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Magmatism in Trans-Pecos Texas, part 1

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ABSTRACT

The lithosphere under the Trans-Pecos region supplied granitic to mafic magmas from 1300 to 1100 Ma. From the Proterozoic to Late Cretaceous time, magmatism was absent. A few occurrences of Late Cretacous and Paleocene rocks are known. Starting in the Eocene, magmatism was voluminous and continued into Miocene time. The general pattern centered around a NW-SE axis, parallel to the strike of the subducting Farallon plate, but was compositionally and temporally asymmetric. Calcalkalic and alkalicalcic rocks tend to be older and are concentrated in the SW. To the NE, rocks become more strongly alkalic, culminating in a 350-km long belt of phonolites and nepheline-normative trachytes. Activity then shifted to the SW from 31 to 27 Ma, and mafic lavas and dikes from 26 to 17 Ma accompanied the onset of Basin-and-Range faulting over the entire width of the Trans-Pecos. Times of magmatic stasis and migration probably reflect roll-back of the subducting and detaching Farallon slab; this roll-back sometimes kept pace with SW migration of the North American plate.

Rock types range from tephrite/basanite through minor alkali basalts to more abundant hawaiites, mugearites, and benmoreites, trachytes, phonolites, and rhyolites. Small discrete areas share distinctive trace-element and isotopic characteristics. Mostly small-volume magma batches stalled in the upper crust, fractionating, mingling, and assimilating crust to achieve the wide variety of compositions.

FOREWORD

With my 80th birthday a few weeks away, and hearing time's winged chariot rushing near, I abandon plans for more detailed and profound analyses of these data. Readers should pick up the torch (no, not by the flaming end!).

Cenozoic igneous rocks crop out in much of Texas west of the Pecos River and in parts of adjacent New Mexico and Mexico, an area exceeding 50,000 km^2. Although erosional remnants of volcanic rocks are exposed over less than half of this area, intrusive bodies (at least 200 with outcrop areas each exceeding 1 km^2, and many smaller dikes and sills) define the total area.

To attempt an overview of such a large and complex region will always be premature, but there are so many studies of small areas within it that it seems necessary and timely to produce a synthesis. If nothing else, it will highlight gaps in knowledge and lead to comparisons over broader expanses. Inevitably, there are hasty conclusions to be refuted, and new ones will be made in this paper.

Trans-Pecos magmatism is one segment of a belt of coeval sodic alkalic rocks that can be viewed as an eastern outlier of the large Cenozoic calcalkalic and alkalicalcic volcanic fields associated with subduction of the Farallon plate. These fields include, from north to south, the Thirty Nine Mile and San Juan in Colorado, the Mogollon-Datil in New Mexico, and the Eastern Chihuahua and Sierra Madre Occidental in Mexico. Total extents of the alkalic outliers are not as well known, but they parallel the calkalkalic front at 38 to 27 Ma.

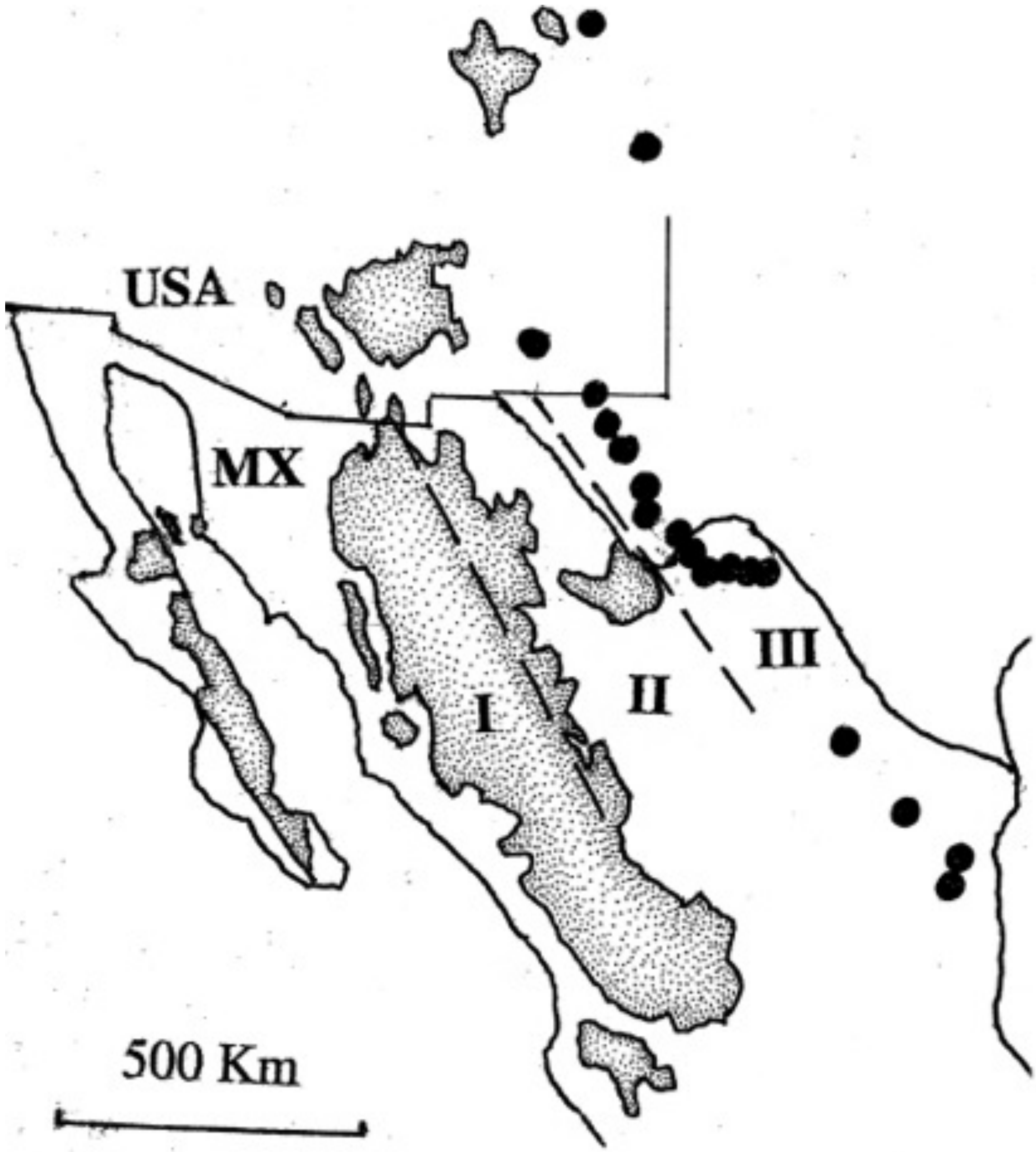

Fig. 1. Outcrop map of Cenozoic volcanic rocks, New Mexico, Texas, and Mexico (after Clabaugh and McDowell, 1979). Zones I, II, and III are respectively calcalkalic, alkalicalcic, and alkalic. Black spots show schematically occurrences of silica-undersaturated alkalic rocks.

