Rapid Eocene extension in the Robinson district, White Pine County, Nevada: Constraints from ^{40}Ar/^{39}Ar dating

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ABSTRACT

Precise ^{40}Ar/^{39}Ar ages on pretectonic, syntectonic, and posttectonic rhyolites from the Robinson mining district, which is within a highly extended domain in east-central Nevada, indicate that extreme extension (~400%) occurred in fewer than 900 k.y. during the Eocene. The duration of extension is tightly delimited by an Eocene lacustrine unit that was horizontal prior to extension and by younger rhyolitic units. The rhyolites represent at least five eruptive episodes, including the preextensional and synextensional rhyolite of White Hill emplaced between 37.6 and 37.4 Ma, and the postextensional rhyolite of Garnet Hill emplaced at 36.7 Ma, although some of it is perhaps as old as 37.1 Ma. Thus, the duration of extreme extension at Robinson was between 0.9 and 0.3 m.y., comparable to or shorter than other highly extended areas in western North America. The extensional domain in east-central Nevada is a composite feature, produced by localized, episodic, rapid extension that began in early Eocene time and continued to at least middle Miocene time.

Keywords: Ar/Ar, geochronology, extension, accommodation zones, rhyolite, tilting.

INTRODUCTION

The Basin and Range Province of western North America contains some of the world's best examples of extensional tectonism. Despite intense study, uncertainties and controversies persist regarding the kinematics of extension, the three-dimensional geometry of structures, the space-time patterns of strain, the role of magmatism, and the broader plate tectonic setting (Gans, 1987, 1997; Wernicke et al., 1987; Gans et al., 1989; Best and Christiansen, 1991; Seedorff, 1991; Axen et al., 1993; Gans and Bohrson, 1998).

Elongate belts within the Basin and Range have undergone much greater supracrustal extension (>100%) than intervening areas (Gans, 1987; Seedorff, 1991; Wernicke, 1992). Recent field and geochronologic studies indicate that much of the cumulative extension in highly extended domains occurs during one or more brief episodes of rapid strain (e.g., Gans and Bohrson, 1998).

In this paper we present new radiometric dates on extrusive and cogenetic, shallow intrusive, Tertiary volcanic rocks from the Robinson mining district. Robinson is located in the central Egan Range west of Ely, Nevada (Fig. 1). The district is part of an extensional accommodation zone within a highly extended domain that includes the Snake Range metamorphic core complex 50 km to the east.

The Robinson district affords an excellent opportunity to bracket the timing of extension. The three-dimensional structure is well understood from decades of surface, open-pit, and underground mapping and geologic logging of 10^6 m of drill holes. The exceptionally well defined Paleozoic stratigraphy, preextensional structures, intrusions, and alteration and grade patterns provide numerous structural markers and piercing points on faults. An Eocene lacustrine unit defines a horizontal surface prior to extension. Rhyolites were emplaced immediately prior to, during, and after a period of large-magnitude extension. Sanidines from these rhyolites provide more precise ^{40}Ar/^{39}Ar ages than ages determined for intermediate to mafic rocks used to bracket extension in other areas.

GEOLOGIC SETTING

Rock Types

A thick section of Proterozoic to Triassic miogeoclinal carbonate and clastic rocks crops out in east-central Nevada (Hose and Blake, 1976). These rocks were intruded by compositionally diverse magmas during the Jurassic, Cretaceous, and Paleogene (Miller et al., 1988; Barton, 1996). The Robinson district encompasses the Ely porphyry Cu-Mo-Au system, which is related to middle Cretaceous monzonitic intrusions (Bauer et al., 1966).

Jurassic to early Tertiary deformation in eastern Nevada generally was expressed as broad, open folds and a few faults of modest displacement (e.g., Gans and Miller, 1983). The age of this deformation

