Controls of pull-apart basin size and subsidence rate
on
arc magmatism:

Examples from the Ancestral Cascades Arc, California

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Papers posted at http://www.geol.ucsb.edu/faculty/busby

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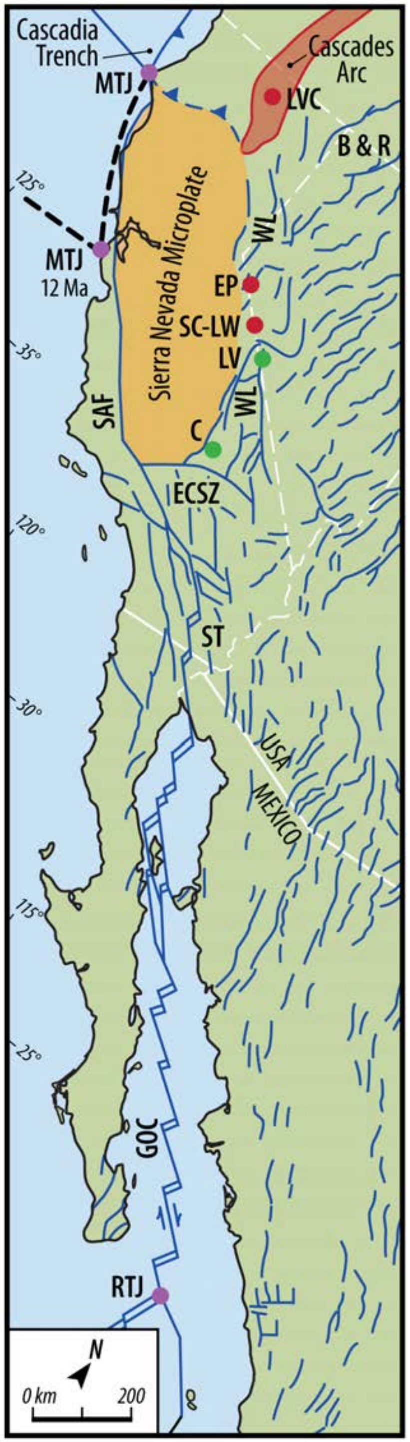
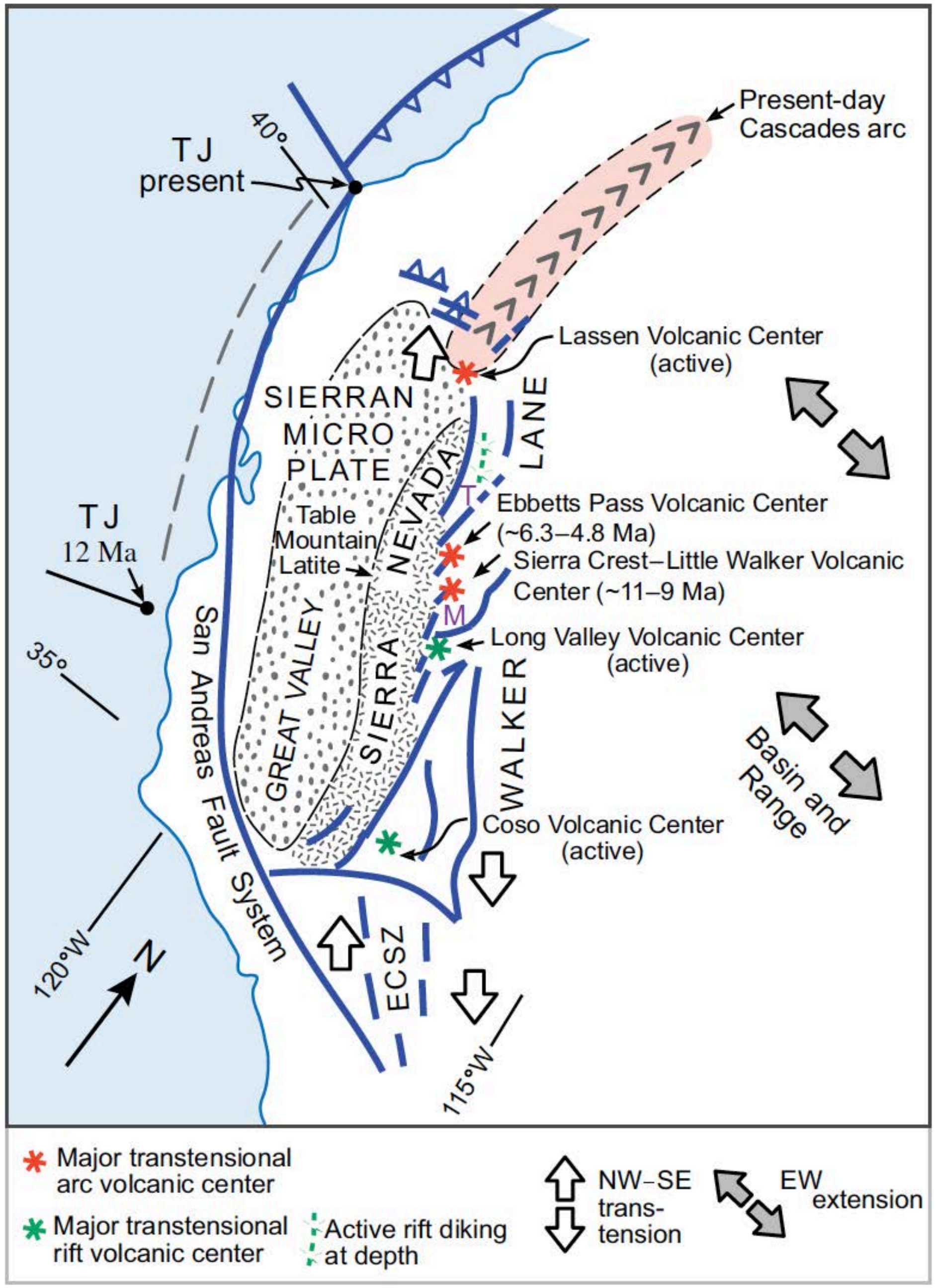
USGS EDMAP support: 03HQAG003 , 05GQAG0010, 06HQA06, 09HQPA0004, G17AC00128-0

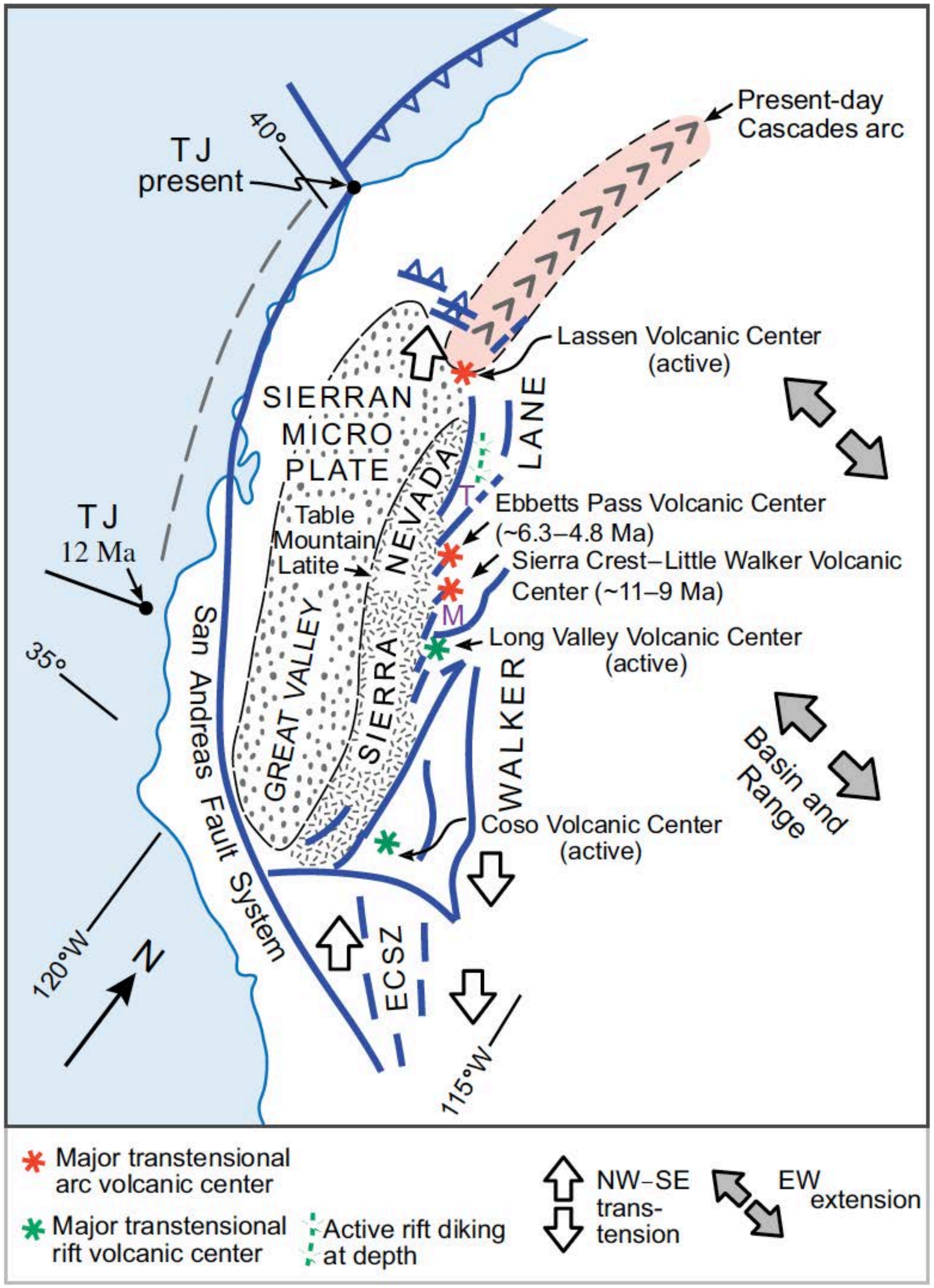




Busby 2013

Walker Lane: the northernmost extension of the Gulf of California transtensional rift.

