IGNIMBRITE CALDERAS AND A LARGE RADIATING MAFIC DIKE SWARM OF OLIGOCENE AGE, RIO GRANDE RIFT, NEW MEXICO: POSSIBLE IMPLICATIONS TO RESTLESS CALDERAS

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ABSTRACT

The Oligocene Socorro-Magdalena magmatic system (SMMS, 7000 km^3; Figs.1 & 2) of the early Rio Grande rift is expressed by three domains: 1) a cluster of 6 large rhyolitic calderas (Socorro-Magdalena caldera cluster, SMCC) at the core, 2) a medial apron of basaltic-andesite lavas (1500 km^3) with intertonguing ignimbrite sheets, and 3) a large diameter (200 km) radial swarm of dominantly basaltic-andesite dikes (Magdalena radial dike swarm, MRDS) broadly focused on the SMCC. Closely spaced mafic dikes near Riley (n ~100) strike NNW to NNE, essentially parallel to the Oligocene rift axis as defined by domino-style early rift faults in the Lemitar Mountains (Fig.3A). Most dikes near Riley exhibit minimal contact metamorphism and are interpreted as non-eruptive dikes. Non-eruptive dikes also contain abundant magmatic carbonate (from trapped CO_2) that has deuterically replaced sparse olivine and clinopyroxene phenocrysts (Fig.3C). Three eruptive (feeder) dikes exhibit 10-20 m wide contact metamorphic aureoles that indicate strong heating of wall rocks below where the dike fed a basaltic volcano (Fig3B). Feeder dikes contain relatively fresh olivine basalt; which implies they lost CO_2 during eruption. Close spacing and relative abundance of mafic dikes at Riley is attributed to local coincidence of outward (northward) magmatic pressures and westward extension of the early Rio Grande rift (i.e. magmatic σ_3 and tectonic σ_3 were both east-west).

Four long dikes of the MRDS —at Pie Town, Hickman, Jones Camp and Ft. McRae (Fig.1)— yield reasonably precise $^{40}Ar/^{39}Ar$ ages (0.4-1.0 % error) analytically equivalent to the large volume (1250 km^3) La Jencia Tuff erupted from the Sawmill Canyon caldera at 29.15 Ma (0.3% error; Fig. 2). Near horizontal flow lineations (Fig.4B) on the chilled margin of the Hickman dike (15 km^3) and relatively precise age data suggest that it propagated northward during a period of high magma pressure shortly before caldera-forming eruption of the La Jencia Tuff (Figs.2& 5). Our cross sectional model (Fig.5) suggests that during periods of high magma pressure (pre-caldera tumescence) large volumes of relatively fluid basaltic magma were driven into fractures that propagated as much as 100 km outward from a lower crustal basaltic sill complex that fueled the caldera cluster (Figs.1 & 5). A restless caldera, such as Yellowstone, that experiences a non-eruptive earthquake swarm propagating several tens of km outward, over a few days, and in an odd direction relative to regional tectonic extension, may be indicative of a large volume magmatic system under extreme magmatic pressure (i.e. pre-caldera tumescence).

Supporting documents are available at *http://geoinfo.nmt.edu/staff/chamberlin/mrds/home.html*

