

Age of the Coso Formation, Inyo County, California

G E O L O G I C A L S U R V E Y B U L L E T I N 1 5 2 7



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and ROBERT E. DRAKE

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*A re-evaluation of the age of the Coso Formation,
based on potassium-argon ages of the volcanic rocks that
are intercalated with, intrude, and overlie the
Coso Formation*



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AGE OF THE COSO FORMATION, INYO COUNTY, CALIFORNIA

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ABSTRACT

The late Tertiary Coso Formation consisting of sedimentary and volcanoclastic rocks occurs in the Coso Range and at the south end of Owens Valley, Calif. Potassium-argon dating of the volcanic rocks that overlie, are intercalated with, and intrude the Coso indicates that the Coso Formation contains strata at least as old as 6.0 m.y. (million years) and no younger than 2.5 m.y. Within the Coso Formation, Blancan fossils from a locality on the northern slope of the Coso Range are probably 3.0 m.y. old and a Hemphillian fossil was recovered northeast of there from beds between 3.6 and 5.3 m.y. old. A rhyodacite and four rhyolite plug domes that intrude sedimentary rocks of the Coso on the northern flank of the Coso Range range in age from 5.7 to 6.0 m.y.

The late Miocene fluvial and lacustrine sedimentary rocks of the Coso Formation suggest that a shallow basin had formed in southern Owens Valley by about 6 m.y. ago. Air-fall tuff and coarse clastic sedimentary rocks of the Coso Formation within the Coso Range suggest that block faulting had begun by about 3 m.y. ago.

INTRODUCTION

Tertiary sedimentary rocks that predate Quaternary alluvial deposits at the south end of Owens Valley, the westernmost basin of the Basin and Range province, and in the Coso Range have been mapped by a number of workers as the Coso Formation (fig. 1). This formation is of interest because it records sedimentation in response to deformation at the western margin of the Basin and Range province, and it contains vertebrate fossils of Hemphillian and Blancan mammalian ages and uranium minerals of potential economic importance.

Late Cenozoic rocks in the area that are now included in the Coso Formation were described by early workers (for example, Knopf, 1918). Schultz (1937) defined the Coso Formation to include all Cenozoic sedimentary deposits in the area that lie beneath late Cenozoic lava flows and described vertebrate fossils from two localities within the Coso at the north end of the Coso Range. In light of more recent work,

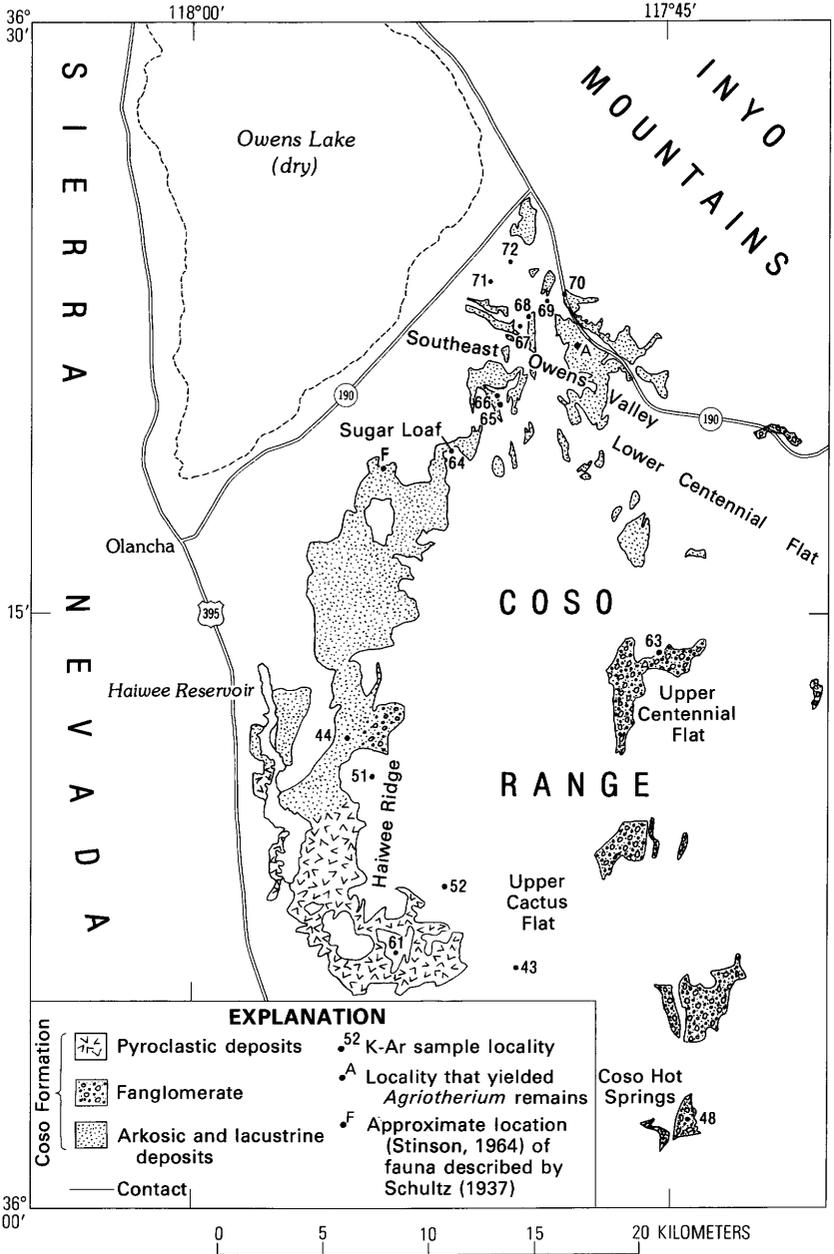


FIGURE 1—Distribution of the Coso Formation generalized and modified from Hall and MacKevett (1962), Stinson (1977a, b), Duffield and Bacon (1981), and Giovannetti (1979a). Numbers refer to sample localities of table 1 and Duffield, Bacon, and Roquemore (1979).

