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^{40}Ar/^{39}Ar, K-Ar, Rb-Sr Whole-Rock and Mineral Ages, Chemical Composition, Strontium, Oxygen and Hydrogen Isotopic Systematics of Jurassic Humboldt Lopolith and Permian(?) and Triassic Koipato Group rocks, Pershing and Churchill Counties, Nevada

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ABSTRACT

K-Ar and $^{40}Ar/^{39}Ar$ ages of 170±2 Ma for hornblende approximate the intrusive age of the Humboldt lopolith, Nevada. K-Ar and Rb-Sr ages range from 142Ma to 155 Ma for coexisting biotite and reflect Ar loss due to heating during emplacement of widely scattered Cretaceous and Tertiary granitoid intrusions in the area. The Rb and Sr compositions of the parent magmas for this mafic body lie between tholeiitic and alkalic on a plot of these elements for average oceanic basalts. Variable initial $^{87}Sr/^{86}Sr$ for gabbros and basalts require at least two magmas from different source materials are represented in the lopolith rocks.

Partial chemical analyses, Sr, oxygen and hydrogen isotopic data for rocks of the nearby Permian (?) and Triassic Koipato Group reflect pervasive alteration. Extreme K to Na ratios and SiO_2 concentrations are present in these rocks. In addition, their $\partial^{18}O$ and ∂D values reflect alteration by formation and organic waters. Fifteen of sixteen samples of whole-rocks are colinear on a Sr evolution diagram and regression of the data yields an errorchron with T=168.6±9.3 Ma, initial $^{87}Sr/^{86}Sr$ = 07141 ± 13, MSWD =48.8. The pervasive alteration of the Koipato Group rocks is the same age as the nearby Jurassic Humboldt lopolith and probably was caused by a circulating hydrothermal system driven by heat supplied during emplacement of the magmas that formed this large mafic igneous rock complex. Paleomagnetic pole positions in the Triassic Koipato group were probably established by remagnetization during the rock alteration in the Jurassic. If so, 1,400 km of southward transport of the Koipato Group on the Golconda thrust before Tertiary time is not required by the paleomagnetic data.

INTRODUCTION

The Humboldt lopolith, with a volume between 1,700 and 2,500 km^3, is a complex of mafic intrusive and extrusive rocks of Middle Jurassic age exposed in the West Humboldt and Stillwater Ranges, and Clan Alpine Mountains in the western Basin and Range province of Nevada (Speed, 1976; Fig. 1). Rocks of the lopolith intruded and lie over a stratigraphic sequence of Upper Lower Jurassic (upper Toarcian) and (or) Middle Jurassic (Bajocian) age comprised of mostly carbonate rocks with intercalated quartz arenite, carbonate conglomerate, and gypsum . These strata lie over a pelite and carbonate sequence that ranges in age from Middle and Upper Triassic to Upper Upper Triassic and Lower Jurassic.The oldest rocks exposed in the area are the Permian (?) and Lower Triassic Koipato Group of rhyolite ash-flow tuff, bedded tuff, intrusive porphyries, and greenstone (Speed, 1976). Paleomagnetic results from Koipato Group rocks exposed in the southern Tobin Range have been interpreted to infer 1,400 km southward transport of these rocks on the Golconda allochthon before Middle Tertiary time (Skalbeck and others, 1989). However, Geissman and others (1990) infer that their paleomagnetic results from the overlying carbonate Triassic Prida Formation in the Humboldt Range and also of the underlying Koipato Group in the southern Tobin Range (Skalbeck and others, 1989) reflect pole positions that resulted from remagnetization in the Jurassic and not southward transport of these rocks.

This report summarizes new chemical, strontium isotopic, and $^{40}Ar/^{39}Ar$ data from several rocks from the Humboldt lopolith that were investigated to constrain its age, isotopic, and chemical signature. In addition, Rb-Sr, oxygen and hydrogen isotopic data are reported for samples of the Koipato Group exposed nearby in the Stillwater and Humboldt Ranges because their isotopic systematics reflect alteration by a major hydrotermal system driven by heat from the lopolith magmas.

ANALYTICAL METHODS

The Rb and Sr concentrations and Sr isotopic data reported in tables 2, 3 and 4 were determined in the Sr isotope laboratory at the USGS in Menlo Park, California. Results are presented for whole-rock powders milled to less than 200 mesh and mineral separates -100+300 mesh. Minerals were isolated by standard techniques of magnetic separation and by gravity in heavy liquids. Rb and Sr abundances of whole-rocks were determined by energy dispersive X-ray fluorescence methods, whereas standard isotope dilution techniques were used to determined these elemental abundances in mineral separates. Concentrations of Rb and Sr by X-ray fluorescence are ± 3%, whereas they are ± 1% by isotope dilution. Strontium isotope ratios were determined using a MAT 261, 90° sector mass spectrometer, using the double Re filament mode of ionization. Strontium isotopic compositions are normalized to $^{86}Sr/^{88}Sr=0.1194$. NBS strontium carbonate standard SRM 987 yielded a mean $^{87}Sr/^{86}Sr$ of 0.710239±0.000015 during this period of analysis. Analytical uncertainties in $^{87}Sr/^{86}Sr$ values are about ±0.008%. The initial $^{87}Sr/^{86}Sr$ values reported in Tables 2 and 4 and whole-rock, mineral isochron ages in Table 2 were calculated using the decay constant for Rb from Steiger and Jager (1977) and the ISOPLOT program of Ludwig (1988), respectively.

Oxygen was extracted from the samples by the BrF_5 method (Clayton and Mayeda ,1963) and converted to CO_2 by reaction with hot carbon. The CO_2 was analyzed on a MAT-250 isotope ratio mass spectrometer. Extraction and analysis of oxygen was by members of the USGS, Water Resources Division, stable isotope laboratory in Menlo Park, California. All of the ∂-values reported in Table 4 are given in per mil relative to the SMOW standard. All samples were analyzed in duplicate with reproducibility of $\partial^{18}O$ of ± 0.15 per mil or better.