CORRELATION OF BASALTIC DIKES AND RHYOLITIC CALDERAS

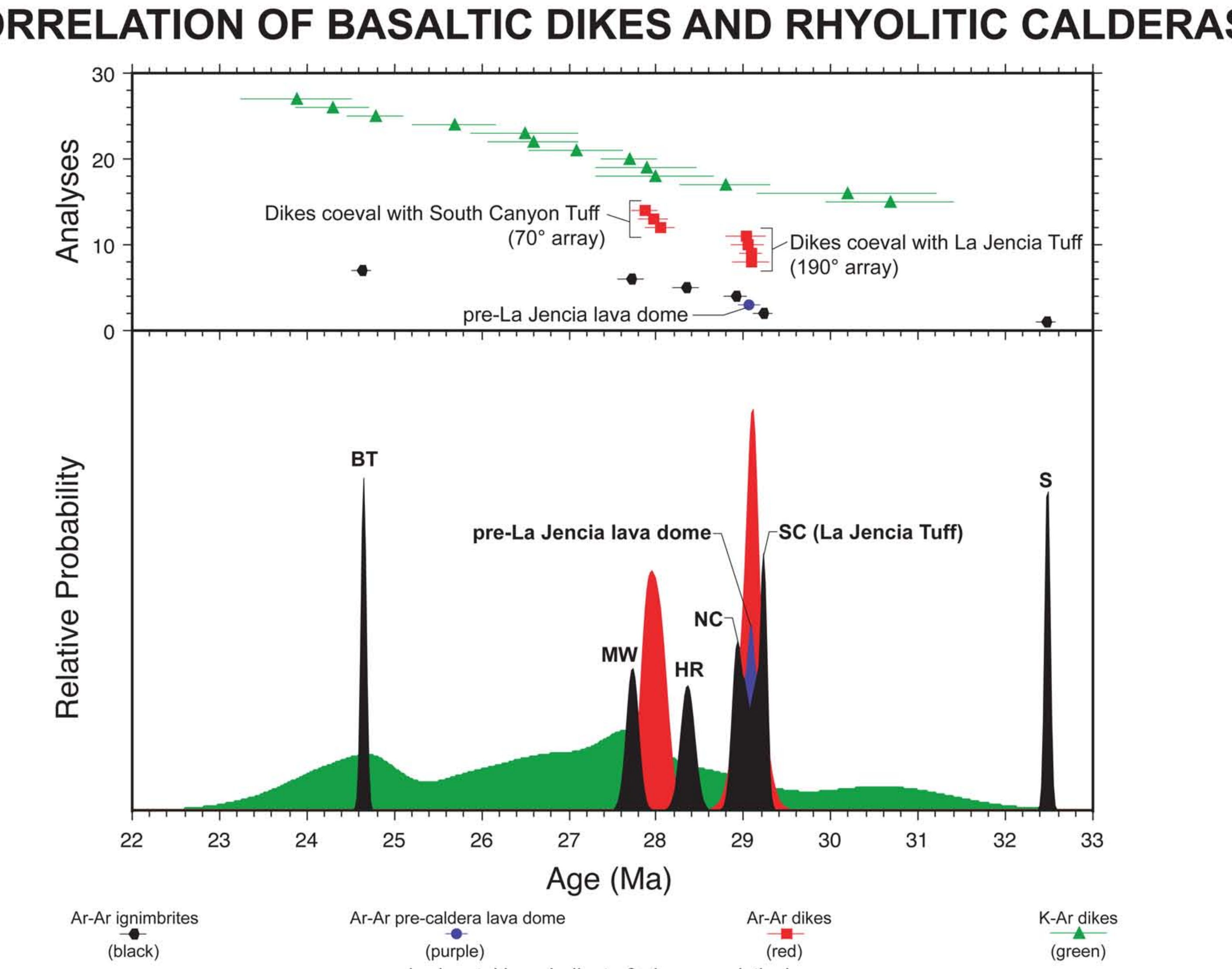

Figure 2—Geochronology of caldera-forming ignimbrites and mafic dikes. Data from Chamberlin et al. 2007 and Chamberlin et al., 2009. Ignimbrite calderas: Bear Trap Canyon (BT), Mt. Withington (MT), Hardy Ridge (HR), Nogal Canyon (NC), Sawmill Canyon (SC), and Socorro (S). Ar-Ar monitor age = 28.201 Ma.