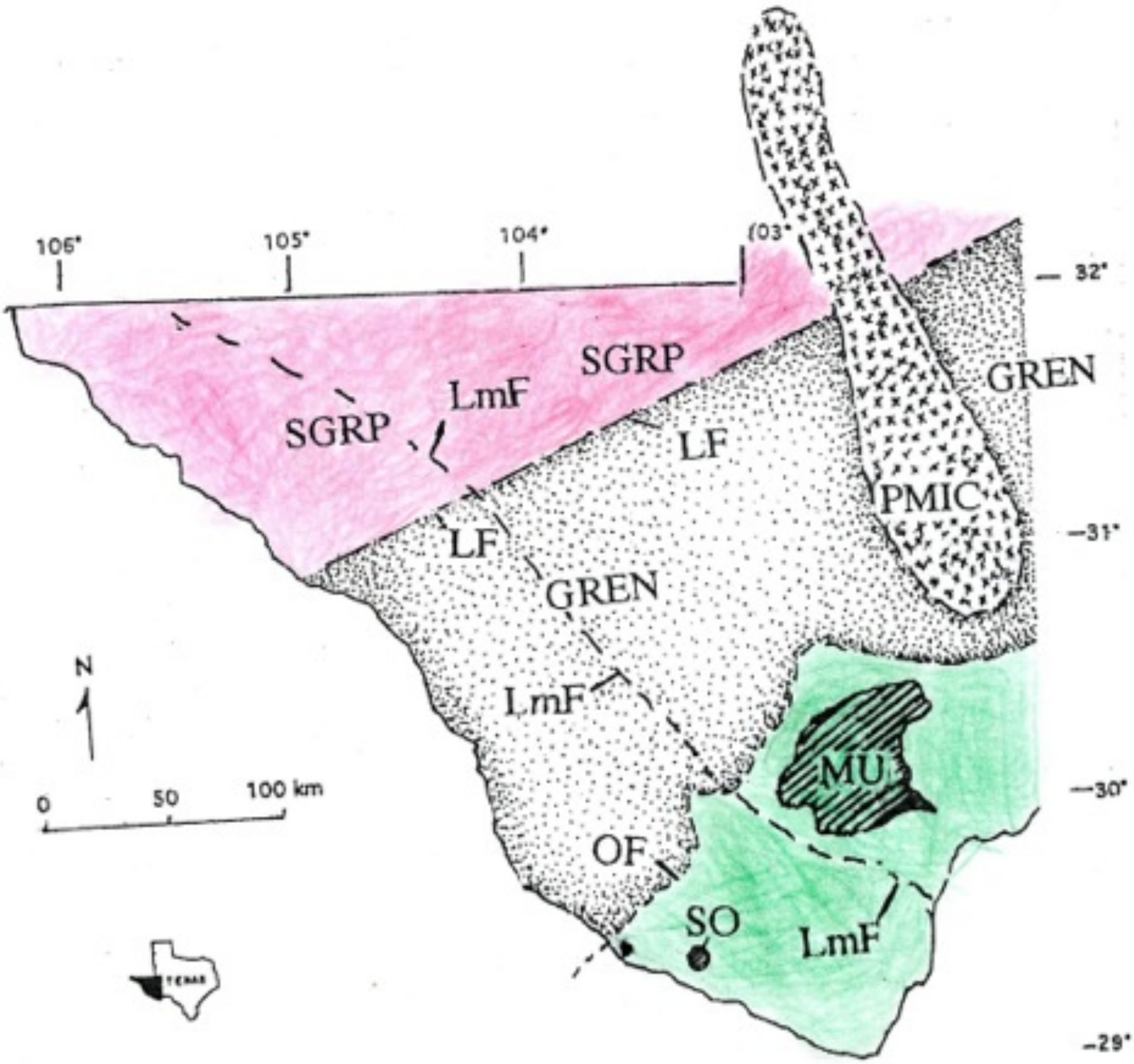

Fig. 2. Schematic basement map, Trans-Pecos region. SGRP = Southern Granite-Rhyolite Province. GREN = Grenville Province.PMIC = Pecos Magmatic Intrusive Complex. Green = Paleozoic rocks of Ouachita Province. LF = Llano Front. OF = Ouachita Front. LMF = Laramide Front. MU = Marathon Uplift. SO = Solitario.

Precambrian crust beneath the Trans-Pecos area consists of the Mesoproterozoic Southern Granite-Rhyolite Province and the Grenville Province. Granites of the Southern Granite-Rhyolite Province have depleted mantle model ages (T_{DM}) of 1.5 to 1.74 Ga and crystallization ages of 1.37 to 1.4 Ga (M. A. Barnes et al., 1999). To the south, the Grenville Province has T_{DM} of 1.35 to 1.47 Ga (ibid.); crystallization ages are poorly known (see the Precambrian chapter following). In Precambrian crust east of the Pecos River lies the Pecos Mafic Intrusive Complex (C. G. Barnes et al., 1999), a layered ultramafic and mafic body 360 km long and 5 km thick in its northern, more concordant, portion. This buried 1.16 Ga intrusive body apparently cuts the Llano Front that separates the two Precambrian basement provinces. Granulite xenoliths with Grenville ages have been found in a few localities in the Davis and Bofecillos Mountains (Cameron and Ward, 1998). There are no known incidents of magmatism in west Texas between Mesoproterozoic and late Cretaceous times.

The Marathon and Solitario uplifts expose Paleozoic sedimentary rocks as a continuation of the Appalachian orogen, which is delimited on the north by the Ouachita Front, the northwestern limit of Paleozoic thrusting. The Paleozoic rocks trapped some shallow Cenozoic magmas and contributed xenoliths (Barker, 2000). Permian and Cretaceous limestones are thick and extensive over much of the Trans-Pecos region; they also confined ascending magmas as sills and laccoliths (Barker et al., 1977).

Northeastward movement of the Farallon plate under the North American plate, in the area southwest of the Laramide Front, continued into the time of early Cenozoic Trans-Pecos magmatism. Its influence on magmatic activity is discussed in a later chapter. The Trans-Pecos region lies in the central part of the Basin and Range tectonic province, and is east of, and older than, the Rio Grande Rift (Barker, 1979; McMillan, 1998). Basin and Range extension began about 32 Ma, and continues (Muehlberger et al., 1978). I include Precambrian, Cretaceous, and Paleocene rocks in this compilation to give perspective on the history of the lithosphere in the Trans-Pecos region.

A warning about geographic names: many names were applied to features when there was little road communication in the region. As a result, Paisano Peak, Needle Peak, Bee Mountain, Black Mountain and Iron Mountain are among names duplicated because more than a day's journey separated the pairs. Madison and Stillwell (1988) give the origins of many names.

GEOPHYSICS

Fast Vp and Vs are found under an area south from Portales, New Mexico through the Trans-Pecos region. The Moho deepens abruptly, from 45 to 58 km, while the lithosphere-asthenosphere boundary remains at ~100 km (Pulliam et al., 2012, 2013). Thinning of the lithospheric mantle is probably caused by detachment of part of the Farallon plate.

DATA BASE

This paper is based on a compilation of data from many researchers, plus unpublished work by DSB and chemical analyses by G. Karl Hoops. For many samples, no petrographic descriptions accompanied the analyses. For a few, the precise localities are unknown but high-quality trace - element and/or isotopic data favored their inclusion.

Most Trans-Pecos igneous rocks are fine-grained, so the total alkali-silica classification (LeMaitre, 2002) is used instead of a modal classification (rock names in italics), because few modes are provided. No analysis of a Cenozoic Trans-Pecos rock plots as foidite, basaltic andesite, or andesite. The number of rock names reduces to ten using the total alkali-silica classification. *Tephrite* and *basanite* cannot be distinguished without modal data, so these are combined. The designations of *hawaiite*, *mugearite*, and *benmoreite* are used because many Trans-Pecos rocks have $Na_2O > K_2O - 2$. These decisions reduce the number of instances in which different samples from the same rock body must be given different names because of minor variations in alkali ratios. All 48 to 27 Ma suites show a continuum that is not bimodal with respect to silica. These italicized names based on total-alkali versus silica are compositional names, because textures and modes are not available for many samples; they describe chemical analyses, not rocks.

