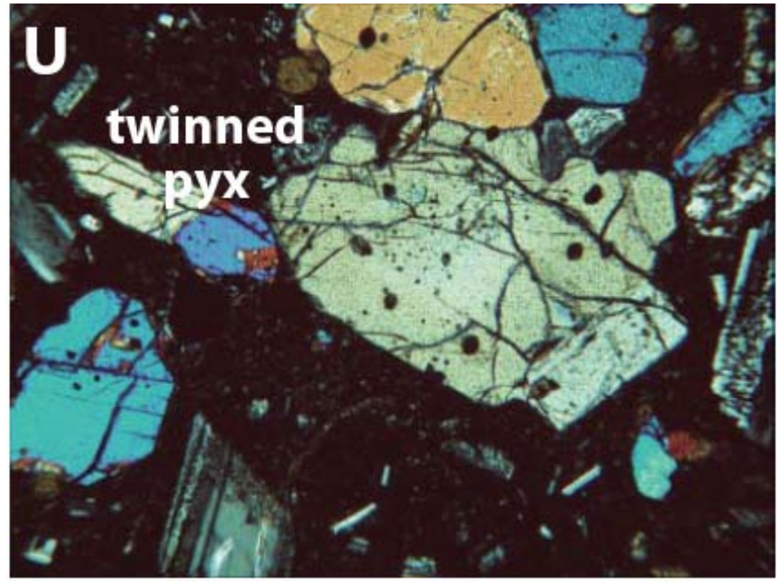
textured plagioclase……..

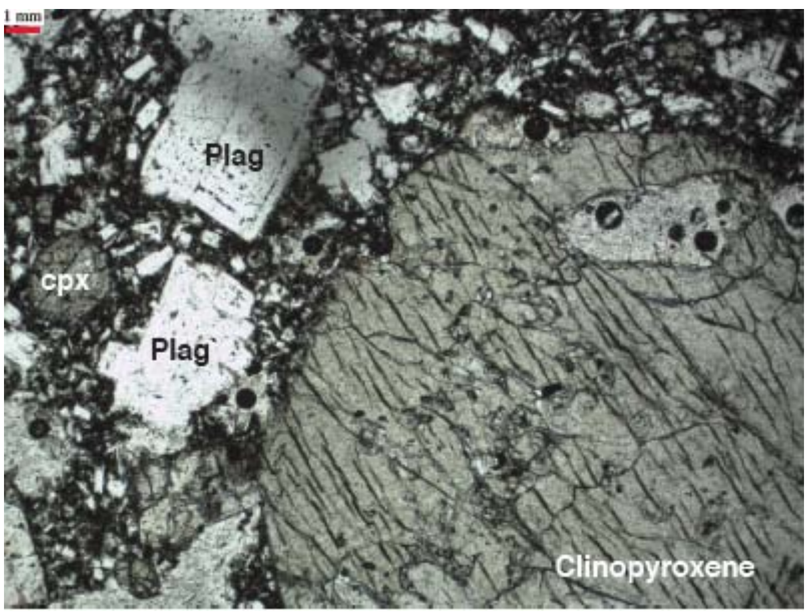


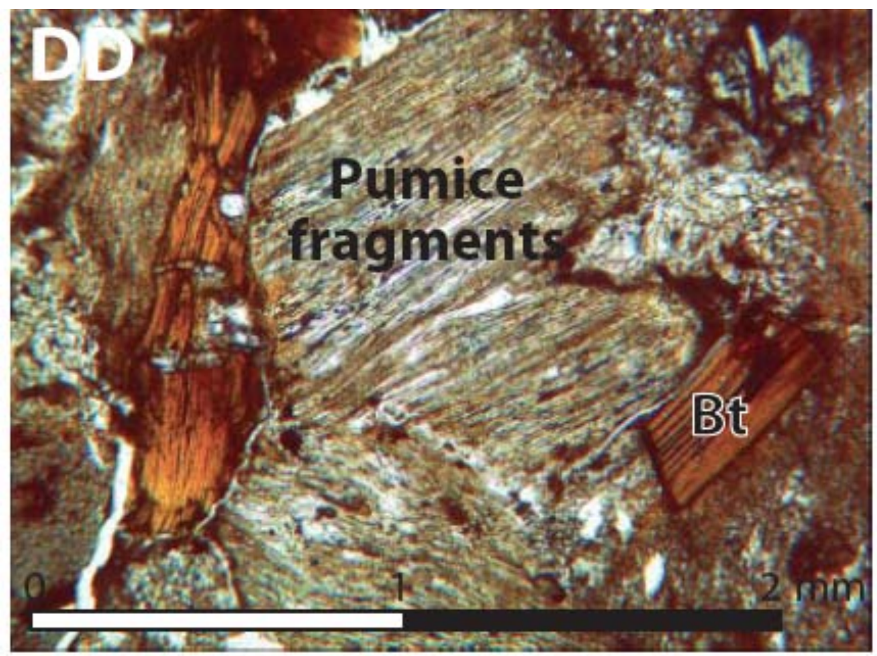
VOLUMINOUS HIGH K VOLCANIC ROCKS continued…

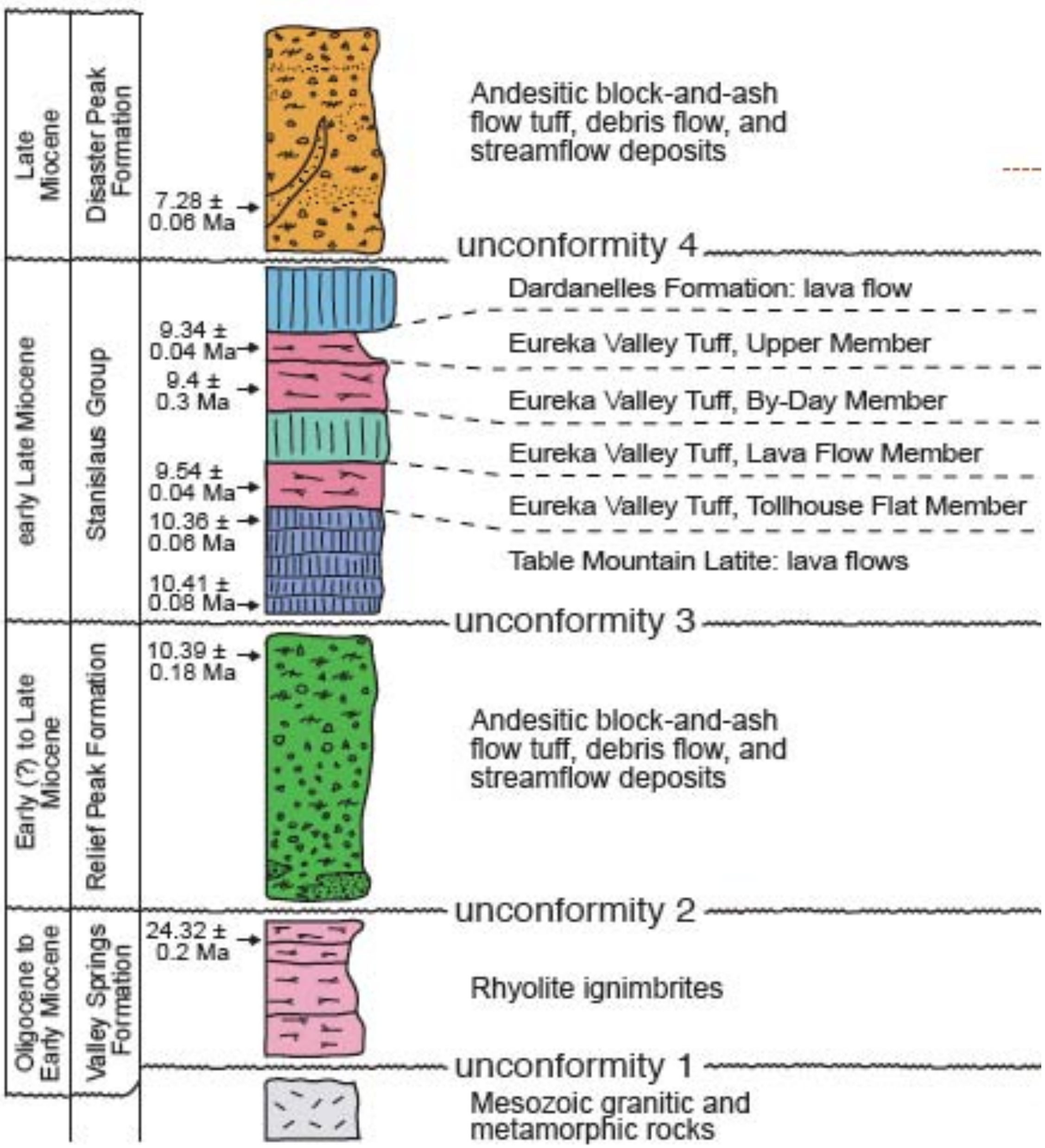
Trachyandesite and trachybasaltic andesite and shoshonite, with cpx +/- groundmass ol.

Lesser trachydacite with biotite, and basalt with olivine.









Return to andesitic arc volcanism, small centers

VOLUMINOUS HIGH-K VOLCANISM AT A BIG CENTER:

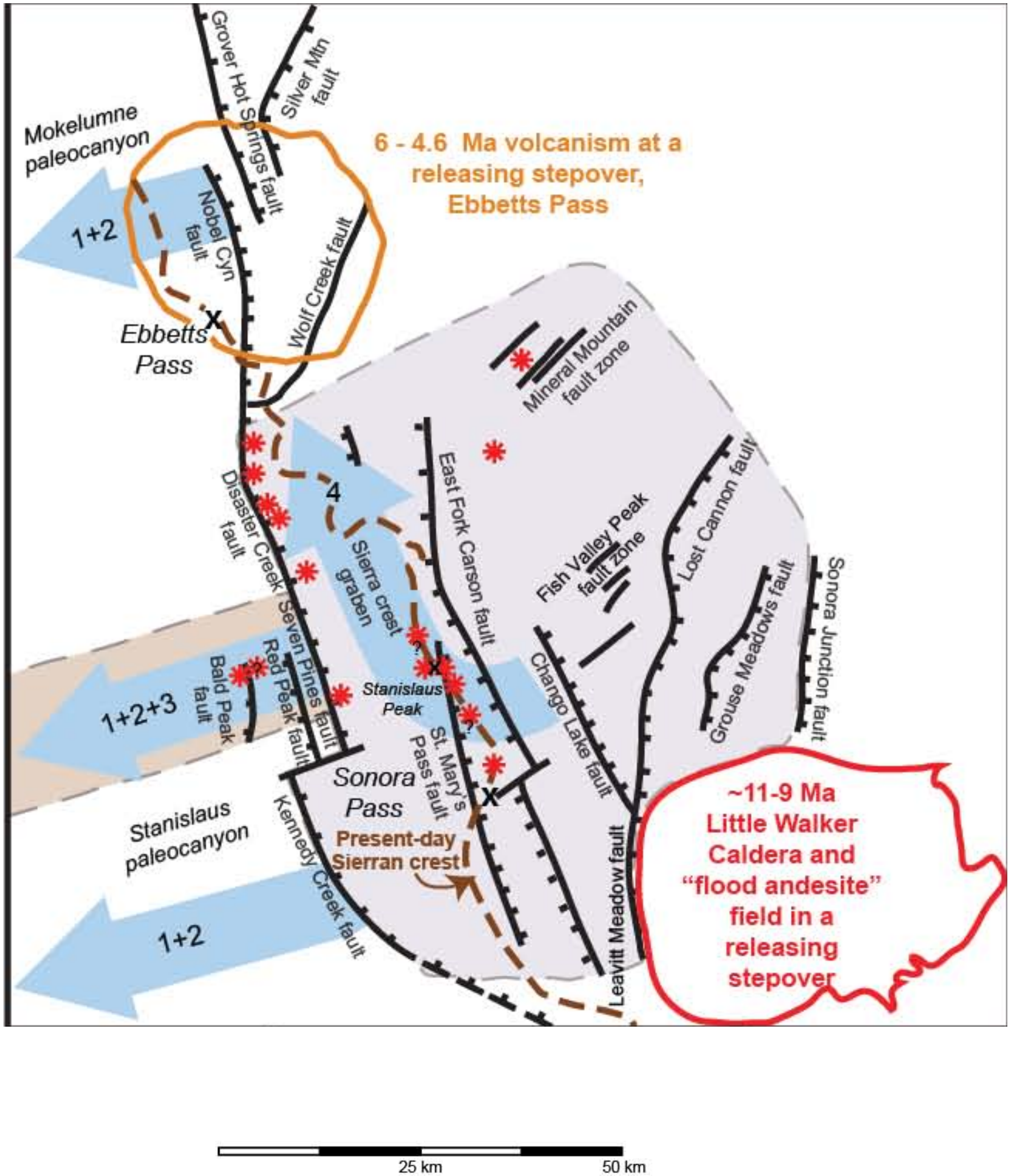
WIDESPREAD STRAIN MARKERS

Miocene andesitic arc volcanic rocks, small centers

Oligocene ignimbrites erupted far to the east, high on the Nevadaplano

Granitic basement

Regional-scale unconformities record uplift events, part II.