The $^{40}Ar/^{39}Ar$ isotopic measurements were made in the USGS K-Ar laboratory on argon purified in a conventional argon extraction system using a 6-inch radius. 60° sector, Nier-type, single-collector mass spectrometer. The sample was irradiated in the core of the U.S. Geological Survey TRIGA reactor at a 1-MW power level. The reactor neutron flux constant, J, was calculated using biotite and sanidine monitor minerals distributed both vertically and horizontally around the samples. The potassium and argon isotopic abundances and the ^{40}K decay constants used in the age calculation are those recommended by Steiger and Jager (1977).

AGE, CHEMICAL, AND STRONTIUM ISOTOPIC COMPOSITIONS OF ROCKS AND MINERALS FROM THE HUMBOLDT LOPOLITH, NEVADA

Published K-Ar dates of hornblende range from 155 to 169 Ma and 148 Ma for biotite from three gabbro specimens of the Humboldt lopolith (Speed and Jones, 1969, Speed and Armstrong, 1971). The variable ages indicate the lopolith has been affected by a post-crystallization thermal disturbance.

Data from an incremental heating, $^{40}Ar/^{39}Ar$ analysis of hornblende from a gabbro specimen JD379 (location 1, figure 1) collected in the West Humboldt Range are reported in table 1. This hornblende proved to be very refractory and, like the K-Ar dates, the incremental Ar release pattern indicates a post-crystallization thermal disturbance. Very little Ar was released during early temperature increments, with 83.4% of the ^{39}Ar released at the 1,100° C step. This doesn't permit a single interpretation of the plateau age, because the 8.3% ^{39}Ar release and apparent age of 229 Ma

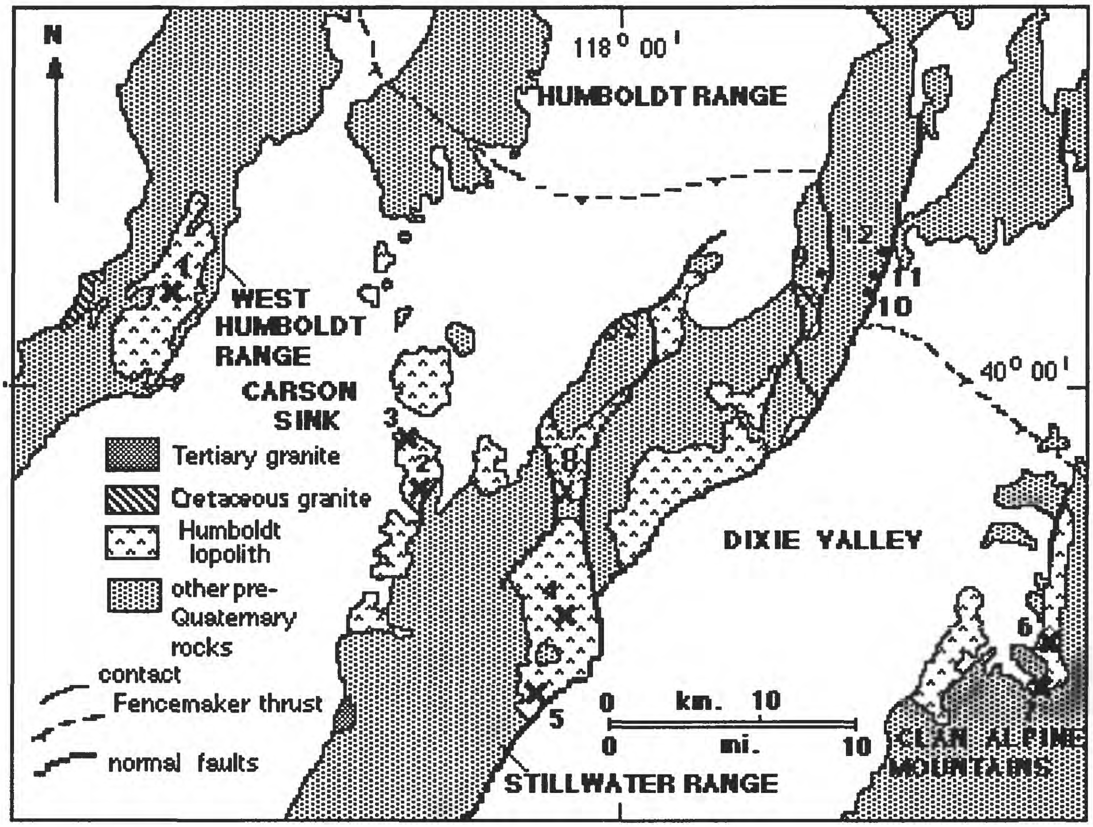

Figure 1. Map showing extent of exposures of rocks of the Humboldt Lopolith, Nevada (modified from Speed, 1976). Specimen locations are numbered, and except for numbers 3 and 8 are keyed to data in tables 1, 2 and 4. Numbers 3 and 8 are the locations of hornblende specimen YU-BV 100, K-Ar dated at 155±4 Ma, and hornblende specimen SW341, K-Ar dated at 160±2 Ma, respectively (Speed and Armstrong, 1971). Hornblende and bitotie from gabbro collected about 5 miles north of location 6 in the Clan Alpine Range, have K-Ar dates of 169±5 Ma and 148±5 Ma, respectively (Speed and Jones, 1969).

at the fusion step indicates a small amount of excess argon is possible in the mineral. However, the most likely age of the gabbro is that given by the hornblende-1,100°C step, 172.4±1.1 Ma (table 1) which is the same within experimental error as the 169±5 Ma hornblende date from gabbro in the Clan Alpine Mountains (Speed and Jones, 1969).

Table 1. Results of $^{40}Ar/^{39}Ar$ incremental heating analysis of hornblende from gabbro specimen JD379 (Map No. 1, Figure 1) in the Humboldt Lopolith. Analyst: J. Y. Saburomaru.

