Geochemistry of mafic dikes and sills from the lower McCoy Mountains Formation, La Paz County, western Arizona

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Abstract

Mafic dikes and sills intrude sediments of the Late Jurassic (Early Cretaceous?) lower McCoy Mountains Formation in western Arizona. Some units show evidence for intrusion into wet, unconsolidated sediments, indicating that intrusion was approximately contemporaneous with sedimentation. Some of the units also show evidence for subaerial crystallization, and may in fact be lava flows. Attempts to directly date these rocks have been hampered by metamorphic recrystallization and by our inability, despite repeated attempts, to extract zircons from them. Five units from the Granite Wash Mountains, and two from the Plomosa Mountains, were sampled for geochemical and isotopic study in order to place some further constraints on their tectonic setting. Major element, trace element, and isotopic data reveal a suite of high-Al basaltic to andesitic rocks that are sub-alkaline to moderately alkaline and slightly to moderately enriched in light rare-earth elements (LREE), and have epsilon Nd values ranging from +5 to –6. Two gabbroic sills from the Granite Wash Mountains have epsilon Nd of +5, indicating they were derived from depleted mantle sources. The geochemical and isotopic variation in the suite can be explained either as a product of heterogeneous mantle sources or variable interaction of depleted basalts with continental crust. These rocks appear to be transitional in composition and tectonic setting between rift-related basalts of the Bisbee basin and Jurassic diorites intruded during crustal extension in the eastern Mojave desert region.

Introduction

The age and tectonic setting of the McCoy Mountains Formation, a thick (> 7 km apparent thickness) clastic sequence in southeastern California and western Arizona, has been a controversial topic in Cordilleran geology since the first modern synthesis was published by Harding and Coney (1985). Stone et al. (1987) and Tosdal and Stone (1994) established that the McCoy Mountains Formation in Arizona is separated by an angular unconformity into a lower part of probable Late Jurassic age and an upper part of Late Cretaceous age. Fackler-Adams et al. (1997) determined that the base of the McCoy Mountains Formation is interbedded with talus derived from underlying 160 Ma volcanics, and that the basal McCoy Mountains Formation is probably only slightly younger than the volcanic rocks. The McCoy Mountains Formation has been correlated with the Upper Jurassic/Cretaceous Bisbee Group in southeastern Arizona to the extent that both are inferred to have been deposited roughly synchronously in adjacent basins that were produced in the same tectonic environment (e.g., Dickinson et al., 1989; Busby-Spera et al., 1990). The Bisbee basin, an extension of the Chihuahua Trough related to Gulf of Mexico rifting (Dickinson et al., 1989), could have extended across southern Arizona and included the basin in which the lower McCoy Mountains Formation was deposited (Fig. 1). Previously, Harding and Coney (1985) had proposed that the McCoy Mountains Formation was deposited in a transtensional basin along the postulated Jurassic Mojave-Sonora megashear, whereas Drewes (1991) argued that it was deposited in a foreland basin along the Cordilleran fold-thrust belt. Mounting evidence that this part of the North American Cordillera was undergoing regional extension in the Late Jurassic and Early Cretaceous (e.g., Bilodeau, 1982; Busby-Spera, 1988; Busby-Spera et al., 1990; Dickinson et al, 1989; James, 1989; Wolf and Saleeby, 1992; Davis et al., 1994; McMillan and Lawton, 1996; Lawton et al., 1997; Gleason et al., 1997b) appears to reinforce arguments for an extensional setting for the lower McCoy Mountains Formation.

In this report, we present new geochemical and isotopic data on several mafic sills and dikes that intrude the lower McCoy Mountains Formation in western Arizona, and discuss implications for tectonic setting. The rocks studied are from the Granite Wash and southern Plomosa Mountains, where Late

Cretaceous metamorphism and deformation within the Maria fold and thrust belt has obscured many of the original field relations. Most of the intrusions appear to have been sills of gabbroic to dioritic composition, with variable grain-size ranging from fine-grained chilled margins to coarse-grained interiors. Metamorphic grade is estimated at about lower greenschist facies. Original pyroxene, hornblende and feldspar have been largely altered to actinolite, chlorite, biotite, sericite, epidote and other secondary minerals, but relict igneous textures exist in some sills. Laubach et al. (1987) originally described these sills, which intrude units within and above the Yellowbird member of the lower McCoy Mountains Formation in the Granite Wash Mountains. Some sills are as thick as 30 meters; other units exhibit characteristics of lava flows. Laubach et al. (1987) describe features, including contorted beds and load casts at the sill/sediment contacts, that suggest some sills were intruded into semi-consolidated sediments. Isotopic ages for the sills are not available, but it is probable that their intrusion was contemporaneous with lower McCoy sedimentation, which we infer to have been latest Jurassic to earliest Cretaceous in age.

Geologic Setting

Stratigraphic correlation of the McCoy Mountains Formation between fault blocks and mountain ranges in western Arizona is complicated by thrust-related deformation and metamorphism in the east-west trending Maria fold and thrust belt (Reynolds et al., 1986; Spencer and Reynolds, 1990). In the Granite Wash Mountains, the Late Cretaceous Hercules thrust places Proterozoic and Jurassic crystalline rocks over lower plate Paleozoic and Mesozoic supracrustal rocks (Reynolds et al., 1986; Laubach et al., 1987, 1989). The thick, multiply deformed clastic sequence structurally beneath the Hercules thrust in the southern Granite Wash Mountains was correlated with the McCoy Mountains Formation of Harding and Coney (1985) by Reynolds et al. (1986, 1989, 1991) and Laubach et al. (1987, 1989). Laubach et al. (1987) divided the McCoy Mountains Formation into a sequence of six sedimentary units. Although ages are not well constrained because of lack of fossils and datable volcanic rocks, regional correlation with the McCoy Mountains Formation has been fairly well established based on lithologic similarities. Most of the sequence consists of sandstone, conglomerate, siltstone, mudstone and marls reflecting mostly fluvial and lacustrine environments of deposition (Laubach et al., 1987). In the southern Plomosa Mountains, gabbroic and dioritic sills intrude three clastic sequences that have been correlated with the McCoy Mountains Formation, including the Apache Wash sequence that was sampled for this study, although correlation with the lower versus upper McCoy Mountains Formation remains somewhat controversial (Richard et al., 1993).

Geochemistry

Several sills from the Granite Wash and southern Plomosa Mountains were sampled for major, trace element and neodymium isotope geochemistry (Figs. 2a-d). XRF major element data for nine samples were commercially obtained from Chemex Labs, Inc. Trace element abundances for five of these samples (all from the Granite Wash Mountains) were determined by instrumental neutron activation analysis at the Lunar and Planetary Laboratory, University of Arizona. Neodymium isotopic analyses for these five samples and for two samples from the southern Plomosa Mountains were performed at the Department of Geosciences, University of Arizona. INAA procedures followed methods outlined in Gleason et al. (1997a), and Nd isotopic procedures followed the methods of Patchett and Ruiz (1987). Data are shown in Tables 1a though 1d. For the suite of ten samples, SiO_2 ranges from 45 to 58 wt. %, Al_2O_3 from 15.9 to 19.0 wt. % , Na_2O from 2.4 to 6.5 wt. %, and K_2O from 0.34 to 4.5 wt. %.. On the alkali-silica diagram (Le Bas et al., 1986) most of the samples plot in the alkaline field, with the exception of the two lowest K samples which are borderline sub-alkaline (Fig. 3; sample 12-11-92-1 from a lava flow in the Plomosa Mountains is suspected to be altered and is not included on most figures). According to their CIPW normative classification, most of

these rocks are nepheline-normative, which places them in the same company as some continental alkaline rocks such as hawaiites (alkaline basalt). Their high K also allies them to the K-rich andesites and shoshonites found in orogenic settings, although the Granite Wash rocks are not strictly potassic because they have $K_2O/Na_2O < 1$. On the other hand, the two low-K samples have more in common with high-Al basalts (Basaltic Volcanism Study Project, 1981; McBirney, 1984). The alkali elements tend to be among the most mobile during deformation and metamorphism, conditions which have clearly affected these rocks. Loss-on-ignition totals range from 1-4 wt. %, indicating that these rocks have suffered some chemical exchange. This is consistent with the abundance of hydrous secondary assemblages in all the thin sections we studied. Feldspathoidal minerals (i.e., nepheline, leucite) have not been found. However, strong correlations between SiO_2 and K_2O, MgO and K_2O, and in particular K_2O/Na_2O and epsilon Nd (Fig. 4), suggest that the alkali elements may nonetheless be somewhat reliable geochemical indicators of original igneous compositions for these rocks (Plomosa Mountains sample 12-11-92-1 is not plotted on Figure 4 and does not conform to this trend).