"Little Walker volcanic center" -

Trachyandesite "flood lava" erupted from

fault-controlled VENTS, including FISSURES (RED STARS)

in the SIERRA CREST FULL GRABEN

and also filled range-front, down to the east synvolcanic grabens

SHOWN IN LAVENDER.

Little Walker caldera = culminating silicic explosive eruptions.

Fault-controlled VENTS for the high-K volcanism include small, well -stratified trachybasalt or shoshonite cinder cones……

Sector of a proximal cone with steeply-dipping strata.

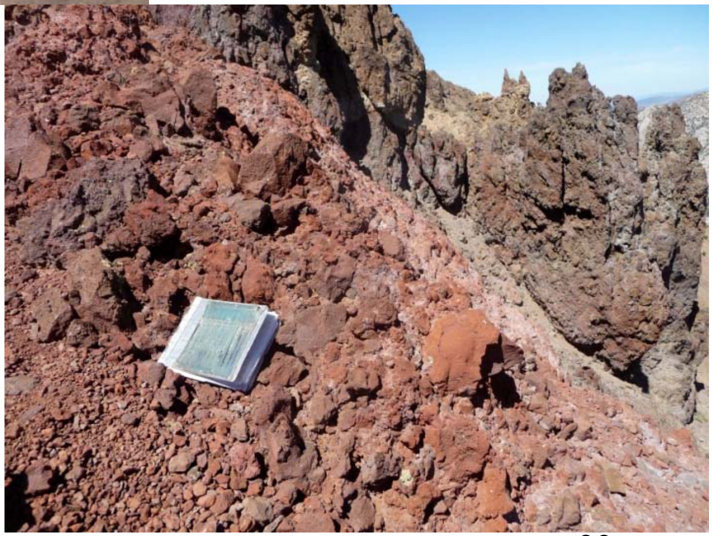
Volcanic bombs (map case for scale).

Scoria fall deposits (pen for scale).

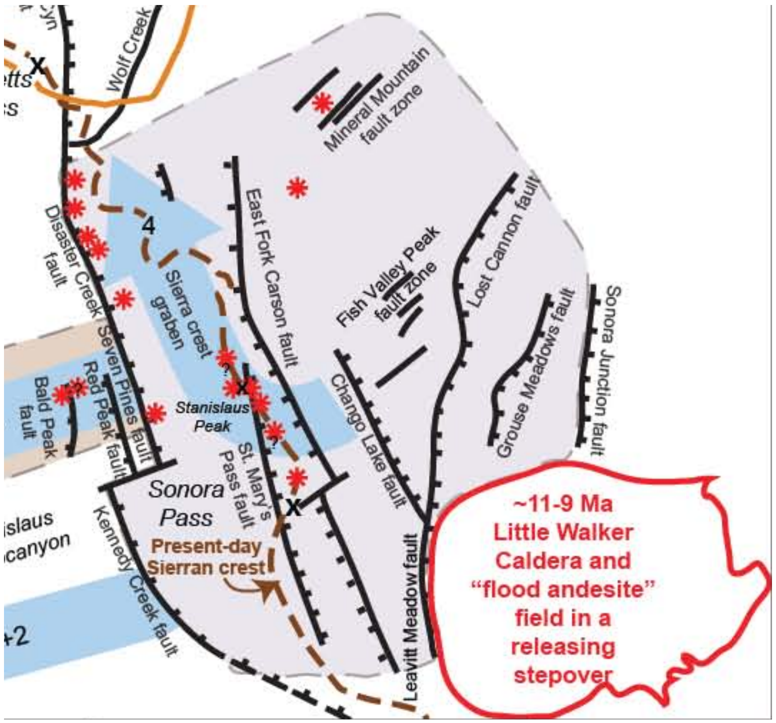
High-K vents also include fault-controlled fissures marked by trachyandesite scoria ramparts 8 - 12 km long and ~ 100-200 m thick…….

Strombolian blocks up to ~5 m across (left) in a red, nonstratified matrix of cinder blocks (field of view ~40 m across).

Close-up of scoria ramparts (map case for scale).



High-K vents also include trachydacite domes, lava flows, and tuff rings….



Flow-banding

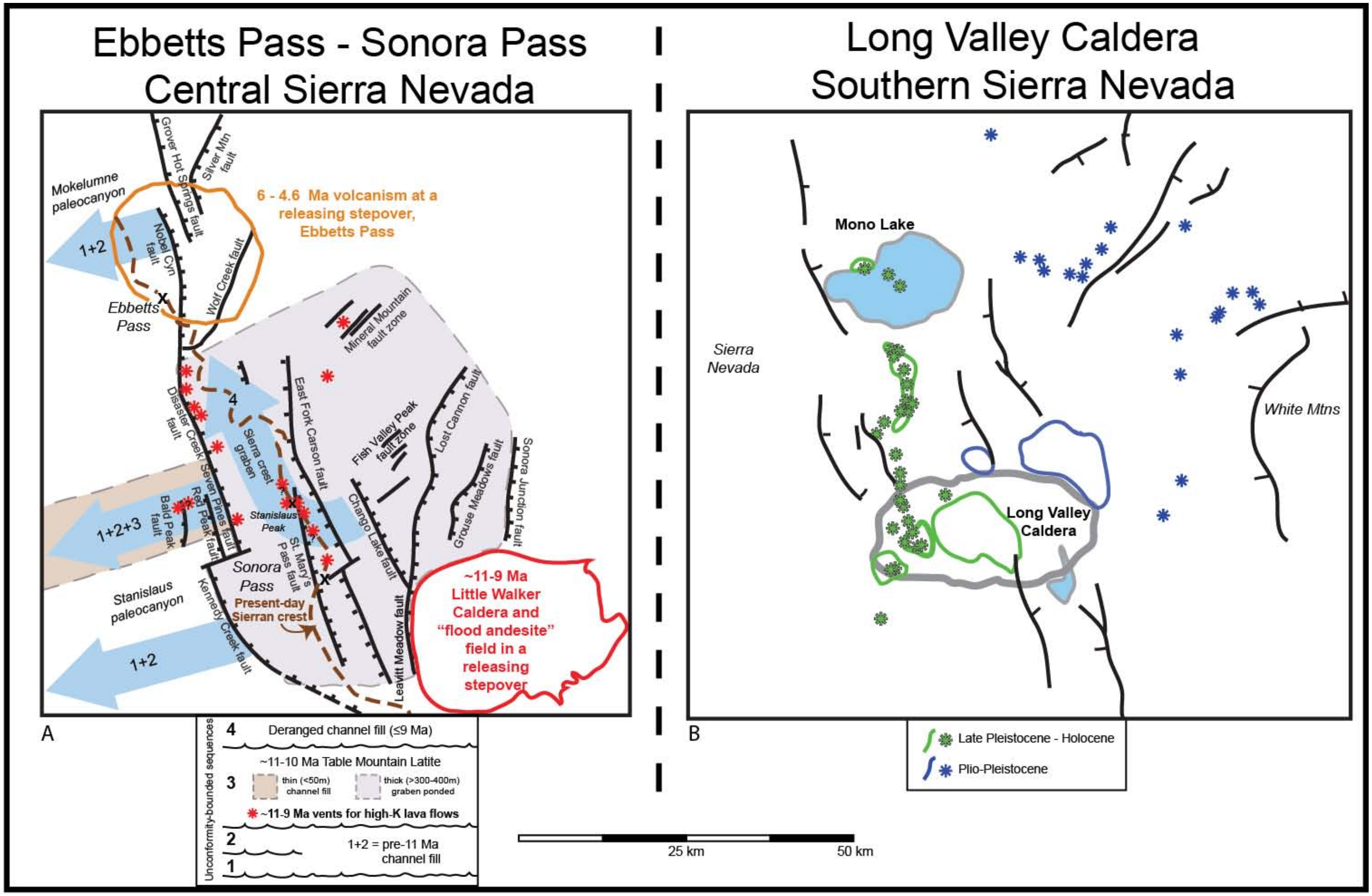
Bomb sag

…while trachydacite welded ignimbrites were erupted from the Little Walker caldera ("Eureka Valley Tuff").

Fiamme

Miocene "Little Walker volcanic center" (left) is STRUCTURALLY SIMILAR TO active Long Valley rift center (right), SHOWN AT SAME SCALE:

NNW faults right transtensional, ENE faults left transtensional Stars = vents.



From Busby, 2012 (Long Valley after Bursik, 2009).