Temp. °C	$^{40}Ar^{*}$ %	$^{36}Ar_{Ca}$ %	^{39}Ar %	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	Age (Ma)
750	27.0	0.49	1.54	128.59	5.908	0.319	276.2±25.5
875	14.7	0.33	1.47	140.24	5.043	0.406	169.2±29.3
920	18.7	0.33	1.28	79.78	2.749	0.217	122.5±31.1
940	6.9	0.30	0.93	66.94	2.379	0.211	39.3±44.6
975	0.0	0.41	0.63	57.99	3.086	0.198	0.0
1000	17.1	0.62	0.86	72.68	4.790	0.205	103.6±46.9
1025	0.0	0.74	0.63	62.29	6.174	0.220	0.0
1050	23.7	1.70	0.98	53.27	8.992	0.140	105.7±40.6
1100	89.8	23.42	83.42	23.38	9.372	0.011	172.4± 1.1
FUSE	83.0	24.55	8.26	33.75	23.839	0.026	228.9± 4.6

J=0.004749

$^{40}Ar^{*}$, radiogenic argon
Recalculated total fusion age = 173.5±1.6 Ma
Weighted mean plateau age = 172.4±1.1 Ma, Fraction of ^{39}Ar in plateau=83.42 %
Estimated uncertainties are quoted at one standard deviation.

Additional evidence of post-crystallization thermal disturbance in gabbro specimen JD379 is given by the Rb-Sr whole-rock, plagioclase, and biotite age of 142 ± 20 Ma, initial $^{87}Sr/^{86}Sr$=0.70422±5, MSWD=2.1 (fig. 2). Rb-Sr systematics of this rock also are complicated by the initial $^{87}Sr/^{86}Sr$ variability of cumulate minerals (hornblende, 0.70445, clinopyroxene 0.70455, and olivine 0.70871, table 2) and these minerals are excluded from the whole-rock, plagioclase, biotite isochron. The isotopic variability is probably due to these minerals crystallizing in magma contaminated with radiogenic strontium assimilated from intruded sedimentary roof-rocks and then settling into uncontaminated magma below.

Gabbro specimen CA 80 (location 7, fig. 1, table 2.) from the Clan Alpine Mountains has a Rb-Sr whole-rock-hornblende-biotite isochron age of 155.1±1.6 Ma, initial $^{87}Sr/^{86}Sr$ = 0.70414±7, MSWD=0.12 (figure 3). This specimen has also suffered a post-crystallization thermal disturbance. Widely scattered granitoid plutons of Cretaceous and Tertiary ages exposed in the West Humboldt and Stillwater Ranges and Clan Alpine Mountains (fig. 1) are the likely sources of the heat to variably reset K-Ar and Rb-Sr dates for minerals from the Jurassic Humboldt lopolith.

The gabbros and basalts from all three ranges have initial $^{87}Sr/^{86}Sr$ = 0.70415 ± 5 (table 2). The concentrations of SiO_2 and K_2O in three of these rocks ranges from 46.51 to 51.52 and from 0.87 to 1.59 weight percent, respectively (table 3). The anorthosite, picrite, and keratophyre have more radiogenic initial $^{87}Sr/^{86}Sr$ = 0.70549 ± 10 and SiO_2 and K_2O that ranges from 43.85 to 52.02 and from 0.30 to 0.67 weight percent, respectively. The initial $^{87}Sr/^{86}Sr$ = 0.70549 ± 10 of these rocks indicates they are from a source different from the coexisting basalts and gabbros with initial ^{87}Sr/^{86}Sr = 0.70415 ± 5. The strong and pervasive deuteric alteration that is a characteristic feature of the Humboldt lopolith is reflected in the high water contents of the analyzed rocks.

Figure 4 is a log-log plot of Rb vs Sr concentrations of the whole-rock specimens in table 2. Average Rb and Sr concentrations of oceanic basalts (OFB= mid-ocean ridge basalt, LKT= Low potassium tholeiitic basalt, TB= Tholeiitic basalt, AB= Alkaki basalt, from Hart and others, 1970) also are shown on this diagram. Except for the albitite, the lopolith data plot between the average Rb and Sr concentrations for tholeiitic and alkali basalts.

Table 2. Rb and Sr concentrations and strontium isotopic compositions of whole-rock and mineral specimens from the Humboldt lopolith, Nevada (fig. 1). Abbreviations: Kerat., keratophyre; Anorth., anorthosite; plag., plagioclase; cpx., clinopyroxene; hbde., hornblende; biot., biotite.

Spec. No.	Map No	Material	Rb (ppm)	Sr (ppm)	Rb/Sr	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr measured	^{87}Sr/^{86}Sr (172 Ma)
JD379-1	1	Gabbro	14.3	297	0.048	0.139	0.70445 (2)	0.70411
-2	1	olivine	0.47	2.90	0.162	0.470	0.70985 (2)	0.70871
-3	1	plag.	3.80	997	0.004	0.011	0.70430 (1)	0.70427
-4	1	cpx	2.11	34.2	0.062	0.179	0.70498 (2)	0.70455
-5	1	hbde	2.92	94.4	0.031	0.090	0.70467 (2)	0.70445
-6	1	biot.	179.8	169.0	1.064	3.080	0.71045 (2)	0.70422 *
JD384	1	Gabbro	17.2	638.7	0.027	0.078	0.70437 (1)	0.70418
JD385	1	Gabbro	14.6	673.3	0.022	0.062	0.70441 (6)	0.70426
JD246	1	Picrite	13.4	225.9	0.059	0.171	0.70589 (9)	0.70547
JD225	1	albitite.	0.6	65.9	0.009	0.026	0.70948 (9)	0.70942
SW232	2	Basalt	15.5	483.7	0.032	0.092	0.70441 (1)	0.70419
SW232 ^	2	Basalt	18.8	506.7	0.037	0.107	0.70441 (9)	0.70415
SW127	4	Kerat.	22.4	484.3	0.046	0.134	0.70573 (9)	0.70540
SW312	5	Basalt	51.7	482.0	0.107	0.310	0.70489 (2)	0.70414
CA71	6	Anorth.	10.4	1267	0.008	0.024	0.70563 (2)	0.70557
CA127	6	Anorth.	16.2	1125	0.014	0.042	0.70569 (2)	0.70559
CA80-1	7	Gabbro	29.6	557	0.053	0.154	0.70447 (2)	0.70410
-2	7	biot.	234.9	34.1	6.90	20.04	0.74833 (3)	0.70414"
-3	7	hbde.	2.60	197.4	0.013	0.038	0.70424 (3)	0.70415