Chondrite-normalized rare earth element patterns (Fig. 5) for five samples from the Granite Wash Mountains show LREE (light rare earth element) abundances slightly to moderately enriched over HREE ($La_N/Yb_N = 2.5 - 6.6$), with moderately to steeply sloping LREE and flat HREE (heavy rare earth element) abundances. HREE abundances range from 10-30x chondritic, while LREE abundances range from 30-200x chondritic. Eu anomalies are small and are correlated with LREE/HREE and absolute abundances of REE, as well as with epsilon Nd (Fig. 6). LREE-enriched REE patterns such as these are typical of basaltic and andesitic rocks from both orogenic and rift-type continental settings (Basaltic Volcanism Study Project). Extended normalized trace element (spider) variation diagrams demonstrate some more features that distinguish the low K samples from the rest of the suite (Fig. 7). The low K samples, in addition to having the lowest absolute abundances of incompatible elements and most positive epsilon Nd values, also have large positive Sr spikes that correspond with their small positive Eu anomalies. Of particular significance for the Granite Wash gabbro-diorite suite is the abundance of the element tantalum, considered one of the most diagnostic elements for distinguishing subduction-modified sources from depleted mantle that has no arc component. Chondrite-normalized La/Ta ratios are all > 1.0 (1.3 to 1.9) for the suite and show no obvious correlation with other parameters. These La/Ta ratios impart a slight negative trough to the spider diagram (except for sample 10-17-94-1, which has lower relative Th and U than the other samples), suggesting either a crustal component was incorporated into these magmas during late-stage processes (i.e., crustal contamination), or a crustal (i.e., subduction) component was incorporated into the source before the magmas were produced. TiO_2 shows the least variation of any element in Figure 7, and its abundance in the Granite Wash gabbro-diorites (0.93-1.66 wt. %) is lower than in typical continental alkaline rocks, such as hawaiites; however, high field strength elements (HFSE) such as Hf, Zr and Ta are higher than in arc rocks such as high-Al basalts and high-K andesites (Basaltic Volcanism Study Project, 1981; McBirney, 1984). Zr/TiO_2 ratios for the basaltic samples plot in the within-plate fields on tectonic discrimination diagrams, generally away from the volcanic arc field (e.g., Pharaoh and Pearce, 1984). On the Zr/TiO_2 vs. SiO_2 plot of Winchester and Floyd (1977), the Granite Wash gabbro-diorites plot within the alkali basalt and trachyandesite fields for volcanic rocks.

Regional comparisons (Fig. 8) suggest that these rocks are transitional in composition and tectonic setting between Late Jurassic pillow basalts from the Bisbee basin in southeastern Arizona (McMillan and Lawton, 1996), and Late Jurassic (ca. 155 Ma) diorites of the eastern Mojave Desert region in southeastern California (Young et al., 1992). The Granite Wash low K samples seem to have most in common with the Bisbee basalts. Both have slightly LREE-enriched REE patterns ($Ce_N/Sm_N \approx 2$) and high positive epsilon Nd values of +5 (Lawton et al., 1993, 1997; McMillan and Lawton, 1996). However, the Granite Wash gabbro-diorite suite is distinct from the Bisbee basalts in other respects. The Bisbee basalts have very low La_N/Ta_N (0.74-0.77) compared to the Granite Wash sills (1.3-1.9). The subchondritic La_N/Ta_N ratios for the Bisbee

basalts strongly indicate derivation from aesthenospheric (oceanic-type) mantle, comparable to the sources of oceanic island basalts (McMillan et al., 1993). Late Jurassic diorites of the Bristol Lake region in the eastern Mojave Desert (Young et al., 1992) have more features in common with the Granite Wash suite as a whole. They have a wide range of SiO_2 (49-60 wt. %), are high in alumina and LREE, and are mildly alkalic and moderately enriched in high field strength elements such as Zr. Neodymium isotopic compositions, however, are much less radiogenic (epsilon Nd = -7.5 to -11.5). Young et al. (1992) interpreted these compositions to reflect derivation from ancient, enriched continental lithosphere within an extensional tectonic regime, with assimilation/fractional crystallization effects superimposed during ascent through the Mojave crust.

The geochemical and isotopic variations in the Granite Wash gabbro-diorite suite can be explained either as a product of heterogeneous mantle sources or variable interaction of depleted basalts with continental crust. Although neither can be established as more likely than the other based on the available data, it can be demonstrated that crustal contamination is a viable working hypothesis. Since assimilation/fractional crystallization models are a variant of mixing models, we can use the Sm-Nd isotopic data as a guide for establishing parameters for AFC/mixing calculations. Assuming that the contaminant was upper crust simplifies the calculations, since upper crust has a fairly fixed $^{147}Sm/^{144}Nd$ ratio of 0.11 (Taylor and McLennan, 1985). On the $^{147}Sm/^{144}Nd$ vs. $^{143}Nd/^{144}Nd$ isotope plot (Fig. 9), mixing lines can be constructed between the most primitive, least contaminated samples (those with epsilon Nd = +5) and those with increasing amounts of assimilant. Where the extension of each of these mixing lines intersects with $^{147}Sm/^{144}Nd = 0.11$ (upper crust) gives the Nd isotopic composition of the assimilant in each sample. For the Granite Wash suite, the composition of the assimilant varies from epsilon Nd = +2 to -10 (likely since the Jurassic crustal column was almost certainly isotopically heterogeneous). These parameters can then be incorporated in AFC models (De Paolo, 1981) to constrain the amount of assimilation and fractional crystallization within the series (fractionation in the crust does not normally affect Sm/Nd ratios). Other variables in the AFC calculation include assimilation rate (r), partition coefficients for Nd in the magma and fractionating phases, and Nd concentration of the end-members (assimilant and magma). By varying these parameters, an envelope of AFC curves is generated which reveal to some extent the amount of assimilation required to generate the observed compositions. In Fig. 10, the actual samples are plotted and only the curves that pass through them are shown. The model predicts that the amount of combined AFC ranges from 20% in the more mafic samples to as much as 60% in the most evolved samples, as reflected by their Mg# (Fig. 10). Increasingly negative Eu anomalies correlate with decreasing Mg# and epsilon Nd, and could in this case be interpreted as a product of both increasing interaction with continental crust (Eu/Eu* = 0.66) and fractional crystallization (plagioclase fractionation also decreases Eu/Eu* in the magma). If an AFC scenario such as this is more or less correct for explaining the variation within this suite, then a close relationship with the Bisbee basin basalts and their depleted mantle sources is favored. Alternatively, if the geochemical variation is mostly a function of lithospheric source age and composition, then these rocks are probably more closely affiliated with the eastern Mojave diorites. Obtaining precise isotopic ages on the Granite Wash suite will be necessary if such regional comparisons are to be more thoroughly evaluated.

Conclusion

Late Jurassic mafic dikes and sills in the Lower McCoy Mountains Formation in western Arizona are high-Al basaltic to andesitic rocks with subalkaline to moderately alkaline and slightly to moderately LREE enriched compositions. Epsilon Nd for the suite ranges from +5 to -2.5 (to –6.1 for a possibly altered sample in the Plomosa Mountains). Two low K gabbroic sills with epsilon Nd = +5 were probably derived from depleted mantle sources. The geochemical and isotopic variation in the suite can be explained either as a product of heterogeneous mantle sources or variable interaction of depleted basalts with continental crust. These rocks appear to be transitional in composition and tectonic setting between rift-related basalts of the

Bisbee basin and extension-related Jurassic diorites of the eastern Mojave desert region.