Schultz's definition (1937, p.79) of the Coso should be clarified because the lava flows in the Coso Range have a wide age range. We believe that the lava flows referred to by Schultz are the rhyodacite flows on the Haiwee Ridge (fig. 1) described in the section on Pliocene rhyodacite lava flows.

Parts of the Coso Formation have been described by Hopper (1947), Power (1959, 1961), Bacon and Duffield (1978), Duffield, Bacon, and Roquemore (1979), Duffield, Bacon, and Dalrymple (1980), and Giovannetti (1979a, b). Deposits mapped as the Coso (fig. 1) Occur in the Haiwee Reservoir (Stinson, 1977a), Keeler (Stinson, 1977b), and Darwin (Hall and MacKevett, 1962) 15-minute quadrangles and have been mapped in the Coso volcanic field (Duffield and Bacon, 1981).

Potassium-argon dating of volcanic rocks intercalated with, and overlying, the Coso Formation has been used by Evernden, Savage, Curtis, and James (1964), Bacon, Giovannetti, Duffield, and Dalrymple (1979), and Duffield, Bacon, and Dalrymple (1980) to constrain the age of the Coso. In this report, we review these potassium-argon ages and present additional data that provide more accurate limits on the age of the Coso Formation.

ACKNOWLEDGMENTS

We thank C. A. Repenning for advice on paleontologic aspects of this study. G. R. Roquemore contributed valuable observations of field relations of pyroclastic rocks near Sugar Loaf. J. Metz painstakingly prepared and analyzed glass fractions of tuffs. C. E. Meyer and M. J. Woodward kindly determined fission-track ages of zircons. Part of this report is based on the second author's M. S. thesis, which was completed under the guidance of Professor R. L. Hay. Potassium-argon age determinations at the University of California, Berkeley, were made possible through National Science Foundation grant EAR76-21833.

DATING TECHNIQUES

Potassium and argon analyses were performed on crushed whole-rock samples of obsidian and basalt and on separates of sanidine, plagioclase, and biotite. The analytical data are presented in table 1 and include some data published previously (Duffield and others, 1980) for the sake of completeness. Analyses of samples from localities 43-66 were performed at the U.S Geological Survey, Menlo Park, Calif., as described by Duffield, Bacon, and Dalrymple (1980); those for localities 67-72 were made at the University of California at Berkley by techniques described by Dalrymple and Lanphere (1969).

Fission-track ages of zircons (table 2) were determined by techniques described by Naeser (1976).

TABLE 1.—Analytical data for potassium-argon measurements on volcanic rocks

[Samples from localities 43 to 66 analyzed at U.S. Geological Survey, Menlo Park, California; 67-72 analyzed at Department of Geology and Geophysics, University of California, Berkeley, California; 43-63 from Duffield, Bacon, and Dalrymple (1980). Analytical constants: $\lambda_{\epsilon} + \lambda_{\epsilon'} = 0.581 \times 10^{-10} \text{ yr}^{-1}$, $\lambda_{\beta} = 4.692 \times 10^{-10} \text{ yr}^{-1}$, $^{40}\text{K}/\text{K} = 1.167 \times 10^{-4} \text{ mol/mol}$. Errors are estimated standard deviations (Cox and Dalrymple, 1967)]

Locality	Sample No.	Lat	Long	Stratigraphic relations	Material	Percentage K_2O	Weight (gm)	$^{40}\text{Ar}_{\text{rad}}$ ($\times 10^{12}$ mol/gm)	Percentage $^{40}\text{Ar}_{\text{rad}}$	Calculated age (million years)	Weighted mean age (million years)
43	9-8-11	36°06'04"	117°50'02"	Near top of Coso Formation, Upper Cactus Flat; air-fall pumice.	Biotite -----	6.48, 6.47	1.151	22.975	2.4	2.46±0.98	2.99±0.20
					Plagioclase -----	0.460, 0.457	5.863	2.004	16.0	3.04±0.20	
48	13-113-6	36°02'10"	117°44'22"	Near top of Coso Formation, East of Coso Hot Springs; air-fall pumice.	Biotite -----	7.01, 6.98	1.96	33.45	4.1	3.31±0.42	3.14±0.15
					Plagioclase -----	0.524, 0.513	6.108	2.203	24.4	2.95±0.13	
44	9-85-2	36°11'56"	117°55'14"	Within Coso Formation, between Cactus Flat and Haiwee Reservoir; pumice in pyroclastic flow.	Biotite -----	7.62, 7.67	1.977	41.34	5.9	3.75±0.32	3.14±0.15
					Sanidine -----	12.31, 12.32	3.835	54.88	66.2	3.09±0.09	
52	75G317	36°08'02"	117°52'00"	Overlies Coso Formation, McCloud Flat; rhyodacite lava flow.	Biotite -----	8.63, 8.63	{ 4.711 5.208 }	30.90	{ 27.8 33.6 }	2.51±0.05	2.52±0.05
								31.69			
61	13-43-13	36°06'00"	117°53'32"	Overlies Coso Formation, Haiwee Ridge; rhyodacite lava flow.	do -----	8.58, 8.55	3.357	31.40	24.5	2.54±0.05	
63	8-191-1	36°14'10"	117°45'20"	Within Coso Formation, Upper Centennial Flat; lava flow.	Basalt -----	{ 0.883, 0.884 0.880, 0.886 }	{ 13.406 15.521 }	4.087	{ 11.7 45.9 }	3.56±0.10	
											4.736
64	13-51-1	36°19'12"	117°52'00"	Intrudes Coso Formation, NW slope of Coso Range; rhyolite plug.	Biotite -----	8.83, 8.84	1.628	72.90	47.0	5.72±0.17	