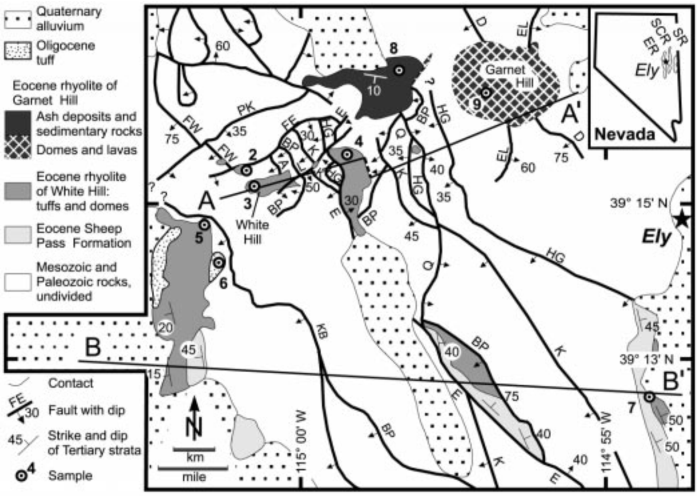

Figure 1. Simplified geologic map of Robinson district. Inset: ER—Egan Range, SCR—Schell Creek Range, SR—Snake Range. Fault abbreviations: A—Alpha, BP—Ball Park, D—Dit, E—Eureka, EL—Elijah, FE—Footwall East, FW—Footwall West, HG—High Grade, K—Keystone, KB—Kaibab, L—Liberty, PK—Pilot Knob, Q—Queen. Modified from Brokaw and Heidrick (1966), Brokaw (1967), Brokaw and Barosh (1968), and Brokaw et al. (1973).

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Geology; June 2001; v. 29; no. 6; p. 475–478; 3 figures; Data Repository item 2001050.

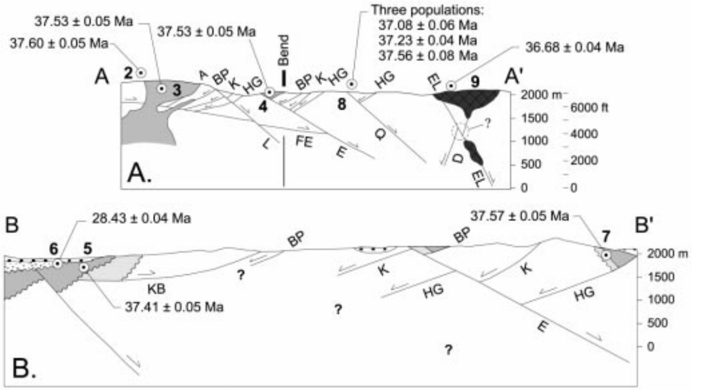

Figure 2. Simplified cross sections; numbered sample sites are projected into sections (locations and fault abbreviations as in Fig. 1). A: Section through heart of district illustrating sequence of cross-cutting relationships: (1) set of gently west dipping faults that includes High Grade, Keystone, Ball Park, and Alpha faults, which are cut and offset by (2) gently southeast dipping Footwall East fault, which is cut by (3) moderate to gently east dipping set that includes Eureka and Queen faults, in turn cut by (4) southeast-dipping Liberty fault. B: Dips of Tertiary strata indicate that western end of district was tilted westward and eastern end of district was tilted eastward. Note: Cross sections do not balance in detail in two dimensions because (1) not all faults are shown and (2) significant movement on some faults was into and out of planes of sections.

is not well determined, but Jurassic and at least two Cretaceous compressional events and local Mesozoic extensional events have been reported regionally (e.g., Miller et al., 1988; Camilleri and Chamberlain, 1997). Nonetheless, relationships at the early Tertiary erosion surface (Armstrong, 1972; Gans and Miller, 1983)—supported by a regional conodont alteration study (Gans et al., 1990)—provide clear evidence that major Mesozoic thrust faults did not break to the surface in east-central Nevada.

The oldest Tertiary unit, the Sheep Pass Formation, was deposited only on Permian units in the central Egan Range (Brokaw and Shawe, 1965; Brokaw and Heidrick, 1966; Brokaw, 1967), consistent with major thrust faults not surfacing in the area. The Sheep Pass Formation consists of a basal conglomerate overlain by lacustrine limestone. Fossils recovered from the study area confirm that these rocks are Eocene (Fouch, 1979, p. 108). Silicic volcanic rocks postdate the Sheep Pass Formation. Brokaw et al. (1973) recognized both an older rhyolite, which we term the rhyolite of White Hill, and a younger rhyolite, which we term the rhyolite of Garnet Hill. A younger tuff is present in the southwestern part of the study area.

Faults

Cretaceous alteration and mineralization in the Robinson district help distinguish different ages of faulting. There is no evidence for Tertiary hydrothermal alteration, other than vapor-phase alteration of the early intrusion at Garnet Hill. A few faults focused hydrothermal fluids of the Ely porphyry system and are thus middle Cretaceous or older. The overwhelming majority of faults in the district, however, cut and offset alteration mineralization and must be younger than middle Cretaceous. These Tertiary extensional faults severely dismembered and tilted the porphyry system, the Sheep Pass Formation, and some younger rocks (Fig. 2).