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Figure Captions

1a. Regional map showing location of the Maria fold and thrust belt and McCoy Mountains Formation in western Arizona and southeastern California.
1b. Map showing the distribution of the McCoy Mountains Formation and related rocks (from Laubach et al., 1987).
2a. Geologic map of the McCoy Mountains Formation and larger outcrops of mafic sills in the Granite Wash Mountains. Geology generalized from Reynolds et al. (1989). Grid is UTM, zone 12, meters.
2b Detailed geologic map of part of the Granite Wash Mountains showing sample locations (map from Reynolds et al., 1989).
2c. Geologic map of the McCoy Mountains Formation and larger outcrops of mafic sills in the southern Plomosa Mountains. Map generalized from Richard et al. (1993).
2d Detailed geologic map of part of the southern Plomosa Mountains showing sample locations (map from Richard et al., 1993).
3. Late Jurassic mafic sills of the Granite Wash and southern Plomosa Mountains plotted on the silica vs. K_2O+Na_2O classification diagram for igneous rocks of Le Bas et al. (1991). Superimposed diagonal line marks boundary between upper alkaline field and lower sub-alkaline field (Le Bas et al., 1986).
4. Epsilon Nd vs. K_2O/Na_2O for Late Jurassic mafic sills of the Granite Wash and southern Plomosa Mountains.
5. Chondrite-normalized rare earth element (REE) patterns for five mafic sills from the Granite Wash Mountains.
6. Epsilon Nd vs. Eu/Eu* for five mafic sills from the Granite Wash Mountains. $Eu/Eu^* = Eu_N/[Sm_N \times Gd_N]^{1/2}$, where N denotes the chondrite-normalized value (value for Gd interpolated from REE pattern). Eu/Eu* is used as a measure of the size of the Eu anomaly relative to a flat REE pattern, i.e., one with no anomaly ($Eu/Eu^* > 1$ is a positive anomaly; $Eu/Eu^* < 1$ is a negative anomaly).
7. Chondrite-normalized extended trace-element variation (spider) diagrams for five mafic sills from the Granite Wash Mountains. Elements are plotted in order of decreasing incompatibility from left to right relative to an oceanic (MORB) mantle source during melting (Sun and McDonough, 1985). Nb calculated for each sample assuming constant Ta/Nb ratios.
8. Comparison of Nd isotopic compositions for Late Jurassic diorites of the Bristol Lake region, southeastern California (Young et al., 1992), Late Jurassic basalts of the Bisbee basin, southeastern Arizona (McMillan and Lawton, 1996), and the mafic sills from this study.
9. Sm-Nd isochron diagram showing possible mixing trends between depleted mantle compositions (represented by sample 10-17-94-1) and continental crust as a test for assimilation/fractional crystallization models.
10. AFC model showing an envelope of possible mixing curves between the most primitive and least evolved members of the Granite Wash suite. Original liquid remaining ranges from 80% down to 40% in the most evolved magmas, and is indicated by the number adjacent to each point. Samples towards the right of the diagram (most evolved, high Nd) are characterized by increasingly negative Eu anomalies and decreasing Mg numbers (the Mg number is an expression of how evolved, or fractionated, a mafic magma is based on the ratio of Mg to Fe).

Table 1a. XRF major element compositions of mafic sills, Granite Wash and southern Plomosa Mountains, western Arizona

wt.%	12-11-92-1 SP	12-11-92-4b SP	11-3-83-1 GW	11-17-83-1 GW	11-17-83-3 GW	10-14-94-1 GW	10-14-94-2 GW	10-14-94-4 GW	10-17-94-1 GW	10-17-94-6 GW
SiO_2	52.81	45.4	52.7	47.3	58.53	47.89	48.35	58.09	45.09	47.06
TiO_2	1.08	1.09	2.17	1.49	1.66	1.42	1.47	0.93	1.24	1.38
Al_2O_3	18.66	16.0	16.7	18.5	15.90	17.41	16.99	18.45	18.95	18.59
Fe_2O_3	7.55	10.23	10.55	9.82	7.60	9.84	9.58	6.20	1.014	9.41
MnO	0.06	0.14	0.14	0.15	0.14	0.14	0.15	0.09	0.15	0.13
MgO	4.33	10.2	2.96	8.74	2.16	6.45	6.45	1.34	8.46	7.73
CaO	3.91	9.87	5.01	8.55	3.17	9.38	9.50	1.48	9.82	9.70
Na_2O	6.43	2.4	5.84	3.55	5.12	3.65	3.71	6.50	2.77	3.80
K_2O	1.46	0.71	3.01	0.28	4.51	1.31	1.76	4.15	0.24	0.58
P_2O_5	0.54	0.37	0.88	0.26	0.60	0.42	0.48	0.32	0.18	0.22
LOI	3.97	3.97	0.89	2.26	1.35	1.96	1.44	1.91	2.92	1.46
Total	100.8	100.4	100.9	100.9	100.8	99.89	99.90	99.47	99.98	100.1

GW = Granite Wash Mountains; SP = southern Plomosa Mountains

Table 1b. INAA trace-element compositions of mafic sills, Granite Wash Mountains, western Arizona

ppm	11-3-83-1	11-17-83-1	11-17-83-3	10-14-94-2	10-17-94-1	BCR-1 meas.	BCR-1 rec.*	±1σ (%)
Hf	6.52	2.87	9.06	4.01	2.09	4.89	4.95	<3
Ta	1.84	0.44	1.88	1.12	0.40	0.80	0.81	<7
Zr	356	162	465	220	125	216	190	<6
Th	3.29	1.16	4.69	1.76	0.33	5.91	5.98	<5
U	1.32	0.43	1.33	0.73	-	1.65	1.75	<20
Ba	599	301	758	500	244	665	681	<3
La	42.5	12.5	47.8	25.3	7.49	25.1	24.9	<2
Ce	92.1	27.8	100	55.5	17.8	52.5	53.7	<3
Nd	47.7	16.2	47.5	28.5	12.1	28.2	28.8	<7
Sm	9.31	4.03	9.47	5.70	3.06	6.50	6.59	<2
Eu	2.84	1.53	2.35	1.84	1.24	1.96	1.95	<2
Tb	1.47	0.77	1.49	0.87	0.624	1.05	1.05	<3
Ho	1.73	0.94	1.87	1.02	0.90	1.30	1.26	<7
Yb	4.33	2.36	4.96	2.51	2.01	3.35	3.38	<2
Lu	0.66	0.36	0.74	0.38	0.31	0.50	0.51	<3
Sc	18.9	33.0	17.8	26.2	27.9	31.9	32.6	<2
V	154	206	110	186	184	393	407	<5
Co	21.4	47.1	13.7	37.2	47.4	36.2	37	<2
Zn	109	65.8	85.7	72.0	69.2	124	130	<5
Ga	21.0	18.7	26.0	19.0	18.8	23.1	22	<20
Rb	62.7	6.80	116	38.8	5.60	46.8	47.2	<10
Sr	275	1030	239	702	684	329	330	<6
Cr	3.10	165	3.30	131	172	10.4	16	<10

*recommended values for Columbia River basalt standard BCR-1 from Govindaraju, 1989

Table 1c. IC-PMS trace-element compositions of mafic sills and flows, Plomosa Mountains, western Arizona (this data probably not within ±10% relative to standards and not of sufficient quality to publish in an academic journal).

ppm	12-11-92-1	12-11-92-4b
Hf	5.19	2.19
Nb	13.20	7.44
Ta	0.96	0.52
Y	27.30	17.10
Zr	238.00	81.00
Th	6.09	1.16
U	3.21	0.45
Ba	880.00	450.00
La	31.80	13.10
Ce	72.20	29.30
Pr	8.65	3.93
Nd	35.30	16.10
Sm	6.80	3.77
Eu	1.06	0.90
Gd	6.38	3.66
Tb	0.92	0.54
Er	3.13	1.96
Yb	2.76	1.68
Lu	0.42	0.26

Table 1d. Sm-Nd isotopic data for Late Jurassic mafic sills, Granite Wash and southern Plomosa Mountains, western Arizona

Sample	Location	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$ measured	ε_{Nd} initial
11-3-83-1	Granite Wash	9.70	46.34	0.1265	0.512598 ± 7	+0.56
11-17-83-1	Granite Wash	4.01	16.59	0.1462	0.512836 ± 6	+4.82
11-17-83-3	Granite Wash	9.53	46.74	0.1233	0.512429 ± 9	-2.68
10-14-94-2	Granite Wash	5.65	26.97	0.1266	0.512546 ± 5	-0.45
10-17-94-1	Granite Wash	2.96	11.24	0.1592	0.512864 ± 7	+5.12
12-11-92-1	Plomosa	7.03	35.24	0.1206	0.512251± 7	-6.10
12-11-92-4b	Plomosa	3.55	15.93	0.1348	0.512675 ± 8	+1.91

Uncertainties in $^{147}Sm/^{144}Nd$ ratios are < 0.5 %

Nd isotopic ratios normalized to $^{146}Nd/^{144}Nd = 0.7219$ (±2-sigma errors reflect in-run precision only)

Initial $e_{Nd} = 10^4 [(^{143}Nd/^{144}Nd_{(t)sample})/(^{143}Nd/^{144}Nd_{(t)CHUR}) - 1]$ using present day CHUR values of $^{143}Nd/^{144}Nd = 0.512638$ and $^{147}Sm/^{144}Nd = 0.1966$; t = 150 Ma (initial ratios reproducible to 0.5 e_{Nd} units)

