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CAMBRIAN-ORDOVICIAN (500 Ma) ALKALIC PLUTONISM IN SOUTHWESTERN NEW MEXICO: U–Th-Pb ISOTOPIC DATA FROM THE FLORIDA MOUNTAINS

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ABSTRACT. **A major alkalic igneous suite in the Florida Mountains of southwestern New Mexico has been dated by the U–Th–Pb method on zircon as latest Cambrian to earliest Ordovician. Zircons from hornblende-pyroxene hornfels and alkali-feldspar granite are only slightly discordant and yield upper intercept ages of 504 ± 10 Ma and 503 ± 10 Ma, respectively. Zircons from a second granite sample (separated from the first sample by a major fault zone) are more discordant and yield less well constrained upper intercept ages but have $^{207}Pb/^{206}Pb$ ages of 495 to 507 Ma, consistent with crystallization at about 500 Ma. Combining data from both alkali-feldspar granite samples gives an upper intercept age of 503 ± 6 Ma. A single sample from a syenite body of the alkalic complex has a $^{207}Pb/^{206}Pb$ age of 523 Ma, possibly indicating a minor component of inherited radiogenic Pb. Zircons from a basement granite gneiss, intruded by the younger alkalic complex, have $^{207}Pb/^{206}Pb$ ages of 1550 to 1570 Ma; these values are interpreted as minimum ages and indicate that the basement is probably Early Proterozoic.**

These results firmly document the presence of lower Paleozoic alkalic plutons in southwestern New Mexico. Implications of these data include: (1) a diamictite that nonconformably overlies the plutonic complex is not Late Proterozoic as suggested by previous workers on the basis of correlation with similar deposits in the Cordillera; (2) the Bliss Sandstone, thought to be Late Cambrian in the Florida Mountains area, is clearly in depositional contact with the alkalic plutonic complex and must be younger than 503 ± 10 Ma; and (3) the alkalic plutonism, a type commonly associated with extensional tectonics, may have considerable significance in deciphering the poorly understood early Paleozoic tectonics in this region.

INTRODUCTION

The Florida Mountains are located in the Basin and Range province of southwestern New Mexico, approx 13 km southeast of Deming (fig. 1). The range is an east-tilted fault block about 16 by 8 km, of which slightly more than half has traditionally been regarded as Precambrian metamorphic and plutonic basement. Paleozoic strata nonconformably overlie these rocks, and Eocene volcaniclastic rocks and other lower Tertiary(?) sedimentary units unconformably overlie the Paleozoic rocks. Late Tertiary andesitic and rhyolitic dikes cut the entire sequence.

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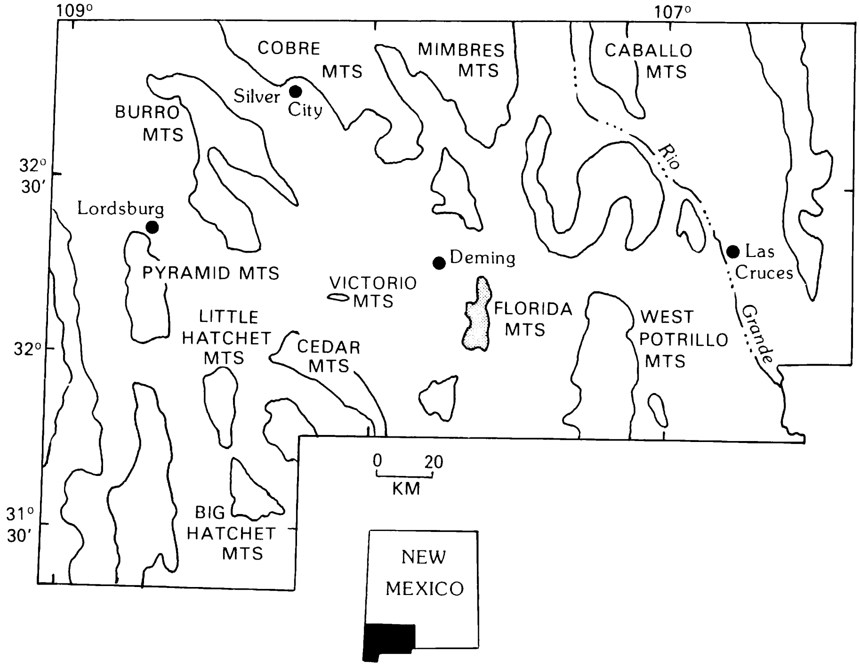

Fig. 1. Index map of the major mountain ranges in southwestern New Mexico. Geology of the Florida Mountains (shaded) is shown in figure 2.

The plutonic rocks of the Florida Mountains were mapped as Precambrian granite by Darton (1916, 1917) and as three kinds of granite and a diorite by Griswold (1961). Corbitt (ms) mapped the range and described the plutonic rocks as Precambrian granite and Mesozoic syenite intruded by gabbro and "anorthosite." He also indicated that a syenite body intrudes the Paleozoic sedimentary rocks but later (Corbitt, 1974) acknowledged that the syenite, gabbro, and "anorthosite" could be Precambrian rocks with partially reset isotopic systems. Most recently, Corbitt (oral commun., 1980) has favored the interpretation that thrust faults, not intrusive contacts, separate the syenite and Paleozoic sedimentary rocks.

Brookins (1974a, b, 1980a, b; Brookins and Corbitt, 1974) began isotopic studies of the plutonic rocks simultaneously with Corbitt's work. Rb-Sr model ages of 456 ± 56 to 515 ± 26 Ma were obtained on feldspar and 500 to 750 Ma on whole-rock samples of quartz syenite from the northern Florida Mountains. K-Ar dates of hornblende from quartz syenite and hornblende gabbro range from 418 ± 8 to 555 ± 11 Ma. Whole-rock Rb-Sr isochron ages include 1600 ± 150 Ma for a so-called quartz monzonite-granodiorite suite, 395 ± 27 Ma for syenite, and 371 ± 19 Ma for quartz syenite. Matheney and Brookins (1983) reported a 35-point whole-rock Rb-Sr isochron of 420 ± 20 Ma for samples of syenite, alkali granite, and gabbro. Because decay constants have not been consistently reported in these papers, we have cited the dates as given and have not recalculated them using the constants of Steiger and Jäger (1977).