For tens of kilometers north of the district in the northern Egan Range, strata generally are west dipping and cut by east-dipping normal faults (Gans and Miller, 1983). In contrast, in the southern Egan Range, west-dipping faults cut east-dipping strata (see maps of Playford, 1961; Kellogg, 1964). The Robinson district is a complex area featuring normal faults of diverse orientations, including sets of earlier west-dipping and later east-dipping faults, like those of the southern and northern Egan Ranges, respectively. Tertiary rocks on the western side of the study area dip moderately westward, and those in the central and eastern parts of the area dip moderately to steeply eastward (Figs. 1 and 2). Hence, Robinson straddles a tilt-domain boundary and occupies an extensional accommodation zone (e.g., Faulds and Stewart, 1998). Fault reconstructions indicate extension of 400%.

SAMPLE DESCRIPTIONS AND GEOCHRONOLOGY RESULTS

Eight samples were collected, Ar2 through Ar9, as part of a larger $^{40}Ar/^{39}Ar$ geochronologic study of the district. The sample prefix Ar is dropped in the remainder of the paper.

Samples were prepared and analyzed at the University of California, Santa Barbara, following procedures described by Gans (1997). Detailed step-heating experiments and single-grain fusions were performed on purified sanidine separates. The $^{40}Ar/^{39}Ar$ ages presented here are reported as integrated total-gas ages (total fusion ages) of 12- to 14-step incremental step-heating experiments $\pm 2\ \sigma$ errors, which are generally indistinguishable from the weighted-mean plateau ages (Table A-1[1]). The single-crystal laser-fusion ages reported are means of individual analyses $\pm 2\ \sigma$ standard error of the mean. The age spectra of samples 2, 3, 4, 6, and 9 are slightly U-shaped spectra with flat central segments, typical of sanidine. Samples 5, 7, and 8 were either petrographically suspect or produced highly disturbed spectra and are discussed further in the following.

Rhyolite of White Hill

The rhyolite of White Hill consists of small-volume extrusive units, reworked pyroclastic rocks, and cogenetic vents of rhyolite flow-domes and diatremes (Bauer et al., 1966). The complex, exposed in the center of the Robinson district (sample 3; Fig. 1), was structurally beheaded by the Eureka fault. In the hanging-wall block, lavas overlie an apron of cogenetic pyroclastic rocks (sample 4) and locally are overlain conformably by conglomerates, sandstones, and mud flows. Smaller shallow intrusive bodies are scattered across the district (Fig. 1).

Extrusive rocks of the rhyolite of White Hill are also found to the south in three fault blocks along section B-B′ (Figs. 1 and 2). The western block contains both glassy, flow-banded lavas and pyroclastic rocks, whereas only pyroclastic rocks are exposed in the central and eastern blocks. In the western block, the pyroclastic rocks generally dip 10°–25° more gently than the underlying lacustrine rocks of the Sheep Pass Formation and in part directly overlie Permian rocks. In the central block, the pyroclastic rocks are apparently conformable with the underlying Sheep Pass Formation. In the eastern block, pyroclastic rocks are conformable with the Sheep Pass Formation, and a small bed of lacustrine limestone is interbedded in the lower few meters of the pyroclastic rocks.

Intrusive rocks of the rhyolite of White Hill include multiple bodies of glassy to holocrystalline rhyolite. The larger masses are typically phenocryst poor, but smaller dikes may be phenocryst rich. Shallow intrusive rocks range from inclusion-free rhyolite to a rhyolite breccia that may contain in excess of 70% heterolithic fragments of wall rock. Some intrusions clearly intruded the High Grade, Keystone, Ball Park, Footwall West, and Footwall East faults, which cut alteration and mineralization (Figs. 1 and 2).

The pyroclastic rocks of White Hill resemble small-volume unwelded ash flows. They contain abundant white pumice and typically 5% lithic fragments, both rhyolitic and pre-Tertiary. The nearly ubiq-

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[1] GSA Data Repository item 2001050, Ar-Ar and K-Ar age data and Ar-Ar step-heating plots, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, editing@geosociety.org, or at www.geosociety.org/pubs/ft2001.htm.

uitous presence of glassy, rhyolitic lithic fragments, well-developed stratification, and local presence of boulder-rich beds suggest that these pyroclastic deposits represent an assemblage of block and ash flows, pumice-fall deposits, and reworked tuffaceous sediments associated with growth and periodic collapse of extruding rhyolite domes.

Pyroclastic rocks near sample site 7 contain lithic fragments of Paleozoic sedimentary rocks, Cretaceous monzonite porphyry, and their altered and mineralized equivalents. The only known source for these monzonite clasts and related altered rocks is the Robinson mining district; this strengthens the link between the pyroclastic rocks and the rhyolitic intrusions at Robinson.