Table 2: Sample locations

Sample No.	Range	Latitude (N)	Longitude (W)	UTM North	UTM East
11-3-83-1	Granite Wash	33° 48.74'	113° 43.38'	3744479	247949
11-17-83-1	Granite Wash	33° 47.08'	113° 42.50'	3741384	249225
11-17-83-3	Granite Wash	33° 47.15'	113° 42.98'	3741532	248483
10-14-94-1	Granite Wash	33° 48.15'	113° 43.38'	3743406	247919
10-14-94-2	Granite Wash	33° 48.18'	113° 43.25'	3743440	248121
10-14-94-4	Granite Wash	33° 47.11'	113° 46.08'	3741586	243699
10-17-94-1	Granite Wash	33° 47.08'	113° 43.45'	3741428	247747
10-17-94-6	Granite Wash	33° 47.06'	113° 42.26'	3741340	249583
12-11-92-4B	Plomosa	33° 35.45'	114° 04.21'	3720443	771900
12-11-92-1	Plomosa	33° 35.96'	114° 03.82'	3721411	772480

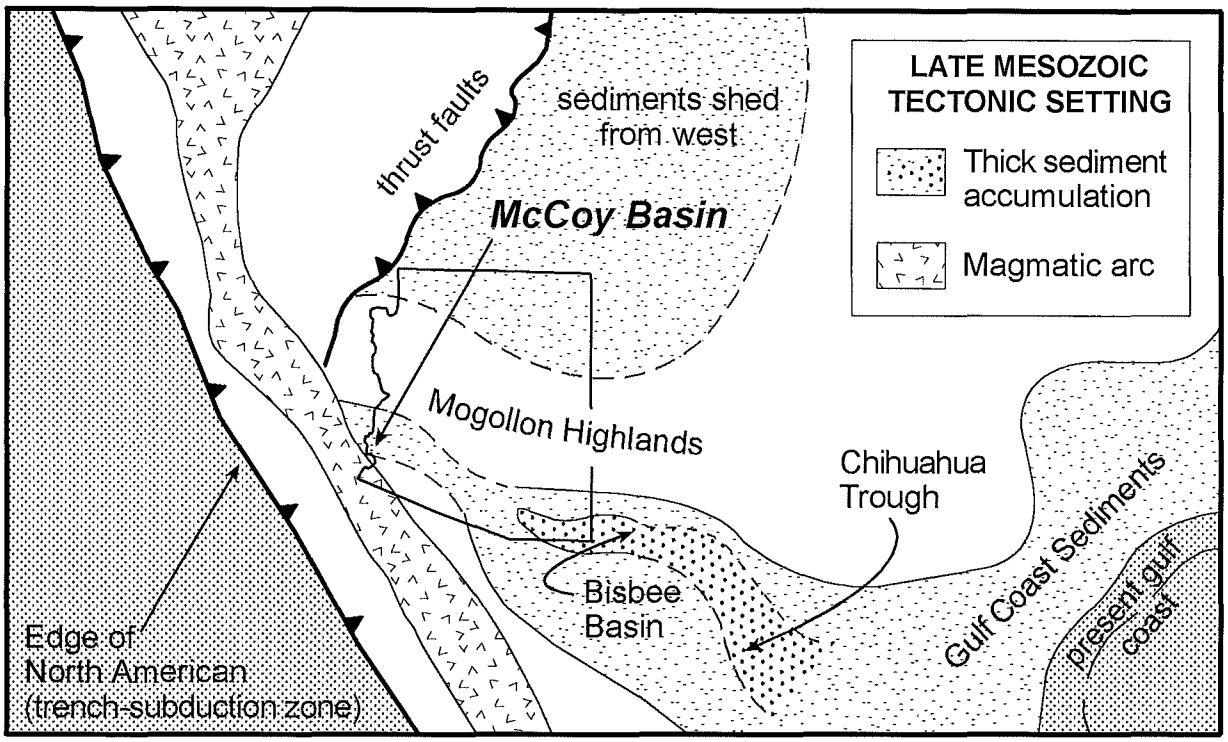


FIG. 1A

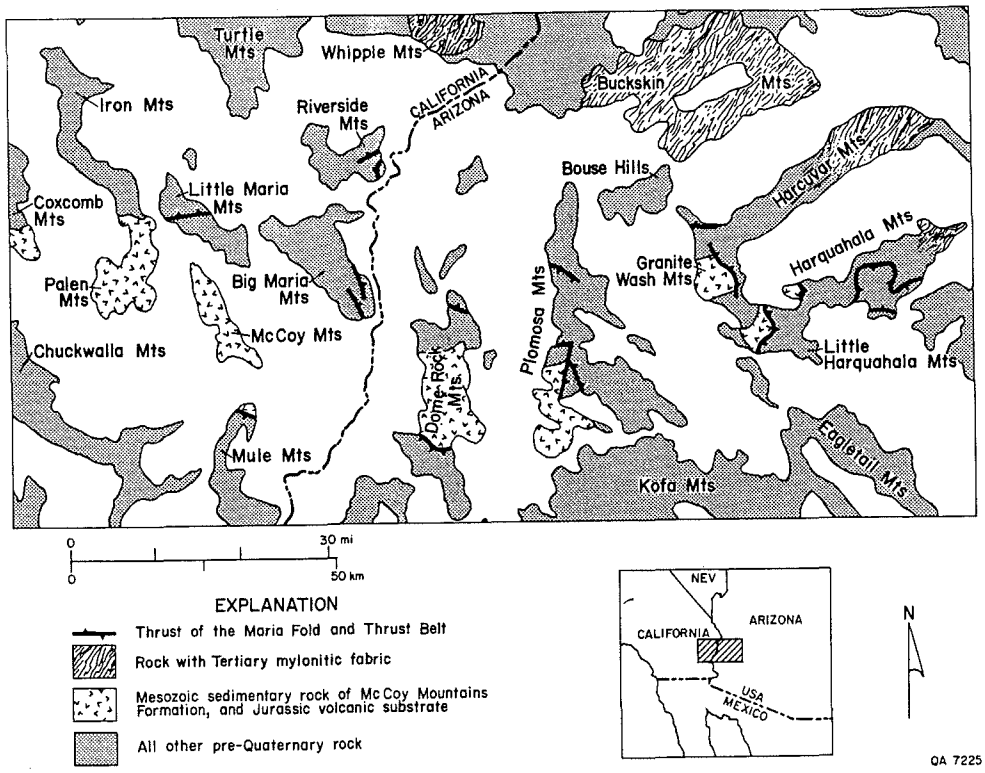
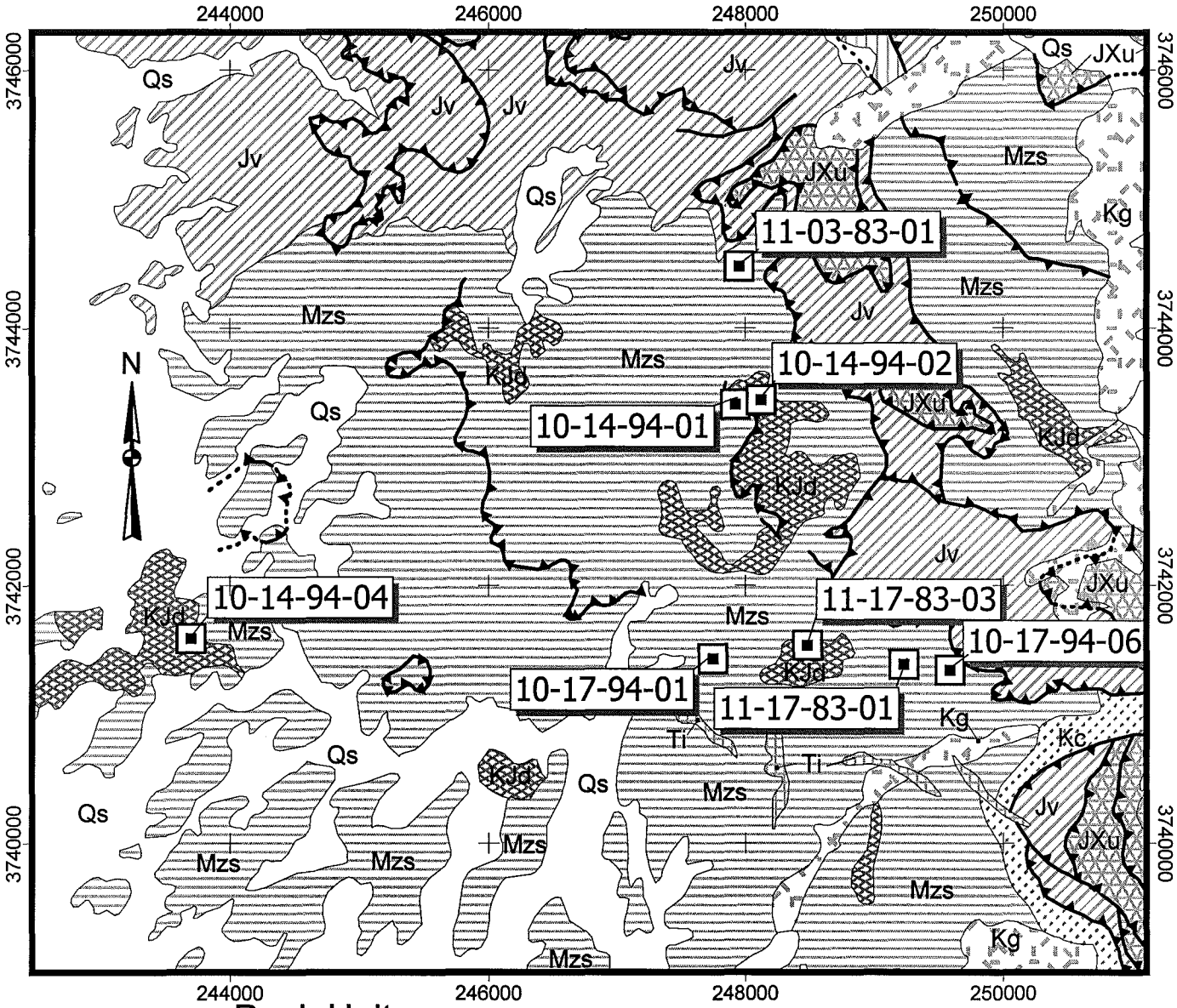