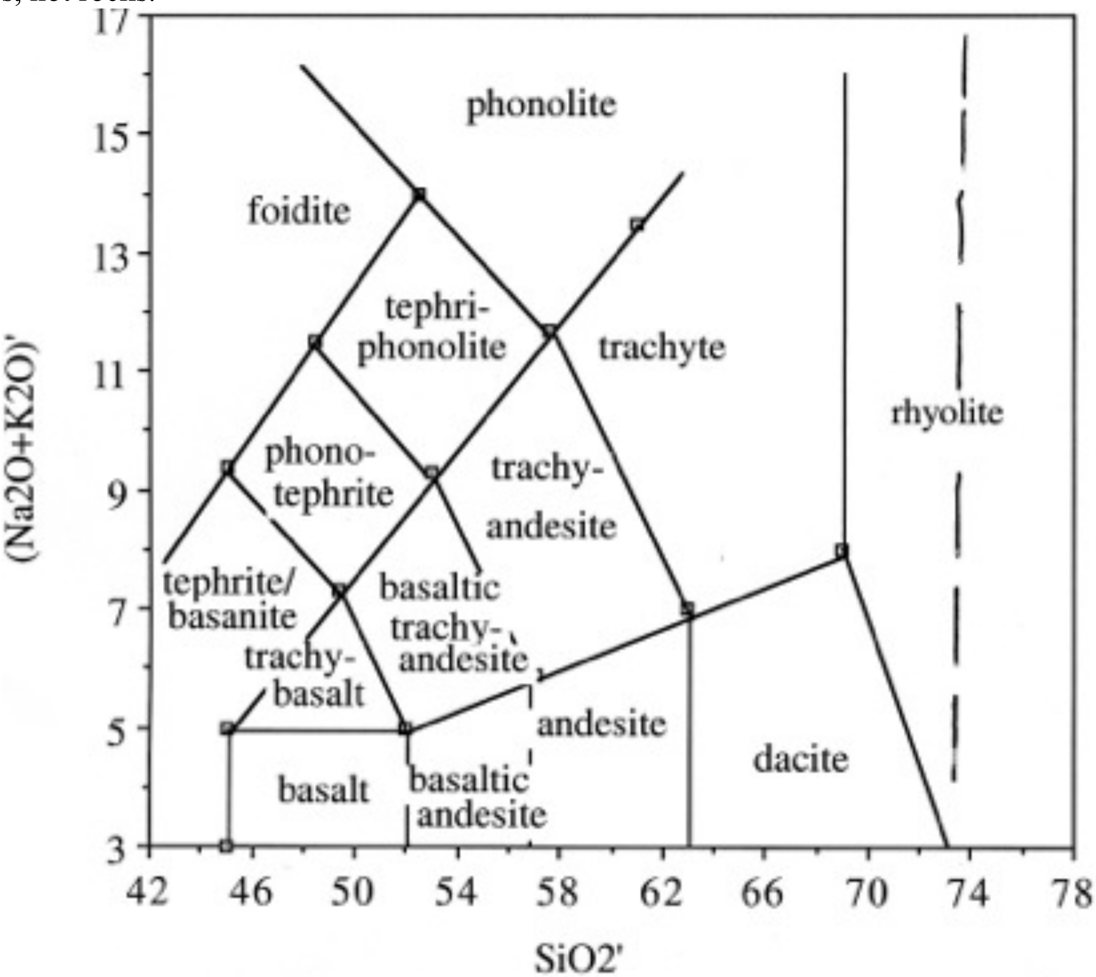

Fig. 3. Total alkali-silica diagram (LeMaitre et al., 2002) Names shown are for calcalkalic and alkalicalcic rocks. For alkalic rocks (the majority in the Trans-Pecos region), the names trachybasalt, basaltic trachyandesite, and trachyandesite are replaced by hawaiite, mugearite, and benmoreite, respectively. In these three names, the accent is on the second syllable, and the “g” in mugearite is hard. The dashed vertical line separates low- and high-SiO_2 rhyolites.

Many of the stratigraphic names that have been applied to volcanic units do not adequately convey the compositions or compositional ranges. As examples, the Ash Spring Basalt includes *tephriphonolite*, *phonotephrite*, *hawaiite*, and *mugearite*, and no *basalt*. Among Tule Mountain Trachyandesite samples are *basalt*, *hawaiite*, *mugearite*, *benmoreite*, and *trachyte*. Clearly, lavas of different compositions have been combined in single stratigraphic units, making discussion of rock type distributions and volumes difficult.

This sequence is used for data presentation:
Sample Age, Ma Long & Lat Quadrangle
SiO_2 TiO_2 Al_2O_3 $Fe_2 0_3$ FeO FeO* MnO MgO CaO Na_2O K_2O P_2O_5 H_2O+ H_2O^- CO_2 LOI Total
Sc V Ni Cu Zn Rb Sr Y Zr Nb Cs Ba La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Hf Ta Pb Th U
MALI @ SiO_2 (Na_2O+K_2O) A. I. Mg# Ce Eu* Ce/Yb Ta/Yb Th/Yb
Nb/Zr Zr/Hf Nb/Ta Y/Nb La/Y $^{87}Sr/^{86}Sr$,i ENdt
$^{206}Pb/^{204}Pb$ $^{207}Pb/^{204}Pb$ $^{208}Pb/^{204}Pb$ Y/Sc
Reference

The sample numbers are those originally reported for the analyses. Ages given to two decimal places are on alkali feldspar by $^{40}Ar/^{39}Ar$, unless otherwise stated; for other ages, methods are indicated. (Na_2O + K_2O) and SiO_2 are coordinates on the total alkali versus silica diagram (LeMaitre et al., 2002). MALI @ SiO_2 is the Modified Alkali Lime Index (Na_2O + K_2O – CaO, wt %) of Frost et al. (2001) at the given silica content. This allows characterization of individual samples, not suites, as alkalic, alkalicalcic, or calcalkalic, without distorting Peacock's (1933) definitions. The MALI @ SiO_2 classification has not been extended below 52 % SiO_2. Where the designation "alkalic" is not specified, it can be assumed here. The lack of basaltic andesite, andesite and dacite shows that Trans-Pecos rocks have no true calcalkalic affinities. A. I. is the alkalinity index, the cation ratio (Na + K)/Al. Mg # is 100MgO/(MgO + FeO*), where FeO* is total iron as ferrous oxide and MgO is magnesium oxide, both in weight percent. Ce and Ce/Yb (in the data block below the analysis) are normalized to the C-1 chondrite averages of Anders and Grevesse (1989), as are Eu, Sm, and Gd in Eu* = Eu/0.5(Sm + Gd). Rare earth elements in other ratios are not normalized. The Ce, Eu*, and Ce/Yb values indicate the intercept, inflection, and slope on a REE plot. Ta/Yb, Th/Yb, Nb/Zr, Y/Nb, La/Y, and Y/Sc give indications of the various sources, but also are functions of the degree of fractionation. Zr/Hf and Nb/Ta are monitors for disturbance of Zr and Nb concentrations, as both are in the normal ranges 30 ± 5 and 15 ± 5, respectively. Asterisks following values indicate that the numbers are anomalous.

Those contributing especially large numbers of analyses are Ken Cameron, Max Carman, Lance Forsythe, Chris Henry, Eric James, Bill McDonough, Dan Miggins, Dennis Nelson, Don Parker, Lee Potter, Jon Price, Roberta Rudnick, Dennis Schucker, Kevin Urbanczyk, Bob Ward, and John White.

I took all of the photos used in this document. Where areas lack illustrations, I was never there, or there was nothing photogenic.

PRECAMBRIAN

Franklin Mountains

A north-south trending array of Basin-and Range fault blocks reveals Precambrian and Paleozoic units. The section is well displayed in road cuts and canyons. Igneous rocks were emplaced in undeformed shelf deposits north of the Llano Front. The Llano Front separates undeformed Grenville-age rocks to the north from deformed and metamorphosed Grenville rocks to the south.

Castner Marble

The oldest exposed unit in the Franklin Mountains, this marble contains mafic sills dated at 1260 ± 20 Ma (U-Pb, zircon; Pittenger et al., 1994). The sills range from 1 to 50 m thick and make up approximately one third of the Castner Marble section (Ray. 1982).

The Mundy Breccia, 1250 Ma

Basaltic pillow fragments are clasts in breccia filling channels in the Castner Marble; these are alternatively interpreted as a mud flow breccia, but could also be from a tectonically disrupted sill like those described above. I have not seen this occurrence. *Subalkali basalt*

Sample 16

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
46.82	1.34	15.52	2.84		8.65	0.19	10.30	8.81	2.38	0.25	0.13					97.25

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
-6.17	46.82	2.63	0.27	53.9

Thomann and Hoffer, 1985

Thunderbird Series

This sequence of rhyolite and trachyte lava flows and ash-flow tuffs above the Castner Marble is cut by the Red Bluff Granite Complex.

Age, Ma: 1111 ± 20 (U-Pb, zircon)

Roths, 1993

Sample IGM-012 *Trachyte*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
62.66	0.26	14.70			11.37	0.04	0.15	0.64	3.84	5.82						99.38

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
9.02	62.56	9.66	0.86	1.30

Thomann, 1980

Sample IGM-076 *Low-silica rhyolite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
69.43	0.35	12.15			7.12	0.10	0.52	1.13	3.24	5.66						99.70

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
7.77	69.43	8.90	0.94	6.81

Thomann, 1980

Sample IGM-171 *Alkalicalcic high-silica rhyolite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
74.30	0.11	12.5			3.30	0.04	0.32	0.56	2.84	6.00						99.97

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
8.28	74.30	8.84	0.89	8.84

Sample 16 *Subalkali basalt*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
46.82	1.34	15.52	2.84		8.65	0.19	10.30	8.81	2.38	0.25	0.13					97.25

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
-6.17	46.82	2.63	0.27	53.9

Thomann and Hoffer, 1985

Sample IGM-120 *Alkalicalcic high-silica rhyolite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
75.63	0.02	11.76			2.68	0.01	0.41	0.82	3.62	4.20						99.15

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
7.00	75.63	7.82	0.89	13.3

Thomann, 1980

Sample 14 *Trachyte*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
62.40	0.58	15.00	10.00		9.00	0.09	1.51	1.93	3.70	4.84						100.03

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
10					87			523			271	84	170			19	2.7		2.7					10	2.0

Hf	Ta	Pb	Th	U
22	3			

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#	Ce	Ce/Yb	Zr/Hf
6.61	62.40	8.54	0.76	14.4	282	14.8	23.8

Norman et al., 1987

Sample 140 *Alkalicalcic high-silica rhyolite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
75.00	0.11	12.10	3.75		14.64	0.01	0.12	0.82	3.53	4.53						99.97

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
16					246			428			111	130	267			23	0.76		5.4					18	2.7

Hf	Ta	Pb	Th	U
18	6.2		33	6.9

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#	Ce	Ce/Yb	Zr/Hf
7.24	75.00	8.06	0.89	1.0	443	14.8	69.0

Norman et al., 1987

Upper porphyritic granite sill, ~ 660 m thick, intruding Lanoria Quartzite with a chilled base (Ray, 1982). This is the most mafic of the Franklin Mountains granites. Alkali feldspar is rimmed by plagioclase; amphibole and biotite form clots in the granophyric groundmass.