Archetype for early rupturing of continental lithosphere along a transtensional rift zone

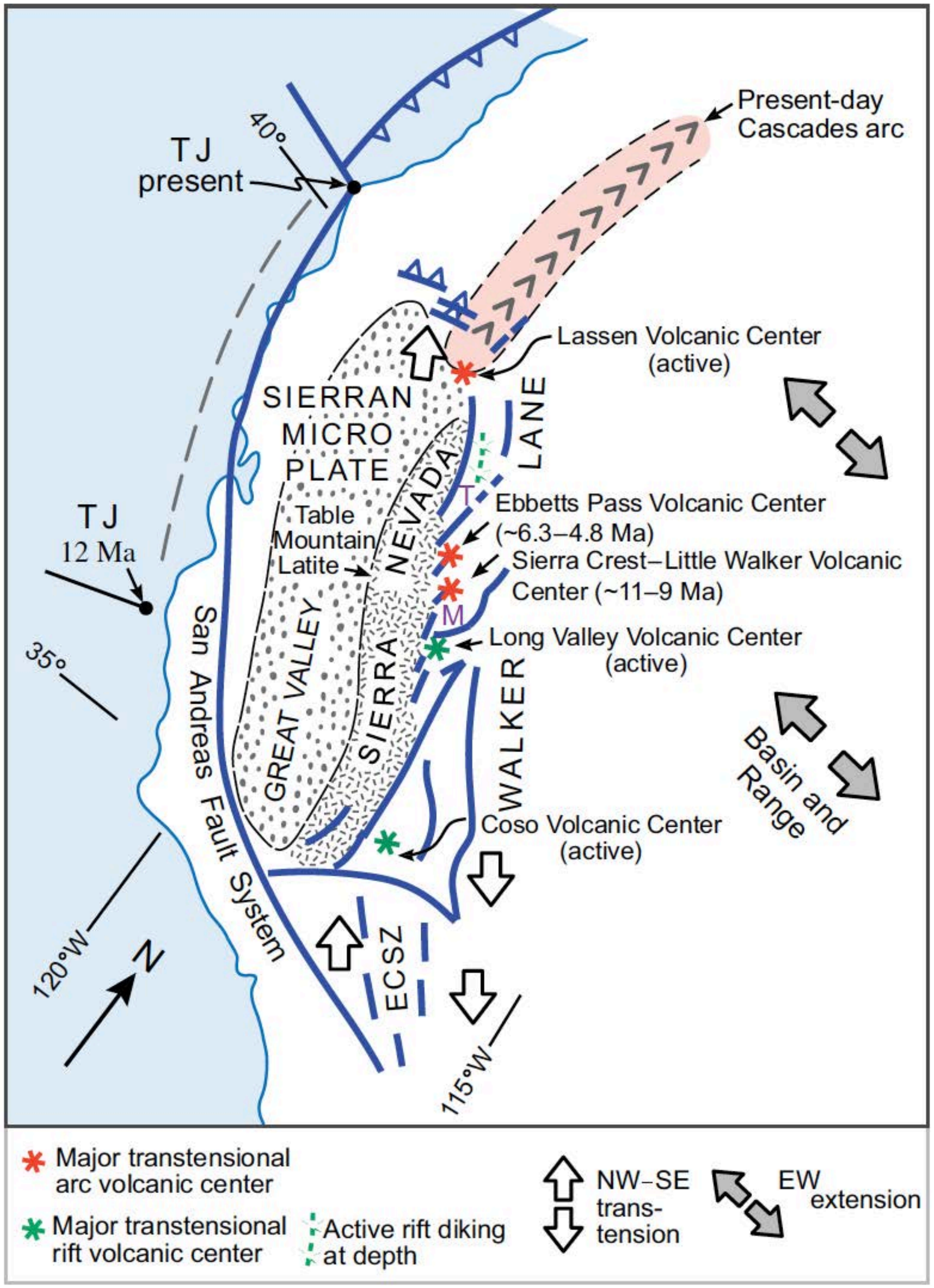


The Walker Lane transtensional rift tip has propagated northward with time by exploiting the Ancestral Cascades arc axis, in concert with northward migration of the Mendocino Triple Junction.

This progressively shut off subduction and lengthens the Sierra Nevada microplate, with rift volcanism following in its wake (cf. Busby et al. 2016, 2018).

Large arc and rift volcanic centers in the Walker Lane have formed within large pull-apart basins formed at major releasing right stepovers or right bends (Busby, 2013).

Busby 2013



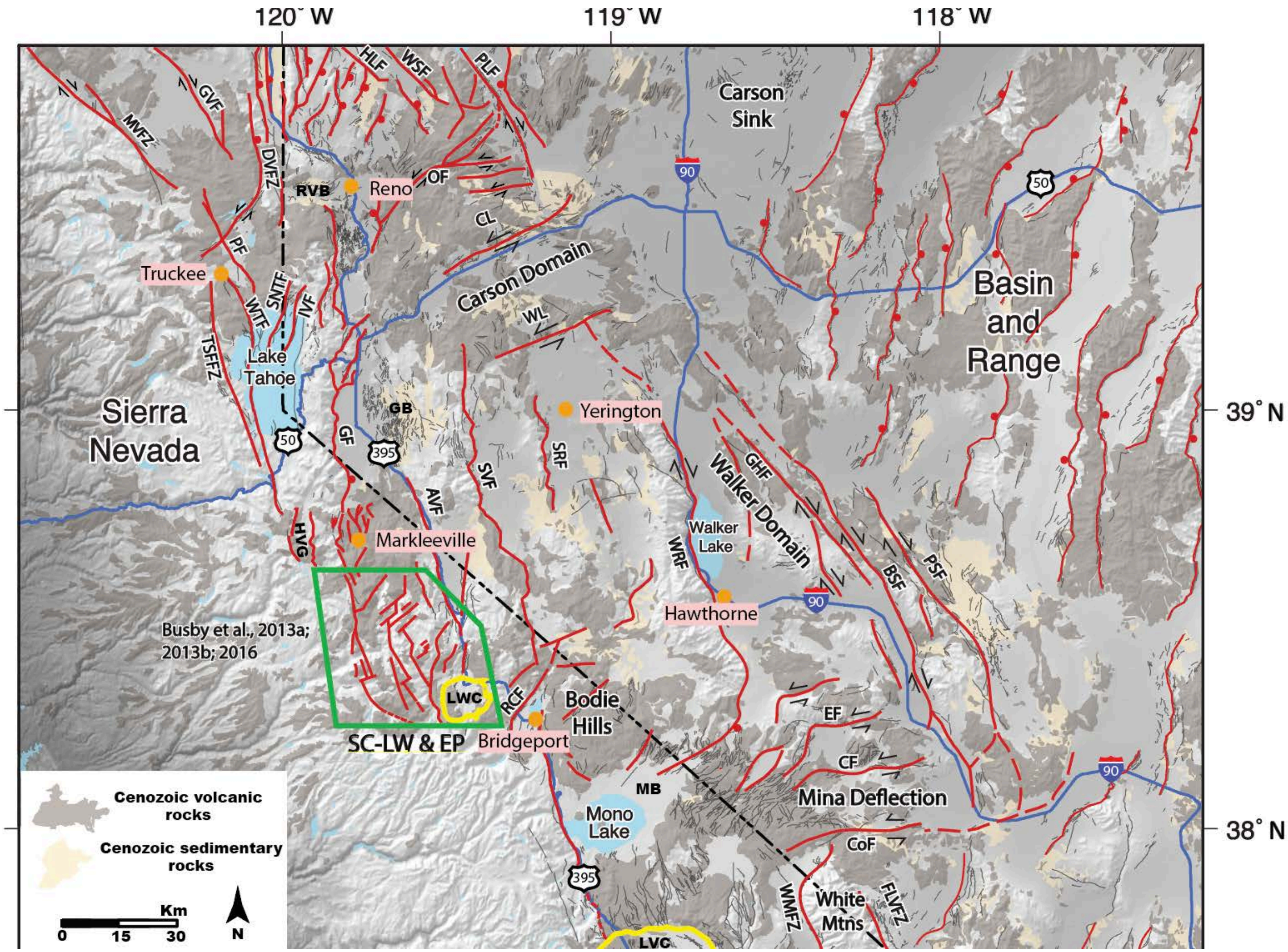
Busby 2013

* Rift tip now lies at Lassen arc volcanic center, in a pull-apart basin

Between 12 Ma and 4.5 Ma, the rift tip lay in two volcanic centers in pull-apart basins described today:

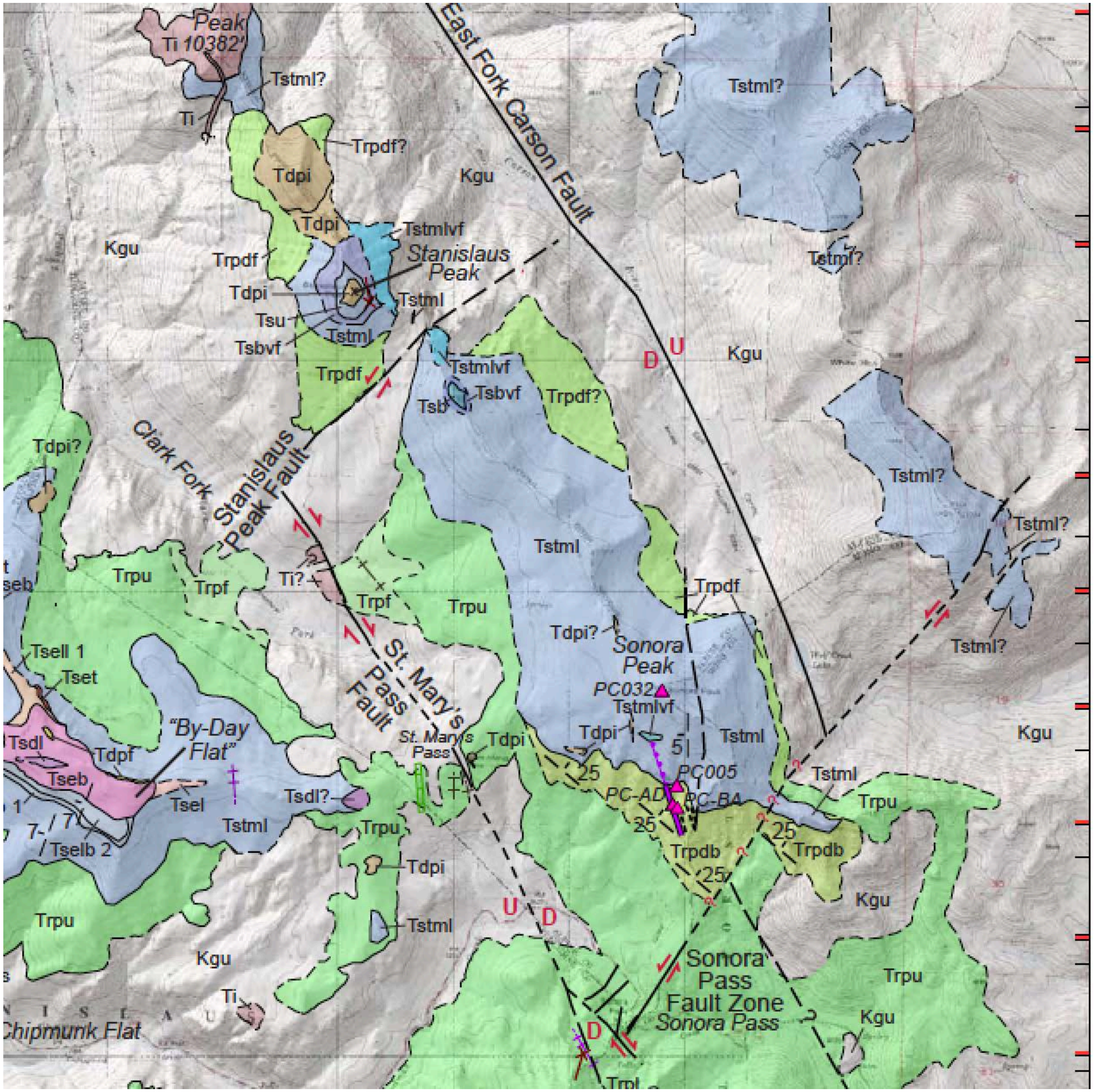
* Miocene Sierra Crest-Little Walker volcanic center

* Late Miocene to Pliocene Ebbetts Pass volcanic center



Position of these two volcanic centers along the western margin of the central Walker Lane (green box): Sonora Pass to Ebbetts Pass, central Sierra Nevada.