Figure 1. Generalized geologic map of west-central Arizona and southeastern California showing location of the Granite Wash Mountains, outcrop belt of the McCoy Mountains Formation, and major faults.

FIG. 1B (from Lanbach et al., 1987)



Rock Units

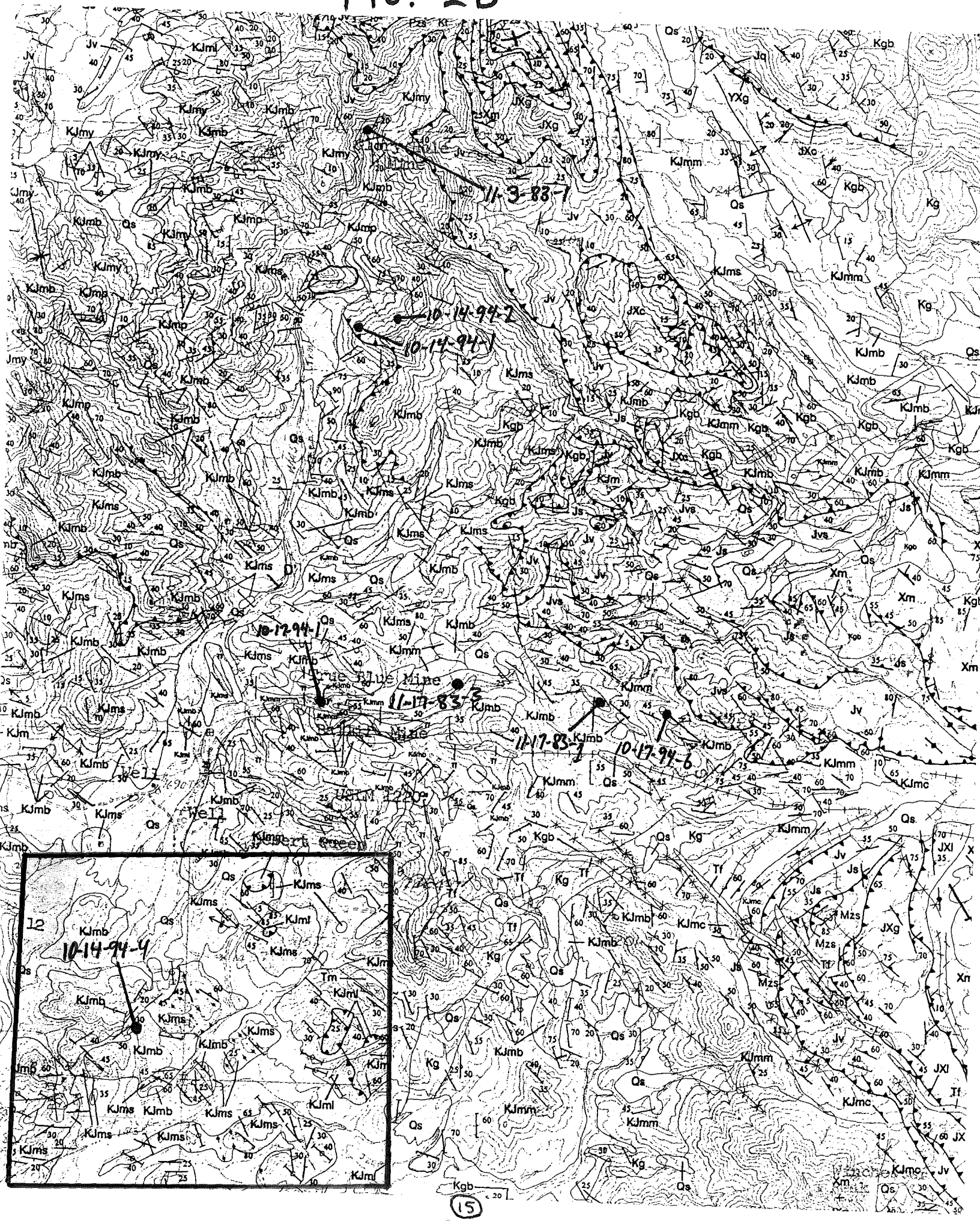
- Qs — Surficial Deposits (Quaternary)
- Ti — Intrusive Rocks (Miocene and Oligocene)
- Kg — Granitic Rocks (Late Cretaceous)
- Kc — Conglomerate (Cretaceous)
- Jg — Granitic Rocks (Jurassic)
- Jv — Volcanic and Sedimentary Rocks (Jurassic)
- KJd — Mafic Intrusive rocks (Cretaceous or Jurassic)
- KJs — Sandstone, Mudstone, Conglomerate (Early Cretaceous or Jurassic)
- JXu — Igneous and Metamorphic Rocks (Jurassic and Proterozoic)