65	13-52-2	36°20'16"	117°50'24"	Intrudes Coso Formation, N. end of Coso Range; rhyolite plug.	Obsidian -----	{4.35, 4.26} {4.32, 4.27}	{3.184 {3.437	36.88 37.44	43.2 54.9}	5.99±0.08
66	13-52-3	36°20'32"	117°50'22"	Intrudes Coso Formation, N. end of Coso Range; rhyolite plug.	- do -----	{4.32, 4.28} {4.32, 4.28}	{3.211 {3.323	36.58 37.37	48.3 42.1}	5.98±0.06
67	78-G-137	36°22'20"	117°49'44"	Invades Coso Formation, between Coso River and Inyo Mountains; lava flow.	Basalt -----	1.238	5.038	10.49	38.30	5.88±0.18
68	78-G-133	36°22'36"	117°49'20"	Overlain by Coso Formation, between Coso River and Inyo Mountains; lava flow.	- do -----	1.450	4.965	10.98	22.8	5.25±0.23
69	78-G-70	36°22'54"	117°48'54"	Interbedded with Coso Formation, between Coso River and Inyo Mountains; rhyolite dome breccia.	Sanidine -----	10.18	3.192	86.55	83.1	5.90±0.12
70	78-G-135L	36°23'12"	117°48'18"	Overlain by Coso Formation, between Coso River and Inyo Mountains; lava flow.	Basalt -----	1.907	5.004	15.40	69.8	5.60±0.17
71	78-G-131	36°23'24"	117°50'42"	Overlies Coso Formation, between Coso River and Inyo Mountains; lava flow.	- do -----	1.299	5.006	10.35	25.1	5.53±0.22
72	78-G-130	36°23'54"	117°50'00"	Overlies Coso Formation, between Coso River and Inyo Mounains; lava flow.	- do -----	1.282	5.070	11.17	22.9	6.04±0.26

TABLE 2.—*Fission-track data from zircons*[First determination by C. E. Meyer, second by M. J. Woodward. Analytical constant $\lambda \geq 7.03 \times 10^{-17} \text{ yr}^{-1}$]

Locality	Sample	Spontaneous tracks		Induced tracks		Neutron flux ²	Age (million years, $\pm 2 \sigma$)
		No. counted	Density ¹	No. counted	Density ¹		
43	9-8-11	217	7.1×10^5	2088	1.4×10^7	9.59×10^{14}	2.97 ± 0.28
43	9-8-11	390	5.3×10^5	3754	1.1×10^7	9.59×10^{14}	2.90 ± 0.20

¹tracks/cm².²neutrons/cm².

STRATIGRAPHIC RELATIONS BETWEEN POTASSIUM-ARGON-DATED VOLCANIC ROCKS AND BEDS OF THE COSO FORMATION

MIOCENE VOLCANIC ROCKS

Between Haiwee Reservoir and the northeast side of the Coso Range, several potassium-argon dates of between 5.3 and 6.0 m.y. (million years) on volcanic rocks (locs. 64-67, 69, 71, 72) indicate that some of the strata mapped as Coso Formation by Stinson (1977b) and Giovannetti (1979a) are late Miocene in age. These rocks occur in three centers of silicic volcanism. Basalt flows occur near all three silicic eruptive centers (fig. 2).

The first center, the northermost of the three, has been studied in detail by Giovannetti (1979a). At locality 69 (fig. 3), a porphyritic rhyolite flow-dome and pyroclastic complex are interbedded with basalt dated at 6.04 ± 0.26 to 5.25 ± 0.23 m.y. (figs. 3, 4; table 1, locs. 67, 68, 70, 71, and 72). Sanidine from the porphyritic allanite-biotite-albite-sanidine-quartz rhyolite yields a potassium-argon age of 5.90 ± 0.10 m.y. (figs. 3, 4; table 1, loc. 69). Compositions of plagioclase and sanidine phenocrysts in this rhyolite are given in table 3. The rhyolite is overlain by basalt with potassium-argon ages of 5.25 ± 0.23 m.y. and 5.53 ± 0.22 m.y. (figs. 3, 4; table 1, locs. 68 and 71).

At locality 67 (figs. 1, 3), basalt dated at 5.88 ± 0.18 m.y. (table 1) intrudes calcareous lacustrine and arkosic fluvial beds of the Coso Formation in the manner of an invasive lava flow (Byerly and Swanson, 1978). Disintegrated lava fragments, generally lapilli size, are thoroughly mixed with sediment underlying and peripheral to the flows. Similar mixtures of sediment and fragmented lava, termed "peperites," have been described by Schmincke (1967) as resulting from the invasion of unconsolidated wet sediments by molten lava (fig. 5). In addition, the basalt is characteristically altered to green and purple mixtures of clay,

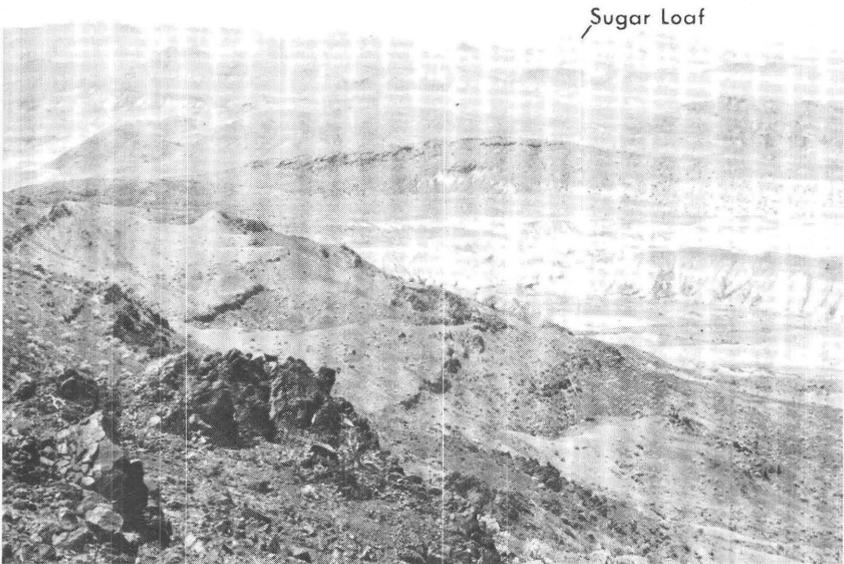


FIGURE 2.—View looking southwest from near locality 68. Basalt lava flows in foreground. Coso Formation underlying 5-m.y.-old basalt lava flow in middle distance; northern end of Coso Range in the far distance; Sugar Loaf, the small rounded feature in the middle distance, is a porphyritic rhyodacite plug-dome; Sierra Nevada forms right skyline.

carbonate, and hydrated iron oxide minerals. Similar relations are evident between basalt and sedimentary rocks between localities 66 and 67 (Bacon and Duffield, 1978).