Despite the imprecision of the Rb-Sr data and the variety of possible interpretations of the K-Ar results, the above authors' work has continued to hint of intriguing early or middle Paleozoic plutonism in an area where such events are supposedly very rare (Loring and Armstrong, 1980; McLemore, 1983). As a supplement to a mapping and geochronologic study of the Florida Mountains, we attempted to resolve the apparent age enigma by U–Th–Pb dating of zircon suites from various plutonic units. Our rock unit nomenclature follows that of Clemons (1982a, b, 1984, 1985, in press) and Clemons and Brown (1983), whose series of maps provide a bibliography of previous work in the range.

STRUCTURAL FRAMEWORK

The most prominent structural feature is the South Florida Mountains Fault (SFMF), which juxtaposes alkalic igneous rocks against various Paleozoic sedimentary units (fig. 2). Before basin-and-range tilting, the SFMF trended north 50 west and dipped 85 degrees southwest. Brown and Clemons (1983) indicated reverse slip on the fault but also noted probability of right slip. In this discussion we distinguish the granites north and south of the SFMF, even though all indications are that the granites and syenitic rocks are consanguineous and part of one alkalic igneous complex (Clemons, 1985, in press).

In addition, a complex system of low-angle faults, which steepen toward the SFMF, place younger rocks generally over older rocks. Brown and Clemons (1983) argued that these are thrust faults, probably analogous to those bordering basement-cored block uplifts. Others have argued that these faults are part of a major regional "thin-skinned" thrust system (Corbitt and Woodward, 1973a; Drewes, 1978; Woodward and DuChene, 1981). The results of our study do not resolve this controversy, but we suggest that the interpretation of uplift associated with transpression along strike-slip faults is most consistent with available data (Brown and Clemons, 1983; Seager, 1983; Seager and Mack, 1986; Sylvester and Smith, 1976; Sanderson and Marchini, 1984). Strike-slip faults subparallel to that in the Florida Mountains have been noted in the northern Cedar Mountains (Thorman and Drewes, 1979), Victorio Mountains (Thorman and Drewes, 1980), and northern Pyramid Mountains (Thorman and Drewes, 1978). Drewes and Thorman (1978) briefly summarize similar fault occurrences in southwestern New Mexico and southeastern Arizona.

LITHOLOGIC UNITS

Our primary concern is the alkalic plutonic complex and its host Proterozoic basement. Descriptions and modal data for these rocks are

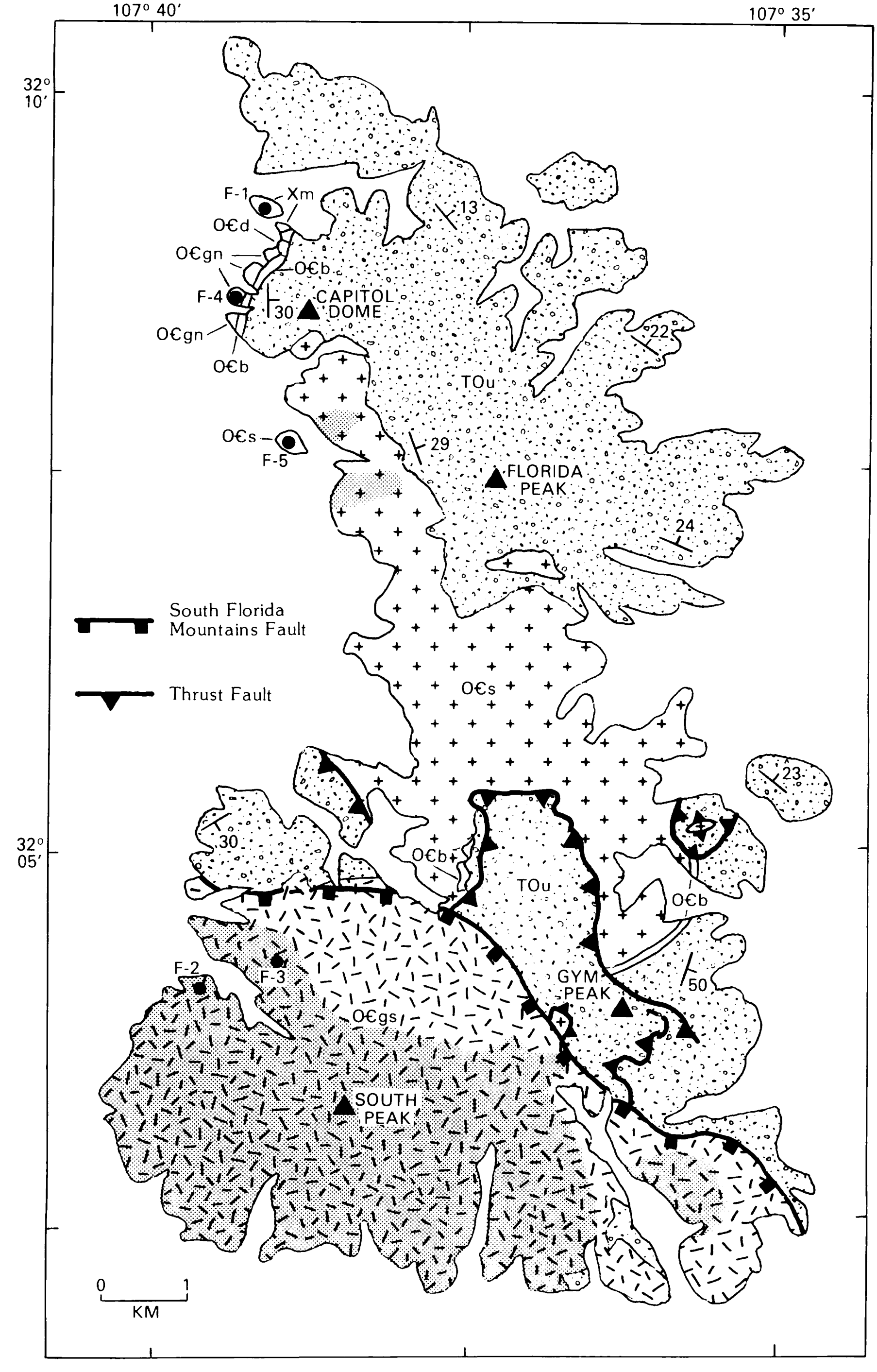

Fig. 2. Geologic map of the Florida Mountains, New Mexico, simplified from Clemons (1982a, 1984, 1985) and Clemons and Brown (1983). Location of sample sites F-1 through F-5 are indicated. Xm = metamorphic basement of Early Proterozoic age; O€s = syenite; O€gs = alkali-feldspar granite south of SFMF; O€gn = alkali-feldspar granite north of SFMF; O€d = diamictite; O€b = Bliss Sandstone, all of Ordovician or Cambrian age; TOu = undifferentiated units of Tertiary to Ordovician age stratigraphically above the Bliss Sandstone. Shaded areas indicate parts of unit O€s and unit O€gs with abundant hornfels inclusions. Areas too small to pattern are identified individually by letter designations. Boxes and barbs on upper plates of fault blocks.

found in Clemons' work (cited above), on which the following abbreviated summary and table 1 are based.