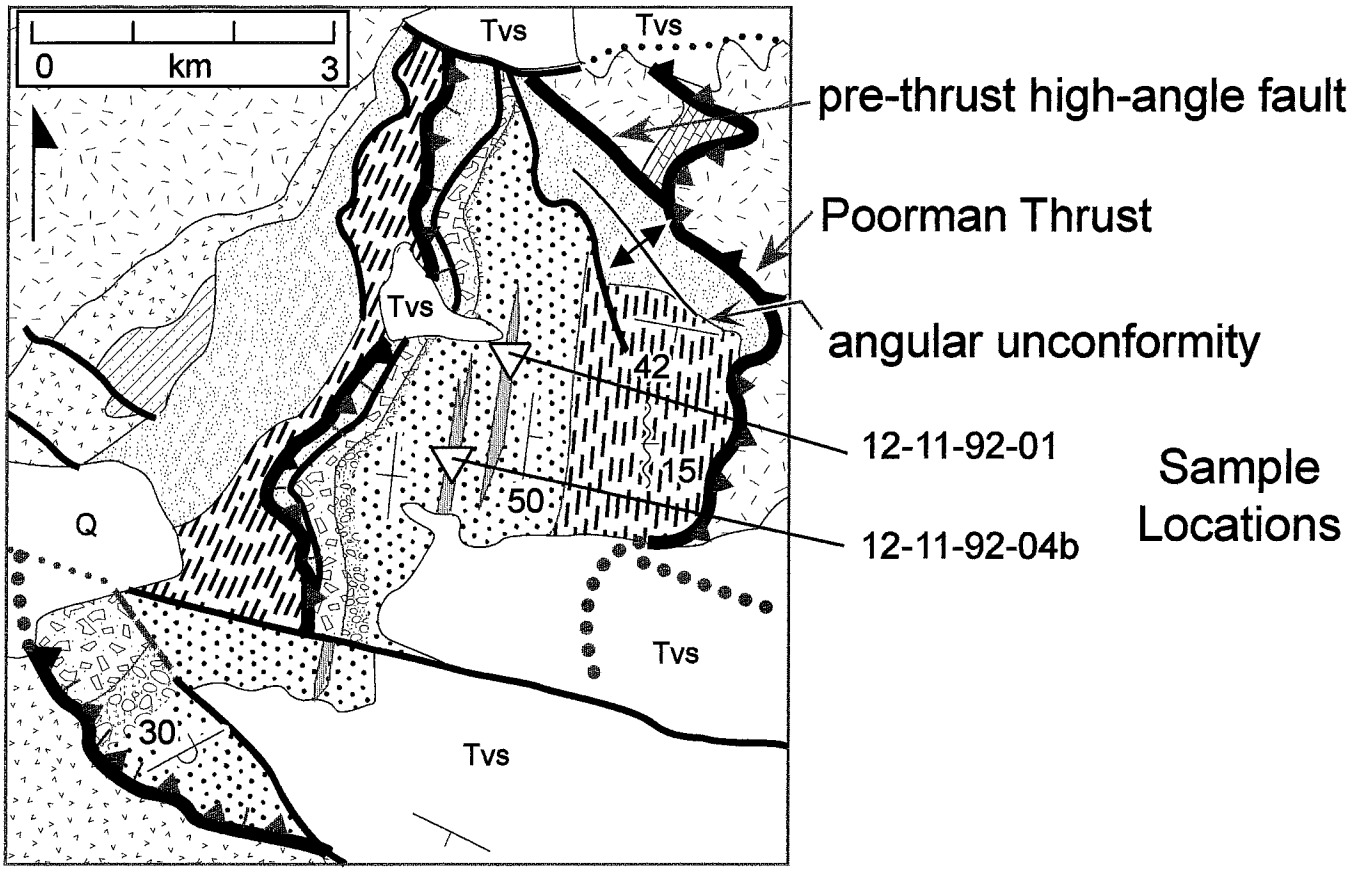
0.5 0 0.5 1 1.5 Kilometers

Sample Locations in Granite Wash Mountains

Fig. 2A

FIG. 2B


11-3-83-1
10-14-94-2
10-14-94-1
10-17-94-1
11-17-83-3
11-17-83-1
10-17-94-6
10-14-94-4
True Blue Mine
Well
Well
Desert Queen
12



Map Units

- Q — Alluvium (Quaternary and Late Tertiary)
- Tvs — Massive conglomerate and volcanic rocks (Miocene)
- Mafic sills (Jurassic or Cretaceous)
- Mudstone and fine-grained sandstone (Jurassic or Cretaceous)
- Lithic-feldspathic sandstone (Jurassic or Cretaceous)
- Conglomerate (Jurassic or Cretaceous)
- Crystal Hill formation (Jurassic or Cretaceous)
- Welded tuff(?) and breccia (Jurassic)
- Volcanic-lithic sandstone (Jurassic)
- Volcanic rocks (Jurassic)
- Sedimentary rocks (Paleozoic)
- Granitic rocks (Proterozoic and Jurassic)

Sketch Geologic map of the Apache Wash area, Central Plomosa Mountains, west-central Arizona

Fig. 2C

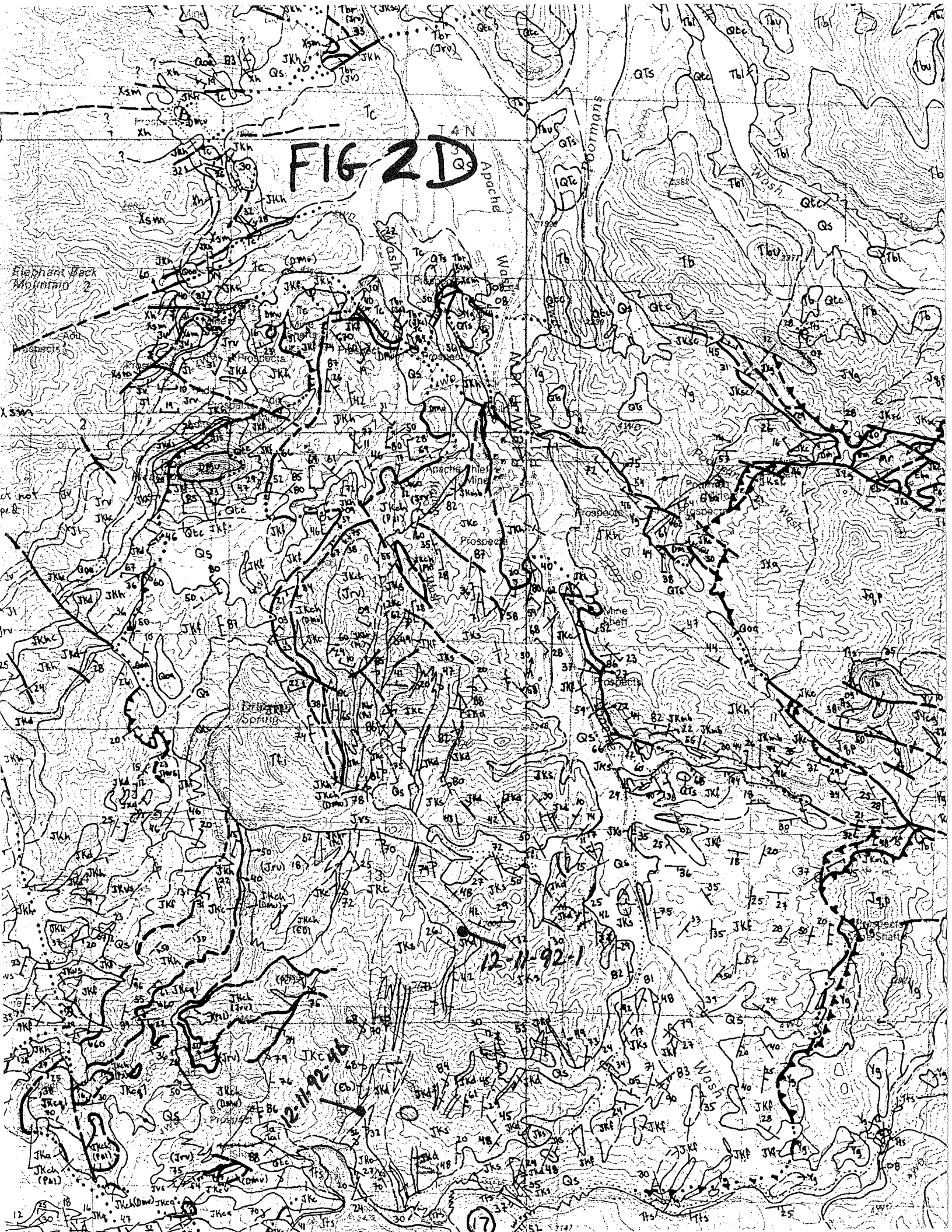


FIG 2D
Elephant Back Mountain
Apache
Wash
Prospects
Adit
Mine Shaft
Drum Spring
12-11-92-1
12-11-92-2
17