Busby et al., 2018



Work at Sonora Pass to Ebbetts Pass is based on 15 years of **geologic mapping** with my students ……

A sample from one map:

Dextral component of slip on NNW normal faults

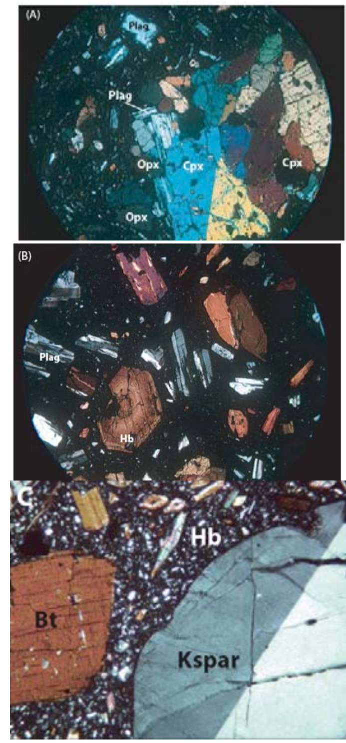
Sinistral component of slip on NE normal faults

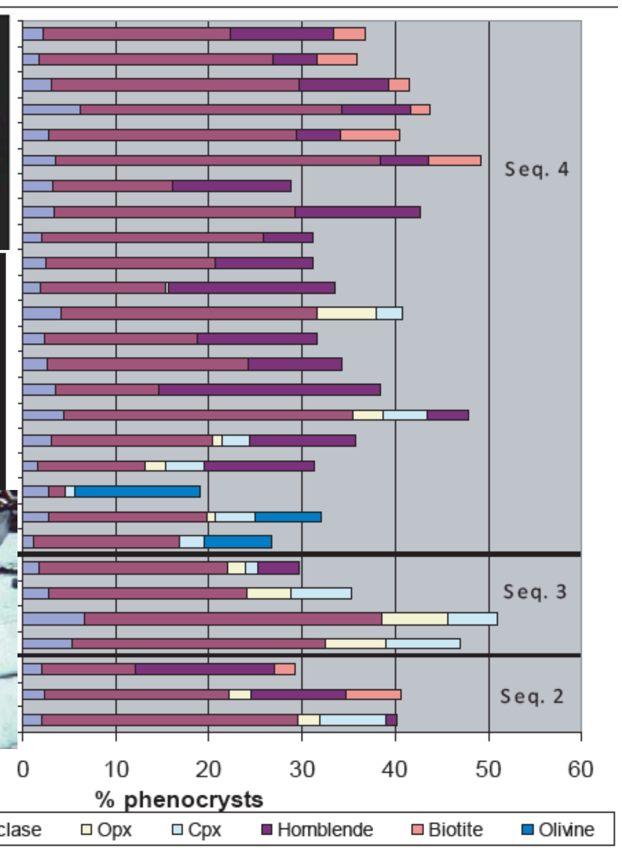
Kinematic indicators and offset of linear features.

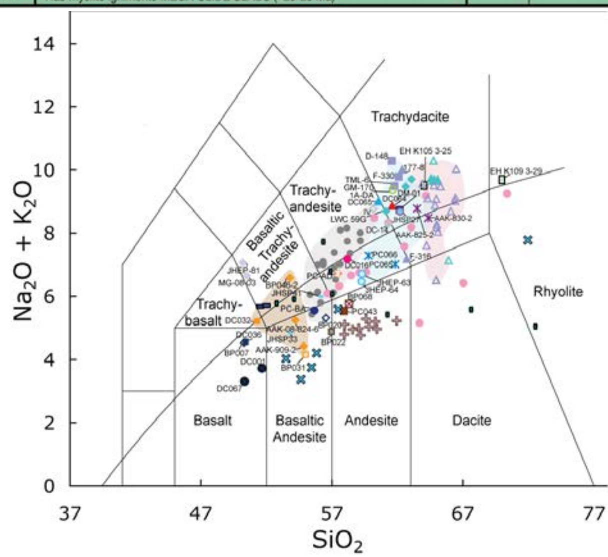
(Busby et al., 2013a, 2013b, 2016, 2018)

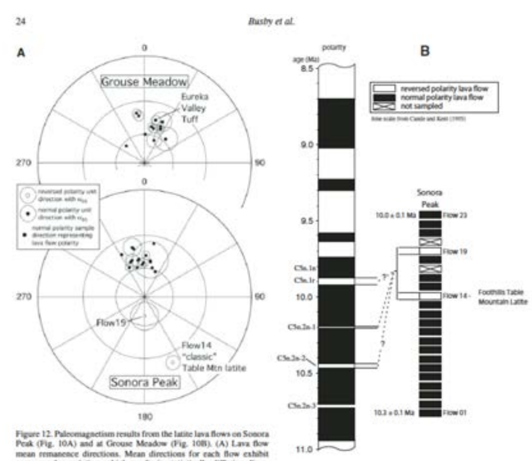
….supported by petrographic, geochemical, geochronological and paleomagnetic work....

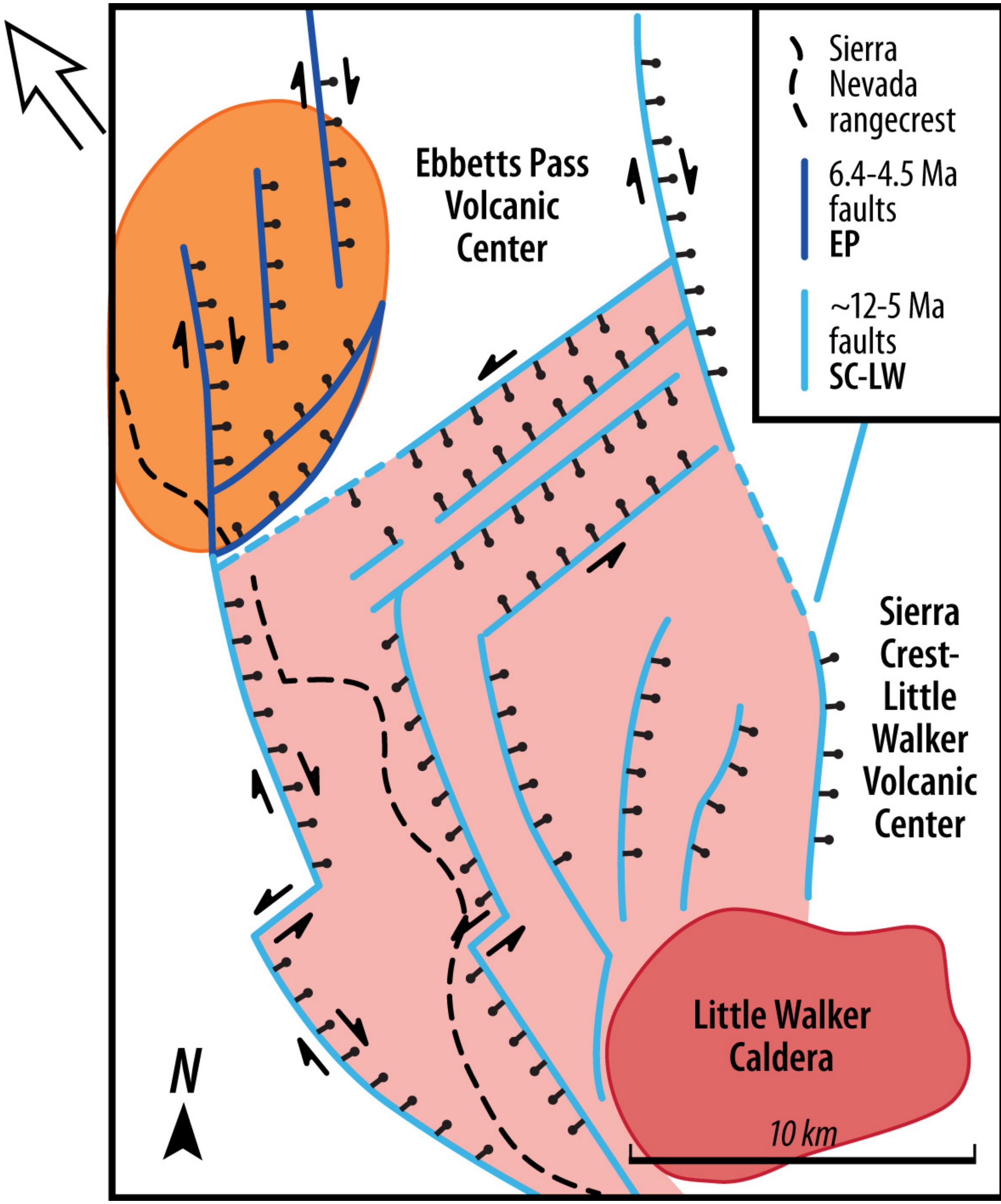
Tectonic Setting	Gp/Fm/Mbr			Rock Types	Ages in Ma		Sample #
Rift	Disaster Peak Formation (Tdp)	Basalt monogenetic center		Basalt plug and cinder cone erosional remnant on Disaster Peak	Plag	3.69 +/- 0.03	JHEP-57
Ebbetts Pass Volcanic Center (Ancestral Cascades Arc)	Disaster Peak Formation (Tdp)	Ebbetts Pass Stratovolcano (Tdpeps)		Dacite intrusion on Highland Peak (Tdpid)	San	4.478 +/- 0.007	JHEP-49
Ebbetts Pass Volcanic Center (Ancestral Cascades Arc)	Disaster Peak Formation (Tdp)	Ebbetts Pass Stratovolcano (Tdpeps)		Rhyolite feeder dike (to Tdpeps)	Plag	4.626 +/- 0.018	JHEP-8
Ebbetts Pass Volcanic Center (Ancestral Cascades Arc)	Disaster Peak Formation (Tdp)	Ebbetts Pass Stratovolcano (Tdpeps)		Andesite lava MEGA-SLIDE SLAB (in Tdpeps)	Hb	6.203 +/- 0.011	MG-08-08
Ebbetts Pass Volcanic Center (Ancestral Cascades Arc)	Disaster Peak Formation (Tdp)	Ebbetts Pass Stratovolcano (Tdpeps)		Basaltic andesite lava (Tdpeps)	Matrix	4.6 +/- 0.7	JHEP-9
Ebbetts Pass Volcanic Center (Ancestral Cascades Arc)	Disaster Peak Formation (Tdp)	Ebbetts Pass Stratovolcano (Tdpeps)		Basaltic andesite lava (Tdpeps)	Plag	4.90 +/- 0.02	JHEP-47
Ebbetts Pass Volcanic Center (Ancestral Cascades Arc)	Disaster Peak Formation (Tdp)	Lower Silicic section		Rhyolite lava (Tdplr)	Hb Pl	4.73 +/- 0.03 4.53 +/- 0.03	JHEP-44
Ebbetts Pass Volcanic Center (Ancestral Cascades Arc)	Disaster Peak Formation (Tdp)	Lower Silicic section		Rhyolite welded ignimbrite (Tdpwi)	Sanidine 14 crystals	4.636 +/- 0.014	MG-08-07
Ebbetts Pass Volcanic Center (Ancestral Cascades Arc)	Disaster Peak Formation (Tdp)	Lower Silicic section		Rhyolite welded ignimbrite (Tdpwr)	Plag	4.665 +/- 0.02	JHEP-21
Ebbetts Pass Volcanic Center (Ancestral Cascades Arc)	Disaster Peak Formation (Tdp)	Lower Silicic section		Dacite lava (Tdpld)	Hb	6.367 +/- 0.017	MG-08-12
Sierra Crest - Little Walker Volcanic Center (Ancestral Cascades Arc)	Disaster Peak Formation (Tdp)			Andesite block-and-ash-flowtuff (in Tdpdf)	Hb Pl	4.96 ± 0.05 4.457 +/- 0.014	JEHP-55
Sierra Crest - Little Walker Volcanic Center (Ancestral Cascades Arc)	Disaster Peak Formation (Tdp)			Basalt lavas (in Tdplb)	Plag	7.25 ± 0.01	JHEP-83
Sierra Crest - Little Walker Volcanic Center (Ancestral Cascades Arc)	Disaster Peak Formation (Tdp)			Dacite lava MEGA-SLIDE SLAB (in Tdpld)	Hb	11.05 +/- 0.031	JHEP-70
Sierra Crest - Little Walker Volcanic Center (Ancestral Cascades Arc)	Stanislaus Group (Ts)	Dardanelles Fm (Tsd)		Shoshonite lava (Tsdl)	WR	9.137 +/- 0.017	BP-46
Sierra Crest - Little Walker Volcanic Center (Ancestral Cascades Arc)	Stanislaus Group (Ts)	Eureka Valley Tuff Formation (Tse)	Upper Member (Tseu)	Previous work 9.34 +/- 0.04 Ma (trachydacite non-welded ignimbrite)[6]			
Sierra Crest - Little Walker Volcanic Center (Ancestral Cascades Arc)	Stanislaus Group (Ts)	Eureka Valley Tuff Formation (Tse)	By Day Mmber (Tseb)	Previous work 9.4 +/- 0.3 Ma (trachydacite welded ignimbrite)[5]			
Sierra Crest - Little Walker Volcanic Center (Ancestral Cascades Arc)	Stanislaus Group (Ts)	Eureka Valley Tuff Formation (Tse)	Lava Flow Mmber (Tsel)	Trachydacite lava MEGA-SLIDE SLAB in Tsel	Pl	11.66 +/- 0.07	JHEP-64
Sierra Crest - Little Walker Volcanic Center (Ancestral Cascades Arc)	Stanislaus Group (Ts)	Eureka Valley Tuff Formation (Tse)	Tollhouse Flat Mmber (Tset)	Previous work 9.54 +/- 0.04 Ma (trachydacite welded ignimbrite)[4]			
Sierra Crest - Little Walker Volcanic Center (Ancestral Cascades Arc)	Stanislaus Group (Ts)	Eureka Valley Tuff Formation (Tse)	Basal Lava Mmber (Tseblt)	Trachydacite intrusion and lava (Tselit)	Hb	9.94 +/- 0.03	JHEP-88
Sierra Crest - Little Walker Volcanic Center (Ancestral Cascades Arc)	Stanislaus Group (Ts)	Table Mtn Latite Fm (Tml)		Previous work 10.41 +/- 0.08 Ma to 10.36 +/- 0.06 Ma (trachyandesite, trachybasaltic andesite and basalt lavas)[2] Has andesite lava MEGA-SLIDE SLAB 12.95 +/- 0.09 Ma[3]			
Sierra Crest - Little Walker Volcanic Center (Ancestral Cascades Arc)	Relief Peak Formation (Trp)			Andesite black-and-ash-flow tuff within andesite debris flow deposits (Trpdf) Previous work includes 10.39 ± 0.18 Ma to > 12.15 ± 0.04[1] Has rhyolite ignimbrite MEGA-SLIDE SLABS (~29-25 Ma)	Hb	11.33 +/- 0.03	JHEP-90