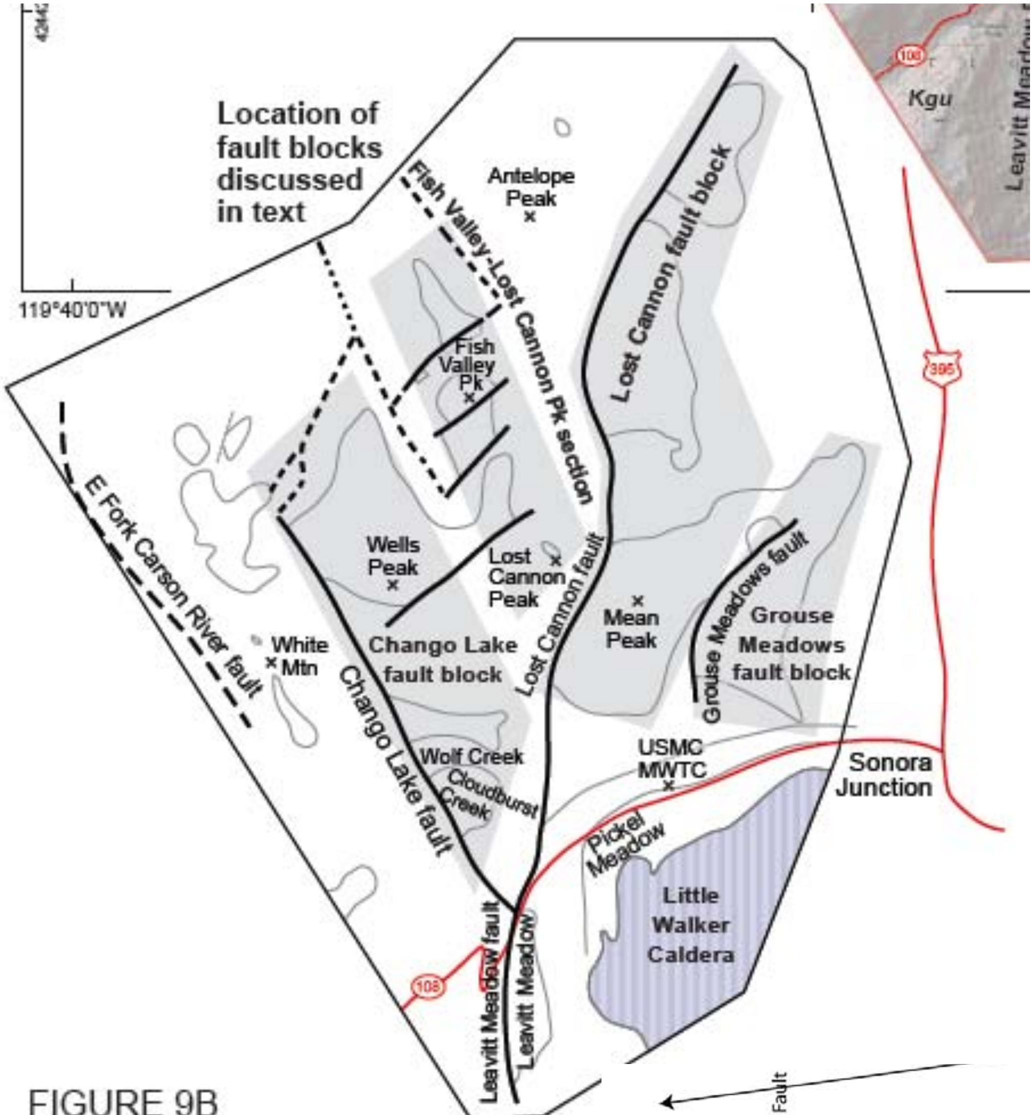
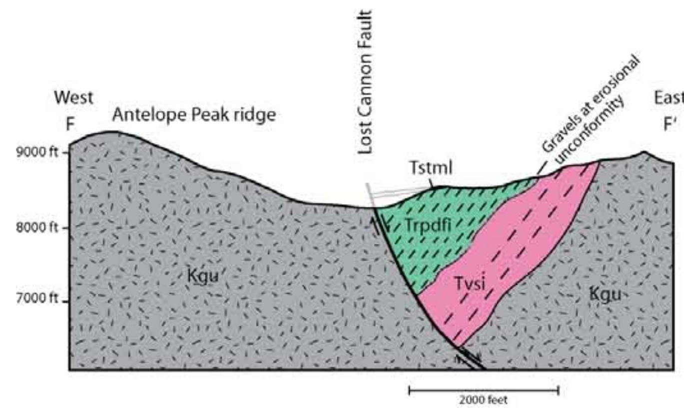
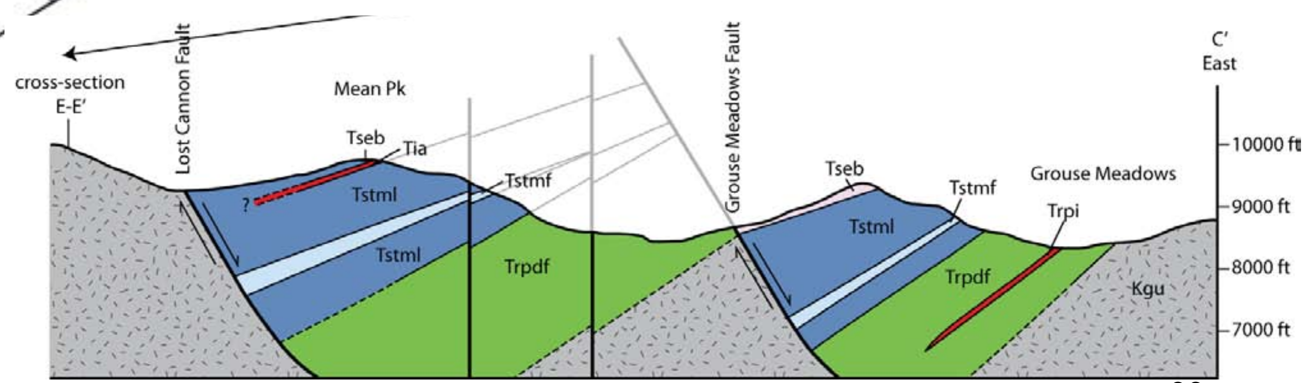


FIGURE 9B

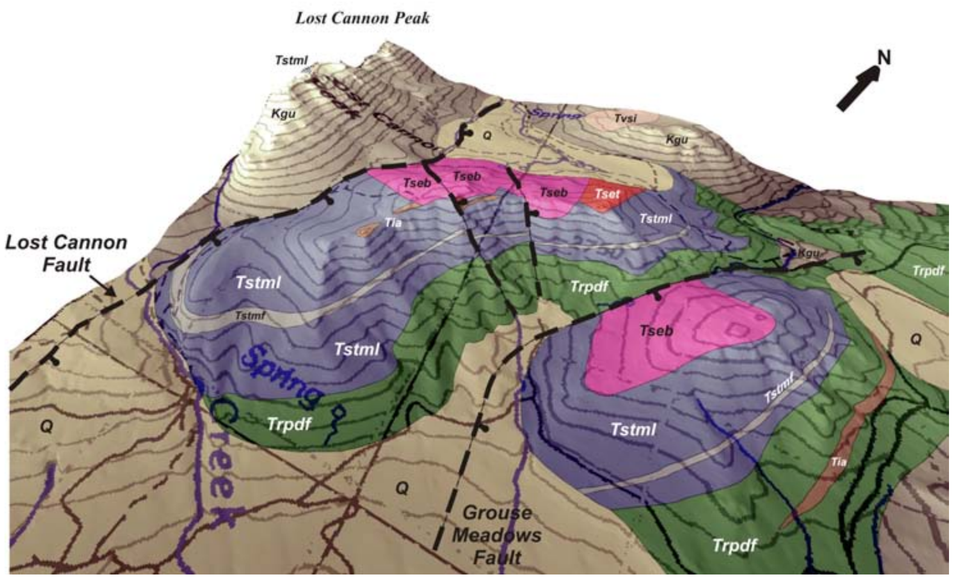
Prior to our work, it was not known that half the slip on central Sierran range-front faults occurred during the 12 - 9 Ma high-K volcanism, under transtension.

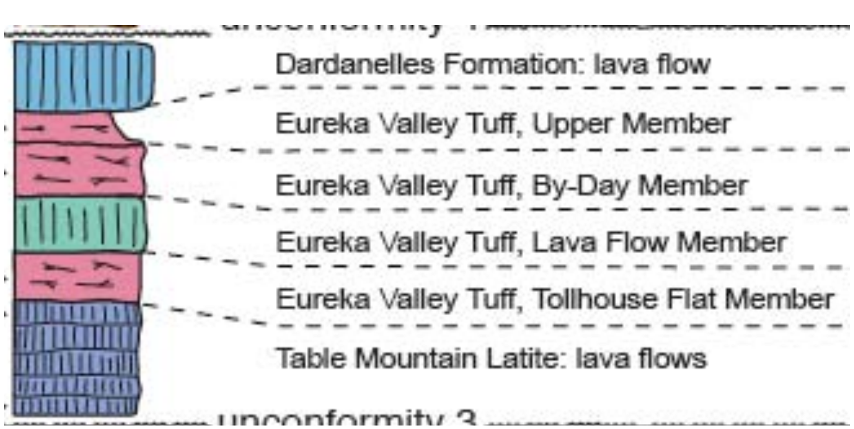




(Busby et al., accepted)

….nor was it understood that the high-K volcanic rocks were ponded to thicknesses of >300-400 m in these grabens and half grabens…..





PRESERVED VOLUME of

Table Mountain Latite alone (in highly glaciated terrane): **200 km^3**

By far the most extreme intermediate-composition effusion we know of,

and the only one fed by FISSURES.

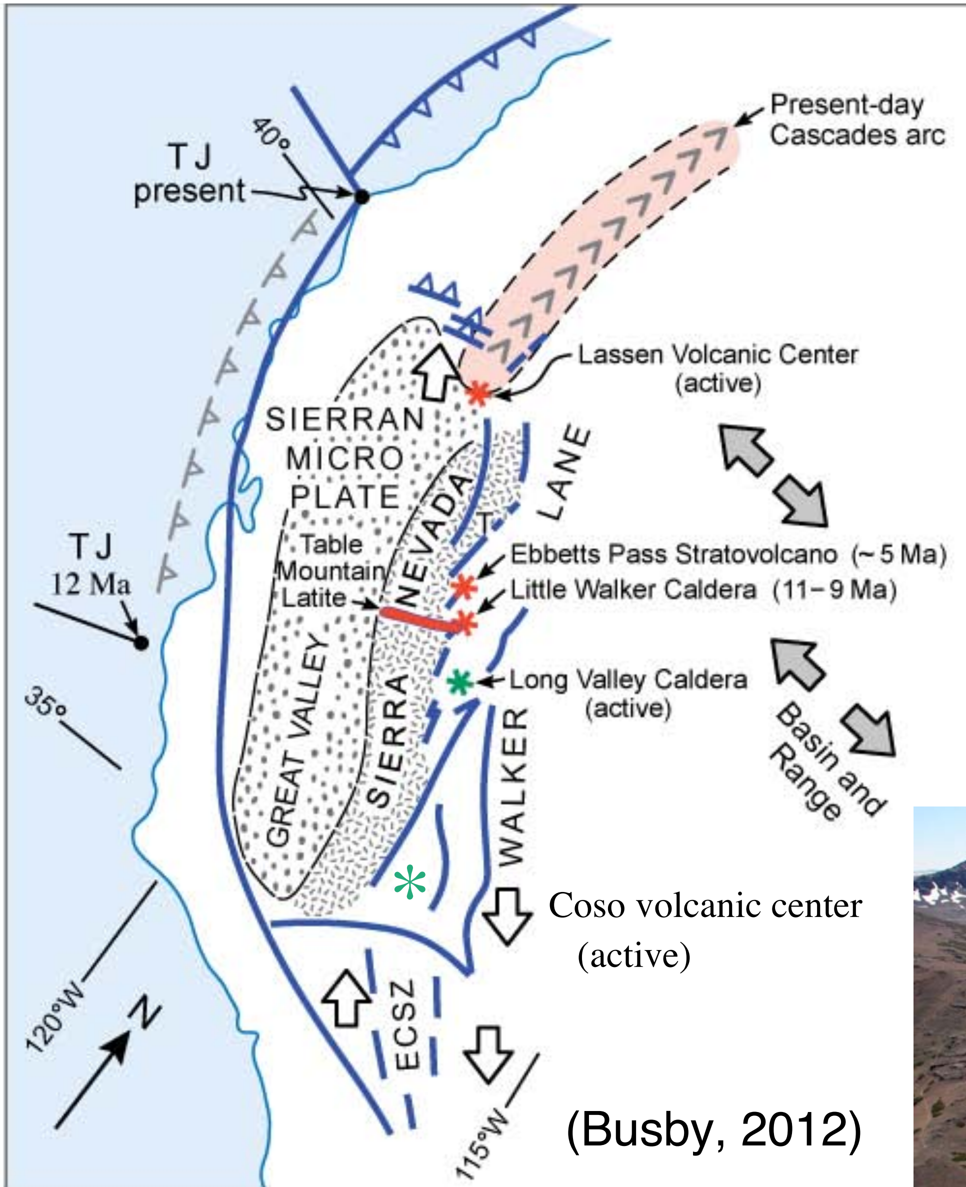
GEOLOGIC SIGNALS OF

TRANSTENSIONAL CONTINENTAL RIFTING

(1) Development of large volcanic centers at sites of maximum displacement on releasing transtensional stepover faults.