Notes: *Biotite Sri calculated from 142 Ma whole-rock, plagioclase, biotite isochron (Figure 2). "Biotite Sri calculated from 155.1 Ma whole-rock-hornblende-biotite isochron (Figure 3). ^Duplicate analysis of different aliquots of basalt sample SW232.

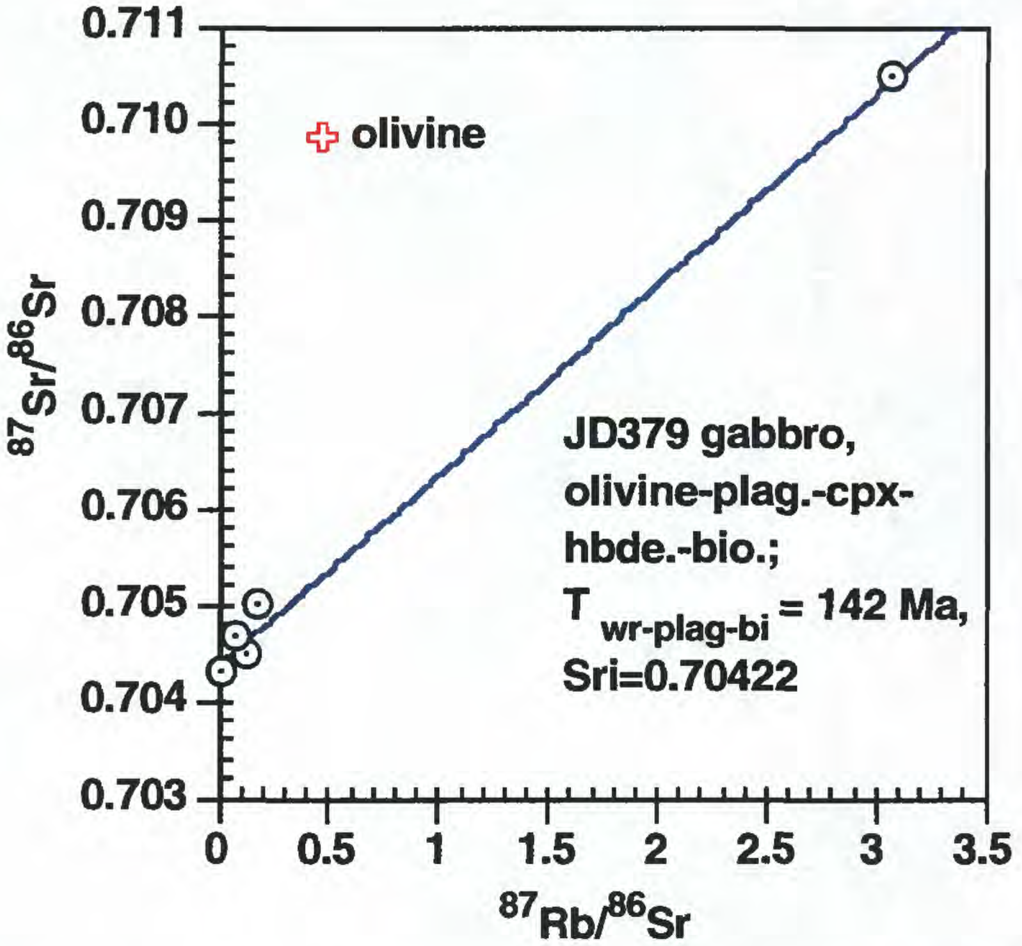

Figure 2. Rb-Sr isochron plot for gabbro specimen JD379, location 1, figure 1.