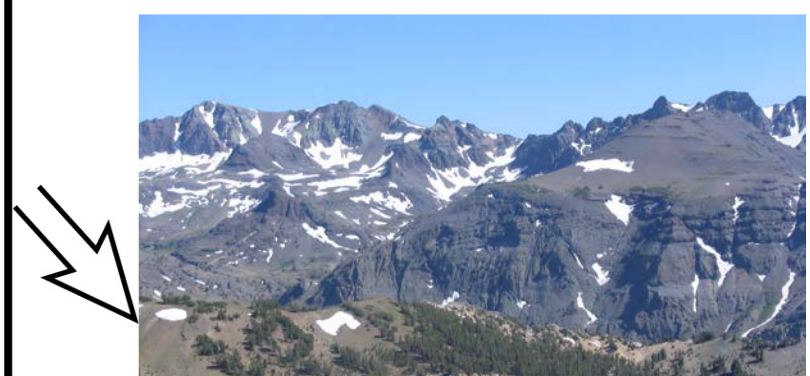






Two adjacent pull-apart basins, very well exposed along the central Sierra Nevada range crest and range front, with 5-km of structural relief.

These centers reveal structural controls that cannot be observed at active volcanoes, where the relevant structures are buried.



We use published maps and $^{40}Ar/^{39}Ar$ age dates (Busby et al., 2013a, 2013b, 2016, 2018) to calculate **subsidence rates** over the lifespan of these two transtensional rift basins and compare these to petrographic and geochemical data.

CONCLUSION:

Subsidence rates and sizes of transtensional rift pull-apart basins

control

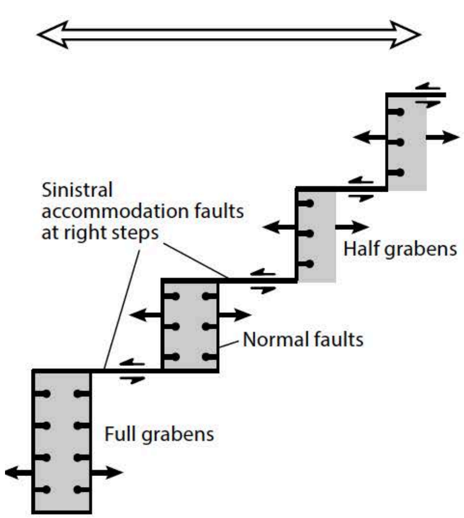
eruptive rates, compositions and vent types.

Structural setting

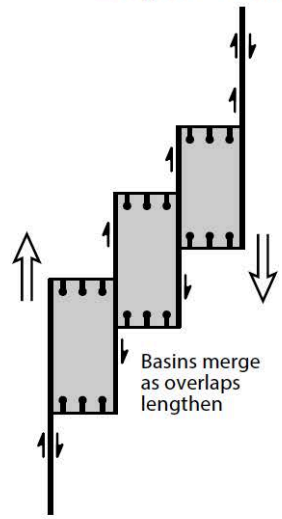
RIFTING UNDER DEXTRAL SHEAR - oblique faults.

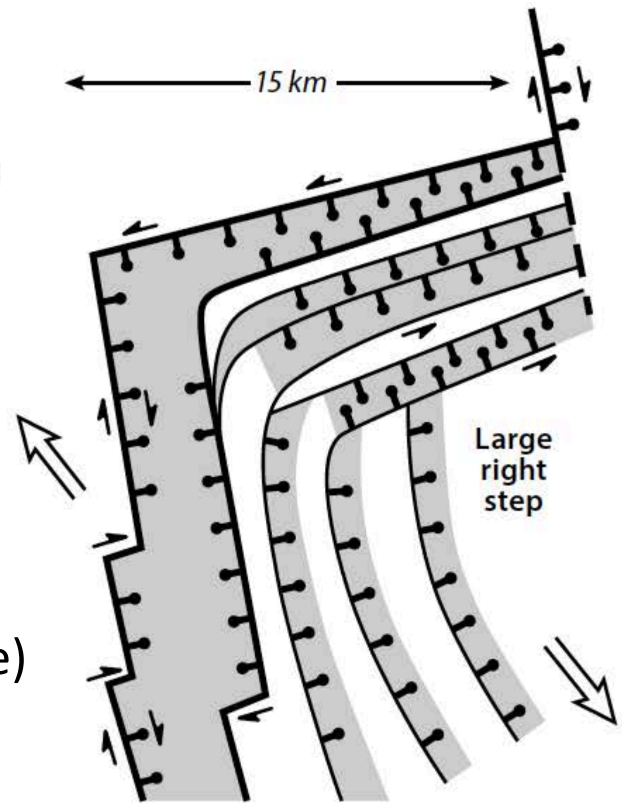
N-S faults are dextral-normal oblique
ENE faults are sinistral-normal oblique