Samples 2, 3, 4, 5, and 7 define the age of the rhyolite of White Hill (Fig. 1). Sample 3, in the footwall block of the Eureka fault—the root of the beheaded flow-dome complex at White Hill—yielded a ^{40}Ar/^{39}Ar age of 37.53 ± 0.05 Ma. Sample 4, from the top of the complex in the hanging-wall block of the fault, yielded an identical age of 37.53 ± 0.05 Ma. Sample 2, from a small glassy rhyolite dike northwest of White Hill, yielded an age of 37.60 ± 0.05 Ma. One split of sample 7, from the pyroclastic rocks in the eastern fault block, was contaminated by Cretaceous K-feldspar from exotic clasts, but a subsequent three-grain split yielded an age of 37.57 ± 0.05 Ma. Sample 5, from White Hill rhyolite that overlies Sheep Pass Formation in slight angular unconformity in the western fault block, yielded a simple spectrum with a slightly younger age of 37.41 ± 0.05 Ma. This date was confirmed by three single-grain total-fusion ages that are within analytical error of the bulk sample data.

All dates on the rhyolite of White Hill are middle Eocene. Samples 2, 3, 4, and 7 are essentially indistinguishable in age, and sample 5 is only 120–190 k.y. younger. The new ^{40}Ar/^{39}Ar ages broadly agree with a K-Ar date of 38 ± 1 Ma on biotite from a rhyolite dike located northeast of White Hill (McDowell and Kulp, 1967, recalculated for new decay constants; Dalrymple, 1979).

Rhyolite of Garnet Hill

The rhyolite of Garnet Hill consists of a composite shallow intrusion, several small elongate dikes, and related pyroclastic and reworked pyroclastic strata. The unit is named for the younger rhyolitic flow-dome complex that crops out as a circular mass at Garnet Hill (Fig. 1).

Garnet Hill is primarily a crystal-poor rhyolite with intense vapor-phase alteration—famous for lithophysal almandine-spessartine garnets (Pabst, 1938; Hollabaugh and Purcell, 1987)—and is not amenable to radiometric dating. The core of the dome subsequently was intruded by an unaltered, crystal-rich (~25% phenocrysts) rhyolite. The dome is flanked by an apron of pyroclastic rocks, fluvially reworked deposits, and small dikes (Fig. 1).

The dome's circular outline supports the contention that it has not been dismembered by major faults, in contrast to the dome at White Hill. The Garnet Hill complex clearly cuts off earlier faults (Figs. 1 and 2). Furthermore, the tuffaceous strata derived from the dome generally dip within 10° of horizontal, crop out continuously over relatively large areas, and overlie a variety of older rock units in marked angular unconformity. These strata mantle several major normal faults, including some of the same faults that dismember the White Hill complex, and are cut by only a few, small-displacement faults.

The age of Garnet Hill previously was thought to be Pliocene (Pabst, 1938) or middle Tertiary (Brokaw et al., 1973), although an earlier K-Ar biotite date of 37.3 ± 1.4 Ma indicated that it might be Eocene (Table A-2; see footnote 1). Samples 8 and 9 support an Eocene age. Sample 8 is from a well-bedded, pumice-rich deposit that shows petrographic evidence of extensive reworking. Total fusions were performed on 10 individual sanidine grains, which yielded three distinct age populations: 37.08 ± 0.06, 37.23 ± 0.04, and 37.56 ± 0.08 Ma. This rock is interpreted to be a mixture of pyroclastic material derived from eruptions of slightly different ages, but as a rock unit, it can be no older than the age of the youngest known population, 37.08 Ma. Sample 9, from the unaltered core of the dome, yielded a ^{40}Ar/^{39}Ar plateau age of 36.68 ± 0.04 Ma.