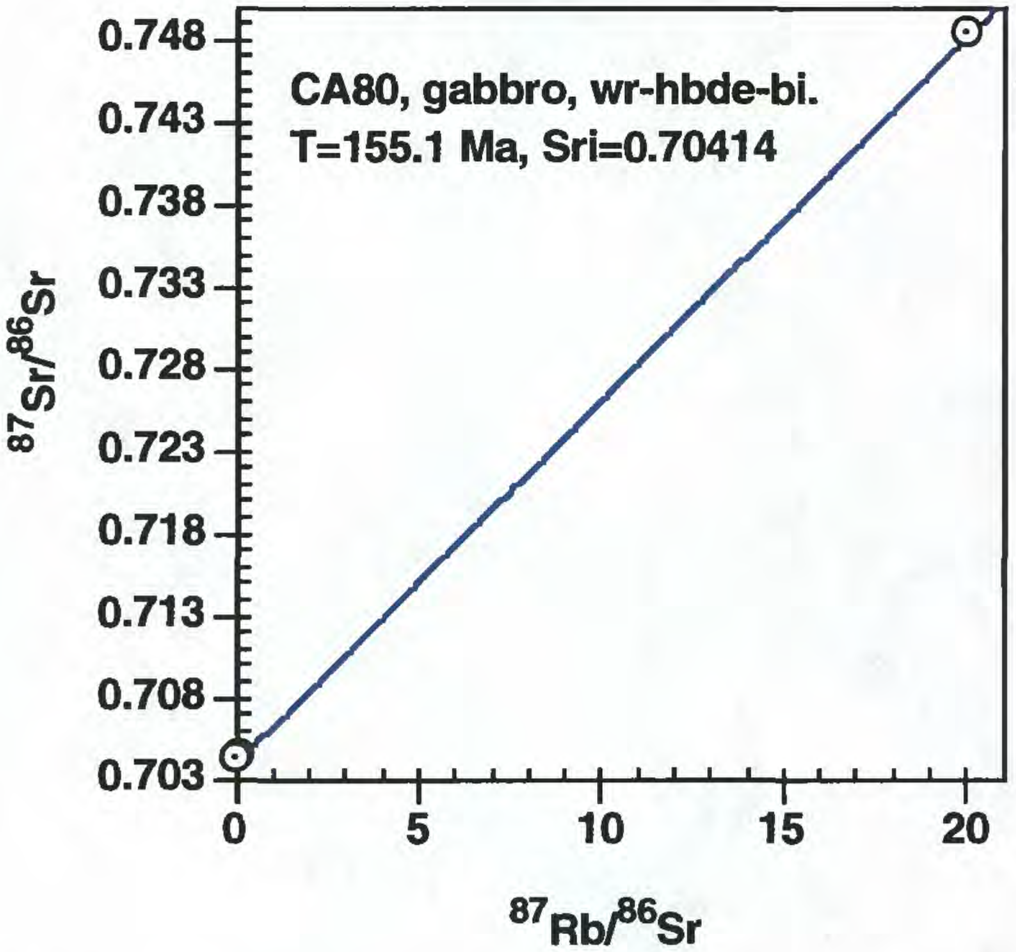

Figure 3. Rb-Sr isochron plot for gabbro specimen CA80, location 7, figure 1.

TABLE 3. Chemical analyses of representative rocks from the Humboldt lopolith, Nevada. All analyses were done at the Japan Analytical Chemistry Research Institute, Tokyo, Japan, Dr. Tamiya Asari, Director. Initial $^{87}Sr/^{86}Sr$ values are from Table 2.

oxide weight %	CA80 gabbro	SW312 basalt	SW232 basalt	CA127 anorthosite	JD246 picrite	SW127 keratophyre	JD225 albitite
SiO_2	46.51	51.15	51.52	52.02	43.85	50.15	73.86
Al_2O_3	17.80	16.80	16.59	27.11	7.85	17.38	14.69
Fe_2O_3	3.54	3.22	4.25	1.33	3.27	4.99	0.78
FeO	6.83	2.88	2.46	0.97	6.10	1.89	0.43
MgO	5.36	6.60	7.13	0.85	23.40	2.84	0.86
CaO	7.86	8.71	9.06	10.97	6.33	7.07	0.06
Na_2O	4.35	3.38	3.74	4.61	1.15	7.35	8.13
K_2O	0.87	1.59	0.89	0.67	0.30	0.51	0.14
H_2O^+	2.97	1.93	1.86	1.23	5.12	1.93	0.40
H_2O^-	1.10	1.58	1.30	0.22	1.14	0.48	0.28
TiO_2	1.78	1.14	0.96	0.19	0.49	1.03	0.12
P_2O_5	0.43	0.24	0.19	0.11	0.14	0.46	0.06
MnO	0.13	0.11	0.11	0.02	0.17	0.05	trace
CO_2	0.90	0.72	0.31	0.34	0.14	3.84	0.09
Cl	0.15	0.014	0.24	0.0	0.053	0.054	0.019
F	0.02	0.001	0.003	0.01	0.016	0.010	0.010
Map No	7	5	2	6	1	4	1
Initial $^{87}Sr/^{86}Sr$	0.70410	0.70414	0.70419	0.70559	0.70547	0.70540	0.70942

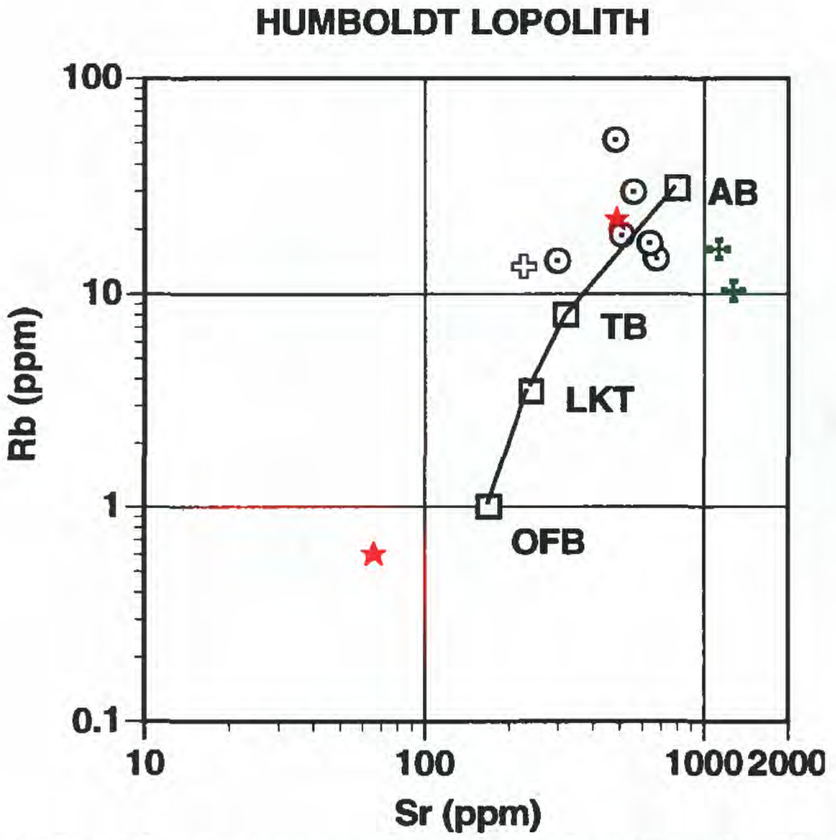

Figure 4. Log-log plot of Rb and Sr concentrations of rocks from the Humboldt lopolith, Nevada (table 2). Symbols: **open circles**, gabbros and basalts; **crosses**, anorthosites; open cross, picrite; **stars**, keratophyre and albitite; **open squares**, averages for oceanic basalts (Hart and others, 1970). See text for oceanic basalt terminology.