Near the northernmost rhyolite complex (loc. 69), arkosic sedimentary deposits are intercalated with basalt flows, some of which may be invasive. A thick (30 m), altered dacite flow appears to be the youngest volcanic rock in the area. Relatively extensive alteration of most of these volcanic rocks suggests water saturation of the sediments into or onto which they flowed. The presence of large euhedral crystals of gypsum and scalenohedrons of calcite in vugs and fractures suggests post eruption exposure of the volcanic rocks to high-salinity, alkaline water, either from groundwater or shallow lakes. Bedded arkosic fluvial sedimentary rocks overlie the entire section of volcanic rocks in this area (Giovannetti, 1979a, b). It was from these sedimentary rocks that the *Agriotherium* remains were recovered. The 4.8- to 6.2-m.y. age implied for *Agriotherium* is consistent with the maximum age for these rocks as indicated by the 5.3- to 5.9-m.y. potassium-argon ages of the volcanic rocks stratigraphically beneath them (locs. 68-70) and the

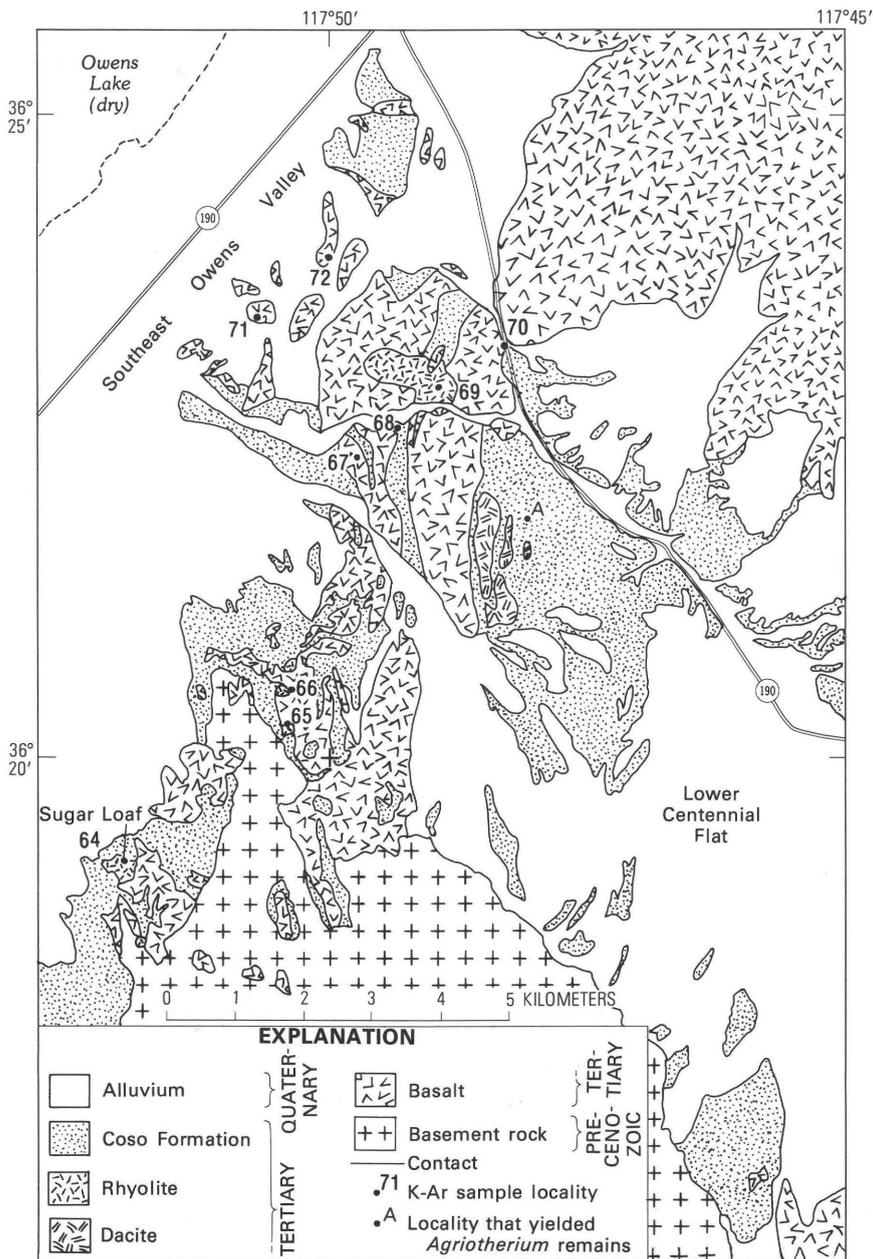


FIGURE 3.—Geologic map of area showing northernmost exposures of Coso Formation, modified from Stinson (1977a, b) and Giovannetti (1979a); faults omitted.