Proterozoic Basement Rocks

In two low hills west of Capitol Dome (fig. 2) are exposed the only foliated metamorphic basement rocks in the Florida Mountains. The lithologies include granite gneiss interlayered with biotite schist, biotite and hornblende gneiss, and amphibolite. These rocks are similar to nearby known Early Proterozoic rocks (Condie, 1981), on the basis of lithologic similarities, stratigraphic position beneath Paleozoic strata, and the isotopic age results discussed below.

Hornfels

Hornfelsic intermediate to mafic igneous rocks occur as inclusions in the alkalic igneous bodies (Clemons, in press). Typically the hornfels average 48 percent intermediate plagioclase and 33 percent hornblende (table 1), the remainder being composed of biotite, pyroxene, alteration products, and accessory apatite, sphene(?), magnetite, and zircon. Plagioclase is extensively altered to clay minerals and sericite, although a few samples of float contain fresh plagioclase (sodic labradorite) and abundant hypersthene and olivine.

Hornfels is most abundant in the southern Florida Mountains where it occurs as ovoid blobs or elongate slabs up to 15 m long in the alkali-feldspar granite (fig 3). Some inclusions have rims that are finer grained than the cores, and many have crenulate margins. On a macroscopic scale these hornfels inclusions define a crude layering, which near South Peak dips 25 to 35 degrees northeast. The origin of the hornfels protolith is poorly understood; they could be xenoliths of intermediate to mafic volcanic rocks completely recrystallized and stoped into the alkalic magma or a mafic comagmatic portion of the plutonic complex. Because the U–Th–Pb data have relevance to the question, we postpone discussion to a later section of this paper.

Alkalic Igneous Complex

Alkali-feldspar granite south of SFMF.—Plutonic rocks near South Peak are almost exclusively alkali-feldspar granite and are subdivided (fig. 1) based on the presence or absence of hornfels inclusions. The alkali-feldspar granite is coarse-grained and light to medium gray where inclusions are absent, whereas it is fine- to medium-grained and reddish where inclusions are abundant. The two types of alkali-feldspar granite are mineralogically indistinguishable in thin section. The average alkali-feldspar granite contains 65 percent perthite and microcline, 27 percent quartz, 2 percent hornblende, and 6 percent chlorite (altered mafic minerals), magnetite, zircon, sphene, and apatite (table 1).

TABLE 1

Summary of Modal Analyses on Rocks of the Florida Mountains

	Quartz		K-feldspar		Plagioclase		Biotite		Amphibole		Pyroxene		Olivine	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Granite gneiss (8)	30–35	33	31–55	38	24–29	28	0–8	2						
Granite (north) (7)	18–33	26	61–80	69	0–3	<1								
Granite (south) (67)	15–43	27	47–87	65					0–11	2				
Syenite (100)	0–18	6	58–93	82			0–3	<1	0–11	2				
Hornfels (29)					21–67	48	0–19	5	8–54	33	0–19	4	0–14	1
Aplites (g) (13)	21–35	30	37–74	59	0–28	6			0–17	3				
Aplites (s) (8)	19–28	24	66–79	71					1–6	3				

Numbers in parentheses indicate number of samples point counted (1000 points). Granite (north) = Alkali-feldspar granite north of SFMF; Granite (south) = Alkali-feldspar granite south of SFMF; Aplites (g) = Aplites in Granite (south); Aplites (s) = Aplites in syenite. Most samples also contain 2 to 10 percent secondary and accessory minerals.