Sample UMG-1 *Alkalicalcic high-silica rhyolite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
75.82	0.16	15.32	0.30	0.94	1.18	0.01	0.68	0.19	4.13	2.86	0.01					100.42

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

Hf	Ta	Pb	Th	U
			8.72	2.45

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
6.80	75.82	6.99	0.65	36.6

Ray, 1982

Sample UMG-5 *Alkalicalcic high-silica rhyolite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
73.12	0.26	15.62	0.28	1.80	2.02	0.01	0.94	0.15	3.79	4.16	0.02					100.15

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

Hf	Ta	Pb	Th	U
			5.26	1.97

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
7.80	73.12	7.95	0.69	31.8

Ray, 1982

Sample UMG-7 *Alkalicalcic high-silica rhyolite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
76.40	0.25	14.28	0.26	1.60	1.81	0.02	0.54	0.32	4.15	3.55	0.01					101.38

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

Hf	Ta	Pb	Th	U
			13.34	3.34

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
7.38	76.40	7.70	0.75	23.0

Ray, 1982

Lower granite sill, ~ 250 m thick, leucocratic, hypersolvus, with 5-m chilled zones and granophyric groundmass. Less extensive than the upper sill (Ray, 1982), and intruded into the Castner Marble.

Sample LMG-1 *Alkalicalcic low-silica rhyolite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
71.16	0.31	17.3	0.51	0.46	0.87	0.01	0.05	0.53	3.87	4.30	0.02					98.52

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
7.64	71.16	8.17	0.64	2.47

Ray, 1982

Red Bluff Granite Complex.

Mostly metaluminous, but with a late peralkaline stage. Intrudes Castner Marble, Mundy Breccia, Thunderbird series, and the upper and lower granite sills.

Stage 1, porphyritic alkali granite. Similar to the lower granite sill; hypersolvus, with < 2% mafic minerals.

Sample PAG-1 *Low-silica rhyolite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
69.69	0.16	13.7	0.55	4.96	5.40	0.02	0.43	0.98	3.47	5.75						99.71

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

Hf	Ta	Pb	Th	U
			31.6	5.5

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
8.24	69.69	9.22	0.87	7.38

Ray, 1982

Sample PAG-2 *Trachyte*

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
67.93	0.15	14.39	0.57	5.08	5.54	0.08	0.28	0.80	3.55	6.14						98.97

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

Hf	Ta	Pb	Th	U
			51.4	13.4

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
8.89	67.93	9.69	0.87	4.81

Ray, 1982

Sample PAG-4 *Alkalicalcic high-silica rhyolite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
74.26	0.06	12.59	0.20	1.81	1.97	0.03		0.98	3.10	5.07						98.10

Sc	V	Cr	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu

Hf	Ta	Pb	Th	U
			30.7	5.2

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.
7.19	74.26	8.17	0.84

Ray, 1982

Stage 2, medium-grained biotite granite, makes up 80 % of exposed granite outcrop area. Intrudes the upper and lower granite sills and the porphyritic alkali granite. Some cassiterite mineralization.

Age, Ma: 1120 ± 35 (U-Pb, zircon)[1]

Sample FM 549, P-160 *Low-silica rhyolite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
71.77	0.36	13.09	0.89	2.10	2.46	0.05	0.12	1.02	3.69	5.83	0.05				0.41	99.37

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm
4.2	4		12	157	257	43	125	677	50	4	486	147	271		138	28.4	2.12		3.57				

Yb	Lu	Hf	Ta	Pb	Th	U
12.6	1.87	19.5	3.1		27.2	4.8

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#	Ce	Ce/Yb
8.50	71.77	9.52	0.91	5.0	449	5.81

Nb/Zr	Zr/Hf	Nb/Ta	$^{87}Sr/^{86}Sr,i$	ENdt	Y/Sc
0.16	34.7	16.1	0.7034	3.8 to 2.3	29.4

$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
16.865	15.382	36.594

Ray, 1982; [1]Patchett and Ruiz, 1989; Shannon et al., 1997; Smith et al., 1997

Stage 3, biotite-hornblende granite, coarsest of the Franklin Mountain granites (Ray, 1982). No analyses.

Stage 4, strongly foliated riebeckite-bearing granite. Apparently from a different source than the earlier three granites. The name "riebeckite" is based on optical properties of the amphibole, not on analyses.

Sample FMRG-1 *Alkalicalcic high-silica rhyolite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
77.25	0.22	10.95	1.13	2.04	2.94	0.05	0.04	0.29	3.64	4.37	0.02					100

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
7.72	77.25	8.01	0.98	1.34

Ray. 1982

Sample FM542 *Peralkaline low-silica rhyolite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
71.01	0.21	8.94	4.23	5.24	9.09	0.13	0.07	0.58	4.74	4.21	0.01				0.16	99.53

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb
0.4	2			4	1186*	649*	33	1307*	1018 *		165	2.4	649	527	1422		679*	205	4.16

Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
43.9					10	2.0			22	3

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
8.37	71.01	8.95	1.38	1.0

References: Ray, 1982; Shannon et al., 1997; Smith et al., 1997

"Ferrobasalt" dikes, cutting all granites**.**

Sample FM BD-1 *Tephrite-basanite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total

44.57	1.74	17.86	1.32	7.52	8.58	0.20	7.18	5.32	2.63	1.98	0.12					90.44*

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
-0.71	44.57	4.61	0.36	45.6

Ray. 1982

Sample FM BD-2 *Tephrite-basanite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
40.21	4.53	18.80	3.72	7.72	10.70	0.04	6.38	6.17	2.87	2.66	0.61					93.71*

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
-0.64	40.21	5.53	0.40	37.4

Ray, 1982

Van Horn area

The north-dipping Streeruwitz thrust separates two domains, the older Carrizo Mountain Group in the south and the younger Allamore and Tumbledown formations to the north.

Carrizo Mountains Group

Rhyolitic ash-flow tuffs and mafic sills in metamorphosed shales, sandstones, and limestones. Mafic sills (now amphibolites, up to 600 m thick) and rhyolite tuffs each contribute ~25% to the total outcrop area. The rhyolites are pyroclastic flow deposits with well preserved textures. They are peraluminous. Metamorphic grade (~1000 Ma) increases perpendicular to strike, from greenschist in the NW to amphibolite in the SE. Metarhyolite contains quartz and microcline phenocrysts in an aphanitic groundmass, and has largely been replaced by sericite or converted to mylonite. The common red to pink crushed rock in many highway pavements in the northern Trans-Pecos region is quarried from this unit. All mafic sills and rhyolites show pervasive shear deformation to varying degrees, and major- and trace-elements are partly remobilized. The amphibolites are interpreted by Rudnick (1983) as having chemical affinities to a back-arc basin in a continental margin. Sources for rhyolite and mafic rocks are unknown.

Sample CM 23 *High-silica rhyolite*

Age, Ma: 1327 ±28 (U-Pb, zircon); 1333 ± 10 (U-Pb, zircon)

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
73.86	0.34	13.88			1.35	0.01		0.43	2.28	7.26	0.10					99.51

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm
4.33	29	22			137	73	47	454	41	0.72	1058	40.11			56.3	7.59	0.87				1.34		

Yb	Lu	Hf	Ta	Pb	Th	U
6.41	0.84	11.79	1.5		13.13	

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Ta/Yb	Th/Yb
9.11	73.86	9.54	0.84	0.23	2.05

Nb/Zr	Zr/Hf	Nb/Ta	Y/Nb	La/Y	Y/Sc
0.09	38.5	27.3	1.15	0.85	10.9

Rudnick, 1983

Sample CM-70 *High-silica rhyolite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
76.94	0.19	12.58	0.19	12.58	12.73	0.015	0.39	0.43	1.51	6.56	0.11					100.75

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm
3.8	54	28			162	79	52	396	39	2.27	754	21.84	42.37		30.57	5.87	0.75		1.38				

Yb	Lu	Hf	Ta	Pb	Th	U
6.01	0.8	10.86	1.24		12.42	

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#	Ce	Ce/Yb	Ta/Yb	Th/Yb
7.64	76.94	8.07	0.76	16.1	116.5	96.7	0.21	2.07

Nb/Zr	Zr/Hf	Nb/Ta	Y/Nb	La/Y	Y/Sc
0.10	36.5	31.5	1.33	0.42	13.7

Rudnick, 1983

Sample CM-21 *Tephrite/basanite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
43.48	0.86	14.50			12.38	0.174	13.75	8.20	1.18	0.65	0.26					95.43