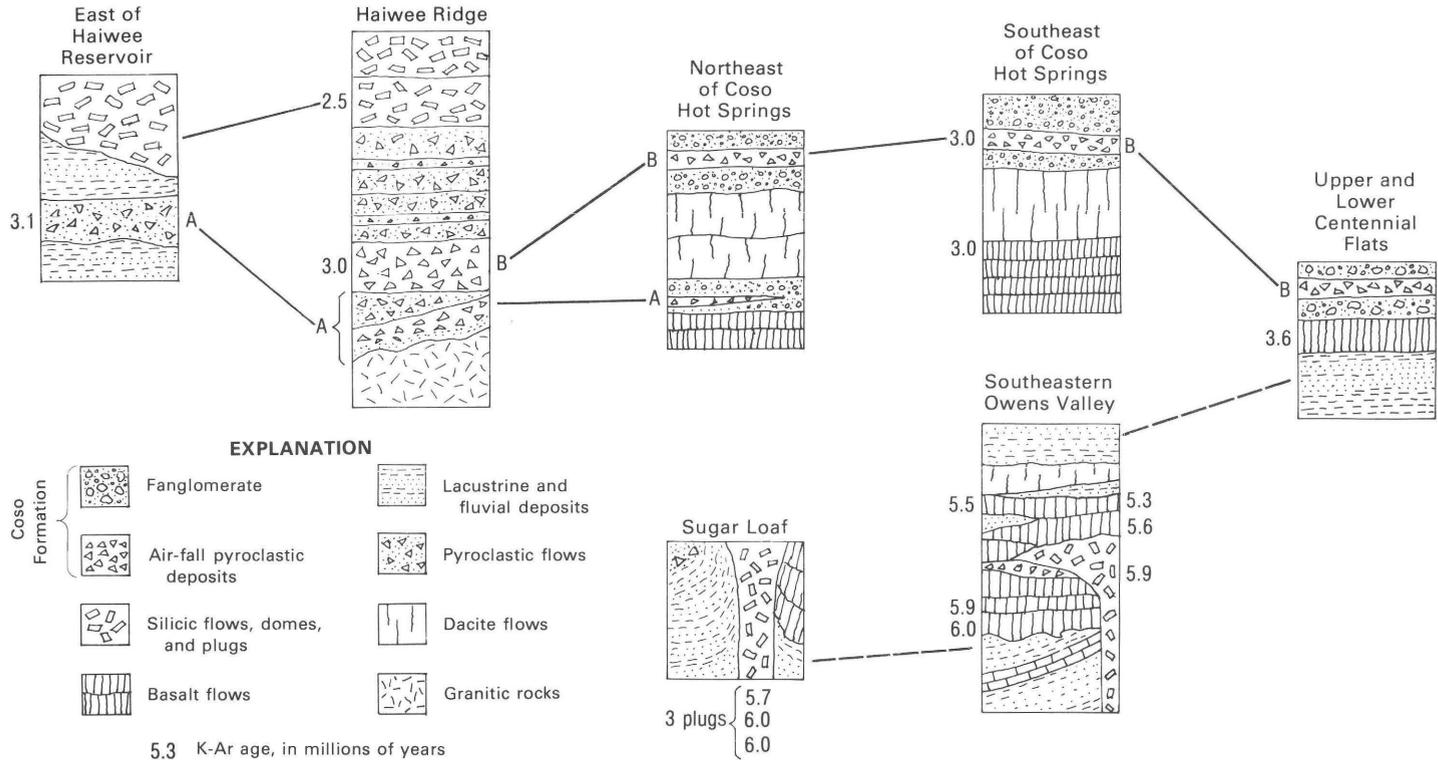


FIGURE 4.—Schematic stratigraphic sections of the southeastern Owens Valley and Coso Range showing correlation and age of volcanic and sedimentary rocks. Unit A is rhyolite pumice of locality 44 and compositionally similar, apparently correlative deposits; B is rhyodacite air-fall pumice of locations 43 and 48. Stratigraphic relation between A and B northeast of Coso Hot Springs inferred.

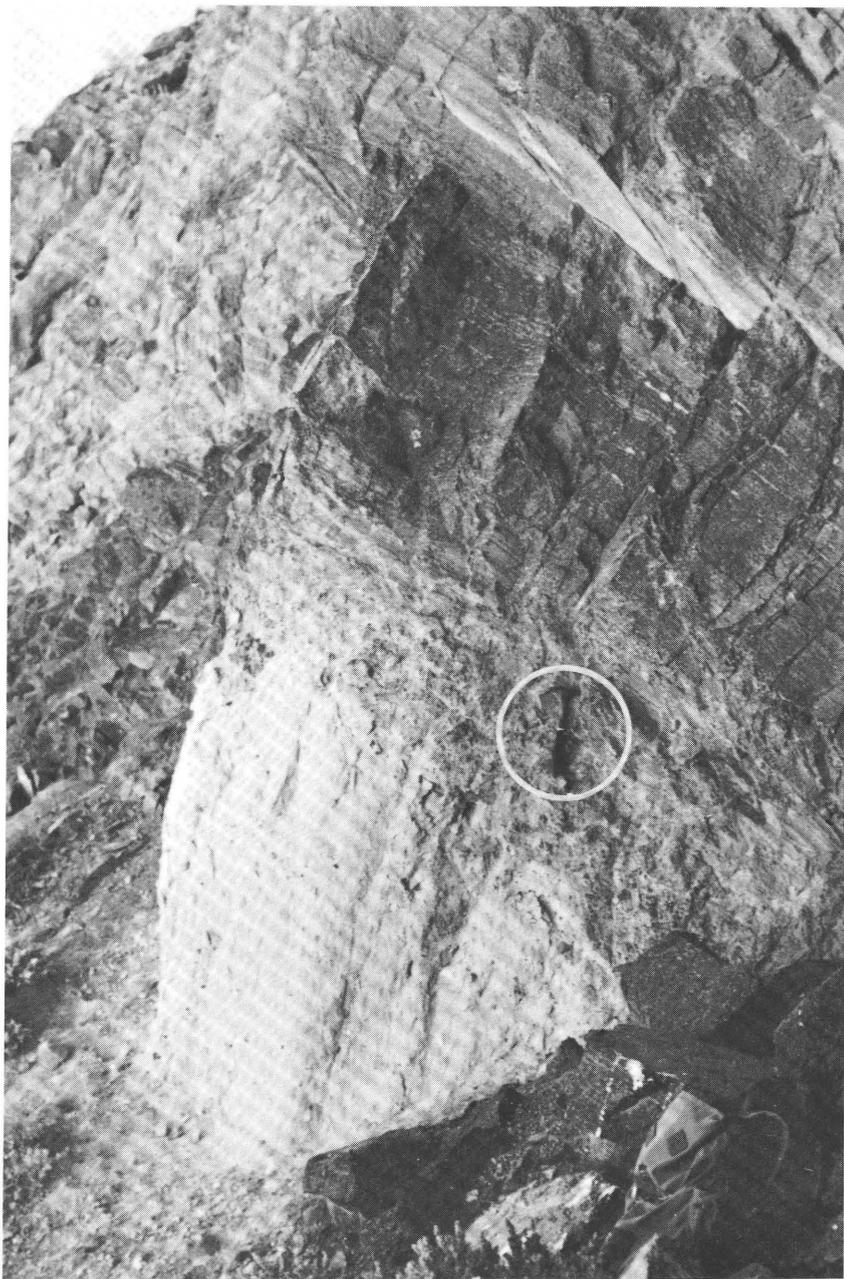


FIGURE 5.—Contact of an invasive basalt flow with sedimentary rocks of the Coso Formation near locality 67. Fragments of highly altered columnar basalt are locally mixed with clay-rich sediment. Pencil gives scale.