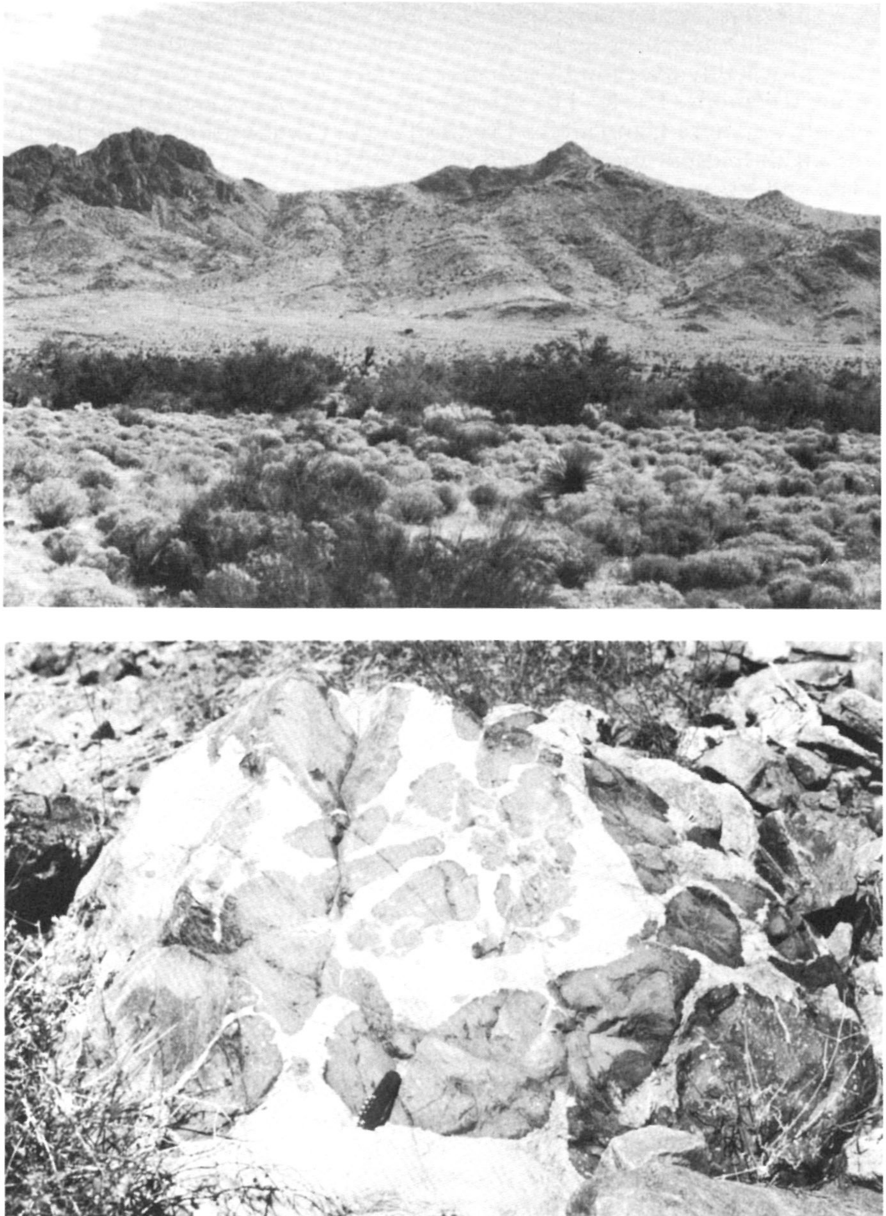

Fig. 3(A) View of the southern Florida Mountains as seen looking east toward South Peak (the high peak slightly to the right of center). Layered terrain below South Peak is alkali-feldspar granite with various sized inclusions of hornfelds.

(B) Boulder showing decimeter-sized inclusions of hornfels in alkali-feldspar granite near South Peak. Knife is 8 cm long.

Alkali-feldspar granite north of SFMF.—Alkali-feldspar granite west of Capital Dome intrudes high-grade Proterozoic basement rocks and is unconformably overlain by a diamictite (see below) and the Bliss Sandstone (Clemons, 1984). The alkali-feldspar granite is a coarse-grained, deeply weathered, and altered reddish rock. Compositionally similar to the alkali-feldspar granite south of the SFMF, it contains more orthoclase and less microcline.

Syenite.—Syenite and alkali-feldspar quartz syenite only occur north of the SFMF. The syenitic rocks are predominantly coarse- to very coarse-grained, but locally they are fine-to medium-grained. Locally the rock is porphyritic with perthite crystals up to 2 cm long. Unaltered, fresh syenite is medium light gray to medium bluish gray, but where hydrothermally altered it varies from pink to red brown and yellowish brown. Modal averages are: 82 percent microcline and perthite; 6 percent quartz; 2 percent hastingsite; and <1 percent biotite (table 1). Accessory minerals include magnetite, apatite, zircon, and sphene. Modally, the syenitic rocks differ from the alkali-feldspar granites only in their K-feldspar to quartz ratio.

Diamictite

A conglomerate, up to 12 m thick, is exposed discontinuously along strike for about 40 m northwest of Capitol Dome (Clemons, 1984). The unit, described as a diamictite by Corbitt and Woodward (1973b), nonconformably overlies both alkali-feldspar granite and Early Proterozoic mafic gneiss and is unconformably overlain by the Bliss Sandstone. Corbitt and Woodward (1973b) examined 127 clasts, of which 45 percent are lithic sandstone with thin cherty limestone interbeds; 17 percent are silty hematite breccia; 17 percent are siliceous ironstone; 12 percent are diabase or basalt; and 10 percent are granite [summing to 101 percent]. All the clasts but the alkali-feldspar granite are exotic to the Florida Mountains. The clasts range from 3 cm to 1.2 m in diam. Matrix in the basal 1.8 m is reddish fissile shale, overlain by 7.5 m of greenish gray fissile shale. The clasts appear to deform the shale, which led Corbitt and Woodward (1973b) to suggest a glacial dropstone origin. The upper 3 m consist of granite boulders in an arkosic matrix.

Bliss Sandstone

The Bliss Sandstone is the basal Paleozoic formation in southern New Mexico and western Texas. In the Florida Mountains it is exposed north of the SFMF and varies from 0 to 60 m in thickness, reflecting the irregularity of the pre-Bliss erosional surface. The Bliss is primarily an arkosic sandstone with hematite, silica, and calcite cements. Basal beds are locally conglomeratic, containing clasts of the underlying syenite and alkali-feldspar granite. Upsection the feldspar content, grain size, and amount of hematite cement decrease, and carbonate cement increases. Regional aspects of the Bliss are described by Hayes (1975), Thompson and Potter (1981), and numerous other publications cited in

Clemons (1982a, 1984, 1985) and Clemons and Brown (1983). Hayes (1975) suggested that the regionally time-transgressive Bliss is Late Cambrian-Early Ordovician in the Florida Mountains area. The overlying El Paso Formation is Early Ordovician.

Post-Bliss Units

Stratigraphically above the Bliss Sandstone are a number of Paleozoic and Tertiary rock units. The Paleozoic section is primarily composed of carbonate rocks interrupted by several disconformities. The conglomeratic Late Cretaceous(?)-Tertiary Lobo Formation rests unconformably on the Paleozoic rocks and is overlain by Eocene volcaniclastic strata. These units are not pertinent to our study, and we refer the interested reader to Clemon's maps of the Florida Mountains and the references cited therein.

GEOCHRONOLOGY

As mentioned, this U–Th–Pb isotopic age study of the alkalic plutonic complex was conducted, because the results by K-Ar and Rb-Sr techniques were judged to be inconclusive. Zircon data from the hornfels and alkali-feldspar granite yield fairly precise upper-intercept ages on a U-Pb concordia diagram, which form the basis for interpreting the more complex isotopic patterns of the other samples.

Analytical Techniques

Approximately 20 kg of rock was collected at each sample locality. We collected the freshest available samples, but it should be noted that alteration is nearly ubiquitous throughout the range. Crushing, pulverizing, and mineral separations were performed at the U.S. Geological Survey in Denver, Colo.