NOT orthogonal extension

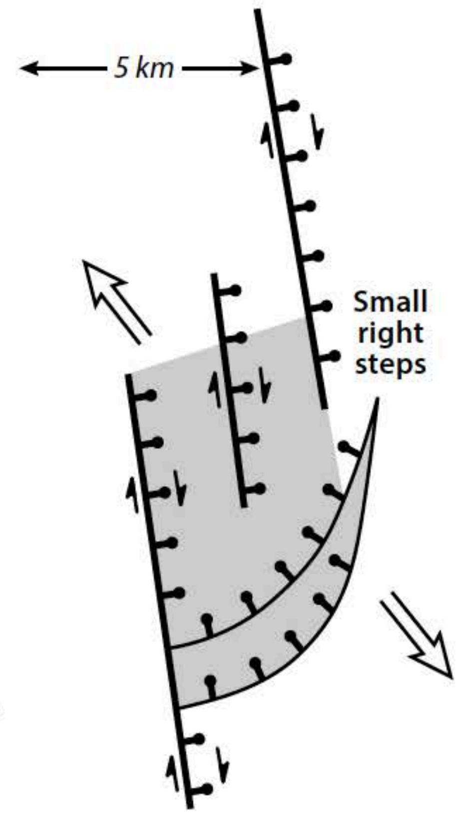


NOT releasing step-overs along strike slip faults





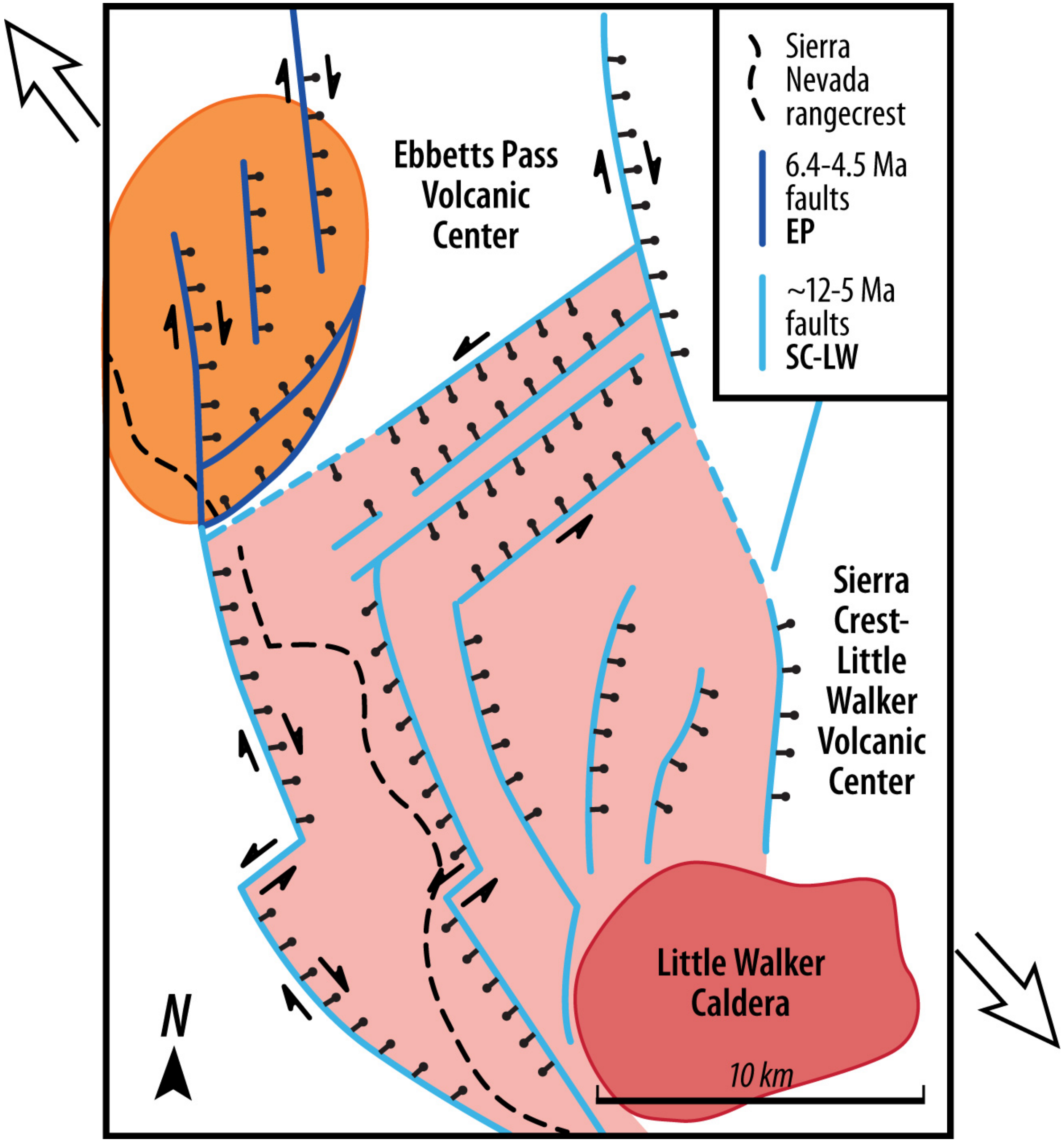
LARGE releasing right step (15 km)



SMALL releasing right step (5 km)

White arrows – obliquity between Sierra Nevada microplate (west side) and N Am plate (east side).

Busby et al., Geosphere, 2018



Sierra Crest-Little Walker arc volcanic center and pull-apart basin:

As large (~4,000 km^2) as the active Long Valley rift volcanic center and pull-apart basin, and similarly contains a caldera over part of the field.
(Busby et al., 2013a, 2013b)

Ebbetts Pass arc volcanic center and pull-apart basin:

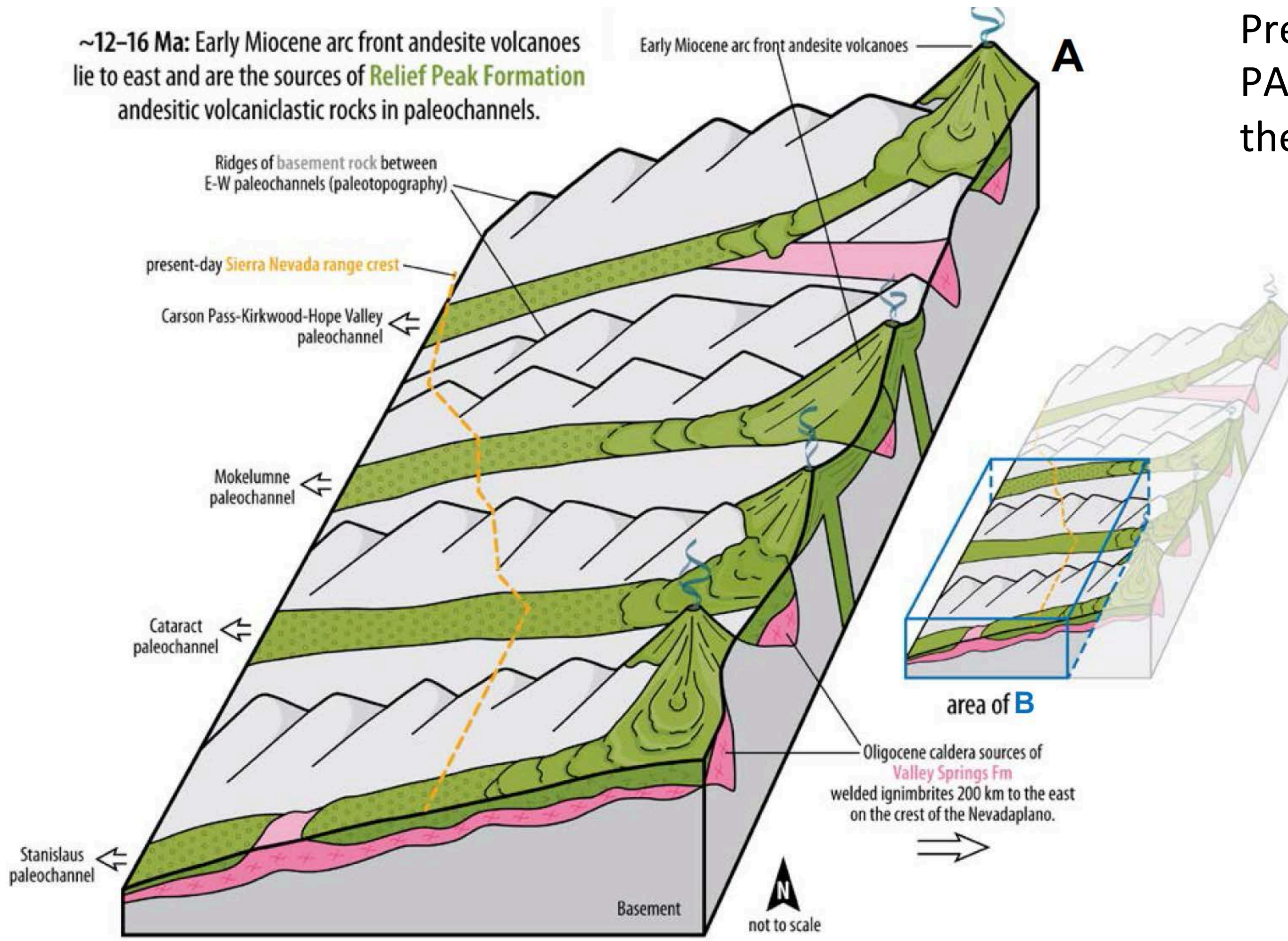
Smaller, comparable in volume to the active Lassen arc volcanic center and pull-apart basin at the present day transtensional rift tip.

(Busby et al., 2018)

PRE-TECTONIC VIEW:

Oligocene to early Miocene ignimbrites (sourced from calderas in eastern Nevada, not shown) overlain by

Early Miocene andesitic fluvial & debris flow strata & block-and-ash-flow tuffs (sourced from stratovolcanoes in western Nevada, as shown)

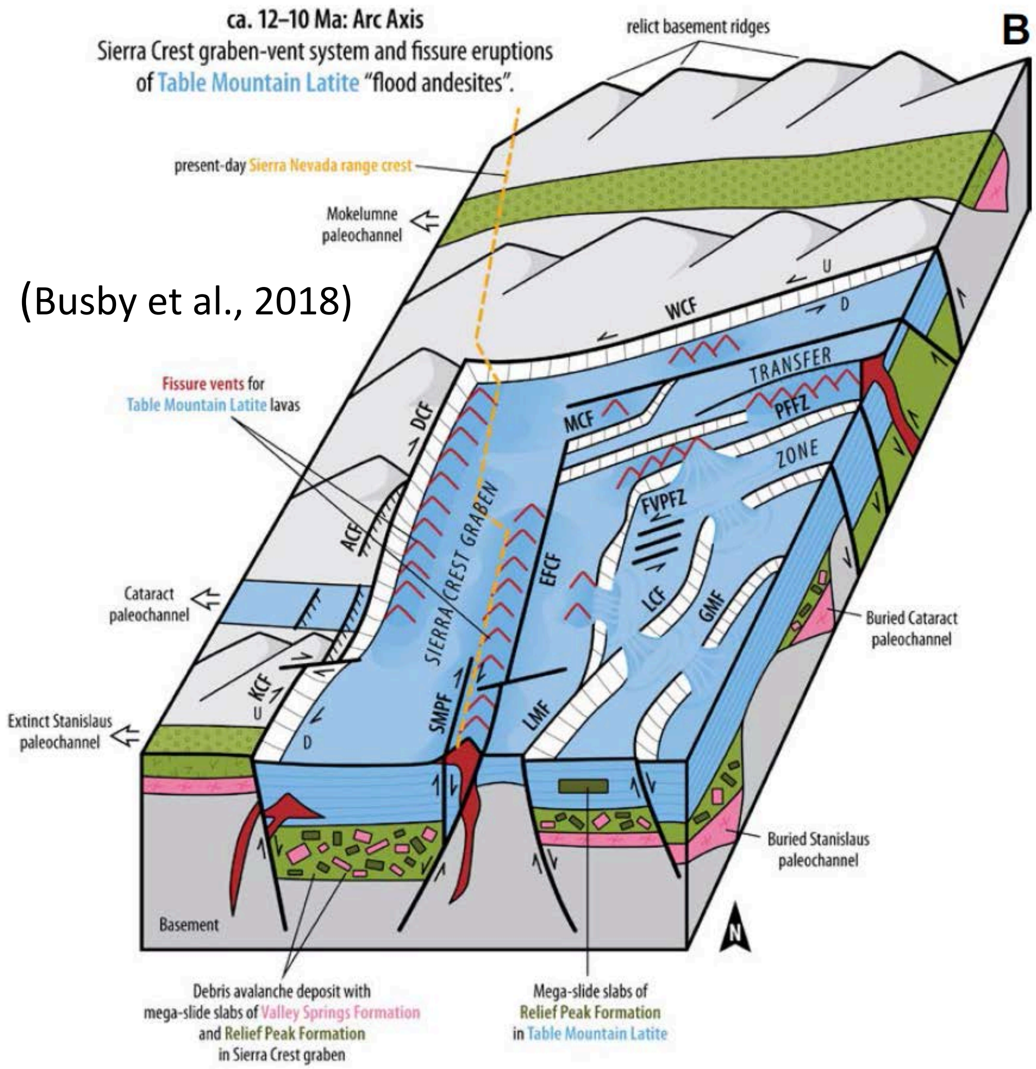


Preserved in East-West PALEOCHANNELS of the Nevadaplano.