THE KOIPATO GROUP

The type area of the Permian (?) and Triassic Koipato Group is in the Humboldt Range (fig. 5) several miles to the north of the Humboldt lopolith (fig. 1). Some rocks of the Koipato Group are exposed just north of the lopolith in the Stillwater Range (Specimen locations 9-12, fig. 1). In the Humboldt Range, the Koipato Group includes the Limerick Greenstone, Rochester Rhyolite, and Weaver Rhyolite in order of decreasing age (Wallace and others, 1969, fig. 5). The Limerick Greenstone, with a base not seen, has a thickness in excess of 6,000 feet, is comprised of mafic volcanic flows, tuff, and breccias in a heterogeneous intertongued pile that seemingly grades upward into Rochester Rhyolite. The greenstone is generally schistose and locally contains metacrysts of albite in a microcrystalline groundmass. Most exposures contain abundant albite and quartz and are called keratophyre or quartz keratophyre. In these rocks, K-feldspar, biotite, chlorite, white-mica, amphibole, calcite, and epidote occur in varying proportions. The overlying Rochester Rhyolite, with a maximum thickness of 6,000 feet, includes rhyolite tuff, breccia, flows, and conglomerate in a heterogeneous intertongued pile. The rock is generally alkali metasomatized and extreme K to Na concentrations are common. In places, the Rochester Rhyolite is a dumortierized and andalusitized rhyolitic rock that is schistose to massive, whitish to gray, violet, or blue, that locally contains anhedral metacrysts of gray andalusite. The Weaver Rhyolite, with maximum thickness of 2,000 feet, includes porphyritiic rhyolite flows, well-stratified tuffaceous siltstone, sandstone, and conglomerate, and flow banded rhyolite flows and subordinate tuff. These rhyolites have a high ratio of K-feldspar to sodic plagioclase, are locally andalusitized and pyrophyllitized, and are believed to be in part extrusive equivalents of rhyolite porphyry plugs and dikes that intrude both of the underlying Rochester Rhyolite and Limerick Greenstone. Fluvial deposits between the two eruptive rhyolites and granite fragments with diagnostic micrographic texture in Weaver ash flows attest to a depositional hiatus during rhyolitic volcanism (Vikre, 1981). Impressions of ammonites in tuffaceous beds interstratified with the rhyolitic rocks near the top of the Weaver Rhyolite are noritacids of Early Triassic and probably of early Early Triassic age (Silberling and Roberts, 1962). Four grains of zircon from the Rochester Rhyolite yielded fission track ages that ranged from 270 to 190 Ma (McKee and Burke, 1972).

On the basis of field observations and K-Ar mineral ages, Vikre (1981) attributed bulk chemical changes and recrystallization in Koipato rocks throughout the Humboldt range to two plutonic events widely spaced in time. The first of these involved intrusion of Permian-Triassic (?) leucogranite into the Limerick Greenstone and Rochester Rhyolite (fig. 5, location 4). The second event occurred about 70 to 85 Ma as determined by K-Ar dates on hydrothermal mineral phases of veins from several mines in the range (summarized in Vikre, 1981). Vikre states (1981) that superimposed effects of the two events are difficult to separate because of the widespread and and overlapping distributrion of similar hydrothermal mineral assemblages.

Partial chemical analyses, Sr, oxygen and hydrogen isotopic data for Koipato Group whole-rocks, biotite and white mica are reported here (table 4). Except for Limerick Greenstone specimen RSK 13, pervasive alteration of the Koipato Group rocks is reflected in both its chemical and isotopic characteristics. The extreme K to Na ratios in the rhyolites noted by Wallace and others (1969) also is present in our specimens. In addition, the $\partial^{18}O$ and ∂D values that range from +9.5 to +13.1 and from -77.9 to -99.2, respectively, reflect alteration by formation and organic waters (Shepard, 1986). Rb-Sr data for all of the rocks are shown on a strontium evolution diagram in figure 6. All samples except for Limerick Greenstone RSK13 are colinear. Regression of these data using ISOPLOT (Ludwig, 1988) yields an errorchron with T=168.6±9.3 Ma, initial $^{87}Sr/^{86}Sr = 0.7141\pm13$, MSWD=48.8. The pervasive alteration of the Koipato Group rocks in the Stillwater and Humboldt Ranges is the same age as the nearby Jurassic Humboldt lopolith and probably was caused by a circulating hyrothermal system driven by heat supplied during emplacement of the magma that formed this large mafic igneous rock complex.

Like the K-Ar vein mineral ages reported by Vikre (1981), the Rb-Sr ages of biotite and muscovite (table 4) from the Limerick Greenstone and Rochester Rhyolite, respectively, are both Cretaceous. These dates represent thermal resetting and vein emplacement during widespread Cretaceous plutonism in the region.