(2) Extreme effusive eruptions along fault-controlled fissures, including *intermediate-composition* fissure eruptions of “flood lava”.

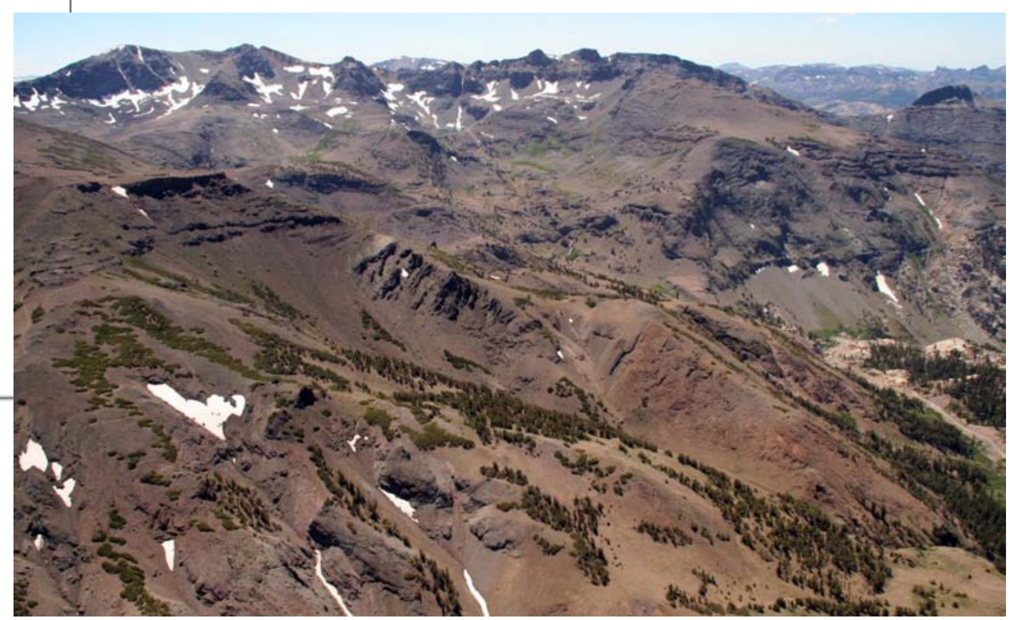
(3) Accumulation of unusually large-volume, widespread landslide deposits in pull-apart basins.



Jumbled strata (foreground) below flat-lying Table Mountain Latite (distance), Sonora Pass.

Both of the MIOCENE AND PLIOCENE CENTERS we have discovered are FULL of giant slide deposits, with avalanche blocks up to 1.6 km long.

* "Little Walker volcanic center": Ancestral Cascades arc, 12 - 9 Ma
* Ebbetts Pass volcanic center: Ancestral Cascades arc/rift transition, 6 - 4 Ma



GEOLOGIC SIGNALS OF

TRANSTENSIONAL CONTINENTAL RIFTING

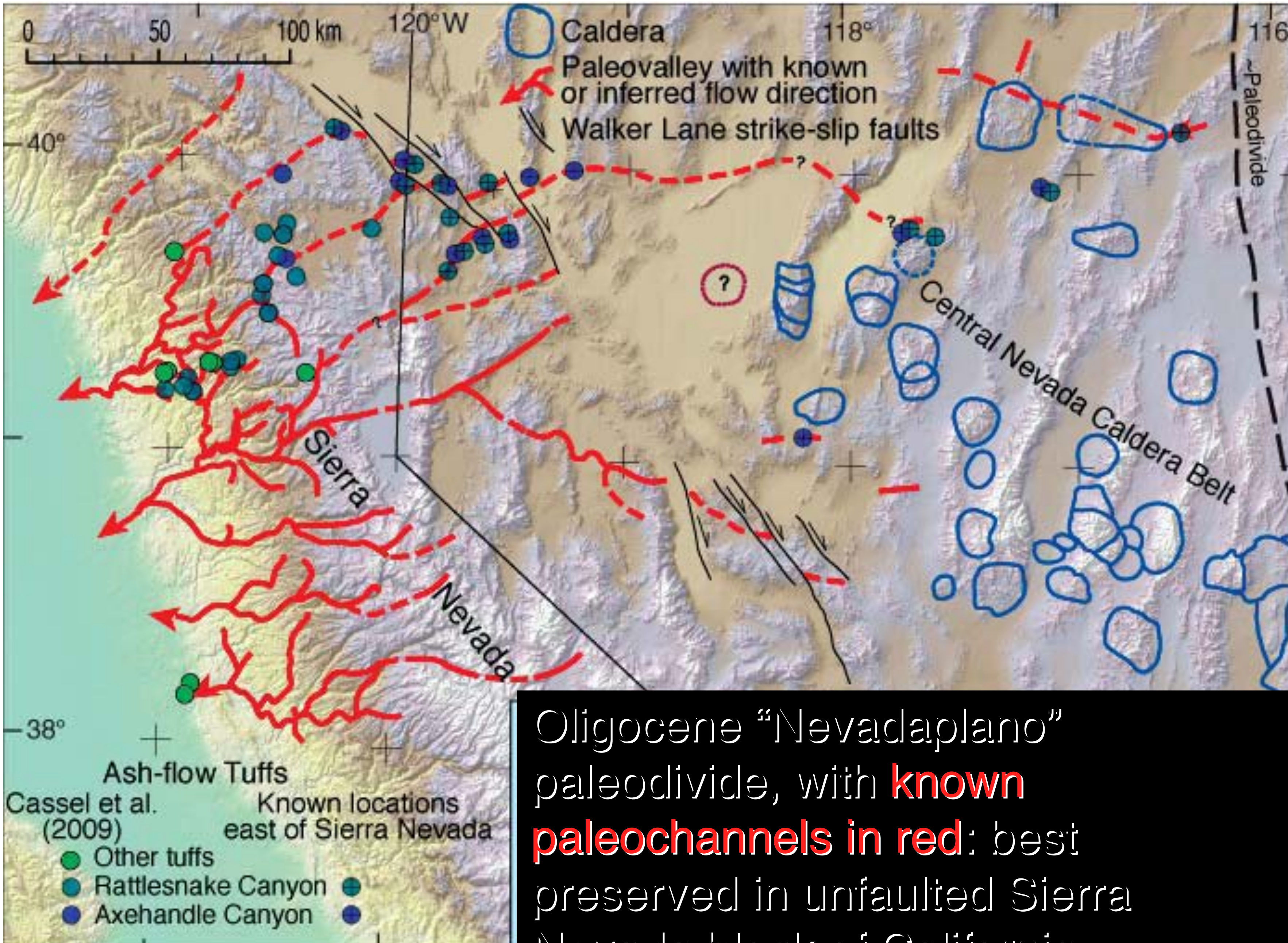
(1) Development of large volcanic centers at sites of maximum displacement on releasing transtensional stepover faults.

(2) Extreme effusive eruptions along fault-controlled fissures, including *intermediate-composition* fissure eruptions of "flood lava".

(3) Accumulation of unusually large-volume, widespread landslide deposits in grabens and rectilinear volcano-tectonic subsidence structures.

(4) Abrupt derangement of ancient E-W drainage systems of the "Nevadaplano", by development of north-south grabens that acted as funnels for lavas and fluvial channels.

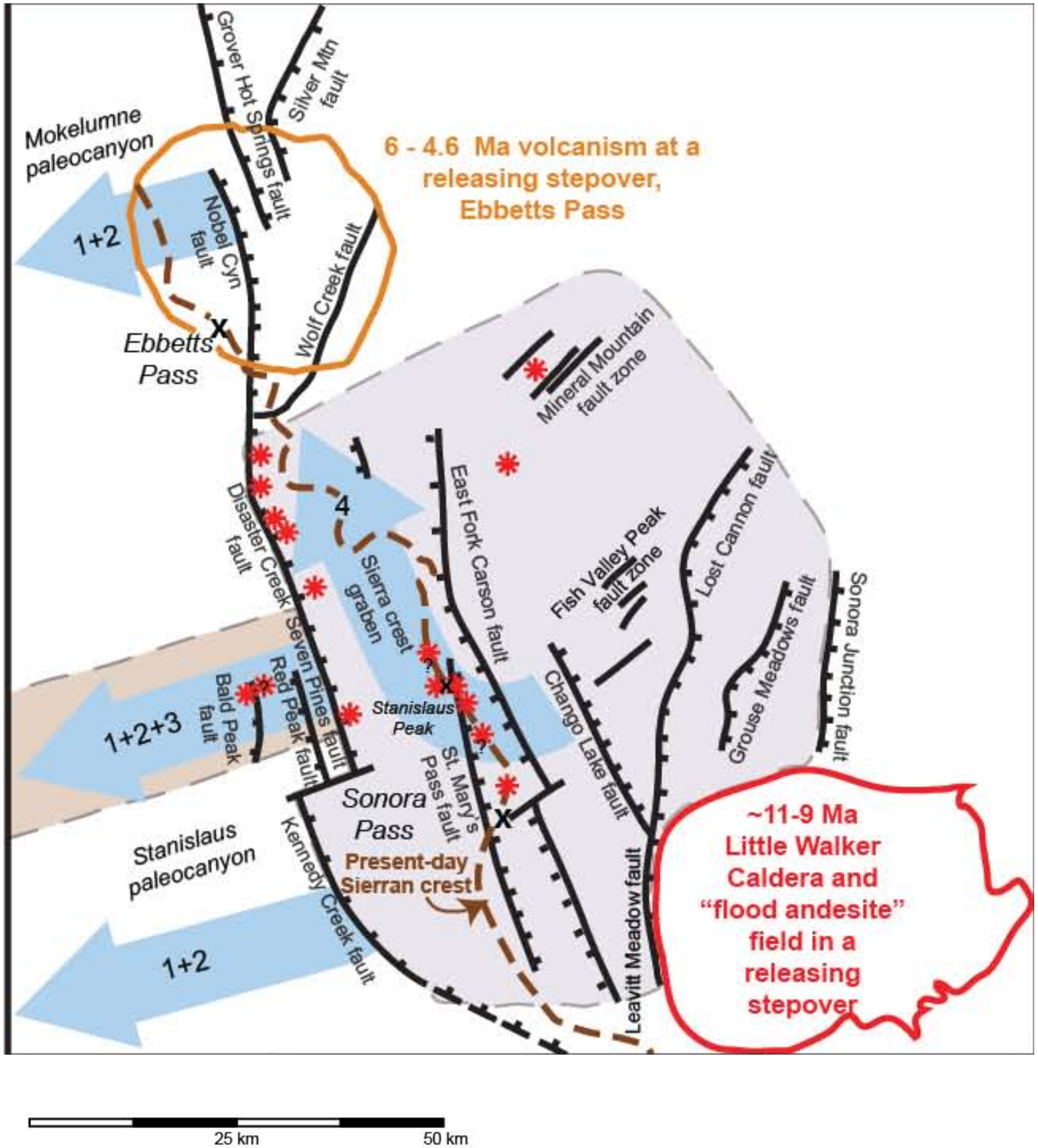
When did the Sierran paleo-channels get beheaded?