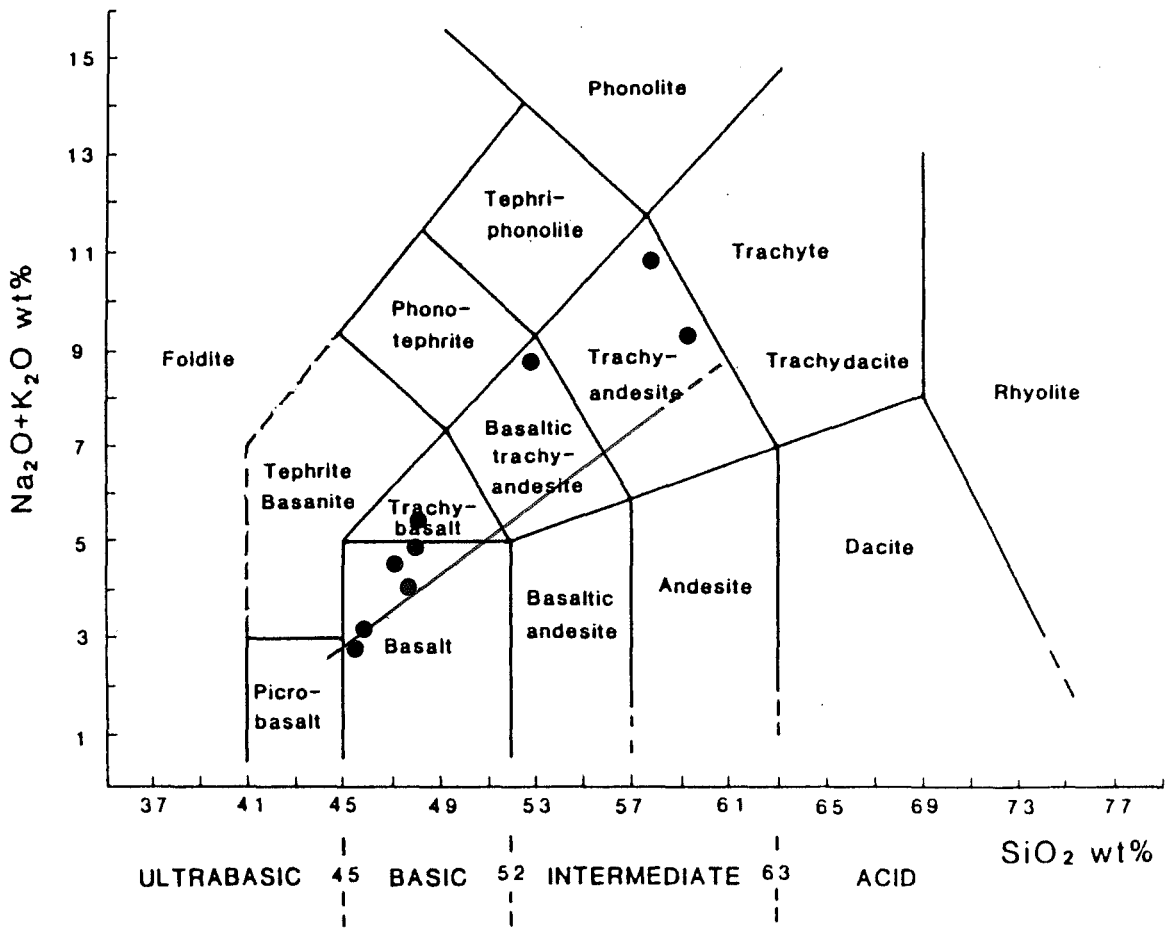

Phonolite
Tephri-
phonolite
Trachyte
Phono-
tephrite
Foidite
Trachy-
andesite
Trachydacite
Rhyolite
Basaltic
trachy-
andesite
Tephrite
Basanite
Trachy-
basalt
Dacite
Andesite
Basaltic
andesite
Basalt
Picro-
basalt
Na_2O+K_2O wt%
15
13
11
9
7
5
3
1
37
41
45
49
53
57
61
65
69
73
77
SiO_2 wt%
ULTRABASIC
45
BASIC
52
INTERMEDIATE
63
ACID

Fig. 3

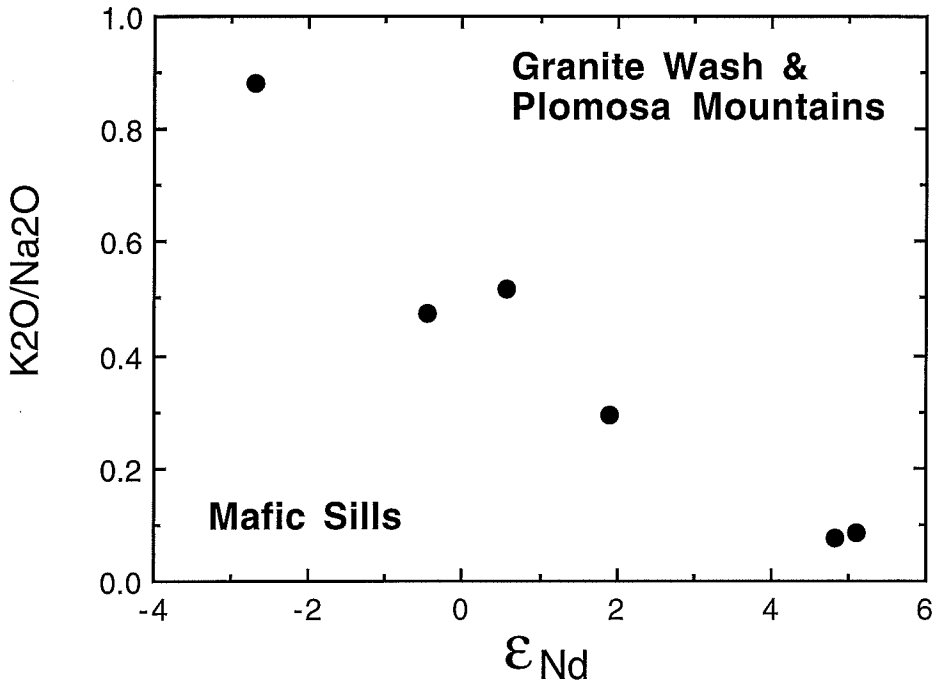

Granite Wash &
Plomosa Mountains
Mafic Sills
K2O/Na2O
1.0
0.8
0.6
0.4
0.2
0.0
-4
-2
0
2
4
6
εNd

Fig. 4

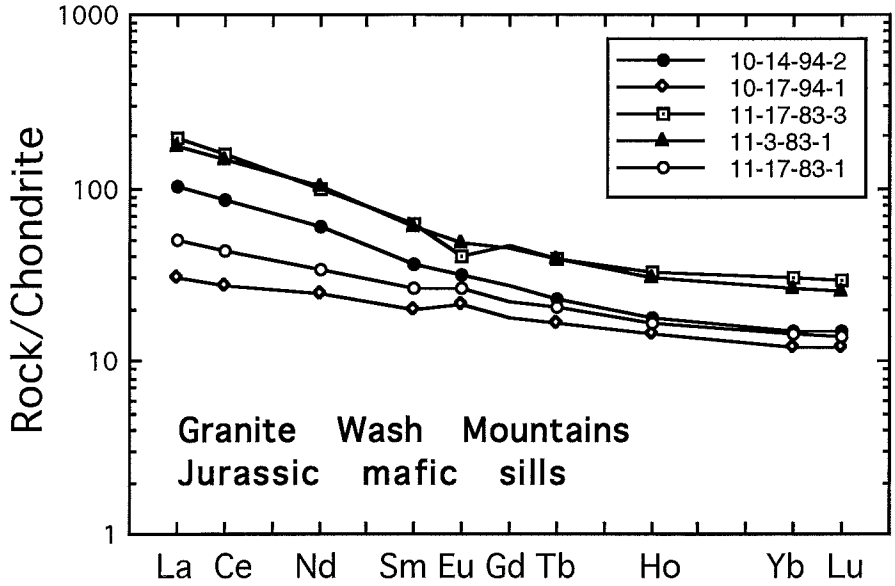

1000
100
10
1
Rock/Chondrite
10-14-94-2
10-17-94-1
11-17-83-3
11-3-83-1
11-17-83-1
Granite Wash Mountains
Jurassic mafic sills
La Ce Nd Sm Eu Gd Tb Ho Yb Lu

Fig. 5

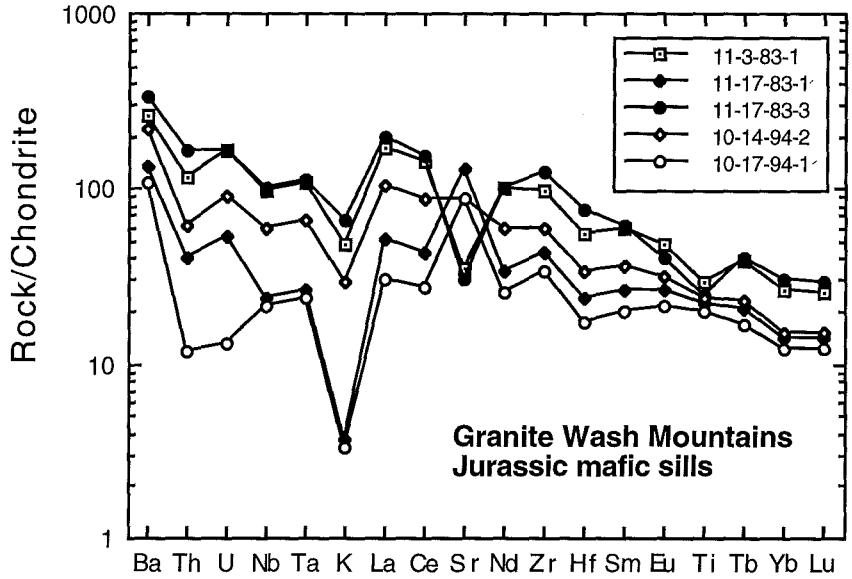

1000
100
10
1
Rock/Chondrite
11-3-83-1
11-17-83-1
11-17-83-3
10-14-94-2
10-17-94-1
Granite Wash Mountains
Jurassic mafic sills
Ba Th U Nb Ta K La Ce Sr Nd Zr Hf Sm Eu Ti Tb Yb Lu