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er
20.44	177	151		120	12	300	23	87	7	1.52	357	5.33	13.43		5.38	2.54	1.06					

Tm	Yb	Lu	Hf	Ta	Pb	Th	U
	1.64	0.24	1.86	0.22		0.55	

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#	Ce	Ce/Yb	Ta/Yb	Th/Yb
-6.37	43.48	1.83	0.17	52.6	22.27	30.33	0.13	0.34

Nb/Zr	Zr/Hf	Nb/Ta	Y/Nb	La/Y	Y/Sc
0.08	46.8	31.8	3.28	0.23	1.13

Rudnick, 1983

Sample CM-65 *Tephrite/basanite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
44.32	4.34	12.90			17.06	0.28	6.78	7.50	2.95	2.05	1.03					99.24

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er
30.74	201	47		62	27	199	42	237	21	2.77	839	25.77	55.68		42.19	8.9	2.9					

Tm	Yb	Lu	Hf	Ta	Pb	Th	U
	3.84	0.53	6.38	1.37		2.37	

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#	Ce	Ce/Yb	Ta/Yb	Th/Yb
-2.50	44.32	5.00	0.59	28.4	92.34	53.7	0.36	0.62

Nb/Zr	Zr/Hf	Nb/Ta	Y/Nb	La/Y	Y/Sc
0.09	37.1	15.3	2.00	0.61	1.37

Rudnick, 1983

Allamore Formation

Rhyolitic and basaltic tuffs and lavas are interbedded with limestones and make up 25 to 50% of the formation (King, 1965). Talc-rich phyllites (metatuffs) have been an important economic resource.

Age, Ma: 1256 ± 5 (U-Pb, zircon)

ENdt
2.37

Roths, 1993; Bickford et al., 2000

Tumbledown Formation

Unconformably overlying the Allamore Formation, this unit is exclusively volcanic. It includes silica-undersaturated basalt, trachyte, and rhyolite, intensely K-metasomatized.

Age, Ma: 1243 ± 10 (U-Pb, zircon)

Sample P-157 Rhyolite

ENdt
4.4

Patchett and Ruiz, 1989; Roths, 1993; Bickford et al., 2000

Pump Station Hills Long & Lat Quadrangle
105 56', 31 40' Padre Canyon

These are low hills of rhyolite; on S and SE sides, lenses of sedimentary breccia containing rhyolite clasts are interbedded with Permian limestone, indicating that rhyolite was exposed during Permian time. Porphyritic and flow-banded rhyolite and ash-flow tuff surrounds amphibolite.

Age, Ma: 1175 ± 25 (U-Pb, zircon)

References: Wasserburg et al., 1962

Huang (1959) reported the occurrence of eucolite/eudialyte, a zirconium-rich silicate, here. The sample came from float that he inferred was derived from "Precambrian nepheline syenite" as "irregular bodies along sheer (sic) zones of a great mass of Precambrian metamorphosed volcanics and shallow intrusives" of the Pump Station Hills. Later field examination showed that the nepheline syenite was actually amphibolite. There is abundant gravel derived from the Sierra Tinaja Pinta, 15 km to the north, and that cluster of eudialyte-bearing intrusions was presumably the source of the float sample.

Subsurface

Drilling for petroleum and natural gas has penetrated to Precambrian basement at many sites in Trans-Pecos Texas. Cores are not used for this compilation because they lack structural or stratigraphic information on the intrusive bodies, and because few cores have been analyzed. Of the terranes recognized by M. A. Barnes et al., (1999), only two extend beneath this region. The northern crystalline terrane of undeformed rocks is separated from the southern deformed crystalline terrane by the Llano Front, which is presumed to be the southeastern limit of Laurentia. The Nellie intrusion or Pecos Mafic Intrusive Complex, a 1163 Ma layered tholeiitic body 360 km long, 50 to 100 km wide, and 5 to 9 km thick, lies east of the Pecos River and therefore outside the Trans-Pecos region (Kargi and Barnes, 1995; C. G. Barnes et al., 1999).

During collision with a plate to the south (in present coordinates), the lithosphere under the Trans-Pecos was capable of yielding abundant granitic and mafic magmas from ~1360 to 1100 Ma. After the Proterozoic, there is no evidence of magmatic activity in the Trans-Pecos region until the Late Cretaceous. Ordovician beds in the Marathon Uplift contain boulders and cobbles of volcanic rocks. These are gravity-flow deposits into deep-water sediments. Zircons have yielded U-Pb ages of 1960 to 670 Ma, but these rocks are allochthonous and thrust 200 km from the southeast (Roberts et al., 2012; Hanson et al., 2013)). Lithologies are alkali basalt, trachybasalt, and trachyte.

CRETACEOUS

Trans-Pecos magmatic activity in the Cretaceous has only recently been recognized, and there are probably more examples outside and inside Big Bend National Park.

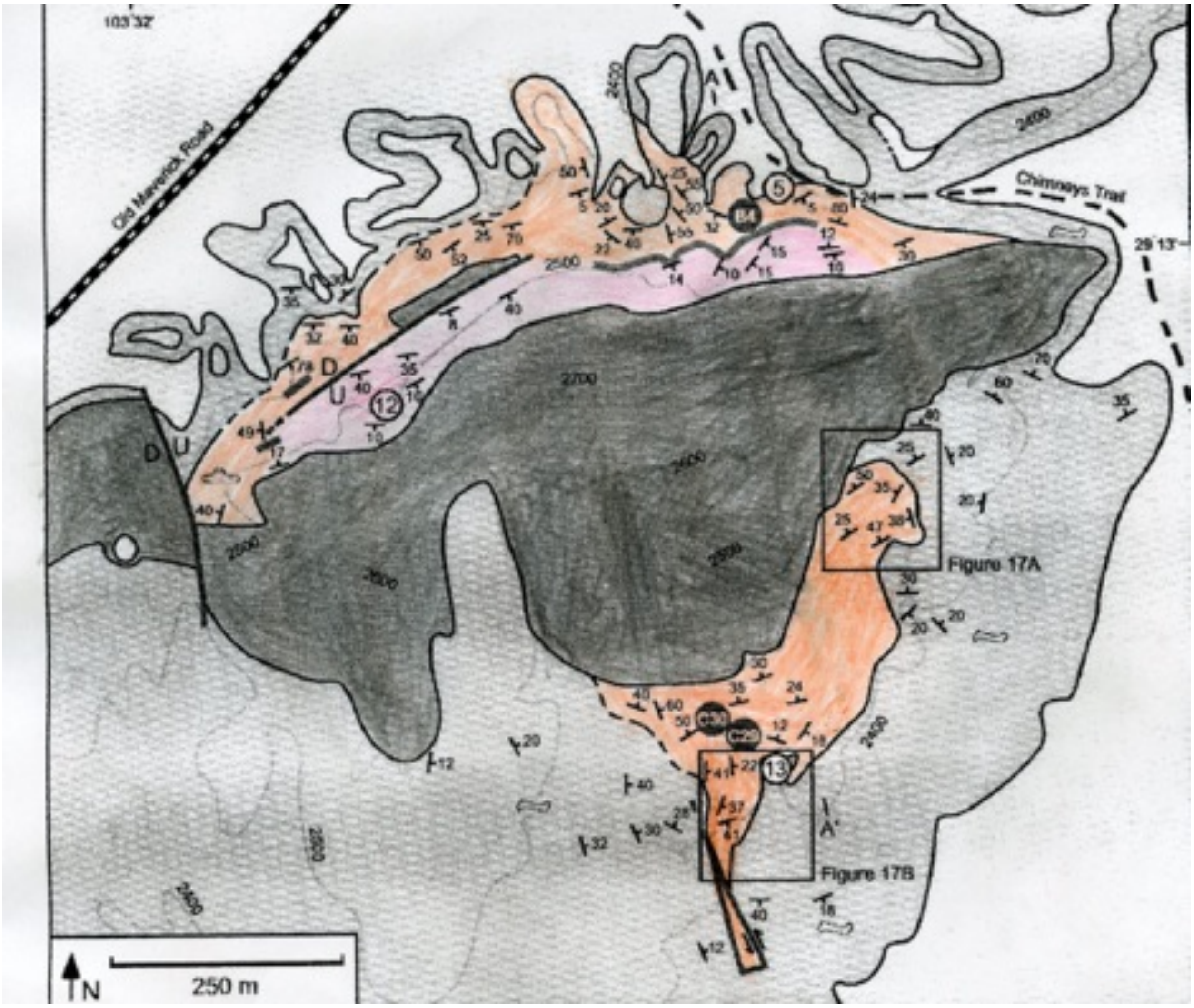

Fig. 4. Pena Mountain sill (gray) and pyroclastic units (orange = older; pink, younger) From Befus et al., 2008.