Oligocene "Nevadaplano" paleodivide, with known paleochannels in red: best preserved in unfaulted Sierra Nevada block of California.

From Cassel et al., 2009, based on Henry, 2008.

Henry, 2009

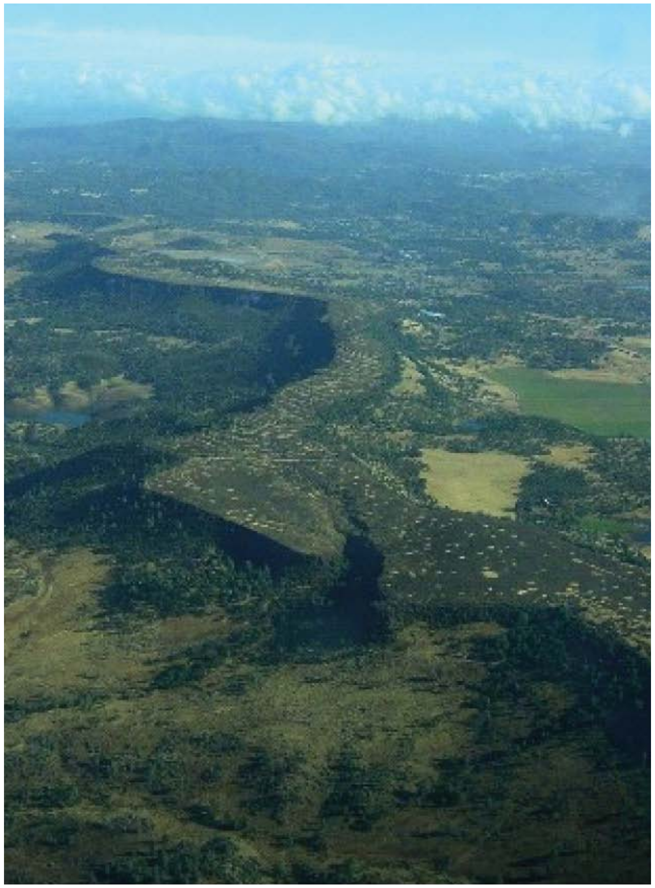


Although most of the high-K lavas were trapped in the Sierra Crest graben and the range-front grabens,

a handful of lavas escaped the graben to westward down a "Nevada-plano" paleo-channel

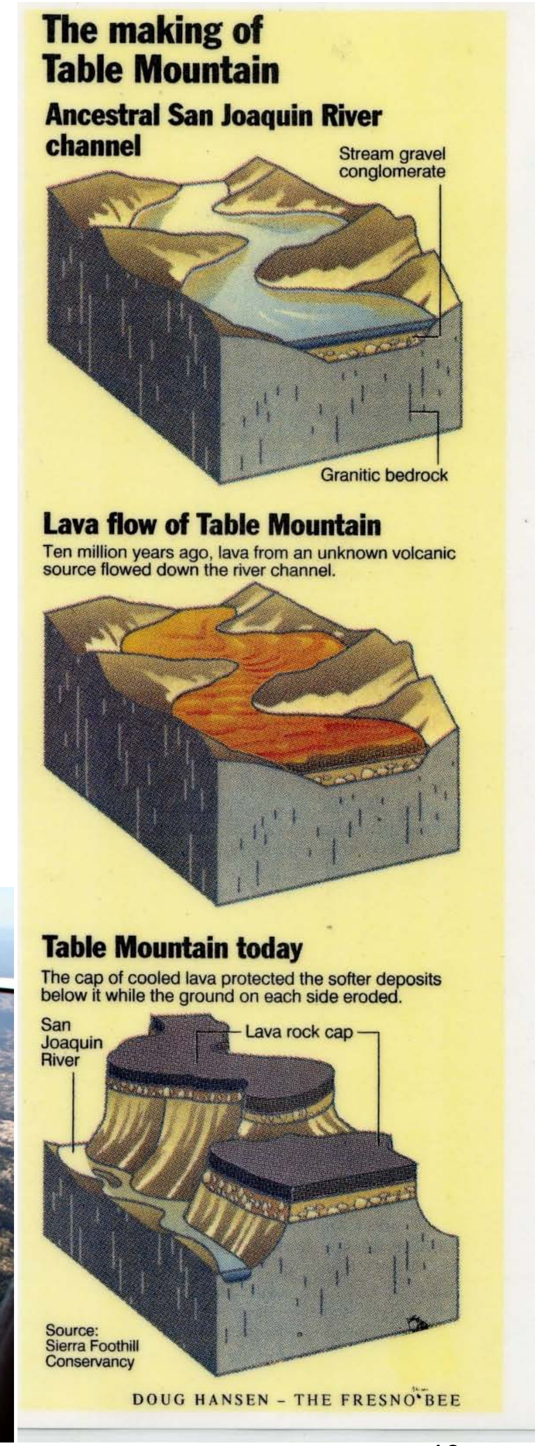
SHOWN IN TAN.

Carolyn Gorny, Senior Honors Thesis 2008, and Gorny et al., 2009; currently PhD student at Otago University.



Our paleomagnetic work (with Chris Pluhar, CSU Fresno - a Cal Tech alum) shows that one single lava flow traveled 130 km to the Sierra foothills and has a minimum volume of 25 km^3

Note: andesites are considered “LARGE VOLUME” at 3 km^3

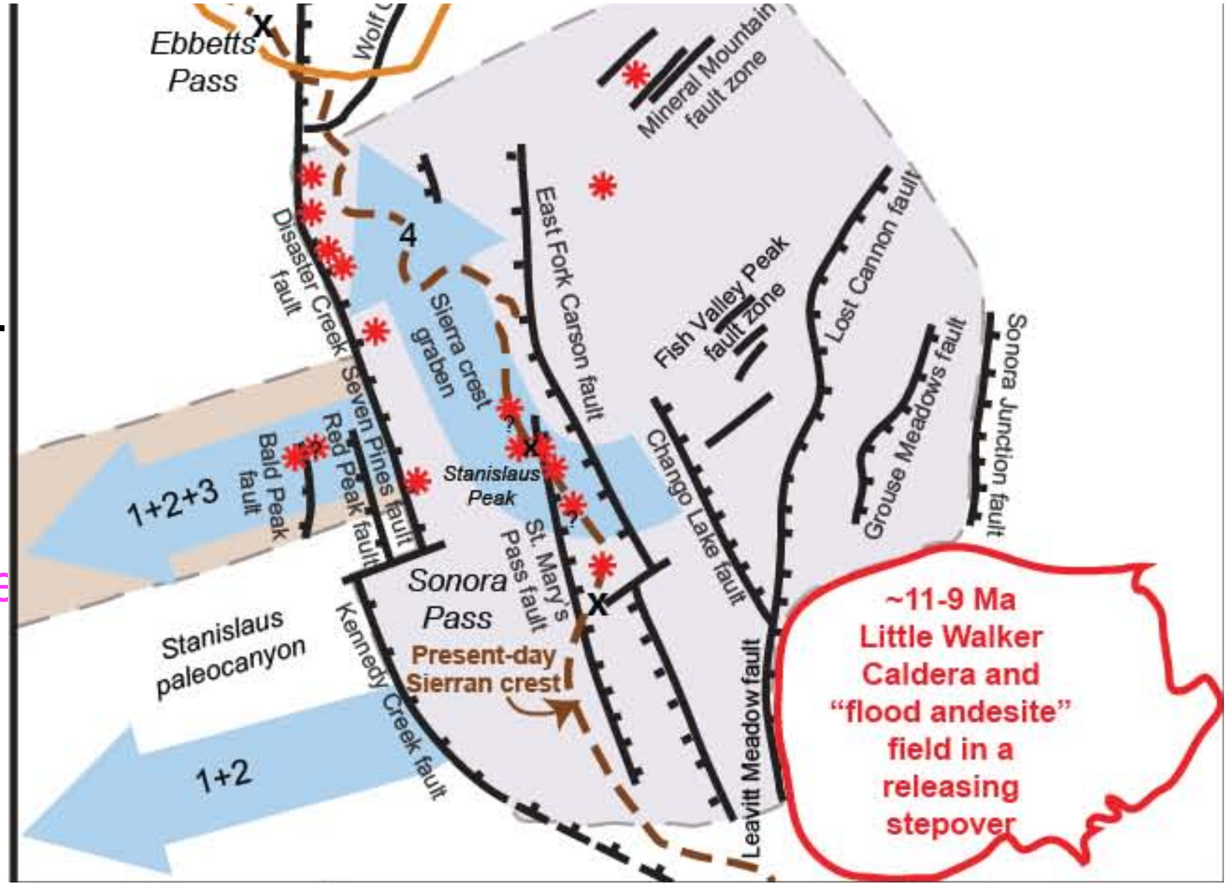


Above from Gorny et al., 2009;

center photo by Busby;

far right from the Fresno Bee

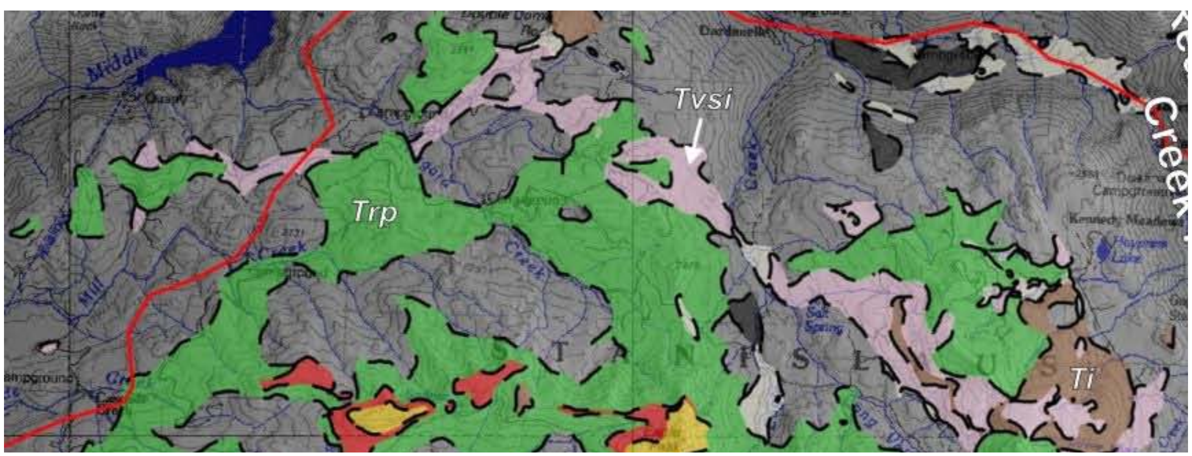
Prior to our work, it was not known that the ancient E-W Nevadaplano paleochannels were disrupted by the 12 - 9 Ma transtensional structures.



BEHEADED PALEOCHANNEL FILL:

1 = Oligocene ignimbrite (see pink map unit, below).

2 = Andesites older than the high-K rocks (green map unit, below).