CLOSELY SPACED DIKES PARALLEL TO RIFT AXIS

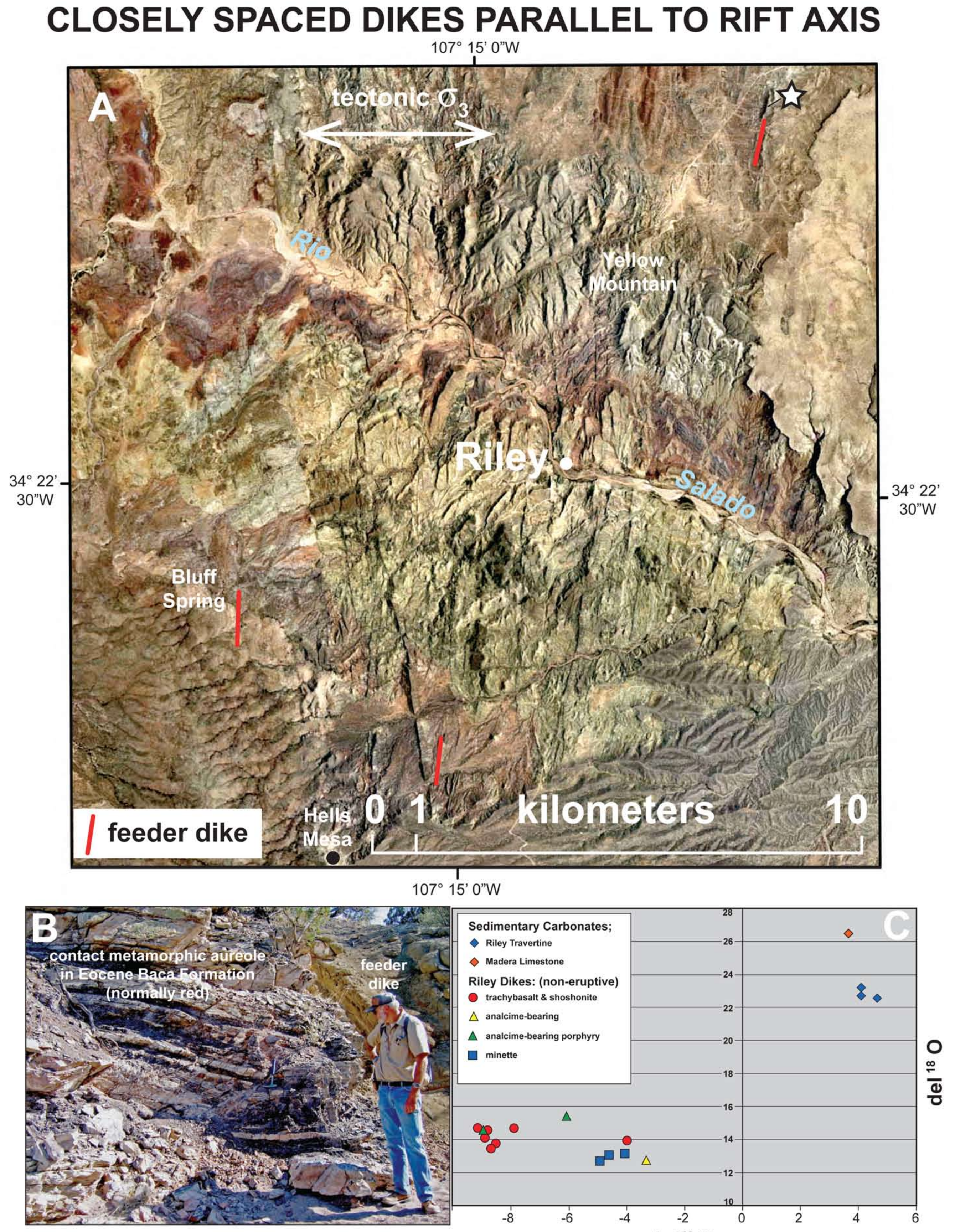

Figure 3— Closely spaced dikes of the Riley subswarm

a. **Digital orthophoto showing dikes with wide contact metamorphic aureoles, interpreted as feeder dikes. Dike spacing is about 6 -13 dikes/ km. Trough and ridges mark feeder dike and aureoles at ☆.**
b. **Feeder dike and contact metamorphic aureole near Hells Mesa**
c. **Isotopic signature of magmatic carbonate in dikes that lack contact metamorphic aureoles, interpreted as non-eruptive dikes. Modified after Dimeo, 2008.**