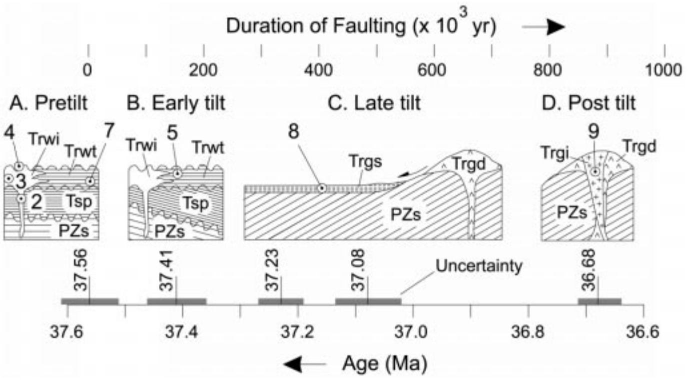

Figure 3. Schematic time line. A: Pretilt: in early eruptions, rhyolite of White Hill (Trwt), which has cogenetic dikes and lavas (Trwi), was deposited on lacustrine rocks of Sheep Pass Formation (Tsp), which had been deposited unconformably on Paleozoic sedimentary rocks (PZs). B: Early tilt: pyroclastic rocks (also Trwt) were subsequently deposited with slight angular unconformity on parts of Sheep Pass Formation. C: Late tilt: reworked tuffs (Trgs) related to vents of rhyolite of Garnet Hill (Trgd) are only slightly tilted. D: Posttilt: a subvolcanic intrusion (Trgi) is emplaced into core of rhyolite dome at Garnet Hill (Trgd); dome cuts youngest major faults and is upright and intact.

Unnamed Volcanic Rock

An unnamed silicic tuff from the upper part of the volcanic section in the western fault block yielded an Oligocene age of 28.43 ± 0.04 Ma (Figs. 1 and 2). This unit could be the distal part of a regional ash-flow tuff.

DISCUSSION

The ^{40}Ar/^{39}Ar geochronologic data indicate that Eocene magmatism in the Robinson district spanned ~900 k.y. This short span, with at least five episodes of eruption at 37.56 ± 0.03 Ma (mean of five samples), 37.41 ± 0.05 Ma, 37.23 ± 0.04 Ma, 37.08 ± 0.06 Ma, and 36.68 ± 0.04 Ma, brackets the period of extreme extension (Fig. 3).

The rhyolite of White Hill dates the inception of faulting. Significant extensional deformation could not have begun prior to ca. 37.57 Ma, when pyroclastic rocks were deposited conformably on lacustrine rocks (Fig. 3). Tilting of the lacustrine rocks must have begun by ca. 37.41 Ma, as evidenced by slight angular unconformity in the western area. The rhyolite of Garnet Hill dates the termination of significant extensional faulting, which likely terminated by 37.08 Ma. Major faulting must have ceased before emplacement of the vapor-phase–altered dome at Garnet Hill, which was subsequently intruded ca. 36.68 Ma (Figs. 2 and 3).

To summarize the structural implications of the study, extreme extension began between ca. 37.57 and 37.41 Ma, persisted at least until 37.41 Ma, could have terminated by 37.08 Ma, and definitely ended before 36.68 Ma. The maximum span of significant normal faulting is between 37.57 and 36.68 Ma ($<$890 k.y.). Faulting was active at least between 37.41 and 37.08 Ma ($>$330 k.y.), and likely between 37.56 and 37.08 Ma ($>$480 k.y.).

For comparison, extreme extension occurred within 1.1 m.y. at Questa, New Mexico (Meyer and Foland, 1991). In southern and southwestern Nevada, it occurred within 0.9–1.0 m.y. in the Eldorado Mountains (Gans and Bohrson, 1998) and within 2 m.y. in the Bullfrog Hills (Maldonado, 1990). For two areas in west-central Nevada, most of the extension is bracketed within 0.7–1.7 m.y. in the Yerington district (Dilles and Gans, 1995) and within 0.2 m.y. in the southern Stillwater Range (Hudson et al., 2000). Brief periods of rapid strain may be the rule for highly extended domains, of which the Robinson area has one of the shortest documented.

As the magnitude, timing, and style of extension in east-central Nevada have been deciphered, it has become apparent that this extensional domain is a composite feature that developed episodically and diachronously. Extension is now known to have affected specific areas within the domain in the middle Eocene, late Eocene, and early Miocene (e.g., Gans et al., 1989; Miller et al., 1999; Gans and Calvert, 2000). In some cases, later extensional events are superimposed on earlier ones (e.g., Snake Range), whereas only a single episode is recorded in others (e.g., Robinson). These shifting loci of short-lived extension imply a complex strain field during Cenozoic evolution of the area.

ACKNOWLEDGMENTS

We thank Libby Gans, Andy Calvert, and Mike Gutierrez for help with mineral separations, analyses, and drafting, and John-Mark Staude, Tim Marsh, Mark Anders, and Neil Mancktelow for helpful reviews. We acknowledge the contributions of the Robinson geologic team, especially Dick Breitrick, and the support of Magma Copper Company and BHP Copper.

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Manuscript received September 29, 2000
Revised manuscript received February 6, 2001
Manuscript accepted February 9, 2001

Printed in USA