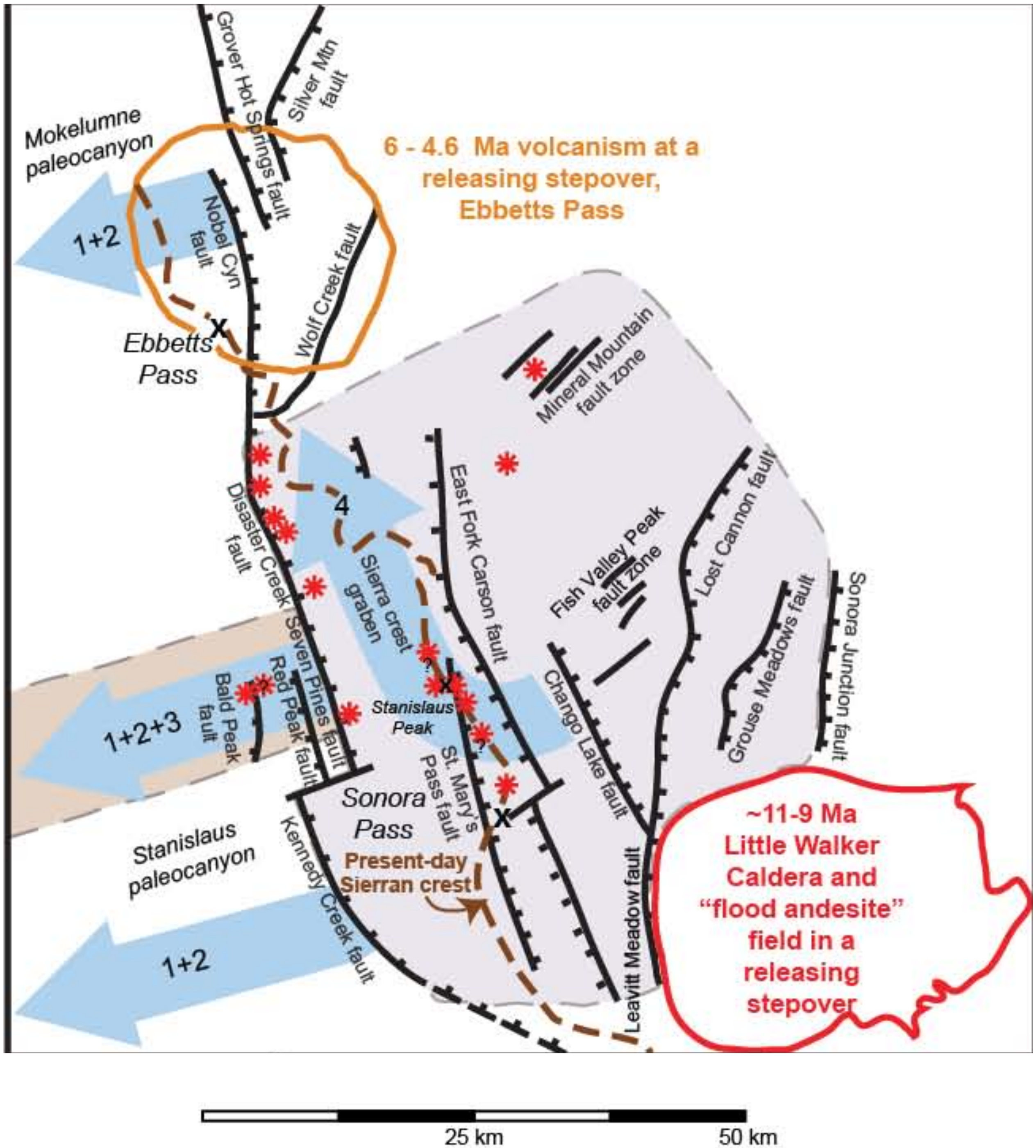


3 (above) - a few high-K lava flows rarely escaped, then -

4 (above) - all material < 9 Ma diverted NORTH, parallel to modern drainages east of the crest.

Derangement of E to W paleochannels/paleocanyons by N-S grabens:

Fluvial wedge dipping to north (right) in the Sierra Crest graben (sequence 4, above the high-K volcanic rocks).

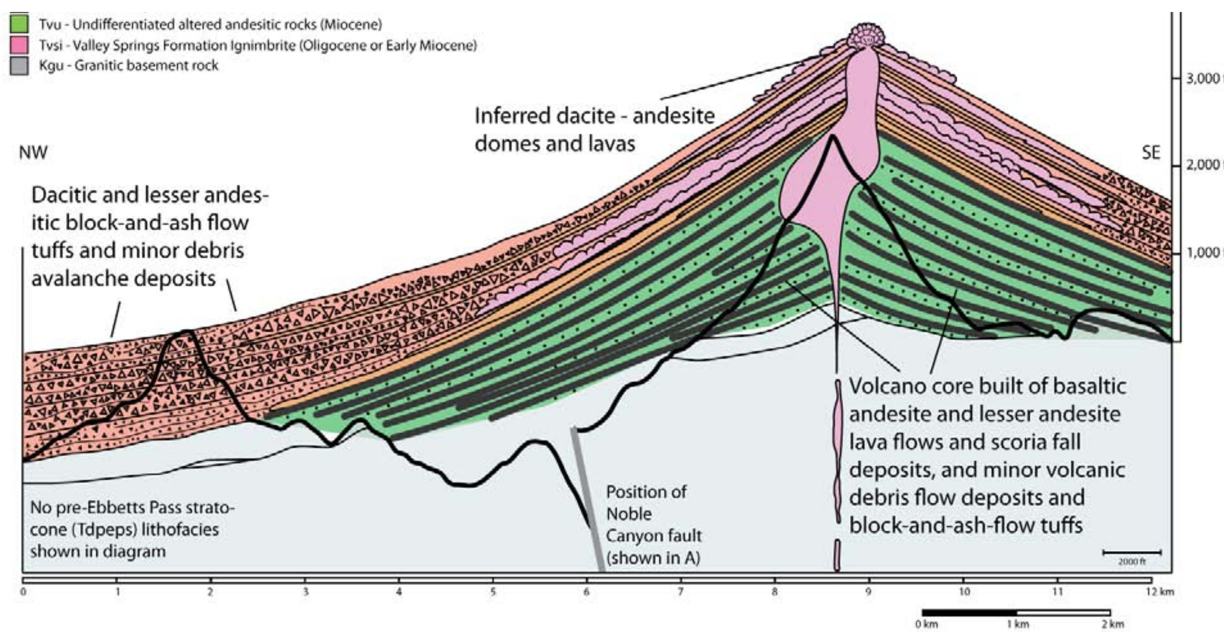


After 9 Ma, the locus of transtension stepped north, dropping the high-K volcanic out of sight and creating the EBBETTS PASS VOLCANIC CENTER.

A Lassen-sized volcanic center only 6.4 to 4 Ma old, and only recognized by us two years ago!

Needs more work but……

Megan Gambs, Senior Honors Thesis 2009; currently a PhD student at University of Washington, Seattle



TWO MAJOR QUESTIONS:

1. When did the Sierra Nevada microplate begin to form?

Part I - Geologic signals of transtension in the Walker Lane belt.

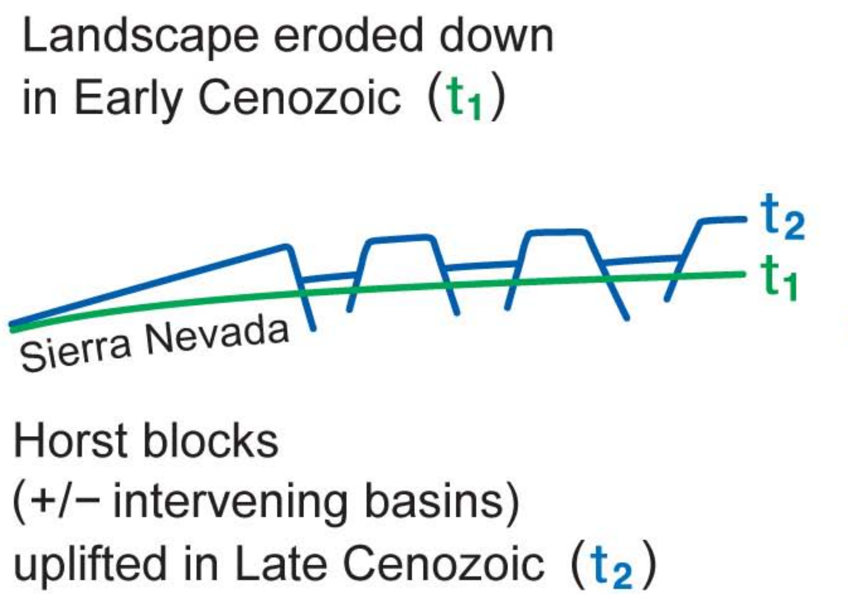
2. What is the uplift history of the Sierra Nevada?

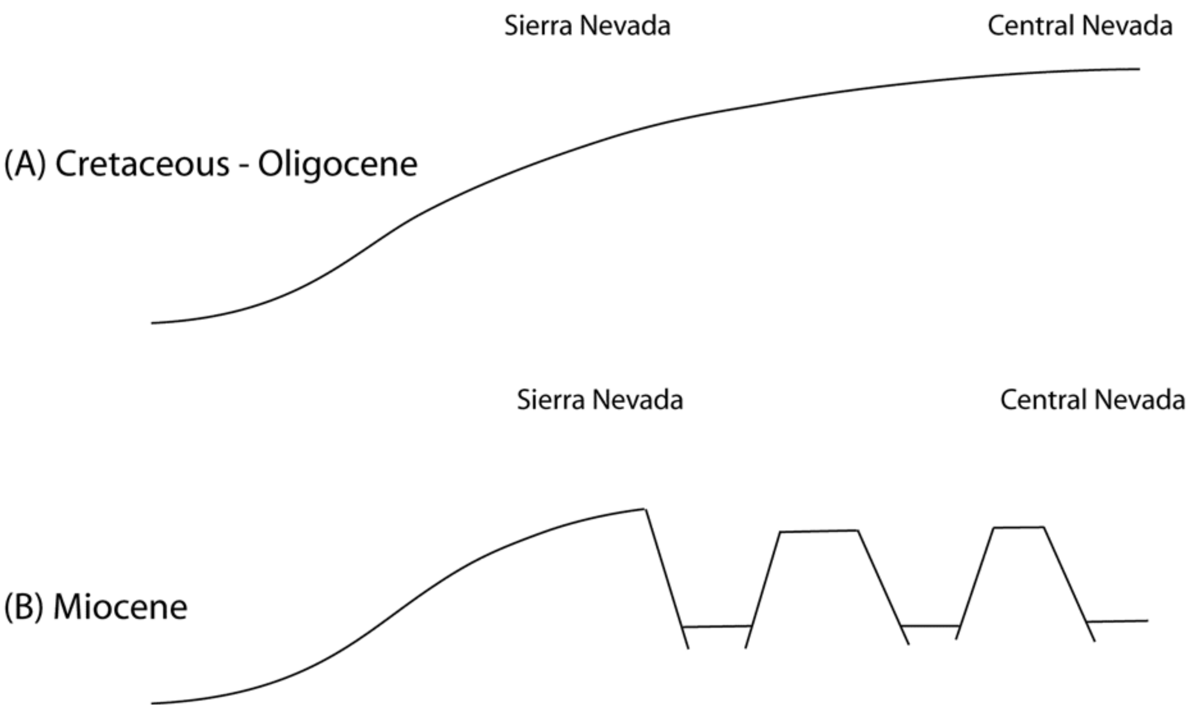
Part II - The record of Cenozoic paleo-channel fills.

Time permitting, a few words on this….