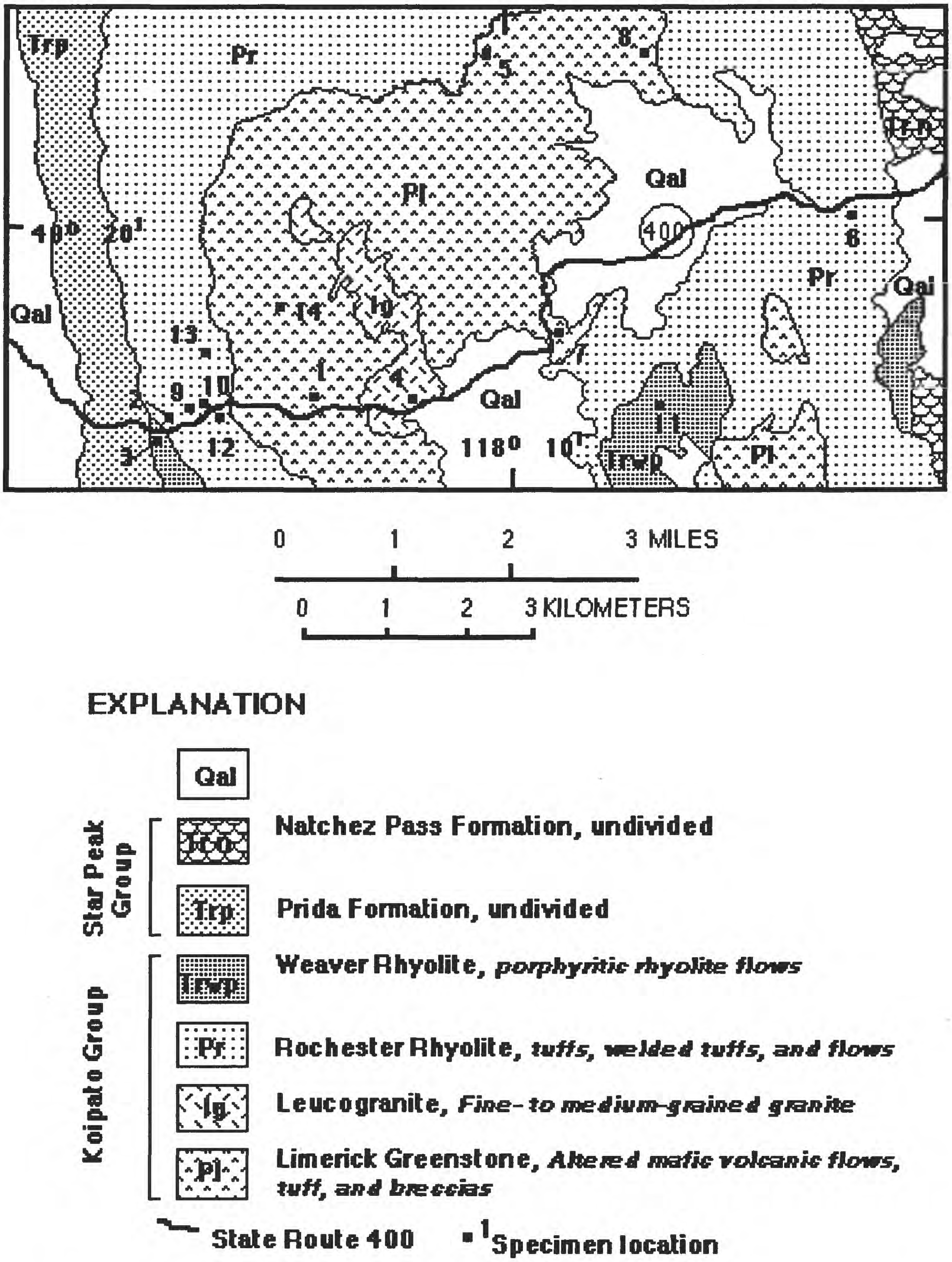

Figure 5. Map (simplified from Wallace and others, 1969) showing lithologies of the Koipato and Star Peak Groups, and locations of samples in table 4.

Table 4. Chemical and isotopic data for Permian(?) and Triassic Koipato Group rocks and minerals

Sample	Rb(ppm)	Sr(ppm)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$(^{87}Sr/^{86}Sr)_0$	Age (m.y.)	$\partial^{18}O$ per mil	∂D per mil	H_20 wt.%	SiO_2 wt.%	Na_2O wt.%	K_2O wt.%
RSK-13	84	613	0.14	0.35	0.70698	0.7059	Triassic?	5.3	-104.4	2.67	47.83	4.21	2.83
Lim-76-13	160	253	0.63	1.83	0.71851	0.7141	169	10.1	-77.9	1.71	58.06	2.16	3.48
Lim-2	173	193	0.9	2.61	0.72081	0.7141	169				61.60	3.52	3.46
Lim-76-66	205	145	1.41	4.09	0.72212	0.7141	169						
RSK-15	170	36.2	4.7	13.65	0.75062	0.7141	169				77.35		4.87
RSK-2	301	45.7	6.58	19.15	0.76598	0.7141	169	9.5	-91.0	0.26	78.84	1.52	7.53
RSK-5	263	29.9	8.8	25.61	0.77239	0.7141	169				77.97		
RSK-6	277	12.9	21.47	63.06	0.8621	0.7141	169	14.0	-96.9	5.63	78.33		7.80
RSK-7*	333	24.7	13.48	39.4	0.81321	0.7141	169	9.6	-99.2	0.16	79.42		
K-20	151	154	0.98	2.84	0.7195	0.7141	169				68.80	4.23	4.67
RSK-1	298	57.5	5.18	15.05	0.75231	0.7141	169	13.1	-98.0	0.26	79.23	0.90	8.23
RSK-16*	264	44.5	5.93	17.23	0.74882	0.7141	169				80.00		
K78-9 musc	265	67.5	3.93	11.39	0.73136	0.7141	106.6						
K78-4 biot	368	41.3	8.91	25.9	0.74119	0.7141	73.5						
SW-113	211	50.4	4.19	12.16	0.74186	0.7141	169				79.25	2.76	3.92
SW-105	219	59.8	3.66	10.62	0.73932	0.7141	169				80.18	0.91	5.55
SW-397	220	69.6	3.16	9.16	0.73501	0.7141	169				79.49	2.36	6.26
SW-11	177	67.6	2.61	7.57	0.73414	0.7141	169				77.82	2.04	5.21

Rock types, Sample Numbers, and locations, for Koipato Group specimens.