minimum age defined by the 3.6-m.y.-old basalt (loc. 63) overlying them.

The second center comprises a group of three aphyric, apparently coeval rhyolite plug-domes (figs. 3, 4; locs. 65 and 66) that intrude tuffaceous lacustrine and fluvial sediments mapped as Coso Formation by Stinson (1977b). The three plugs consist predominantly of felsite and minor perlitic glass; the southern and middle ones contain small amounts of obsidian (marekanite) that are chemically identical (C. R. Bacon and R. L. Smith, unpub. data, 1977) and yield potassium-argon ages of 5.99 ± 0.08 and 5.98 ± 0.06 m.y. (table 1, locs. 65 and 66, respectively). Thin beds of arkosic fluvial and tuffaceous lacustrine sediments are nearly flat lying within less than 100 m of the plug-domes but have been forced into nearly vertical attitudes adjacent to the plug-domes by intrusion of the rhyolite (fig. 6). Glassy and devitrified zones appear to parallel contacts with sedimentary rocks, although not so clearly as at Sugar Loaf (fig. 7). Moderately dipping air-fall and base-surge rhyolitic pyroclastic deposits with abundant, well-developed accretionary lapilli are exposed in a small drainage adjacent to the northernmost plug-dome on its northwest side. These plug-domes are the Olancha domes of Friedman and Smith (1958) and Smith and Shaw (1975).

The third center, Sugar Loaf, is a porphyritic rhyodacite plug-dome. This dome has yielded a potassium-argon biotite age of 5.72 ± 0.17 m.y. (figs. 3, 4; table 1, loc. 64). Several lines of evidence here suggest that the rhyodacite intrudes the tuffaceous fluvial and lacustrine beds of the Coso Formation and the intercalated basalt: (1) the sedimentary deposits dip steeply away from the contact with the rhyodacite, whereas less than 100 m from the contact, they dip gently; (2) foliation in the rhyodacite, as defined by platy jointing and by preferred orientation of phenocrysts, is steep to vertical everywhere near the contact and is nearly parallel to the contact (fig. 7); (3) abundant columnar joints, 10 cm in diameter, are oriented perpendicular to the contact (fig. 7); (4) crystallization of the rhyodacite is concentrically zoned, with a discontinuous band of dark vitrophyre about 1 m thick at the margin (fig. 7), followed by several meters of gray perlite that grade into a pink, largely devitrified core; and (5) the sediments, particularly those rich in clay, are altered and appear to be baked near contacts with the rhyodacite. Stinson (1977b) also noted the intrusive nature of the contact between this rhyodacite and the Coso. Approximately 350 m due west of the southern margin of the Sugar Loaf plug-dome, a 3-m-thick bed of pumiceous rhyodacite blocks is interbedded with clayey arkosic sandstone. The blocks form an avalanche or pyroclastic-flow deposit from Sugar Loaf, indicating that the rhyodacite reached the surface and that sedimentation of the Coso was in progress before and at the time of emplacement of the plug-dome.



FIGURE 6.—Intrusive north contact between middle rhyolite plug-dome (left; middle Olancha dome of Smith and Shaw, 1975) and sedimentary rocks of the Coso Formation. Prominent, steeply dipping outcrops are flow-banded vitrophyre just within rhyolite from contact. Bedding in Coso sedimentary rocks is virtually parallel to contact and flow banding. Note man (in circle) for scale.

PLIOCENE BASALTIC LAVA FLOW

At the north end of Upper Centennial Flat in the Coso Range, basalt dated at 3.56 ± 0.10 m.y. (Duffield and others, 1980; fig. 1; table 1, loc. 63; fig. 4) is overlain by alluvial fan deposits of the Coso Formation. These deposits contain a bed of hornblende-biotite-rhyodacite pumice lapilli. The pumice in this bed is probably correlative with pumice (table 1, locs. 43 and 48) dated at about 3.0 m.y. Thus, these alluvial fan deposits are probably in the upper part of the Coso Formation. Five kilometers to the north, at Lower Centennial Flat, the same basalt flow lies on about 100 m of calcareous lacustrine and arkosic fluvial deposits (fig. 3) that were assigned to the Coso Formation by Hall and MacKevett (1962) and by Stinson (1977b). The arkosic deposits may be correlative with similar deposits 10 km to the north-northwest (figs. 1, 3, loc. A) where a mandibular ramus identified as *Agriotherium* sp. cf. *A. sivalensis* (C. A. Repenning, written commun., 1979) was found by D. W. Andersen. According to Repenning, *Agriotherium* lived in North America in late Hemphillian time, most probably between 4.8 and 6.2 m.y. ago.

PLIOCENE RHYOLITIC PYROCLASTIC DEPOSITS

Rhyolitic air-fall and ash-flow deposits of the Coso Formation occur at several localities. All the occurrences described in the following paragraphs apparently represent a single eruption, or a series of eruptions closely spaced in time, from vents immediately east of Haiwee Reservoir.