OPTION 1:

OPTION 2:

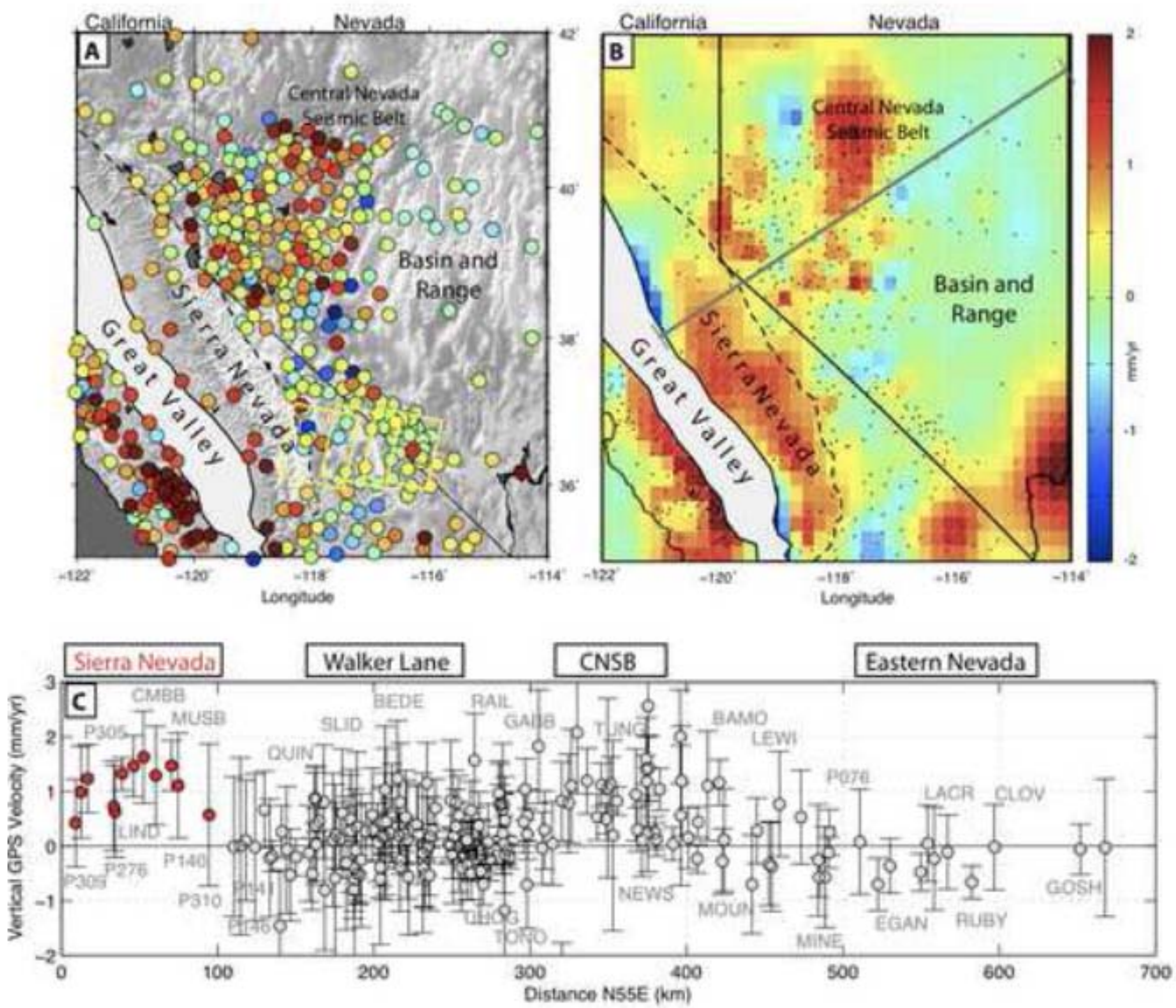




I THINK THE REALITY LIES SOMEWHERE IN BETWEEN.

(Busby and Putirka, 2009)

Hammond et al., Contemporary uplift of the Sierra Nevada, western U.S., from InSAR and GPS measurements: Geology, 2012.



CONTEMPORARY VERTICAL MOTION

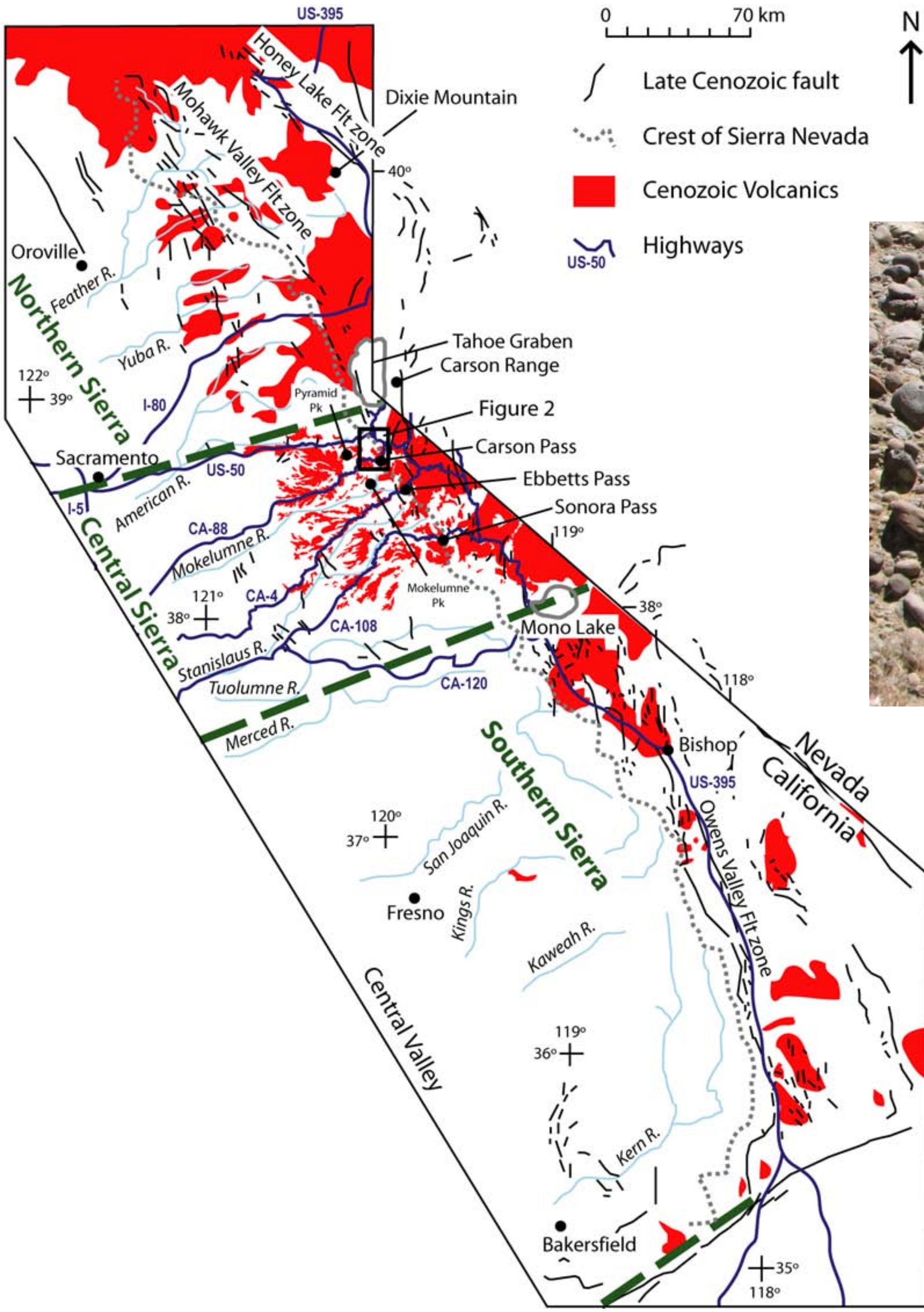
Between 1 and 2 mm/year

along entire length of range.

This rate could have generated the entire modern range in

< 3 million years!

But that extrapolation flies in the face of many other data.



N

WHAT DO SIERRAN PALEOCHANNELS TELL US?

Cenozoic volcanic rocks of the Sierra Nevada are largely preserved in E-W “paleochannels” recognized by Whitney (1880) and Lindgren (1911).

From Busby et al., 2008

CENTRAL SIERRA NEVADA
PALEOCHANNEL FILL:

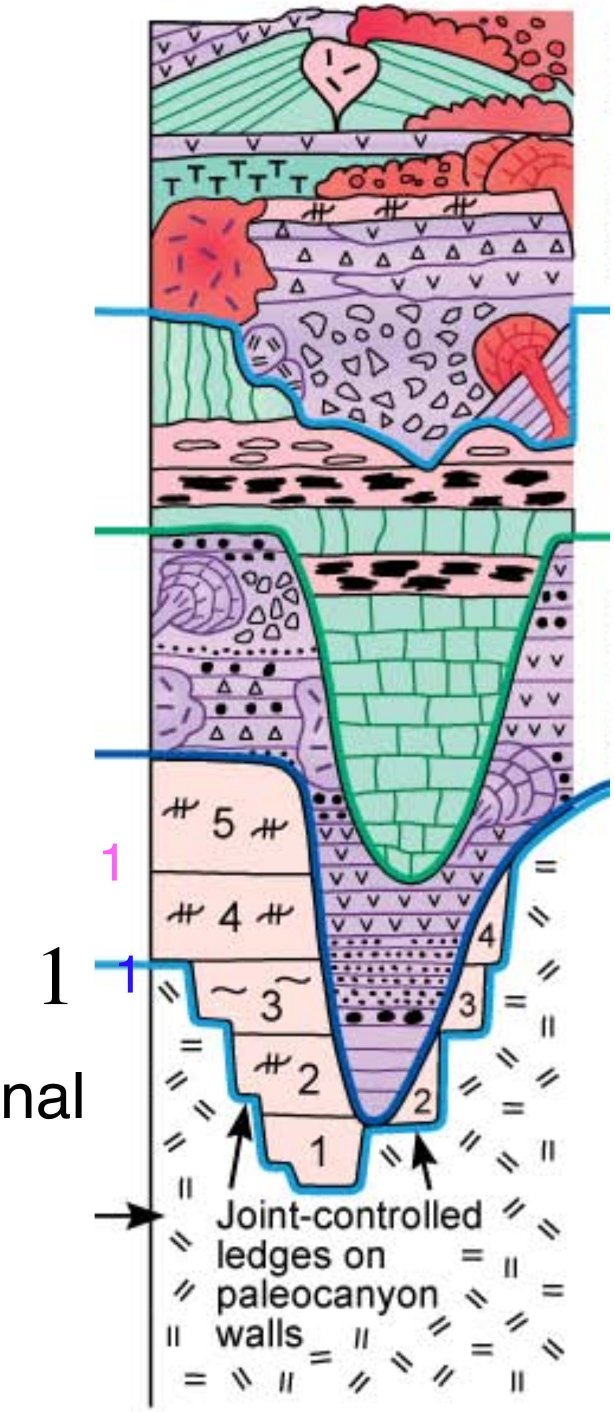
Four regional-scale unconformities

that may record Cenozoic tectonic events.