FLOW STRUCTURES ON DIKE MARGINS

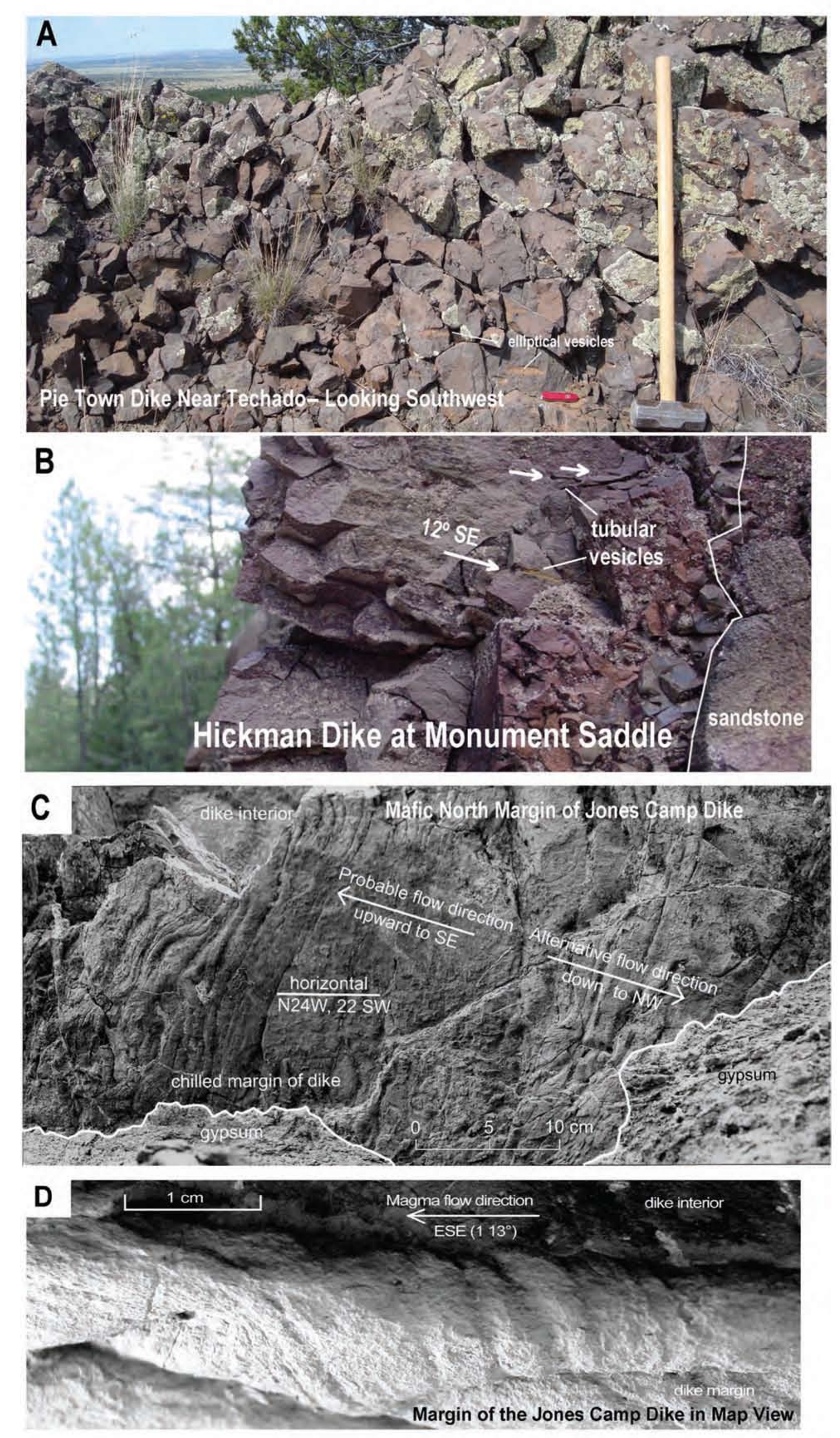

Figure 4—Near horizontal flow structures on long dikes

a. Elliptical vesicles on the NE margin of the Pie Town dike near Techado. Long axes of vesicles plunge gently to the SE and NW. (P1, Fig.1)
b. Tubular vesicles on the SW margin of the Hickman dike at Monument Saddle plunge gently to the SE. (P2, Fig.1)
c. Millimeter scale pahoehoe-type flow folds on the north margin of the Jones Camp dike. Inferred flow direction approximately perpendicular to steeply plunging fold axes. (P3, Fig.1)
d. Asymmetric flow folds on the north margin of the Jones Camp dike in map view. Asymmetry is consistent with magma flow to the ESE. (P3, Fig.1) After Chamberlin, 2009