Following slides focus on area of present-day central Sierra Nevada range crest (shown in gold).

Busby et al., 2018

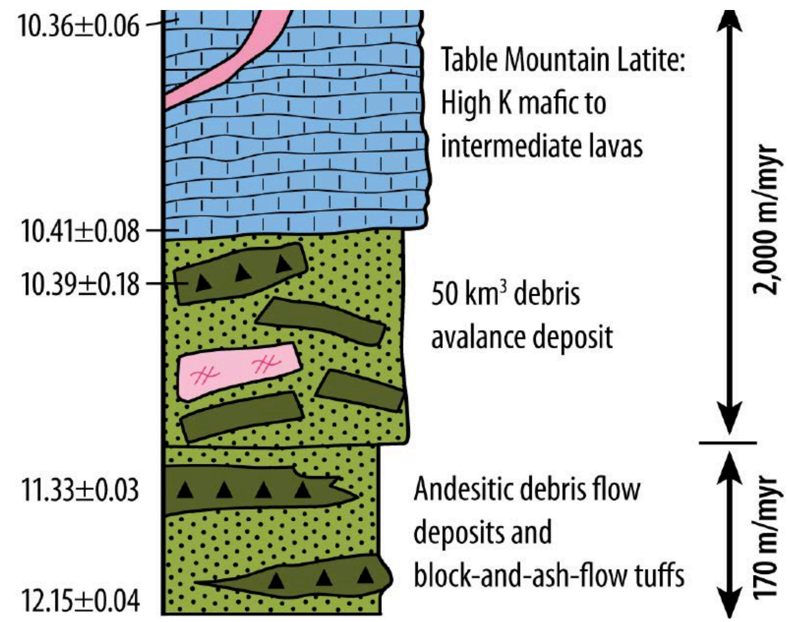
Sierra Crest-Little Walker volcanic center and pull-apart basin (LARGE)



(Busby et al., 2018)

1. Initial low volume calcalkaline volcanic rocks interstratified with massive debris flow deposits: 170 m/myr (relatively slow subsidence).

2. Debris avalanche immediately followed by eruption of high-K "flood lavas" (Table Mountain Latite): 2,000 m/myr **(peak subsidence)**



(Busby and Putirka, in prep)

High-K andesite "flood lavas" fed from fissure vents 8-12 km long ΛΛΛΛΛΛ VOLUME: 400 km^3

Volcanic production rate 10X greater than the median for andesites erupted worldwide (**peak production**).

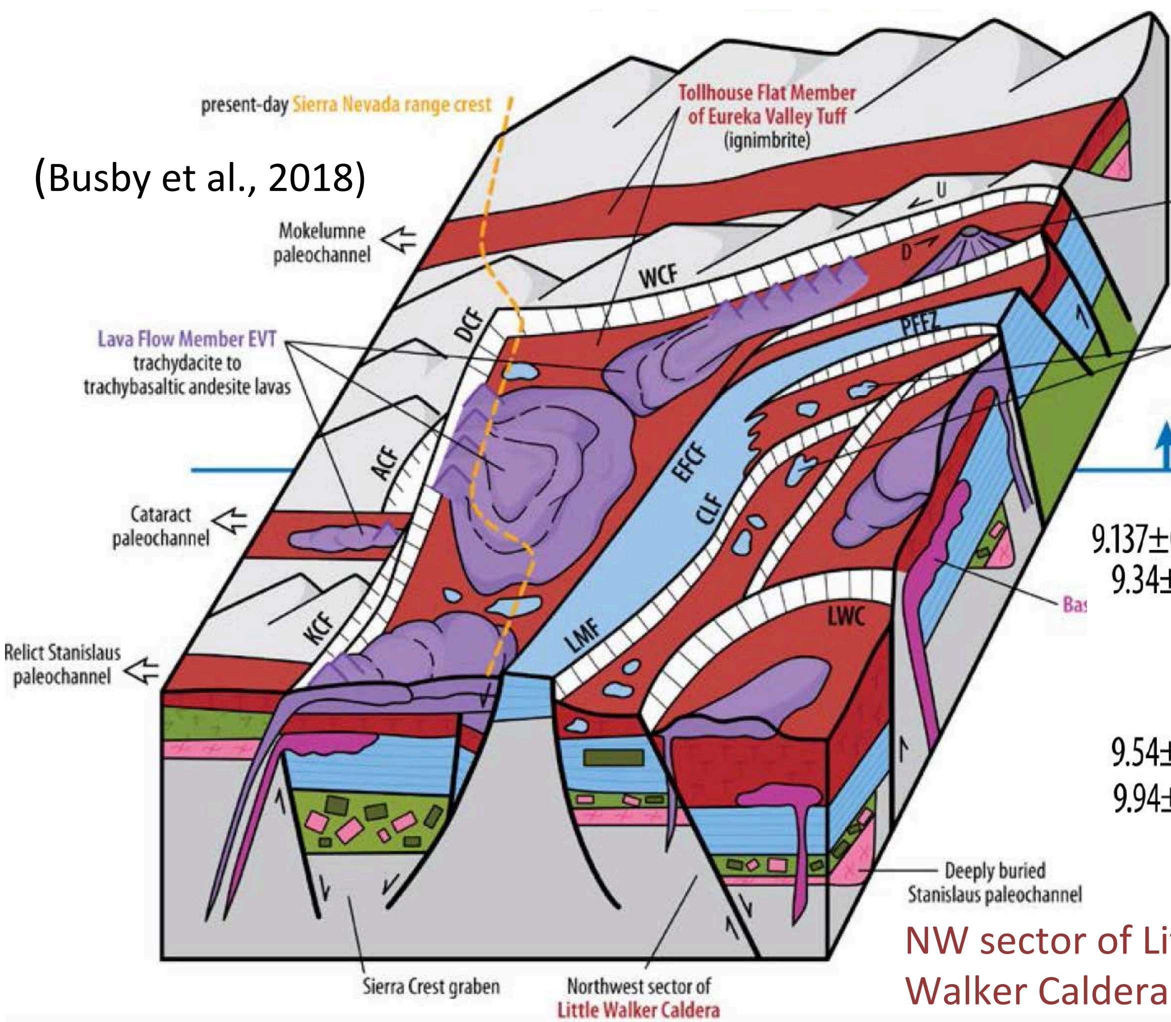
TABLE MOUNTAIN LATITE: High-K andesite "flood lavas" fed from fissure vents 8-12 km long

MARKED BY SCORIA RAMPARTS 100-200 METERS THICK

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

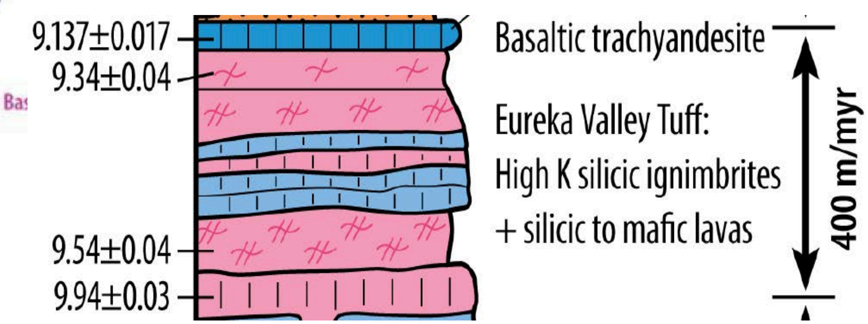
Sierra Crest-Little Walker volcanic center and pull-apart basin (LARGE), *continued*

(Busby et al., 2018)



NW sector of Little Walker Caldera

Eruption of high-K silicic ignimbrites from Little Walker caldera,
coeval with
eruption of high-K mafic to silicic lavas from faults across the length and width of the pull-apart basin.