Zircon separates were split into size fractions and in most cases were further split into magnetic and nonmagnetic portions. With one exception, all analyzed fractions were nonmagnetic and ranged from 2 to 7 mg. Standard techniques of decomposition and ion-exchange chemistry as modified from Krogh (1973) were employed. Isotope ratios were measured on an NBS 30-cm mass spectrometer with digital control and data processing.

Uranium, thorium, and lead concentrations are considered accurate to ±1 percent. Lead composition ratios have uncertainties of ±0.1 percent, except for $^{206}Pb/^{204}Pb > 1000$, for which uncertainties are probably 1 to 3 percent. A common lead correction was made by first subtracting lead equal in amount and composition to the analytical blank, which over the course of this study was about 0.7 ng. For the granite gneiss (sample F-1) the remaining ^{204}Pb was assumed to be 1700 Ma model lead with the composition $^{204}Pb:^{206}Pb:^{207}Pb:^{208}Pb$ = 1:15.764:15.323:35.398. Common lead in all other samples was assumed to be 500 Ma model lead with composition 1:17.918:15.584:37.708. Model lead compositions are from Stacey and

Kramers (1975); all constants are from Steiger and Jäger (1977). Uncertainity of the upper intercept age is the 95 percent confidence limit calculated according to Ludwig (1980, 1985).

Zircon Morphology

The shape, color, and length-to-width ratios (L/W) of zircon from the plutonic complex of the Florida Mountains are all similar, but the color differs distinctly from that of zircon from the granite gneiss. Alkali-feldspar granite, the hornfels, and syenite have euhedral zircon with L/W of 2:1 to 4:1. Zircon from these samples is pinkish but with a slightly deeper, purplish tinge for zircon from hornfels. Zircon from the granite gneiss is similar but light brown or honey-colored.

Analytical Results and Interpretations

Granite gneiss.—Three size fractions of zircon from the granite gneiss (F-1) were analyzed (table 2). Despite the relatively low uranium content of the zircon (~300–330 ppm), the U-Pb data are moderately discordant (fig. 4). Data points for the two coarser fractions plot adjacent to one another and are not colinear with the data point for the third fraction. $^{207}Pb/^{206}Pb$ ages range from 1554 to 1570 Ma, and two-point discordias utilizing data from the finest-grained fraction and either of the other fractions yield upper intercepts exceeding 1500 Ma. We interpret these $^{207}Pb/^{206}Pb$ and upper intercept ages, which are distinctly older than for any of the other samples, as minimum ages for the granite gneiss. This interpretation is consistent with estimated ages for the regional basement in southern New Mexico of 1600 to 1700 Ma (Condie, 1981). The complex data pattern for zircon of the granite gneiss could result from multistage Pb loss associated with any or all of the following: (1) high-grade regional metamorphism at about 1600 to 1650 Ma; (2) intrusion of the alkalic plutons, which occurred more than 1000 Ma after crystallization of the gneiss; (3) Laramide uplift; or (4) intrusion and alteration accompanying emplacement of middle to late Tertiary dike and deep plutons. There is also the possibility that the $^{207}Pb/^{206}Pb$ ages record an episode of Proterozoic plutonism somewhat younger than expected from regional studies of age provinces (Condie, 1981).

Hornfels.—In contrast, zircon from the hornfels sample (F-2) demonstrates simple U-Pb systematics. Four size fractions (three nonmagnetic and one fraction not split magnetically) provide only slightly discordant data (fig. 5) which yield an upper intercept of 504 ± 10 Ma (MSWD = 0.29). The negative lower intercept (with a large error) is an artifact of the small dispersion of data points near the upper end of discordia, but it is consistent with lead loss during a Tertiary thermal event and range uplift. We interpret 504 ± 10 Ma to be the crystallization age of the hornfels.

Two alternatives for the origin of the hornfels protolith were outlined above. According to the first, zircon grew metasomatically,

TABLE 2

U, Th, Pb Analytical Data and Ages

Sample and Size Fraction	Concentration (ppm)			Measured $^{206}Pb/^{204}Pb$	Isotopic composition of lead (atom percent)				Ages (Ma)			
	U	Th	Pb		^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{232}Th$
F-1 Granite gneiss												
−100 + 150 nm	302	133	65.4	816	0.0918	77.38	8.720	13.806	1,127	1,283	1,554	1,144
−150 + 200 nm	309	141	65.4	1,535	0.0486	78.51	8.296	13.147	1,128	1,289	1,570	1,172
−250 + 325 nm	328	—	62.9	1,528	0.0476	78.18	8.197	13.571	1,027	1,211	1,556	—
F-2 Hornfels												
−50 + 100 nm	345	421	33.0	3,629	0.0126	68.69	4.128	27.167	473	479	508	470
−100 + 150 nm	379	423	36.2	5,478	0.0069	70.12	4.123	25.746	481	485	505	488
−150 + 200 nm	366	398	33.5	4,564	0.0086	70.43	4.168	25.390	465	472	507	474
−200 + 250	376	416	35.0	3,659	0.0128	70.02	4.206	25.759	469	475	507	477
F-3 Alkali-feldspar granite (south)												
−100 + 150 nm	232	178	21.2	1,323	0.0532	76.26	5.145	18.540	496	497	503	443
−150 + 200 nm	285	210	23.7	1,303	0.0482	76.16	5.068	18.721	451	460	504	429
−200 + 250 nm	307	223	27.8	1,352	0.0526	76.00	5.120	18.832	490	492	503	471
−250 + 325 nm	301	221	27.7	579	0.1191	73.57	5.943	20.368	475	479	499	447
F-4 Alkali-feldspar granite (north)												
+100 nm	287	164	22.8	272	0.2522	71.06	7.736	20.949	383	400	499	357
−100 + 150 nm	270	159	20.8	440	0.1608	74.31	6.607	18.925	399	415	507	380
−150 + 200 nm	300	180	22.8	584	0.1204	75.97	6.107	17.801	408	423	504	378
−200 + 250 nm	350	207	30.3	252	0.2604	70.04	7.790	21.908	411	424	495	398
F-5 Syenite												
+200 nm	234	—	19.0	942	0.0668	79.61	5.576	14.743	460	471	523	—

Note: Isotopic composition of lead corrected for laboratory blank only; ages corrected for laboratory blank and common lead. nm = nonmagnetic.