DISCUSSION AND INTERPRETATION

A dike is a magma-filled crack that propagates along a vertical plane in the direction perpendicular to the least principal horizontal stress at the time of emplacement (Rubin, 1995). Oligocene mafic dikes of central New Mexico appear to faithfully record crustal stress fields at time of emplacement, but they do not tell us the origin of the stresses (e.g. tectonic, magmatic, edifice effects, complex interactions of stresses) or the effects of preexisting anisotropy. A strong temporal and spatial link now exists between the large diameter Magdalena radial dike swarm and the large volume Socorro-Magdalena caldera cluster of the early Rio Grande rift (Figs. 1 &2; McIntosh et al. 1991; Chamberlin 1983). Most of the basaltic magma-filled fractures in the MRDS probably represent lateral dike injections (LaDI) that did not erupt (Figs 3 & 4). With the MRDS as a guide, most "seismically expressed lateral dike injections" (SELaDI) that occur adjacent to a restless caldera (e.g. Krafla, Iceland, 1975; Sigurdsson, 1986) would be labeled as non-eruptive "false alarms".

Considering analytical error, the Hickman dike could be about 200 ka younger than the Sawmill Canyon caldera (Fig.5). We suggest, however, that it was more likely that lateral injection of the Hickman dike occurred "shortly" (perhaps 10^2-10^4 yrs) before eruption of the large volume La Jencia Tuff, when the upper crustal magma system was almost certainly over pressured (cf. Cole et al., 2005). Based on Fig. 5, the estimated volume of Hickman dike is 15 ± 5 km^3. Four long dikes are coeval with the Sawmill Canyon caldera (Figs. 1 & 2); thus about 60 km^3 of magma may have filled basaltic "mega dikes" prior to that cataclysmic eruption.

In their comprehensive review of restless calderas, Newhall and Dzurisin (1988) ask the following. "Can one tell whether an impending eruption will be of caldera-forming magnitude?" They initially considered the following indicators: 1) simultaneous eruptions from multiple ring fracture vents, 2) pronounced caldera-wide uplift, and 3) seismicity along entire ring fracture systems, but then rejected them based on limited data. We note that such intra-caldera features would be obliterated by a large caldera-forming eruption. We suggest that long dikes of the MRDS represent ancient SELaDI, that in today's world, could signal pre-caldera tumescence.

Following is a speculative scenario for SELaDI events that might signal a condition of pre-caldera tumescence for the Yellowstone caldera. Length scale and geometric relationships are based on the MRDS. Temporal scales are based on well documented SELaDI at Krafla caldera, 1975; and the 2005 mega dike of the Afar rift (Sigurdsson,1986: Ebinger et al., 2010).