Fig. 7

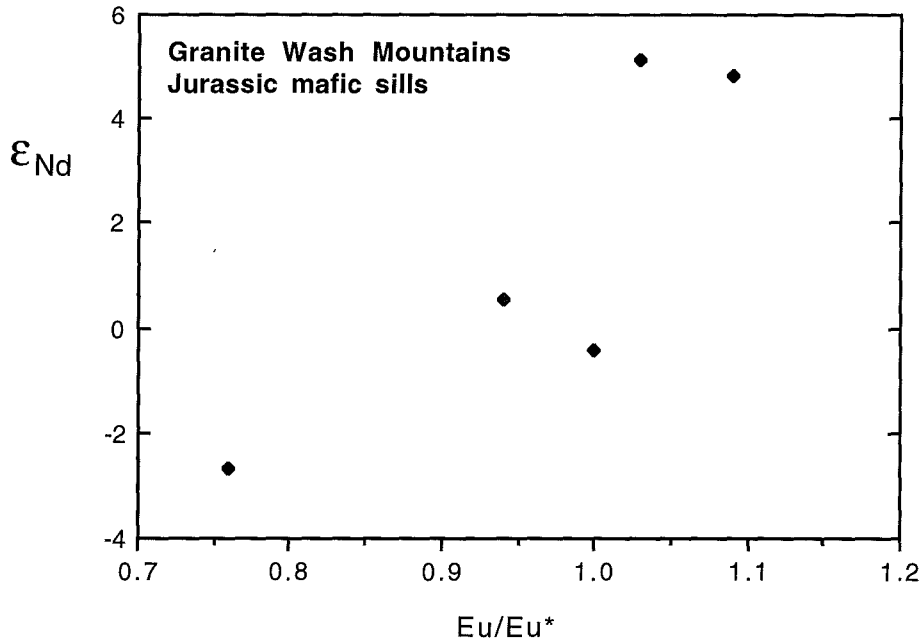

6
4
2
0
-2
-4
εNd
Granite Wash Mountains
Jurassic mafic sills
0.7
0.8
0.9
1.0
1.1
1.2
Eu/Eu*

Fig. 6

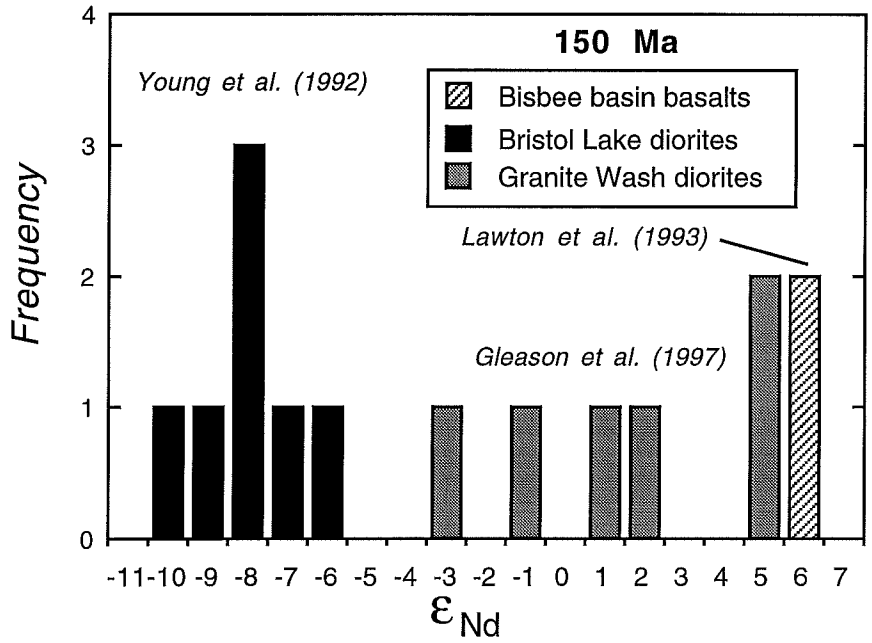

150 Ma
Young et al. (1992)
Bisbee basin basalts
Bristol Lake diorites
Granite Wash diorites
Lawton et al. (1993)
Gleason et al. (1997)
Frequency
0
1
2
3
4
-11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
εNd

Fig. 8

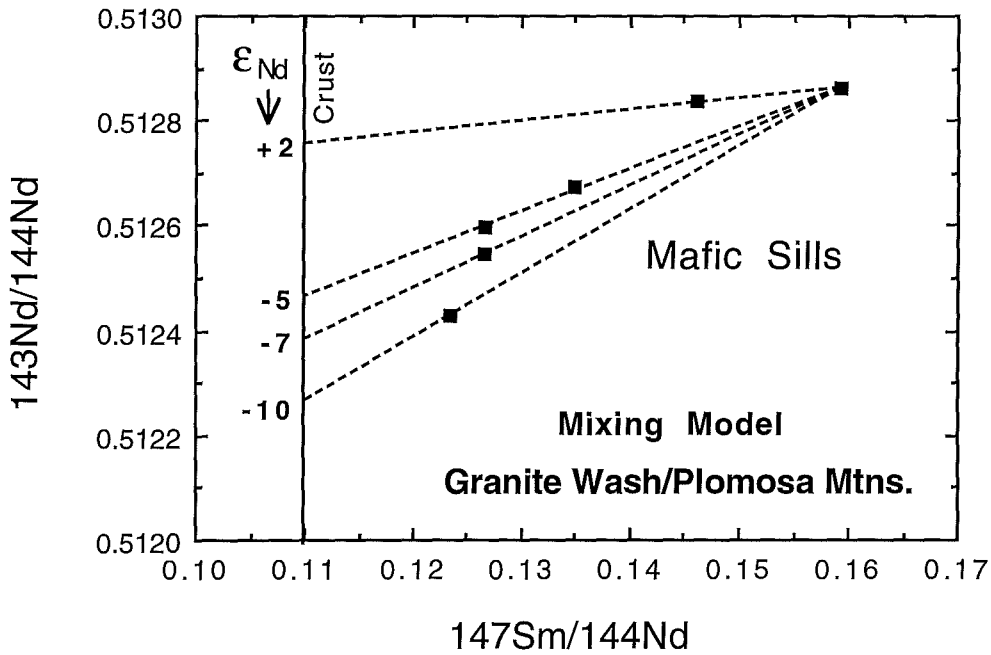

0.5130
0.5128
0.5126
0.5124
0.5122
0.5120
143Nd/144Nd
εNd
Crust
+2
-5
-7
-10
Mafic Sills
Mixing Model
Granite Wash/Plomosa Mtns.
0.10
0.11
0.12
0.13
0.14
0.15
0.16
0.17
147Sm/144Nd

Fig. 9

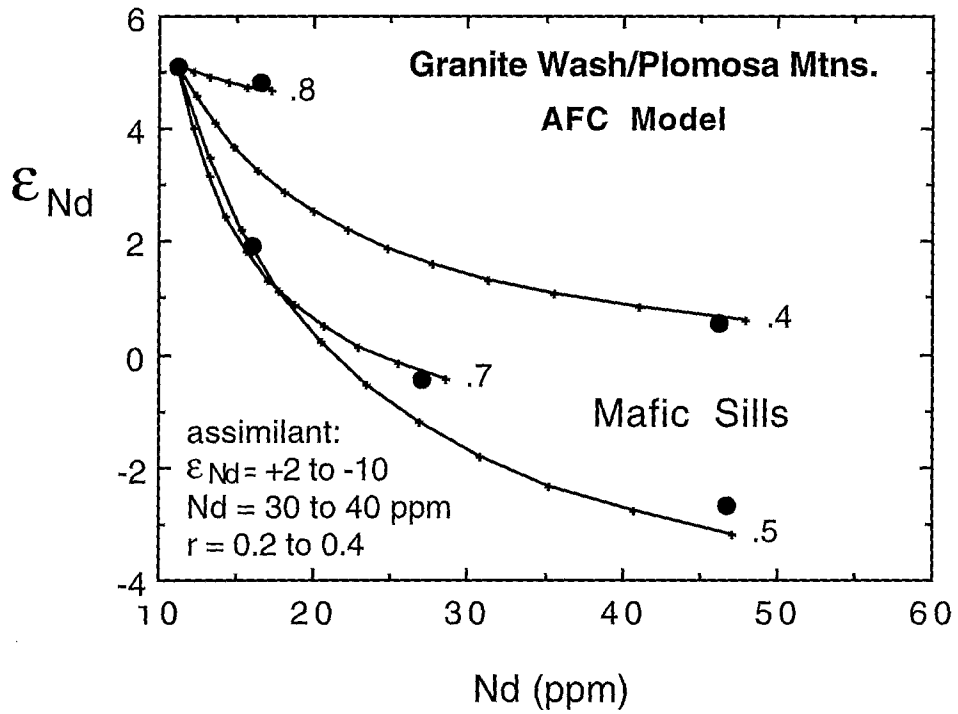

Granite Wash/Plomosa Mtns.
AFC Model
.8
.4
.7
.5
Mafic Sills
assimilant:
εNd = +2 to -10
Nd = 30 to 40 ppm
r = 0.2 to 0.4
εNd
Nd (ppm)
6
4
2
0
-2
-4
10
20
30
40
50
60

Fig. 10