RSK-13	Limerick greenstone, #1, Fig. 4	SW-11	Koipato Group, Stillwater Range, #11, Fig 1
Lim-76-13C	Limerick greenstone, #5, Fig. 4		
Lim-2	Limerick greenstone, #7, Fig. 4		
Lim-76-6c	Limerick greenstone, #8, Fig. 4		
RSK-15	leucogranite, #4, Fig. 4		
RSK-2	Weaver Rhyolite, #2, Fig. 4		
RSK-5	Weaver Rhyolite, #9, Fig. 4		
RSK-6	Weaver Rhyolite, #10, Fig. 4		
RSK-7	Rochester Rhyolite, #12, Fig. 4		
K-20	Rochester Rhyolite, #6, Fig. 4		
RSK-1	porphyritic rhyolite, Weaver Rhyolite, #3, Fig. 4		
RSK-16	porphyritic rhyolite, Weaver rhyolite, #11, Fig. 4		
K78-9	Rochester Rhyolite, white mica, #13, Fig. 4		
K78-4	Limerick greenstone, biotite, #14, Fig. 4		
SW-113	Koipato Group, Stillwater Range, #12, Fig. 1		
SW-105	Koipato Group, Stillwater Range, #10, Fig. 1		
SW-397	Koipato Group, Stillwater Range, #9, Fig. 1		

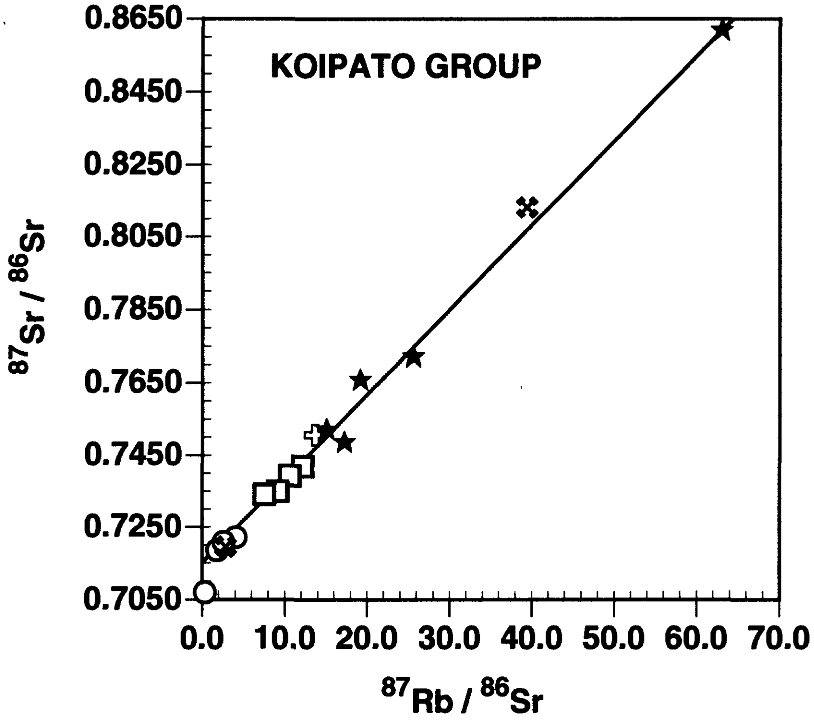

Figure 6. Strontium evolution diagram for Koipato Group whole-rocks samples (table 4). Symbols: stars, Weaver Rhyolite; crosses, Rochester Rhyolite; open cross, leucogranite; open squares, Stillwater Range rhyolites; open circles, Limerick Greenstone. T=168.6 ± 9.3 Ma, initial $^{87}Sr/^{86}Sr$= 0.7141±13, MSWD=48.8.

SUMMARY

The Humboldt lopolith (Speed, 1976) is a complex of mafic intrusive and extrusive rocks with a volume between 1,700 and 2,500 km^3 that intruded a suite of marine sedimentary rocks of Upper Lower Jurassic (upper Toarcian) and (or) Middle Jurassic (Bajocian) age (193-176Ma) that lie above a basement of Permian (?) and Triassic andesitic to rhyolitic volcanic rocks. The intrusive age of the complex is approximated by K-Ar and $^{40}Ar/^{39}Ar$ hornblende dates between 169 and 172 Ma, respectively. K-Ar and Rb-Sr biotite ages range from 142 to 155 Ma from three gabbro specimens and reflect Ar loss because of thermal effects from intrusion of Cretaceous and Tertiary plutons in the area.

Rb-Sr systematics of minerals from gabbros are complicated because cumulate phases are not in initial Sr isotopic equilibrium with intercumulus phases. In spite of this, whole-rock gabbros and basalts from widely separated locations of the complex have a uniform initial $^{87}Sr/^{86}Sr$ value of 0.70415±5. However, a picritic basalt, a keratophyre, and two anorthosites have a uniform initial $^{87}Sr/^{86}Sr$=0.70549±10 that indicates at least two different magma batches were involved in lopolith formation. An albitite dike has an initial $^{87}Sr/7^{86}Sr$ = 0.70948±9. The radiogenic strontium in this rock is from a crustal source, possibly a brine. The gabbros and basalts have Rb and Sr concentrations that are between concentrations of these elements in average oceanic tholeiitic and alkalic basalts.

In the immediate vicinity of the Humboldt lopolith, the Permian (?) and Triassic Koipato Group rocks have petrographic and chemical signatures that are due to pervasive hydrothermal alteration. Extreme values of K/Na and SiO_2 concentrations are common in the Koipato. In the Koipato Group, isotopic compositions of oxygen and hydrogen of whole-rock specimens are not magmatic, but have values that reflect alteration by formation or organic waters. In addition, all but one of 15 whole-rocks specimens are colinear on a strontium evolution diagram and regression of the data yields an age of 169 Ma with initial $^{87}Sr/^{86}Sr$=0.7141.This age and radiogenic initial $^{87}Sr/^{86}Sr$ indicates the Sr isotopic composition of whole-rock specimens of the Koipato Group was homogenized by pervasive alteration caused by a hydrothermal system composed of organic rich formation waters driven by heat from emplacement of the Humboldt lopolith. This result supports the contention of Geissman and others (1990) that their paleomagnetic results from the carbonate Triassic Prida Formation in the Humboldt Range and also from the underlying Koipato Group in the nearby southern Tobin Range (Skalbeck and others, 1989) reflect pole positions that resulted from remagnetization in the Jurassic and not southward transport of 1400 km before Tertiary time.

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