A weighted-mean potassium-argon age of 3.14 ± 0.15 m.y. on sanidine and biotite from large pumice lumps in a rhyolite ash-flow tuff of the Coso Formation (loc. 44; Duffield and others, 1980) provides age control for the upper part of the Coso. This ash-flow tuff, mapped as rhyolite tuff breccia by Stinson (1977a), is interbedded with lacustrine deposits of the Coso east of the northern part of Haiwee Reservoir (fig. 4). Pumice in the ash-flow tuff contains phenocrysts of quartz, oligoclase, sanidine, and biotite. Rhyolite pumice identical in appearance to that in the ash-flow tuff east of the Haiwee Reservoir occurs northeast of Coso Hot Springs in a bed 1 m thick within alluvial deposits, which are overlain by a dacite lava flow (fig. 4).

Similar pumice and ash form base-surge and near-vent explosion deposits at the base of the pyroclastic section mapped as Coso Forma-

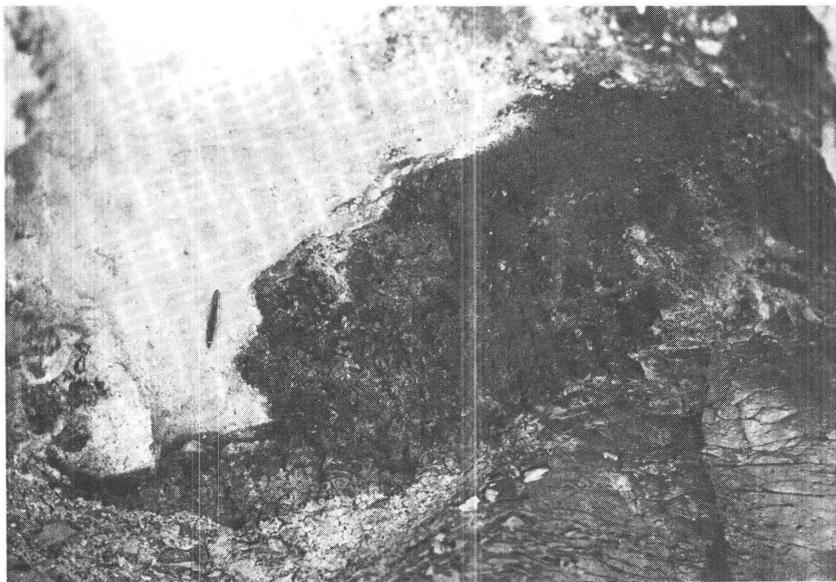


FIGURE 7.—Intrusive contact between rhyodacite of Sugar Loaf and sedimentary rocks of the Coso Formation. Flow banding and dark vitrophyric zone in rhyodacite are parallel to contact; columnar joints are perpendicular. Sugar Loaf is to right (west) in photo. Pick at contact gives scale.

tion at the south end of Haiwee Ridge (fig. 4; Duffield and Bacon, 1981; Duffield and others, 1980).

An approximately 30-cm-thick bed of reworked rhyolite pumice lapilli is present within sedimentary rocks of the Coso about 1.5 km northwest of the vertebrate fossil locality (fig. 1, loc. F) described by Stinson (1964). This material apparently came from the same volcanic source as the rhyolite ash flow, on the basis of phenocryst assemblage and rubidium, strontium, yttrium, and zirconium content (X-ray fluorescence analyses) of glass separated from pumice. Microprobe analyses show the oligoclase and sanidine to be similar to, but slightly more sodic than, the same phases in pumice from the ash-flow tuff (table 3). This observation is consistent with the idea that the bed of pumice lapilli represents the reworked air-fall component of the same eruption that resulted in emplacement of the ash-flow tuff (Hildreth, 1979). By similar reasoning, it is unlikely that the pumice lapilli are related to emplacement of the late Miocene rhyolitic plug-domes because feldspars from the only porphyritic rhyolite (table 3, loc. 69) are more sodic than would be expected if the reworked pumice lapilli were to represent an early phase of emplacement.

TABLE 3.—*Compositions of feldspars in silicic rocks*

[Compositions calculated from average analyses of phenocrysts determined with ARL-EMX electron microprobe. See Bacon and Duffield (1981) for operating conditions and data reduction techniques]

Locality	Sample No.	Weighted mean K-Ar age of deposit (million years)	Average composition of feldspar (mole percent)						Type of deposit
			Sanidine			Plagioclase			
			An	Ab	Or	An	Ab	Or	
F	9-90-2	- - -	Not present - - -			42.4	55.2	2.4	Pumice in water-laid tuff.
43	9-8-11	3.0	- - -do. - - - - -			41.2	56.5	2.3	Pumice in air-fall tuff.
48	13-113-6	3.0	- - -do. - - - - -			33.6	63.1	3.3	- - -Do. - - - - -
	9-90-1	- - -	0.5	30.5	69.0	11.9	82.8	5.3	Pumice in reworked tuff.
44	9-85-2	3.1	.6	26.5	72.9	15.5	79.4	5.1	Pumice in ash-flow tuff.
69	77CDG-70	5.9	.6	34.4	65.0	9.0	84.4	6.6	Pumiceous rhyolite from dome.

PLIOCENE RHYODACITIC PYROCLASTIC DEPOSITS

A thick sequence of porphyritic rhyodacite air-fall, ash-flow, and base-surge deposits overlies the rhyolite pumice deposits at the south end of Haiwee Ridge (Fig. 4; Duffield and others, 1979, 1980). These rhyodacite deposits were mapped as andesite tuff and breccia by Stinson (1977a). Biotite and plagioclase from pumice in correlative rhyodacite air-fall deposits from two widely separated localities in the

Coso Range yield a weighted-mean age of 2.99 ± 0.20 m.y. (Duffield and others, 1980; locs. 43 and 48). Fission-track ages of zircons from the pumice (table 2) are in good agreement with the potassium-argon age. This rhyodacite pumice is easily recognized by its biotite-hornblende-andesine phenocryst assemblage and thus provides a means for the correlation of sedimentary rocks throughout much of the Coso Range (fig. 1, this report; Duffield and Bacon, 1981; Duffield and others, 1980). Air-fall deposits of this rhyodacite pumice occur interbedded with coarse alluvial sedimentary deposits mapped as Coso in a series of grabens south of lat. $36^{\circ}15' N$ (Duffield and others, 1979).