Locations: F-1 – 32° 09′ 15″ N, 107° 39′ 11″ W; F-2 – 32° 04′ 08″ N, 107° 39′ 35″ W; F-3 – 32° 04′ 16″ N, 107° 39′ 00″ W; F-4 – 32° 08′ 40″ N, 107° 39′ 19″ W; F-5 – 32° 07′ 40″ N, 107° 38′ 55″ W

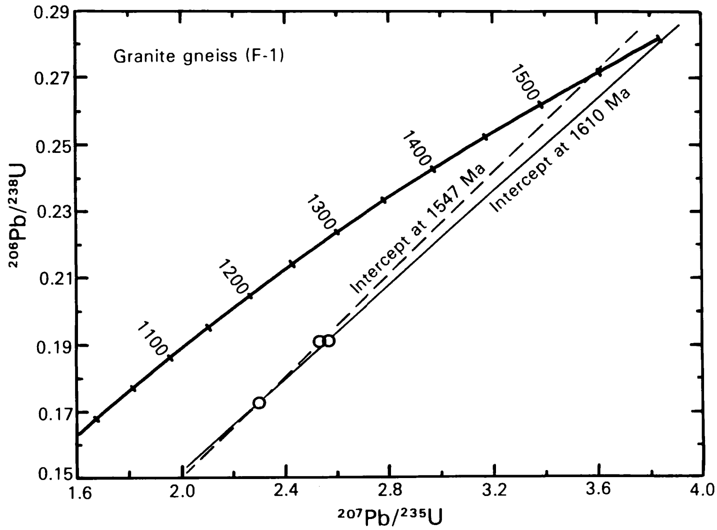

Fig. 4. Concordia plot of zircon from the granite gneiss (F-1). Shown are two-point discordias defined by the finest-grained fraction and each of the coarser fractions. See text for interpretation.

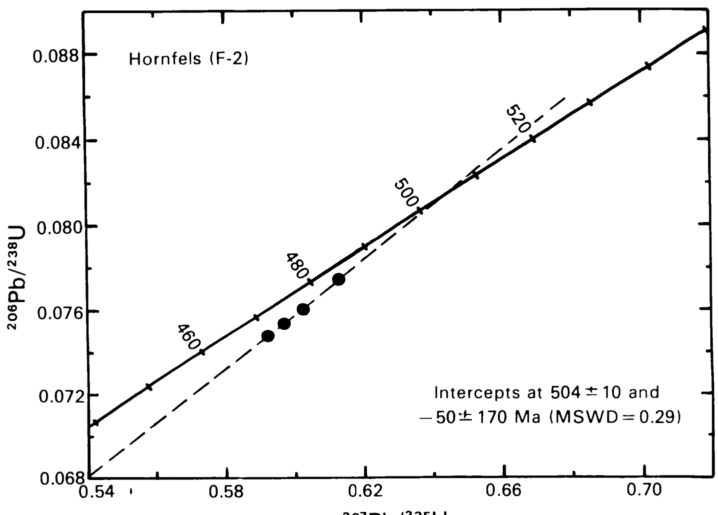

Fig. 5. Concordia plot of zircon from the hornfels (F-2).

when the alkalic magma incorporated layered Proterozoic intermediate to mafic volcanic(?) basement rocks. In this case, 504 ± 10 Ma is the crystallization age of the alkali-feldspar granite. This interpretation may best explain the origin of the northeast-dipping interlayers of hornfels inclusions in alkali-feldspar granite in the southern part of the range but does not account for other available data. For instance, the excellent linear fit of our data indicates that the zircons did not inherit Proterozoic radiogenic Pb and that negligible amounts of Proterozoic xenocrystic zircon were present in the protolith of the hornfels. This is an anomalous situation, as virtually all studied Proterozoic mafic basement rocks in nearby Arizona contain original Proterozoic zircon (E. DeWitt, oral commun., 1986). Moreover, the F-2 zircon is thorium-rich, whereas typical Proterozoic zircon from mafic basement in the region is not. Also, abundant pyroxene in the hornfels is not likely a reaction product of amphibole at the relatively cool temperatures of the alkali-feldspar granite magma, nor is the pyroxene likely a relict of Proterozoic regional metamorphism.

In an alternative explanation, the hornfels are autoliths of a coeval mafic magma which did not mix with the alkali-feldspar granite. In this case, the upper intercept age of F-2 dates the crystallization of the mafic magma, which is the same as the age of alkali-feldspar granite. No atypical basement lithology needs to be postulated. Pyroxene in the hornfels was a liquidus phase of the mafic magma which chilled against the granite magma forming finer-grained rims in some places. The crenulate shape of many margins, mentioned above, is commonly produced by interaction of mafic "pillows" with a compositionally distinct magma (Blake and others, 1965; Walker and Skelhorn, 1966; Wiebe, 1973; Elwell, Bruck, and O'Connor, 1974).

Geochemical data of Brookins and others (1978) from felsic plutonic rocks further support these conclusions. Their data plot in two fields in the R_1R_2 diagram of La Roche and others (1980); one field trends from syenite to alkali granite, and the other is sited well within the nepheline syenite field. Between the fields is the "critical plane" of silica saturation (Yoder and Tilley, 1962) and a thermal divide which prevents alkali granite magma from generating nepheline syenite magma (or vice versa) by equilibrium crystallization or fractionation (Gittins, 1979). On the other hand, if a mafic magma (approximately gabbro), whose composition lies athwart the critical plane, were to differentiate producing syenitic rocks, the remaining liquids would trend toward nepheline syenite and syenite-alkali granite. Unfortunately, chemical analyses are not available for the hornfels, so we can not directly test this suggestion at present. By this interpretation, however, the interlayering of hornfels inclusions and alkali-feldspar granite perhaps can be explained as being part of a poorly preserved alkalic ring-dike complex. Petrologic and geochemical studies are needed to test this hypothesis.

Alkali-feldspar granite (south).—U-Pb systematics of zircon from the alkali-feldspar granite south of the SFMF (F-3) are fairly simple (upper and lower intercepts are 503 ± 10 and 2 ± 170 Ma (MSWD = 1.9), respectively (fig 6). U-Pb data from the −100 + 150NM size fraction are concordant within analytical limits, and the $^{207}Pb/^{206}Pb$ age is 503 Ma. Therefore, we interpret 503 ± 10 Ma to be an accurate indication of the age of the alkali-feldspar granite (south).