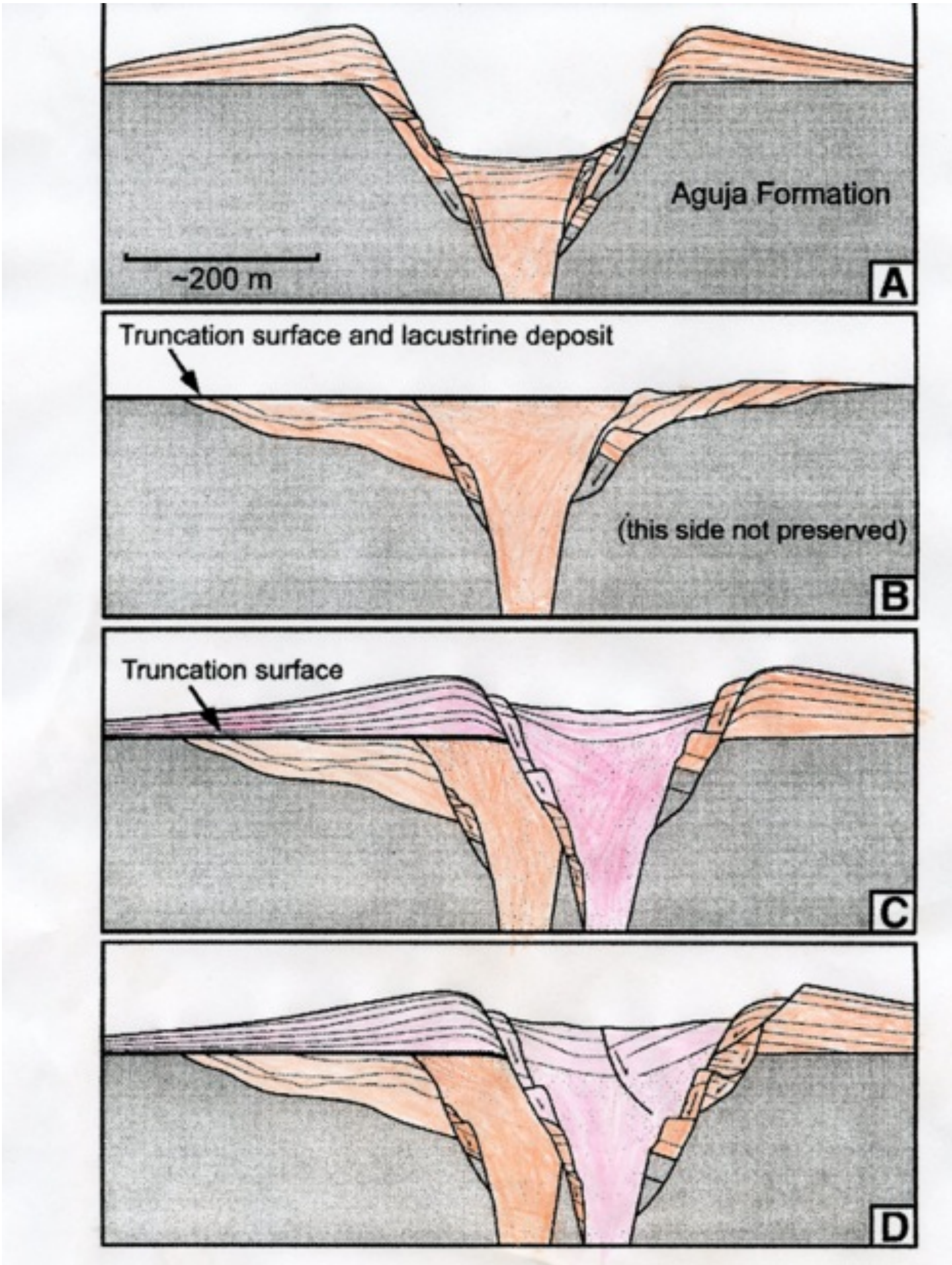

Fig. 5. Schematic north-south sections, maar complex at Pena Mountain (Befus et al., 2008)

Maar complex at Pena Mountain

Two overlapping maars produced > 70 m of phreatomagmatic surge deposits in the upper Aguja Formation. A truncation surface between the upper and lower maar deposits is locally covered by lacustrine deposits. The 28.7 ± 0.4 Ma Pena Mountain sill intruded the pyroclastic layers and the host Aguja rocks. The age and analyses are from pyroclastic bombs.

Sample B4 *Alkali basalt* lower pyroclastic section, north side of Pena Mountain.

	Long & Lat	Quadrangle
Age, Ma: 76.9 ± 1.2 (U-Pb, zircon)	103°32', 29° 13'	

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
46.61	1.482	19.35			7.30	0.133	3..74	15.34	4.23	0.31	1.499					100

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb
36.9	210	130	40	99	1.9	969	55.82	969	100	0.15	403	39.74	72.62	8.68	37.78	8.44	2.58	8.78	1.43

Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
8.91	1.86		0.69	4.21	0.65	2.93	0.63	6.84	2.59	38.55

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#	Ce	Eu*	Ce/Yb	Ta/Yb	Th/Yb	$^{87}Sr/^{86}Sr$,i
-10.8	46.41	4.54	0.38	33.9	120	0.90	4.66	0.15	0.62	0.7053

Nb/Zr	Zr /Hf	Nb/Ta	Y/Sc
0.10	331*	159*	1.51

Befus, 2008

Sample C30 *Mugearite* upper pyroclastic section, south side of Pena Mountain.

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
54.77	1.61	20.93			3.84	0.10	3.33	7.53	5.71	1.54	0.64				5.93	92.31

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd
47.7	242	123	97	46	24.1	1122	36.09	107	11.01	0.34	913	34.70	69.47	8.42	36.73	8.51	2.54	8.15

Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
1.24	7.11	1.36	3.33	0.43	2.45	0.36	3.20	0.70	7.38	2.89	0.94

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#	Ce	Eu*	Ce/Yb	Ta/Yb	Th/Yb
-0.28	54.77	7.25	0.53	46.4	115.2	0.91	7.67	0.29	1.18

Nb/Zr	Zr/Hf	Nb/Ta	Y/Nb	La/Y	Y/Sc
0.10	33.4	157*	3.28	0.96	0.76

Befus, 2008

East of Pena Mountain

Dikes, sills, and plugs of alkali basalt form an intricate network of feeders to phreatomagmatic vents in an area1500 X 300 m, in unconsolidated Black Peaks and Chisos Formations (Hill and Hanson, 2013).

Rosillos Ranch

In the upper Aguja Formation, faulting preserves a sequence, less than 15 m thick, of pyroclastic deposits consisting of agglomerate overlain by surge and airfall deposits. Deposition appears to have been subaerial. Breyer et al. (2007) infer that this volcanism represents a western extension of the Balcones magmatic province along the north side of the Ouachita Front. The Balcones province has similar ages to these rocks, but records subaqueous eruptions and intrusions of melilite nephelinite, olivine nephelinite, alkali basalt, and phonolite, all more silica-undersaturated that the west Texas bodies. A pyroclastic block was analyzed.

Sample A19c *Tephrite/basanite*

Age, Ma 72.6 ± 1.5 (U-Pb, zircon) Long & Lat Quadrangle

SiO_2 TiO_2 AL_2O_3 Fe_20_3 FeO FeO* MnO MgO CaO Na_2O K_2O P_2O_5 H_2O+ H_2O^- CO_2 LOI Total
43.41 3.54 17.66 14.29 0.24 4.83 10.16 5.12 0.06 0.70 100
Sc V Ni Cu Zn Rb Sr Y Zr Nb Cs Ba La Ce Pr Nd Sm Eu Gd
29.8 304 303 90 123 1.2 500 24.00 178 34.86 0.17 266 28.86 58.20 7.35 32.58 7.81 2.65 6.7 Tb Dy
Ho Er Tm Yb Lu Hf Ta Pb Th U
0.99 5.40 0.95 2.35 0.30 1.73 0.25 4.80 2.27 4.13 3.61 1.05
MALI @ SiO_2 (Na_2O+K_2O) A. I. Mg# Ce Eu* Ce/Yb Ta/Yb Th/Yb
-4.98 43.41 5.18 0.48 25.3 96.5 1.08 9.07 0.29 2.09
Nb/Zr Zr/Hf Nb/Ta Y/Nb La/Y $^{87}Sr/^{86}Sr,i$ Y/Sc
0.20 37.1 15.4 0.69 1.20 0.7053 0.81