RHYOLITIC CALDERAS AND RADIATING BASALTIC DIKES

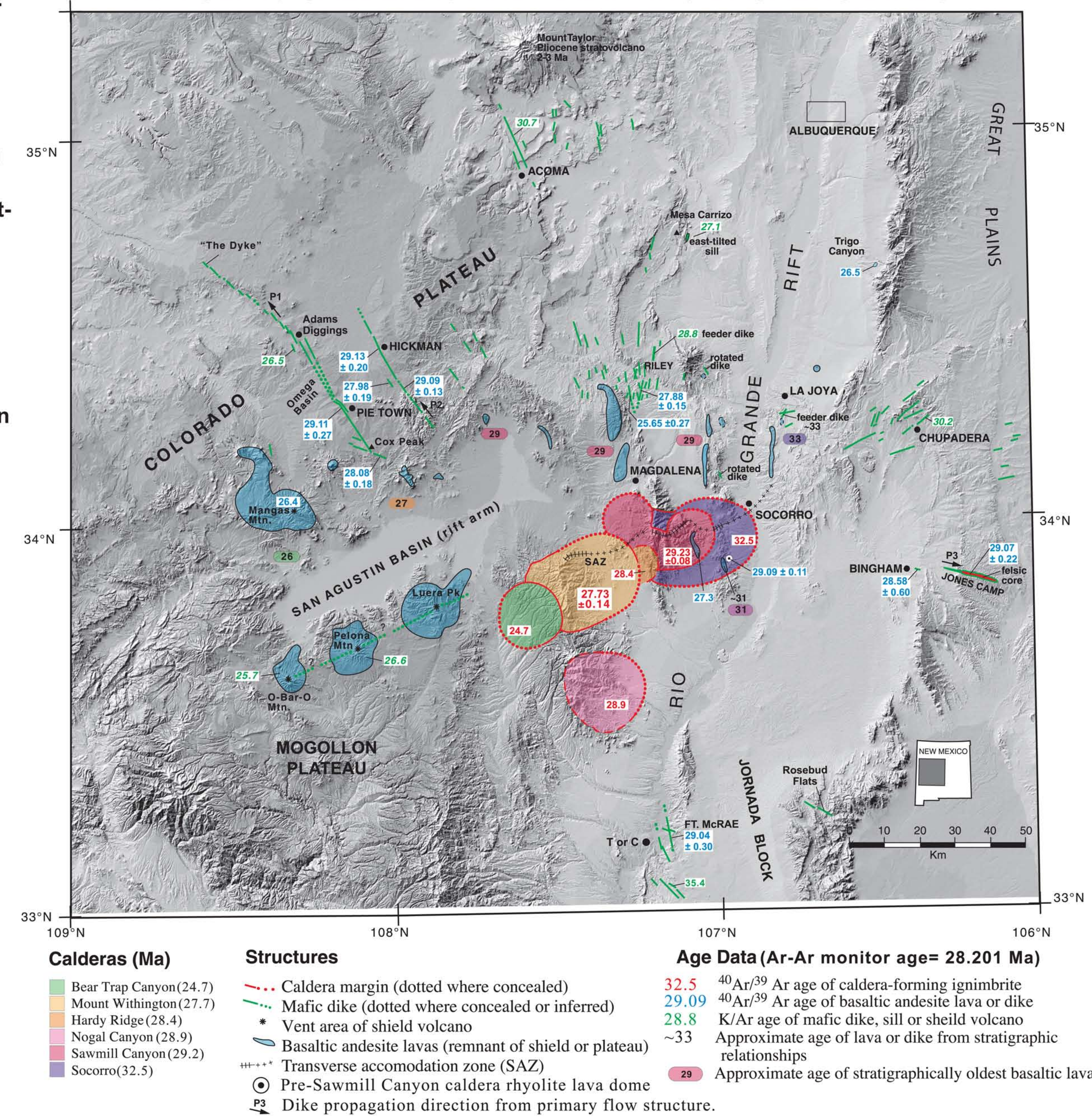

Figure 1— Oligocene calderas, mafic lavas and radiating mafic dikes of the Socorro-Magdalena magmatic system (SMMS). Colorado Plateau, Great Plains and Jornada block are cratonic microplates. Mogollon Plateau is a batholithic microplate. SAZ is the Socorro accommodation zone.