Alkali-feldspar granite (north).—Data from four zircon fractions from the alkali-feldspar granite (F-4) north of the SFMF define an elongate but noncolinear pattern on a concordia plot (fig. 6). Although containing similar U and Th concentrations, zircon from sample F-4 is more discordant than zircon from sample F-3. F-4 zircon $^{207}Pb/^{206}Pb$ ages range from 495 to 507 Ma, very similar to the age of 503 ± 10 Ma preferred for sample F-3. In spite of scatter, the data indicate that the granite north of the SFMF cannot be part of the regional Early Proterozoic basement as suggested by early workers (Darton, 1916, 1917). We interpret the span of $^{207}Pb/^{206}Pb$ ages in the vicinity of 500 Ma as approximating the crystallization age.

The very similar lithologies and geochemistry of the granites north and south of the SFMF (Brookins, Rautman, and Corbitt, 1978) lead us to believe that they are derived from genetically related, if not the same magmas. A combined regression of data from F-3 and F-4 (fig. 6) provides an upper intercept age of 503 ± 6 Ma (MSWD = 4.8), which is identical within error with data for F-3 alone.

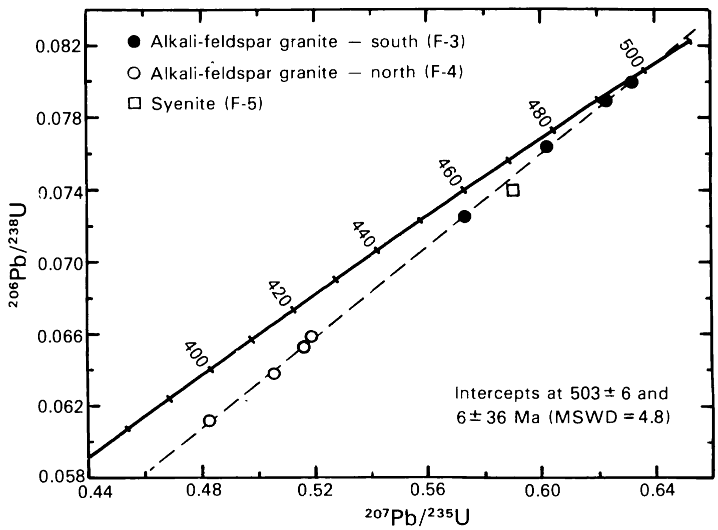

Fig. 6. Concordia plot of zircon from the alkali-feldspar granites south (F-3) and north (F-4) of the SFMF. See text for discussion of the results when data are regressed as two separate samples. The analyzed fraction from the syenite (F-5) is shown for comparison only and was not used in any regression.

Syenite.—A single zircon fraction from the syenite (F-5; fig. 6) north of the SFMF had been analyzed prior to our study, and the unpublished results were kindly supplied to us by C.E. Hedge and L.B. Fischer (U.S. Geol. Survey). U-Pb ages of 460 and 471 Ma and a $^{207}Pb/^{206}Pb$ age of 523 Ma are slightly older than the ages discussed above (due to minor interited Pb?), but nevertheless this syenite also is likely part of the Cambrian-Ordovician alkalic complex of the Florida Mountains. The syenite is not in intrusive contact with other dated units.

DISCUSSION

Our studies in the Florida Mountains have resolved some questions but inevitably raised others. The following discussion focuses on conclusions and implications, some of them rather speculative.

Cambrian-Ordovician Plutonism

Our study firmly establishes the fact of 500 Ma plutonism in southwestern New Mexico. According to major element geochemical data (Brookins, Rautman, and Corbitt, 1978) the plutonic rocks are alkali-calcic to alkalic. We suggest that the granitic and syenitic rocks are probably part of a coeval magmatic system that developed at the end of Cambrian time. Compositions ranging from alkali-feldspar granite to syenite and into silica-undersaturated syenite are typically associated in many alkalic complexes.

Is the alkalic complex in the Florida Mountains of a unique age in southern New Mexico? The situation is complicated by the fact that alkali-calcic to alkalic igneous complexes of Proterozoic age are well documented. For example, the Burro Mountains batholith northeast of Lordsburg (fig. 1) is a composite body of alkali-feldspar granite, syenite, diorite, and other phases (Gillerman and Whitebread, 1956), some of which at least resemble the Florida Mountains rocks. Nevertheless, Stacey and Hedlund (1983) provide a zircon U-Pb age of 1445 ± 15 Ma. We suspect that other Cambrian-Ordovician igneous complexes are present in southwestern New Mexico, but careful geochronologic studies will be needed to identify them. Zeller (1965) mapped a "Precambrian" granite near Hatchet Gap, between the Little Hatchet and Big Hatchet Mountains west of the Florida Mountains (fig. 1), and cited two Pb-alpha ages of 605 and 640 Ma. Although these Pb-alpha ages do not reveal the possible effects of disturbance or inheritance, they are intriguing. This "Precambrian granite" is depositionally overlain by Bliss Sandstone and intrudes a metasedimentary quartzite (Zeller, 1965: K.V. Evans, unpub. data, 1986) which possibly correlates with Early Proterozoic supracrustal rocks of southeastern Arizona (Condie, Bowling, and Vance, 1985). This granite could quite possibly be another lower Paleozoic pluton, and we hope to test this suggestion in the near future. In addition, Loring and Armstrong (1980) reported a Rb-Sr isochron age of 469 ± 7 Ma on whole rock samples of syenite dikes about

100 km southeast of Albuquerque, and McLemore (1983) reported a K-Ar age of 449 ± 16 for a carbonatite dike near Socorro. McLemore (1986) is currently studying alkalic rocks in the Caballo Mountains, about 80 km north of the Florida Mountains, which may be of similar age.

Basal Paleozoic Strata

If the alkalic igneous complex of the Florida Mountains developed in a brief interval about 503 ± 10 Ma, then several conclusions may be made regarding the overlying basal Paleozoic strata. At least the lower portion of the immediately overlying diamictite was considered by Corbitt and Woodward (1973b) to be glacially derived and related to similar deposits known from southern California to Canada. Traditionally the age of these units was thought to be about 800 Ma (Stewart, 1972; Miller, McKee, and Yates, 1973), although recent studies have suggested a younger age of roughly 600 Ma (Knoll and others, 1981; Bond and Kominz, 1984; Bond, Kominz, and Devlin, 1983; Bond, Nickeson, and Kominz, 1984). An age of 500 Ma for alkali-feldspar granite in the Florida Mountains implies (1) that the diamictite does not correlate with other Cordilleran diamictite bodies, or (2) these diamictite bodies do correlate, but glaciation was much more recent than previously thought, or (3) several glaciations (about 500-800 Ma) took place. Inasmuch as some Cordilleran diamictite bodies are overlain by Lower Cambrian strata (Stewart, 1970; Christie-Blick, 1982), alternative (2) may be ruled out.