Sequence 1: WELDED AND NONWELDED IGNIMBRITES (pink)

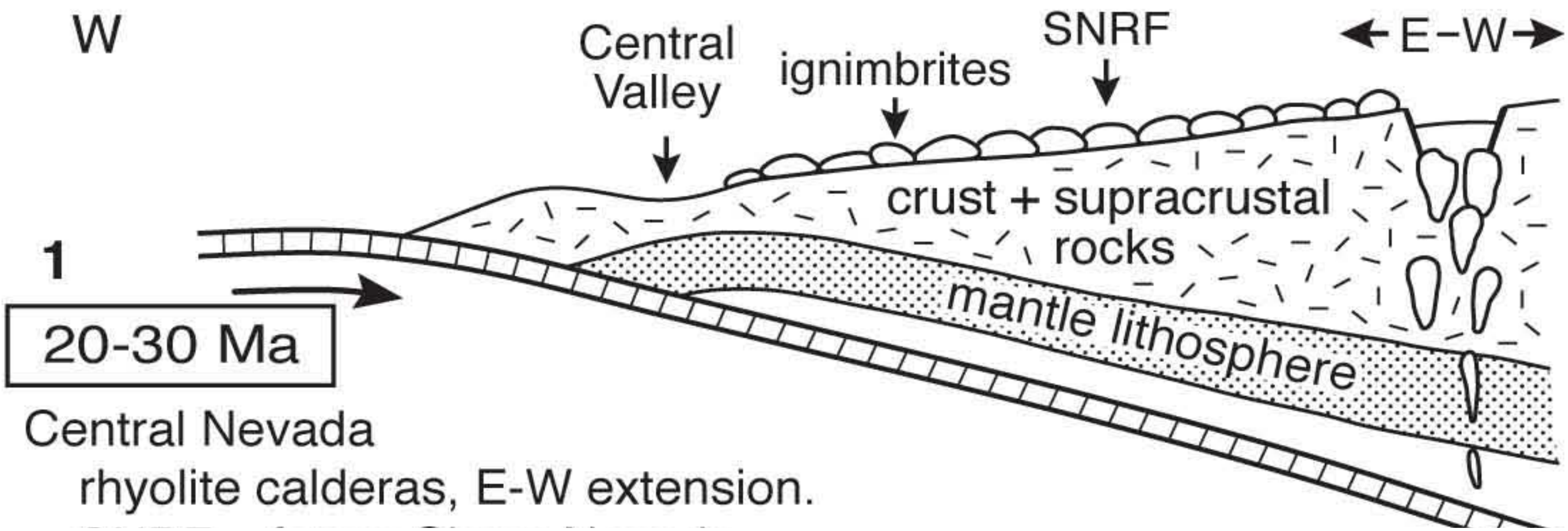
rest on

Unconformity 1 Cretaceous mesozonal batholith (white)



From Busby, 2012

THE SILICIC IGNIMBRITES ARE IMPORTANT FOR DEMONSTRATING THAT IT WAS DOWNHILL ALL THE WAY FROM EASTERN NEVADA TO CENTRAL CALIFORNIA (over 230 km, after Basin and Range extension is restored):



HIGH PLATEAU SLOPING WESTWARD IN EARLY CENOZOIC TIME

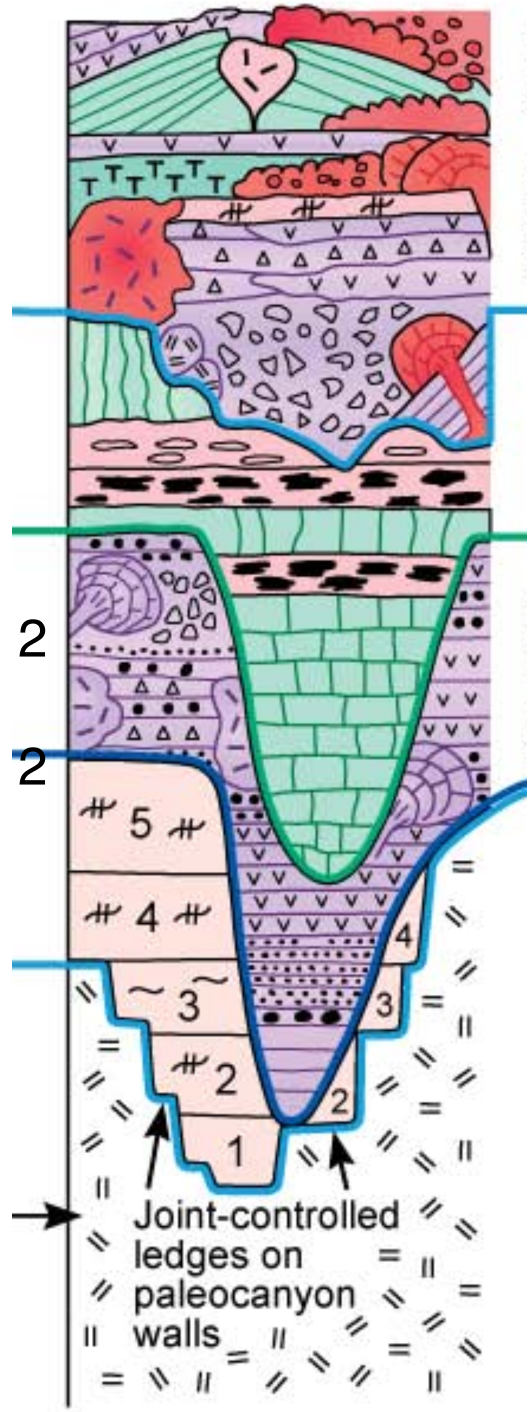
(from Busby and Putirka, 2009)

CENTRAL SIERRA NEVADA PALEOCHANNEL FILL, continued

Unconformity 2: Thermal uplift and extension, followed by…. …Sequence 2: onset of arc volcanism at 16 Ma (purple).

Early Miocene columnar-jointed lava flow.

Alice Koerner examining petrified wood in Miocene paleochannel fill.



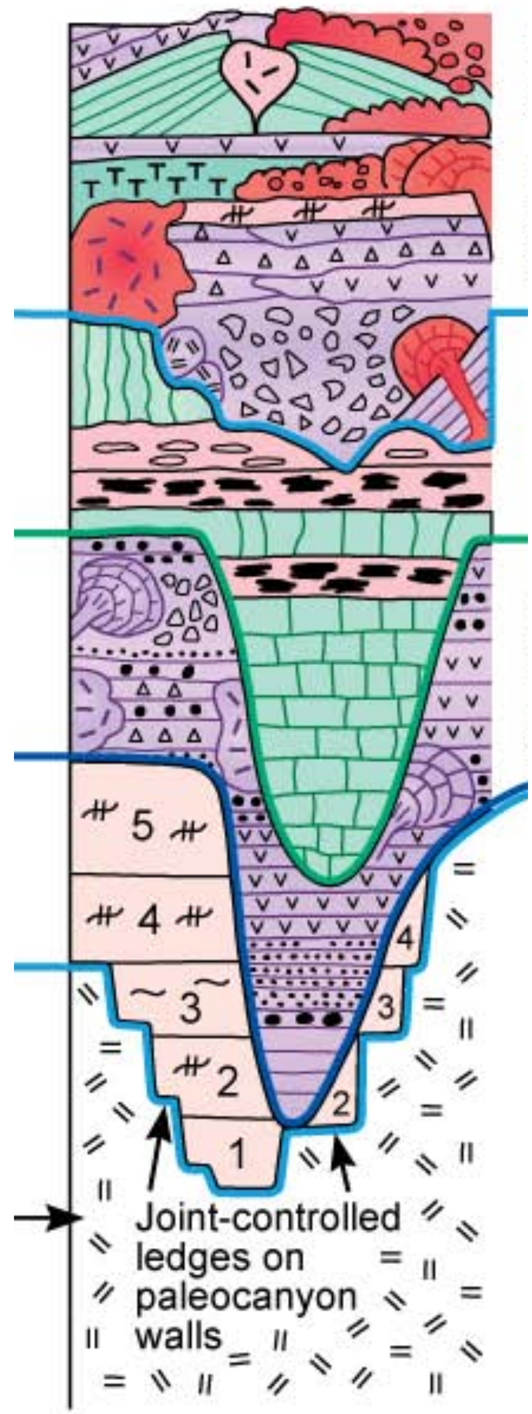
CENTRAL SIERRA NEVADA PALEOCHANNEL FILL, continued

Sequence 3: ~ 12 - 9 Ma

Unconformity 3: ~12 Ma

Sierra Nevada microplate begins to calve off the western shoulder of the Nevadaplano:

HIGH-K VOLCANISM AT LITTLE WALKER VOLCANIC CENTER (Sonora Pass - Bridgeport area).



From Busby, 2012

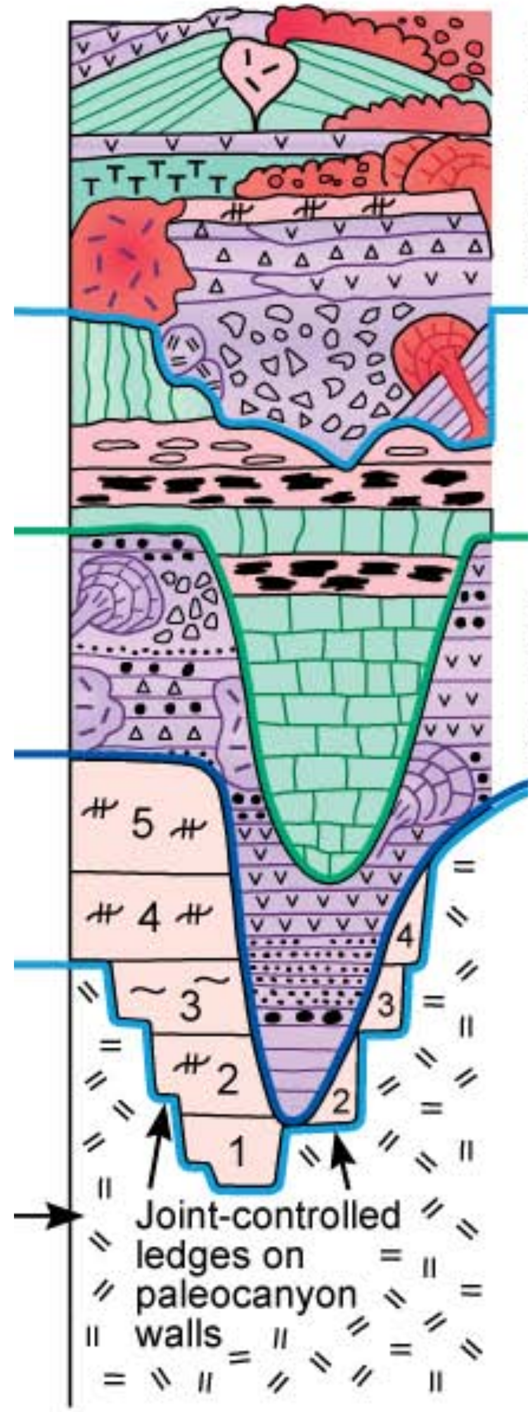
CENTRAL SIERRA NEVADA PALEOCHANNEL FILL, continued

Sequence 4 - Beheaded paleocanyons locally filled with fault breccia - talus cone deposits, or with local volcanic constructs

Sequence 4

Unconformity 4,- regional correlation and age least certain

From Busby, 2012



SOME ANSWERS???? From Cenozoic volcanic and sedimentary rocks….

1. **When did the Sierra Nevada microplate begin to form?** Using geologic signals of transtension in the Walker Lane belt, I'd say by 12 Ma.

2. **What is the uplift history of the Sierra Nevada?** The record of Cenozoic "paleo-channel" (paleo-canyon) fills suggest Miocene rejuvenation at 16 Ma, and especially at ~10-12 Ma. This is consistent with thermochronologic evidence for Late Cenozoic rejuvenation.

Thank you for inviting me to the NAGT meeting!