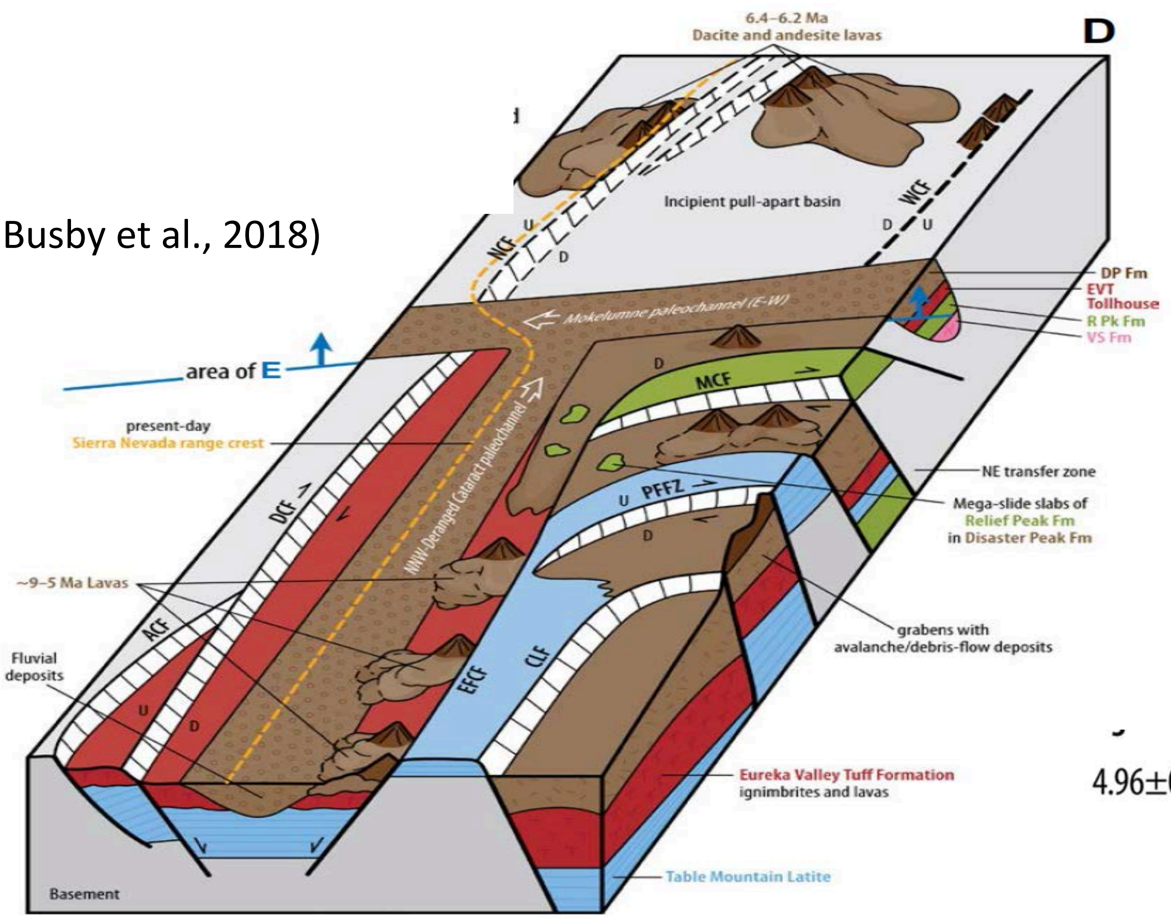


(Busby and Putirka, in prep)

Slowing but still high subsidence rate of **400 m/myr**

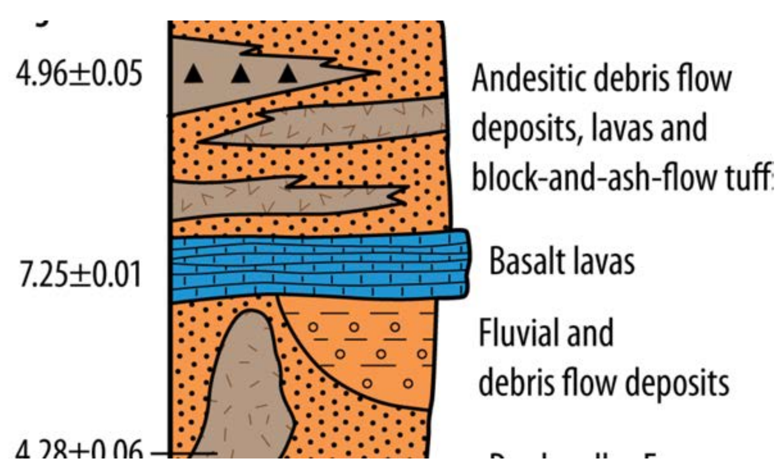
Sierra Crest-Little Walker volcanic center and pull-apart basin (LARGE), *continued*

(Busby et al., 2018)



Return to low volume calcalkaline eruptive products interstratified with reworked andesitic debris (including N-S paleochannel).

Return to relatively slow subsidence rate of 170 m/myr

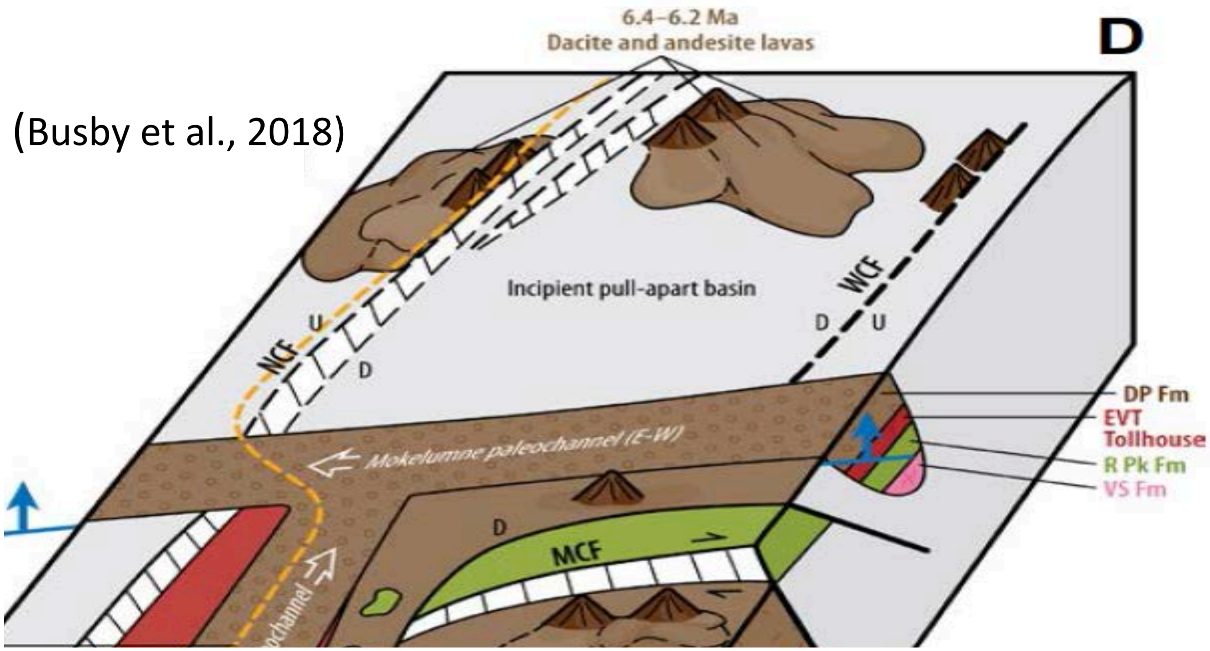


(Busby and Putirka, in prep)

Meanwhile, incipient volcanism and subsidence begin at Ebbetts Pass volcanic center to the north……..

Ebbetts Pass volcanic center and pull-apart basin (SMALL)

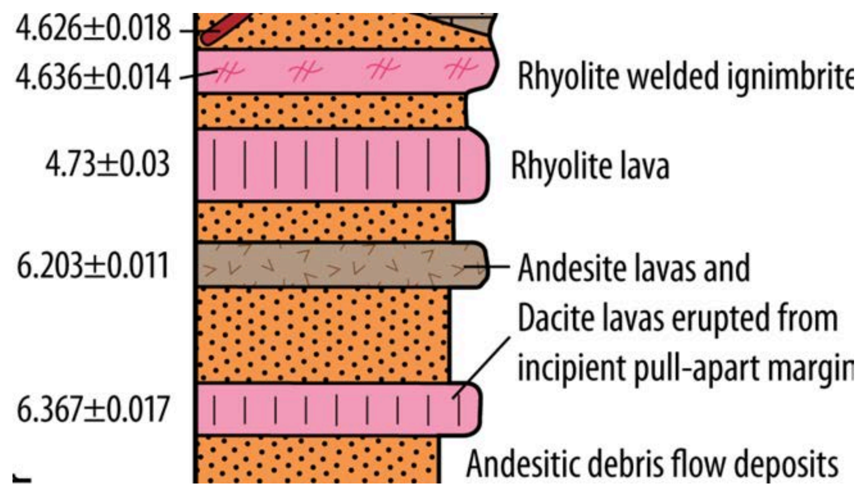
(Busby et al., 2018)



1. Initial low-volume calcalkaline volcanic rocks erupted from basin-margin faults; basin largely filled with reworked andesitic debris.

170 m/myr (relatively slow subsidence).

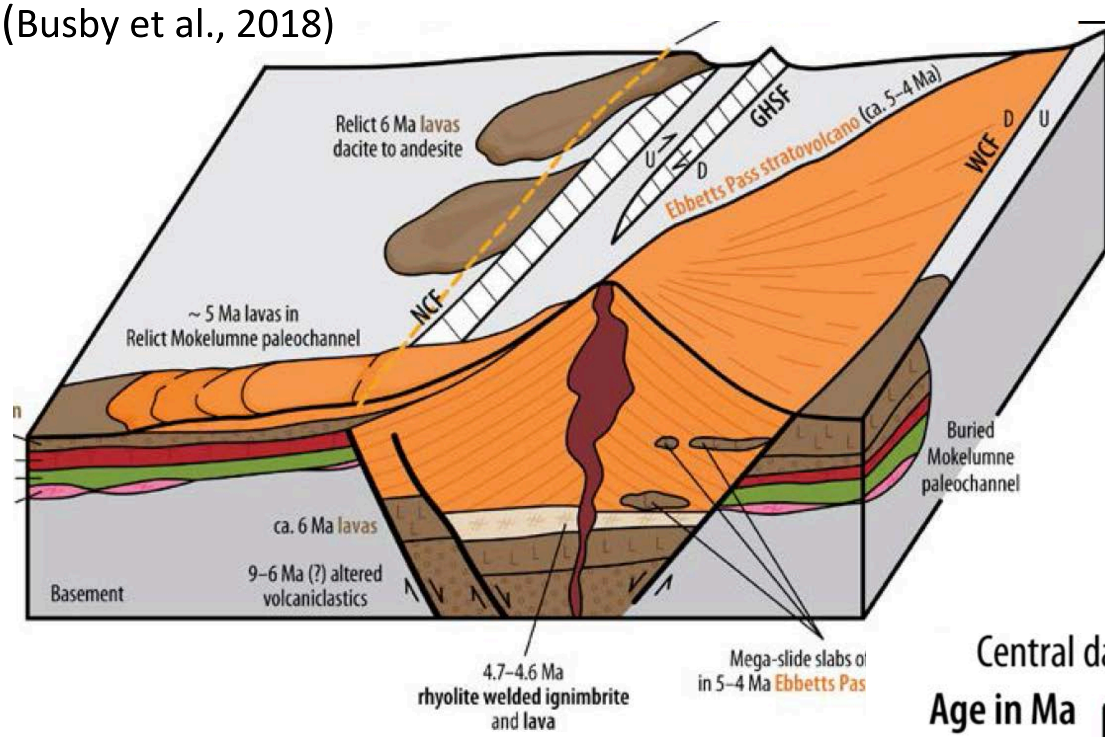
Including an ultra-welded rhyolite ignimbrite first recognized by Garniss Curtis in the 1950s!