Breyer et al., 2007; Befus et al., 2009

Intrusive body in Cottonwood Wash
Sample B 6 *Hawaiite*
SiO_2 TiO_2 AL_2O_3 Fe_20_3 FeO FeO* MnO MgO CaO Na_2O K_2O P_2O_5 H_2O+ H_2O^- CO_2 LOI Total
48.16 2.95 18.56 11.47 0.15 3.68 9.42 4.00 1.08 0.52 2.48 95.65
Sc V Ni Cu Zn Rb Sr Y Zr Nb Cs Ba La Ce Pr Nd Sm Eu Gd
21.6 284 11 13 101 16.2 713 26.62 202 25.41 1.1 710 27.56 56.30 6.90 29.88 7.13 2.43 6.51
Tb Dy Ho Er Tm Yb Lu Hf Ta Pb Th U
0.97 5.46 1.02 2.50 0.34 2.00 0.30 4.88 1.73 3.28 2.75 0.89
MALI @ SiO_2 (Na_2O+K_2O) A. I. Mg# Ce Eu* Ce/Yb Ta/Yb Th/Yb
-4.34 48.16 5.08 0.42 24.3 93.4 1.06 7.61 0.8 1.38
Nb/Zr Zr/Hf Nb/Ta Y/Nb La/Y Y/Sc
0.13 41.4 14.7 1.05 1.04 1.23

Befus et al., 2009

Sample C15 *Mugearite*
SiO_2 TiO_2 AL_2O_3 Fe_20_3 FeO FeO* MnO MgO CaO Na_2O K_2O P_2O_5 H_2O+ H_2O^- CO_2 LOI Total
53.16 2.14 17.55 9.77 0.19 2.43 6.14 5.00 2.59 1.02 2.21 95.74
Sc V Ni Cu Zn Rb Sr Y Zr Nb Cs Ba La Ce Pr Nd Sm Eu Gd
14.1 69 6 7 102 39.3 838 38.46 325 47.46 0.48 681 48.11 95.30 112.0 47.8 10.56 3.41 9.41
Tb Dy Ho Er Tm Yb Lu Hf Ta Pb Th U
1.36 7.65 1.46 3.67 0.50 3.05 0.46 7.57 3.24 5.98 5.45 1.65
MALI @ SiO_2 (Na_2O+K_2O) A. I. Mg# Ni,ppm Ce,ppm Eu* Ce/Yb Ta/Yb Th/Yb
1.45 53.16 7.59 0.63 19.9 6 158.0 1.02 8.42 1.06 1.79
Nb/Zr Zr/Hf Nb/Ta Y/Nb La/Y Y/Sc
0.15 42.9 14.6 0.81 1.25 2.73

Befus et al., 2009

PALEOCENE

Red Hill

Brecciated quartz monzonite hosts Cu-Mo-Ag porphyry deposits, ~ 1 km from the southern margin of the 32 Ma Chinati Mountains caldera. This is the easternmost recognized of the Laramide porphyry deposits, and the oldest known Cenozoic igneous rock in the Trans-Pecos region. *Trachyte*.

Sample RH59[1]

Age, Ma	Long & Lat	Quadrangle
64.2 ± 0.2 (U-Pb, zircon)[2]	104 23.42, 29 48.06	Cerro Orona

SiO_2 TiO_2 AL_2O_3 Fe_20_3 FeO FeO* MnO MgO CaO Na_2O K_2O P_2O_5 H_2O+ H_2O^- CO_2 LOI Total
68.41 0.62 14.34 2.82 2.54 0.10 0.36 0.79 3.98 4.88 0.11 1.50 98.09
Sc V Ni Cu Zn Rb Sr Y Zr Nb Cs Ba La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb

6 83 62 459 53 489 200
Lu Hf Ta Pb Th U

MALI @ SiO_2		(Na_2O+K_2O)	A. I.	Mg#	Nb/Zr	Ce	Y/Sc
8.07	68.41	8.86	0.83	12	0.12	332	10.3

[1]Gilmer, 2001; [2]Gilmer et al., 2003

CENOZOIC

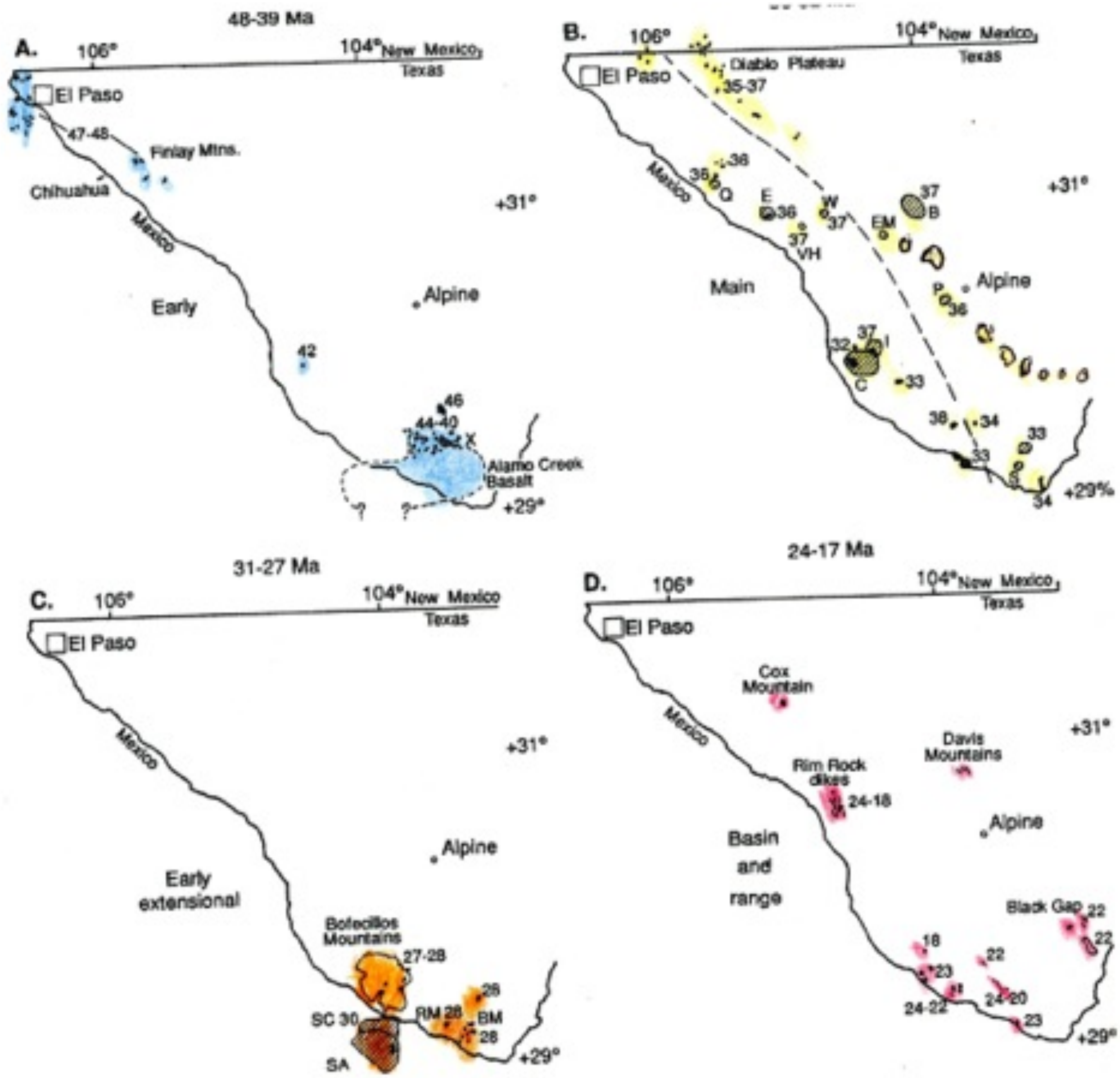

Fig. 6. Sketch map (from Henry and Price, 1984) showing age distributions of Trans-Pecos magmatism. Map B represents 38 to 32 Ma.

Fig. 7. Sketch map, intrusions in the El Paso area (from Hoover et al., 1988).

El Paso area

A north-south line of at least ten small intrusive bodies goes through El Paso, cutting Pennsylvanian and Permian rocks. They extend from 20 km SW of Cuidad Juarez, Chihuahua to the Vado Hills, New Mexico for a total length of 50 km. These are alkalicalcic to calcalkalic, silica-oversaturated trachyandesites and trachytes, in contrast to Trans-Pecos igneous rocks to the east and south. Most are poorly exposed and surrounded by Rio Grande alluvium. All are porphyritic, with phenocrysts of plagioclase and alkali feldspar, amphibole and biotite in a fine-grained groundmass of alkali feldspar, quartz, magnetite and apatite (Garcia, 1970; Hoover et al., 1988).