Deposition of the Bliss Sandstone must be younger than 503 ± 10 Ma, which corresponds approximately to the Cambrian-Ordovician boundary (Palmer, 1983) and is in potential conflict with the suggestion of a Late Cambrian age by Hayes (1975). However, Palmer (1983) assigns a 32 Ma uncertainty to the Cambrian-Ordovician boundary age of 505 Ma, and the biostratigraphic position of the Bliss is not precisely established. Corbitt and Woodward (1973b) report Early Ordovician gastropods from low in the Bliss in the Florida Mountains, consistent with a rapid, but not unreasonable, rate for unroofing of the plutons after emplacement at 503 ± 10 Ma.

Alkalic Plutonism and Tectonic Setting

Alkalic igneous rocks similar to those in the Florida Mountains are commonly associated with extensional tectonic environments, both failed and well developed rift systems. For instance, Larson and others (1985) attribute early Paleozoic alkalic igneous activity in Colorado, northern New Mexico, Texas, and Oklahoma to rifting in association with formation of the southern Oklahoma aulacogen (fig. 7). Loring and Armstrong (1980) implied a similar set of circumstances for probable Cambrian-Ordovician syenite bodies in central New Mexico, although these bodies (and the Florida Mountains) occur well off the trend proposed by Larson and others (1985).

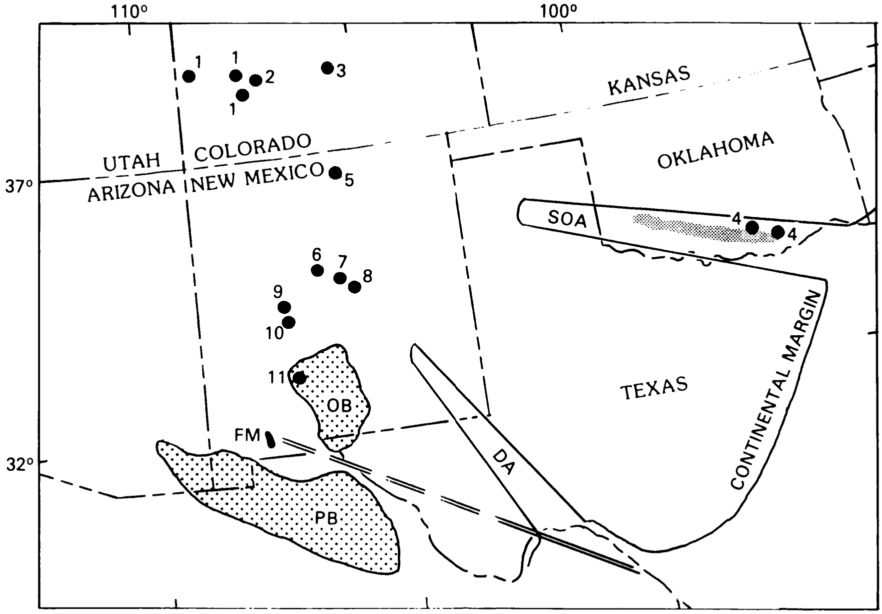

Fig. 7. Paleozoic tectonic features and locations of known or suspected Cambrian and Ordovician igneous rocks in New Mexico, Colorado, and Oklahoma (modified from Keller and others, 1983; Thomas, 1977). FM = Florida Mountains; SOA = southern Oklahoma aulacogen; DA = Delaware aulacogen; OB = Orogrande basin; PB = Pedregosa basin; double line = transform fault of Thomas (1977), dashed where projected farther than on his map. 1 = mafic dikes; 2 = complex of Powderhorn; 3 = alkalic complex of Wet Mountains; 4 = Arbuckle Mountains outcrops plus subsurface (shaded); 5 = Sangre de Cristo Mountains dikes; 6 = Monte Largo carbonatite; 7 = Lobo Hill syenite; 8 = Pedernal Hills syenite; 9 = Lemitar carbonatite; 10 = Chupadera carbonatite; 11 = Caballo Mountains syenite. Data from Loring and Armstrong (1980), Larson and others (1985), McLemore (1983, 1986), and this study.

Although much remains to be learned about Cambrian-Ordovician alkalic plutonism in New Mexico, we may speculate on several possibilities. The rifted late Precambrian-early Paleozoic continental margin between the Cordilleran and Ouachita regions is not well constrained but appears to be located in Mexico, considerably south of the Florida Mountains area (Poole and Madrid, 1986). Thus a direct correlation of alkalic plutonism with the rifted margin, as suggested for other regions of the Cordillera (Evans, 1984; Okulitch, 1985), is unlikely. Walper (1977) proposed that the early Paleozoic Tobosa basin is part of the Delaware aulacogen which extends from the continental margin into the craton of southeast New Mexico (fig. 7). By analogy with the argument of Larson and others (1985), this could account for at least some of the alkalic rocks mentioned by Loring and Armstrong (1980) and McLemore (1986). The alkalic plutons of the Florida Mountains are off this trend as well but may relate to extension associated with precursors of the Orogrande and Pedregosa basins. These possibilities are consistent with the diverse models proposed by Stewart (1982), Stewart, McMenamin, and Morales-Ramirez (1984), and Goetz and Dickerson (1985) for the early Paleozoic continental margin.

Alternatively, Thomas (1977) postulates that a transform fault that extends into the Marathon salient of west Texas connects segments of the rifted continental margin. Sykes (1978) has suggested that alkalic rocks, carbonatites, and ring dikes in continental areas are located preferentially along zones of weakness at the end of major transform faults. If the postulated transform of Thomas (1977) is approximately correct, this would provide a ready explanation for the alkalic plutons of the Florida Mountains. More likely, a complex interplay of all these factors is probably responsible for Cambrian-Ordovician alkalic plutonism in New Mexico.

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