LATERAL DIKE INJECTION DURING PRE-CALDERA TUMESENCE

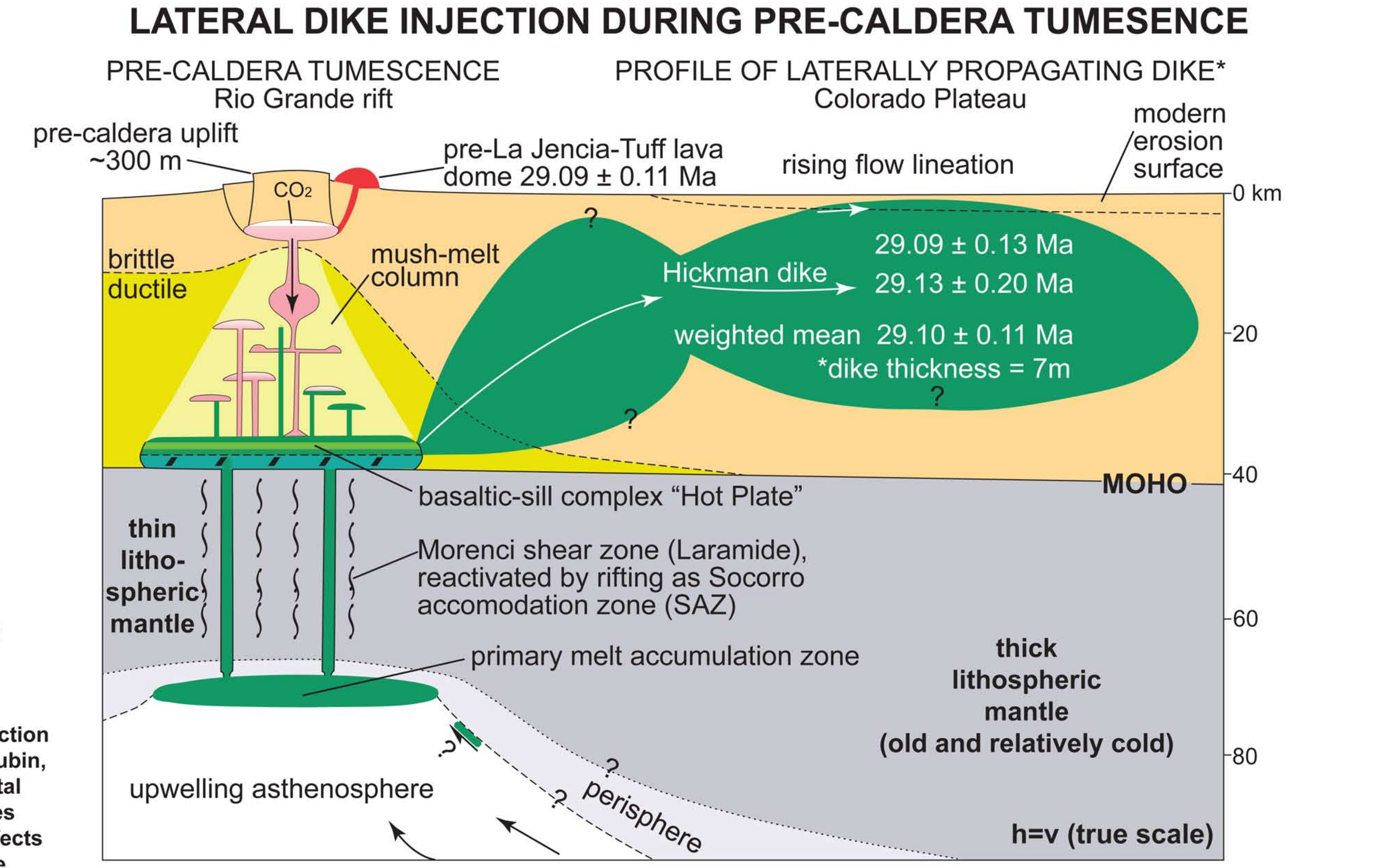

Figure 5— Cross sectional model of lateral dike injection during pre-caldera tumescence. Absence of phenocrystic plagioclase in most basaltic andesite dikes implies the inferred mafic sill complex was deeper than 30 km (Wilson, 1989; p. 163). Segmented dike geometry inferred from data of Ebinger et al., 2010.

SPECULATIVE PRE-CALDERA-TUMESENCE SCENARIO AT YELLOWSTONE

- Seismically expressed lateral dike intrusions (SELaDI) that propagate outward from caldera are dominantly perpendicular to tectonic extension.
- Most SELaDI do not produce eruptions, they are false alarms.
- Long periods of "quiescence" (~10^2-10^3 yrs) may occur between SELaDI.
- Years to decades of intracaldera uplift occur prior to a SELaDI.
- Intracaldera subsidence occurs over a few days during a basaltic SELaDI.
- Length scale of SELaDI increase over time, as the volume and pressure of the crustal magmatic system increases.
- A 50 to 100-km long SELaDI that propagates to the NW, over a few days, implies a large volume magmatic system interacting with tectonic stress.
- A 50-100-km long SELaDI that propagates to the NE would suggest the Yellowstone magmatic system is large enough to have overwhelmed regional tectonic stress; perhaps representing a stage of pre-caldera tumescence.

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REFERENCES:

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