Campus "Andesite"

Sample CAMPA

Age, Ma	48.4 ± 2.3 (K-Ar, biotite)	Long & Lat	Quadrangle
Calkalkalic trachyte, center of intrusion.		106 30.6, 31 46.5	Smeltertown

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
62.52	0.30	17.42			1.45	0.29	1.29	3.55	5.86	2.90	0.41					96.09

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho

2.592 6.9 47.9 45 810 123 5.8 1.88 1285 20.08 40.9 18 2.97 0.977 0.251
Er Tm Yb Lu Hf Ta Pb Th U
0.64 0.094 3.36 0.628 3.16 0.91
MALI @ SiO_2 (Na_2O+K_2O) A. I. Mg# Ce Ce/Yb Ta/Yb Th/Yb
-1.40 62.52 8.76 0.73 47 67.8 17.3 0.98 4.94
Nb/Zr Zr/Hf Nb/Ta
0.05 36.6 9

Hoffer, 1970; Henry et al., 1986; Hoover et al., 1988

Cristo el Rey

Sample Cr6f

Alkalicalcic trachyte

On the international border. Long & Lat Quadrangle
106 32.5, 31 47.5 Smeltertown

SiO_2 TiO_2 AL_2O_3 Fe_20_3 FeO FeO* MnO MgO CaO Na_2O K_2O P_2O_5 H_2O+ H_2O^- CO_2 LOI Total
61.90 0.72 17.2 2.54 2.22 4.51 0.09 2.29 428 5.29 2.95 0.46 99.96
Sc V Ni Cu Zn Rb Sr Y Zr Nb Cs Ba La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm
6.1 30 68 1328 12 158 3 1.62 1736 21.6 40.7 23.3 4.2 1.03 0.4
Yb Lu Hf Ta Pb Th U
0.8 0.12 3.28 0.51 4.49 1.71
MALI @ SiO_2 (Na_2O+K_2O) A. I. Mg# Ce Ce/Yb Ta/Yb Th/Yb
3.96 61.9 8.24 0.69 34 67.5 13.8 0.64 5.61
Nb/Zr Zr/Hf Nb/Ta Y/Nb Th, ppm Y/Sc
0.02 5.88 4.0 1.80 4.28 1.97

Hoover et al., 1988

Alkalicalcic trachyandesite, enclave in trachyte

Sample CR5E

SiO_2 TiO_2 AL_2O_3 Fe_20_3 FeO FeO* MnO MgO CaO Na_2O K_2O P_2O_5 H_2O+ H_2O^- CO_2 LOI Total
60.00 0.83 18.50 2.05 3.16 4.96 0.16 1.79 4.47 5.35 3.04 0.71 100.10
Sc V Ni Cu Zn Rb Sr Y Zr Nb Cs Ba La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm 4.5
12 55 1270 132 6 1.06 1580 18.9 36.7 17.8 4.1 1.13 0.38
Yb Lu Hf Ta Pb Th U
0.77 0.12 0.26 2.86 1.39
MALI @ SiO_2 (Na_2O+K_2O) A. I. Mg# Ce Ce/Yb Ta/Yb Th/Yb
3.31 60.40 7.78 0.65 26.5 60.9 12.9 0.34 3.71
Nb/Zr Nb/Ta
0.05 23.1

Barnes et al., 1991

Alkalicalcic trachyandesite, enclave in trachyte

Sample CR69 EN

SiO_2 TiO_2 AL_2O_3 Fe_20_3 FeO FeO* MnO MgO CaO Na_2O K_2O P_2O_5 H_2O+ H_2O^- CO_2 LOI Total
60.40 0.92 17.40 3.34 2.30 4.97 0.10 2.74 4.45 5.37 2.41 0.56 100
Sc V Ni Cu Zn Rb Sr Y Zr Nb Cs Ba La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb
11 32 33 1707 16 157 5 1595
Hf Ta Pb Th U
MALI @ SiO_2 (Na_2O+K_2O) A. I. Mg# Nb/Zr Y/Nb Y/Sc
3.33 60.40 7.78 0.66 35.5 0.03 3.20 1.45

Barnes et al., 1991

Alkalicalcic trachyandesite, enclave in trachyte

Sample CR40A

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
61.10	0.81	17.00	3.47	1.88	4.66	0.11	2.16	4.81	5.31	2.88	0.53					100.10

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
8.1					64	1062	15	143	5		2013													

Lu	Hf	Ta	Pb	Th	U

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#
3.38	61.06	8.19	0.70	31.7

Nb/Zr	Y/Nb	Y/Sc
0.03	3.00	1.85

Barnes et al., 1991

Coronado Hills (Three Sisters)

Sample Acorn 2A — Long & Lat — Quadrangle

Alkalicalcic trachyandesite — 106 32, 31 49 — Smelter Town

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
58.82	0.68	17.67			4.69	0.11	4.04	4.70	4.68	2.49	0.26					98.12

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb
12.57		65		47.5	56.2	931		163	14.9	1.61	1216	29.7	62.9		27.6	5.76	1.819		0.578

Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
				1.35	0.199	4.76	0.782		4.28	

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#	Ce	Ce/Yb	Ta/Yb	Th/Yb
2.44	58.2	7.17	0.59	46	102.8	12.6	0.58	3.17

Nb/Zr	Zr/Hf	Nb/Ta
0.09	34.2	19.1

Hoover et al., 1988

Sample Acorn 2B *Alkalicalcic trachyandesite*

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
60.05	0.69	17.20			4.42	0.05	3.57	4.21	4.77	3.00	0.21					98.17

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho
10.83		66		54.5	49.3	690		145	7.7	1.26	1300	25.85	54.3		24.5	5.07	1.589		0.56		

Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
		1.41	0.184	4.21	0.925		4.1	0.96

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#	Ce	Ce/Yb	Ta/Yb	Th/Yb
3.70	61.17	7.91	0.65	44.7	90.0	10.5	0.66	2.91

Nb/Zr	Zr/Hf	Nb/Ta
0.05	34.5	8.32

Hoover et al., 1988

Thunderbird intrusion

Sample THA

Low on west flank of Franklin Mtns — Long & Lat — Quadrangle

Alkalicalcic trachyandesite — 106 41, 31 52 — Strauss

SiO_2	TiO_2	AL_2O_3	Fe_2O_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
60.22	0.90	16.93			5.52	0.05	3.58	4.32	4.47	2.54	0.26					98.79

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb
10.27		45		84.4	58.7	851		175	10.8	0.82	1202	30.6	64.7		28.1	5.82	1.785		0.544

Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
				1.31	0.184	5.11	0.768		4.75	

MALI	@ SiO_2	(Na_2O+K_2O)	A. I.	Mg#	Ce	Ce/Yb	Ta/Yb	Th/Yb	Nb/Zr	Zr/Hf	Nb/Ta
2.78	60.96	7.10	0.70	39.3	107.3	13.4	0.59	3.63	0.06	34.2	14.1

Hoover et al., 1988

Hueco Tanks State Park

Residual tors of quartz syenite protrude from alluvium. Cavernous weathering makes this a favorite with rock climbers. *Trachyte*, with alkali feldspar, plagioclase, clinopyroxene, biotite, < 5% quartz (Wise, 1977).

Sample Hut-2	Long and Lat	Quadrangle
Age, Ma: 32.3 ± ?	106°02.7’, 31°55.4’	Hueco Tanks

SiO_2	TiO_2	AL_2O_3	Fe_20_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
64.60	0.64	17.80	1.77	1.27	2.86	0.14	0.46	0.93	6.62	5.74	0.24	0.33	0.14			100.68

MALI	@ SiO_2	(Na_2O+K_2O)	A.I.	Mg#
11.43	64.60	12.36	0.96	14

Barker, 1987; Henry et al., 1986

Cerro Alto	Long & Lat	Quadrangle
Age, Ma: 34.3 ± 0.5 (K-Ar, biotite)	105°58.0’, 31°56’	Cerro Alto Mountain

Note that this is the only *calcalkalic dacite* in the database. Alkali loss during weathering is suspected. This, like the Hueco Tanks body, according to Wise (1977) is zoned, with plagioclase-rich margins and alkali-feldspar-rich interiors. Both bodies intrude Pennsylvanian and Permian limestones.

Sample Alto-1

SiO_2	TiO_2	AL_2O_3	Fe_20_3	FeO	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O^-	CO_2	LOI	Total
66.60	0.34	16.65	1.62	0.52	1.82	0.15	0.26	0.74	6.28	5.31	0.11	0.33	0.11	0.05		99.06

Sc	V	Ni	Cu	Zn	Rb	Sr	Y	Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
				72	150	129	29	547	118															

Lu	Hf	Ta	Pb	Th	U

MALI	@ SiO_2	(Na_2O+K_2O)	A.I.	Mg#	Nb/Zr	Y/Nb
-0.86	66.60	5.42	0.97	83	0.22	0.25

Barker et al., 1977; Henry et al., 1986; Barker, 1987