Pumice studied by Evernden, Savage, Curtis, and James (1964; sample KA 451) from a water-laid tuff reported to be about 30 m stratigraphically above the Blanchan vertebrate fossil locality (fig. 1, loc. F) described by Schultz (1937; loc. 131) and Stinson (1964) is apparently reworked 3.0-m.y.-old rhyodacite air-fall tephra. We collected several rounded pumice lumps 1–5 cm in diameter from a bed of water-laid tuff believed to be that described by Evernden, Savage, Curtis, and James (1964). This pumice contains the same phenocryst assemblage as does that from Haiwee Ridge; glass separated from one large lump has contents of rubidium, strontium, yttrium, and zirconium (determined by X-ray fluorescence) that are closely similar to glass from pumice of the 3.0-m.y.-old rhyodacite air-fall tuff of Haiwee Ridge. Plagioclase phenocrysts in all Coso rhyodacitic rocks are complexly zoned; consequently, microprobe analyses of crystal fragments separated from pumice lumps are variable. Despite this fact, the average compositions determined by analyzing many grains are very similar for the pumice lumps from the water-laid tuff and for dated air-fall pumice (table 3), and this similarity provides further evidence for correlation. The large, rounded pumice lumps were probably derived from air-fall tuff shortly after its deposition. The possibility that the pumice was reworked much more recently is considered remote but cannot be ignored. Thus, the rocks containing the vertebrate fossils at this locality are probably about 3.0 m.y. old. Evernden, Savage, Curtis, and James (1964) determined the potassium-argon age of biotite from pumice lumps, apparently from the same outcrop of water-laid tuff. The biotite concentrate analyzed by them (sample KA 451) contained only 4 percent radiogenic ^{40}Ar and 3.87 percent K_2O . When recalculated using current decay constants (table 2), the original analytical data yield an age of 2.31 m.y. with a large unevaluated analytical error; we believe that this defines only an imprecise minimum age for the pumice because of the apparently altered or very impure nature of the biotite concentrate.

Wilson (1932) described a small rodent, *Cosomys primus*, from the same locality studied by Schultz (1937, loc. 131). He tentatively assigned a Pliocene (Blanchan) age to fossiliferous strata, on the basis of

horse material. Neville, Opdyke, Lindsay, and Johnson (1979), investigating the magnetic stratigraphy, radiometric age relationships, and fossil mammals of the Glens Ferry Formation in Idaho, determined an age of 3.75 m.y. for the lowest stratigraphic occurrence of *Cosomys*. According to C. A. Repenning (written commun., 1979) *Cosomys primus* from the Coso Formation is about 3.4 m.y. old. The pumice-bearing water-laid tuff appears to be no older than 3.0 m.y. Consequently, if the relation of the tuff to the fossiliferous strata is correct, a gap in the record may be present or an unusually low sedimentation rate may have pertained to the intervening period.

PLIOCENE RHYODACITE LAVA FLOWS

Several thick flows of porphyritic rhyodacite overlie both the rhyolite and rhyodacite pumice deposits of the Coso Formation in the vicinity of Haiwee Ridge (Duffield and Bacon, 1981; Duffield and others, 1980). These flows were described as andesite by Stinson (1977a) and Chesterman (1956). All the flows are similar in appearance and composition; the weighted mean of two biotite age determinations is 2.52 ± 0.05 m.y. (table 1, locs. 1 and 2; Duffield and others, 1980). This age is probably consistent with an age of 2.01 m.y. calculated from the original data of Evernden, Savage, Curtis, and James (1964, sample KA 1026) for low-potassium biotite from the northernmost flow. Duffield, Bacon, and Dalrymple (1980, loc. 51) were unable to obtain a meaningful age for either biotite or hornblende from the same locality studied by Evernden and coworkers (sample KA 1026). Some of the rhyodacite flows fill canyons in the underlying pyroclastic rocks of the Coso Formation (fig. 4; Duffield and others, 1980) and provide a minimum age of approximately 2.5 m.y. for the Coso Formation.

CONCLUSIONS

The potassium-argon ages of volcanic rocks that overlie, are interbedded with, and intrude the Coso Formation indicate that the formation includes strata that range in age from somewhat greater than 2.5 m.y. to at least 6.0 m.y. old and that the Coso Formation is Miocene and Pliocene in age. The oldest exposed part of the Coso Formation crops out from the north end of the Coso Range northeast to the Inyo Mountains. Sedimentary rocks of the Coso Formation northeast of the Coso Range contain a vertebrate fossil (*Agriotherium*) that is not younger than 4.8 m.y. old. The 3.0-m.y. age implied for the Blanchan fossil-bearing strata of the Coso in the Coso Range (fig. 1, loc F) described by Schultz (1937, locs. 131 and 284) is consistent with radiometric age

determinations on rocks associated with Blanchan faunas from other areas (C. A. Repenning, oral commun., 1978; Repenning, 1980); the 2.3-m.y. age calculated from the data of Evernden, Savage, Curtis, and James (1964) is probably a minimum age.

The age of the Owens Valley, the westernmost basin of the Basin and Range province, is of considerable significance to the history of Basin and Range extension. Fluvial and lacustrine deposits exposed northeast of the Coso Range indicate that a basin, possibly the tectonic precursor to the Owens Valley, began collecting sediment at least 6 m.y. ago. Crustal instability in the region is documented by the presence of arkosic sedimentary rocks and by the contemporaneous eruption of mafic and silicic volcanic rocks. Sedimentary rocks slightly older than 2.5 m.y. occur in the northwestern Coso Range and coarse 3-m.y.-old clastic sedimentary deposits are cut by graben-forming faults in the interior of the range. Volcanism began within the Coso Range approximately 4 m.y. ago (Duffield and others, 1980). The ages of volcanic and sedimentary rocks in southern Owens Valley show a shift from early volcanism and sedimentation (5-6 m.y.) on the north flank and northeast of the Coso Range to later volcanism, block faulting, and sedimentation (2.5-4 m.y.) within the range.

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