(Busby and Putirka, in prep)

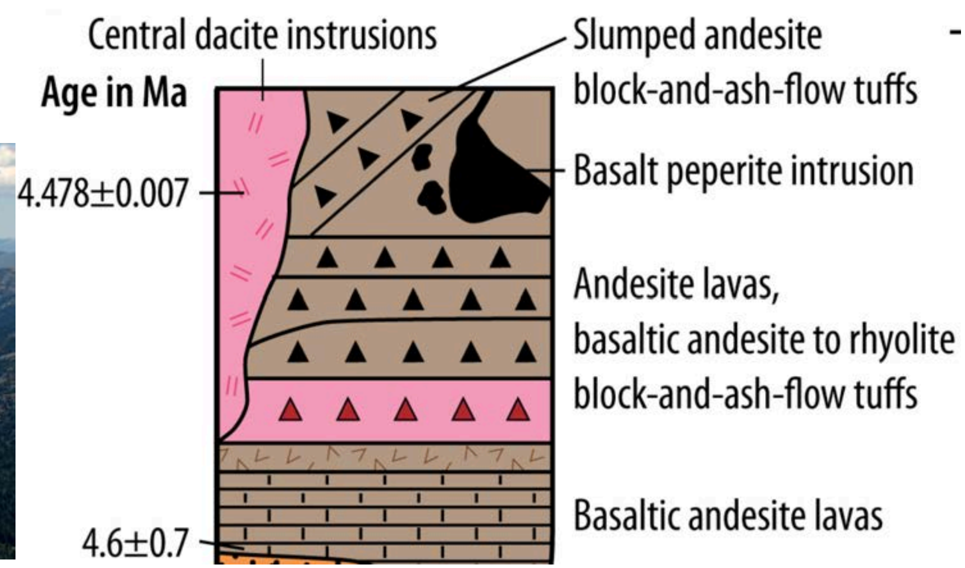
Ebbetts Pass volcanic center and pull-apart basin (SMALL), *continued*

(Busby et al., 2018)



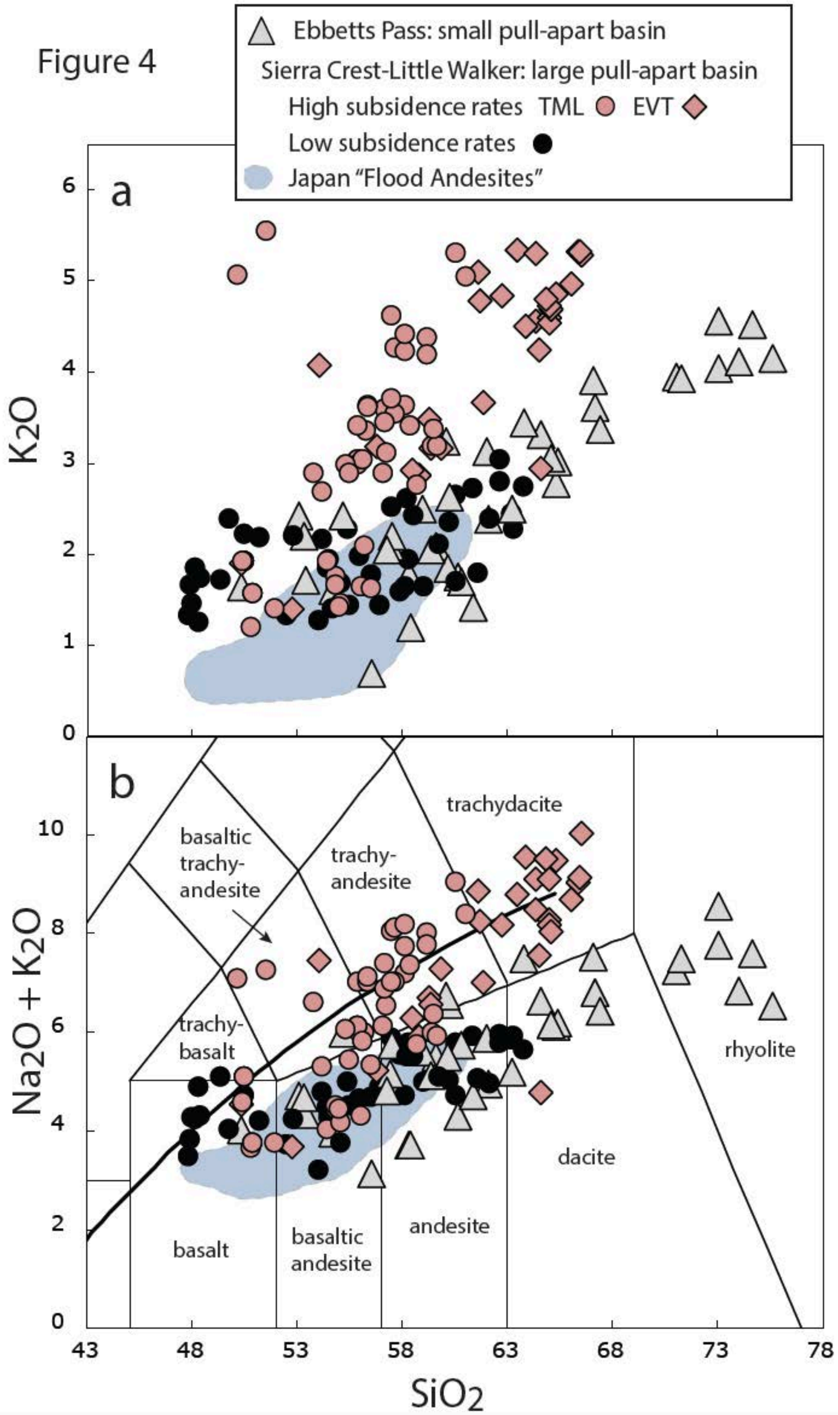
2. **Peak volcanism** produced a 270 km^3 central cone built of lavas and block-and-ash-flow tuffs, which overfilled the basin.

Very high subsidence rate of >3,000 m/myr



(Busby and Putirka, in prep)

Figure 4



The smaller Ebbetts Pass volcanic center (gray triangles) is more evolved and less alkalic than the large Sierra Crest-Little Walker volcanic center.

In the larger Sierra Crest-Little Walker volcanic center, alkalic rocks correspond to times of higher subsidence relative to calcalkaline rocks.

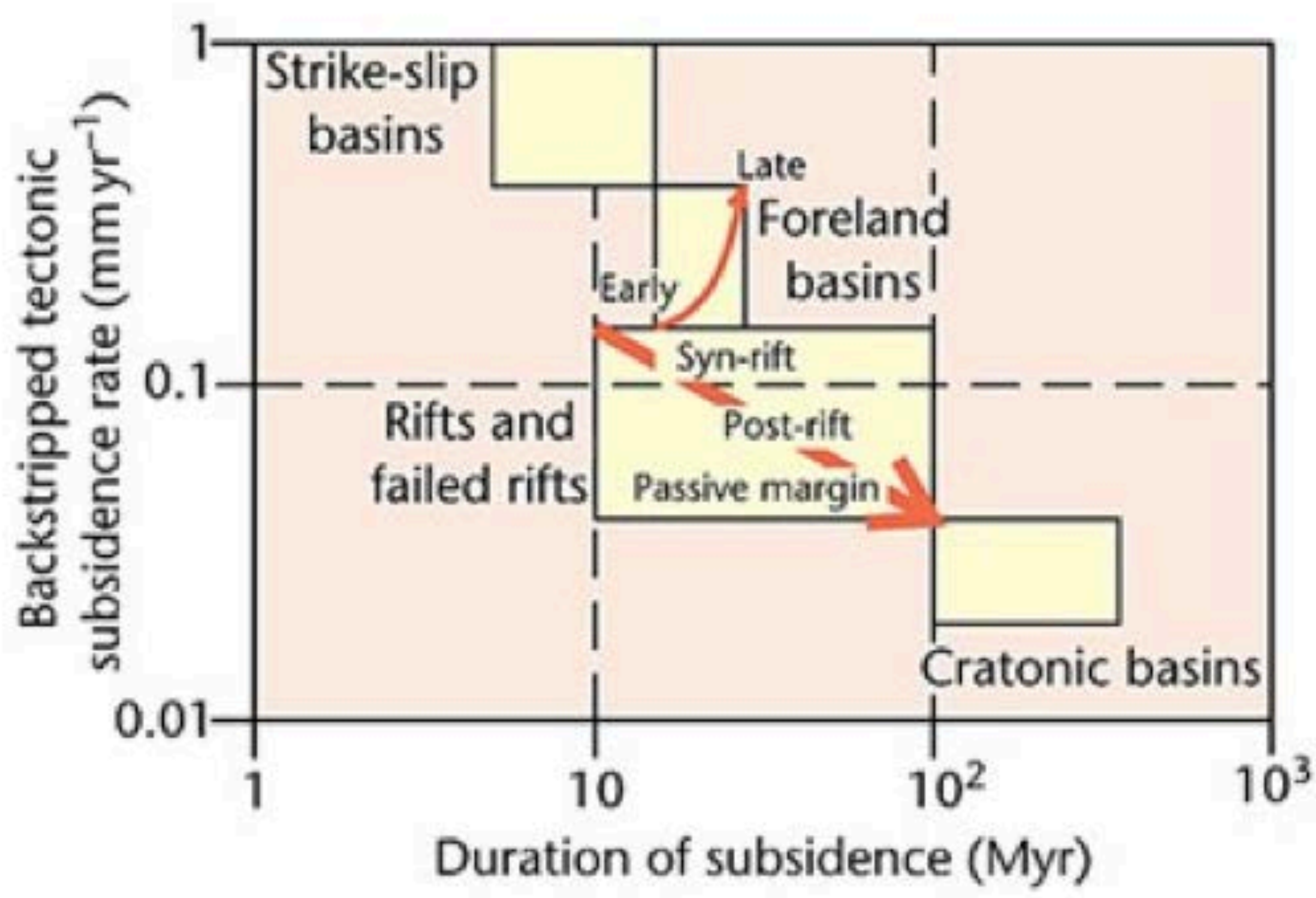
INTERPETATION: The smaller basin experienced lower tensile stresses, and magmatic dikes could not extend deeply enough to tap low-degree partial melt stored in the mid- to lower-crust.

Clinopyroxene, olivine and plagioclase compositions indicate markedly greater crystallization depths for the high-K rocks than for the calcalkaline rocks (Larson, Putirka and Busby, AGU 2019 abstract).

(Blue shade = Miocene to Pleistocene flood andesites in Japan)

(Busby and Putirka, in prep)

In both centers, peak erupted volumes correspond to peak fault-controlled subsidence rates in transtensional basins (2000-3000 m/myr). This is an order of magnitude faster than orthogonal rift basins.



Allan and Allan, Basin Analysis, 2013

CONCLUSIONS

Subsidence rates and sizes of transtensional rift pull-apart basins

control

eruptive rates, compositions and vent types

Lower transtensional strain rates produce small-volume eruptions from point sources along faults.

Higher transtensional strain rates in the large basin produced large-volume eruptions from fissure vents and a caldera. Higher transtensional strain rates in the smaller basin produced a Lassen-sized central cone.

Larger pull-apart basins tap deeper magma sources.

Transtensional rift settings may uniquely provide rapid magma throughput.