1.08 Ga diabase sills in the Pahrump Group, California: Implications for development of the Cordilleran miogeocline

Miogeocline = miogeosyncline = obsolete pre-plate-tectonics term for a rift

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ABSTRACT

U-Pb baddeleyite ages of 1087 ±3 and 1069 ±3 Ma for two diabase sills that intrude the Crystal Spring Formation of the Pahrump Group, southeastern California, provide a minimum estimate for the depositional age of the Crystal Spring Formation. The new ages highlight the potential range in deposition ages for the Pahrump Group, from ⩾1087 Ma to possibly as young as 600 Ma for Kingston Peak glaciogenic sediments. Consequently, there probably are significant disconformities within the Pahrump Group that separate unrelated, tectonically distinct episodes of basin subsidence. The Crystal Spring and Beck Spring Formations are considered to be platform-cover rocks preserved as a result of block faulting during deposition of the upper Kingston Peak Formation. The age of the Pahrump sills is in excellent agreement with the age of sills that intrude the Apache Group (central Arizona) and the Unkar Group (Grand Canyon) and supports earlier correlations of those units.

INTRODUCTION

The Pahrump Group is a succession of Middle to Late Proterozoic sedimentary rocks exposed in the highly extended Death Valley region of southeastern California. The succession commonly is interpreted to represent rift-basin fill deposited during the early development of the Cordilleran miogeocline (e.g., Burchfiel and Davis, 1972; Wright et al., 1976). Estimates for the timing of initial rifting in the U.S. part of the Cordillera range from as old as 1400 Ma (Burchfiel and Davis, 1972, 1975; Burke and Dewey, 1973) to ~850 Ma (Stewart, 1972), or as young as Early Cambrian (Bond et al., 1984). This broad range of estimates results in part from the paucity of direct age constraints on the Pahrump Group and other Proterozoic successions of the southern Cordillera (Apache Group, Arizona; Unkar and Chuar Groups, Grand Canyon; Belt-Purcell Supergroup, Montana and adjacent Canada). The lack of time control also serves to obscure recognition of superimposed, possibly unrelated episodes of basin subsidence separated by substantial disconformities that have been previously unappreciated.

In order to decipher the history of early tectonic events that controlled the Cordilleran miogeocline, it is essential to obtain accurate age constraints on stratigraphic successions within the individual Proterozoic basins. Prior to this study there were no reliable direct age constraints on the Pahrump Group; ages have been inferred principally through correlation of diabase sills that intrude the lower Pahrump to similar sills that intrude the Apache Group (Wrucke and Shride, 1972), which have U-Pb zircon ages of about 1.1 Ga (Silver, 1978). However, diabase sills also intrude the lower part of the Belt-Purcell Supergroup but have yielded U-Pb zircon ages in the range of 1.435 to 1.455 Ga (Zartman et al., 1982; Hoy, 1989). These results demonstrate that correlations based on lithology alone should be scrutinized by independent tests, thus providing the motivation for this study. We report U-Pb baddeleyite ages for two diabase sills that intrude the lower unit of the Pahrump Group (Crystal Spring Formation), and we comment on the significance of these ages, both in terms of regional stratigraphic correlations and the timing of Cordilleran miogeocline development.

GEOLOGIC SETTING

The Pahrump Group is an ~3- to 4-km-thick succession of marine and nonmarine sedimentary rocks (Hewett, 1940; Wright and Troxel, 1967) that unconformably overlie crystalline basement deformed and metamorphosed at about 1.7 to 1.6 Ga and intruded by anorogenic granites at about 1.4 Ga (Lanphere et al., 1964; Labotka et al., 1980). The Pahrump Group is subdivided into three formations. The Crystal Spring Formation is lowest and consists of shallow-marine to fluvial siliciclastic and minor carbonate facies, intruded by diabase sills (Roberts, 1976). Next is the Beck Spring Formation, a well-developed carbonate-platform unit that includes deeper water basinal and slope-deposited micrites shallowing to oolitic and stromatolitic peritidal facies (Gutstadt, 1968; Marian, 1979; Shafer, 1983). The uppermost unit is the siliciclastic-dominated Kingston Peak Formation, which includes coarse conglomerates, diamictites, and breccias, in part glaciogenic, deposited in deep-water to alluvial environments (Miller, 1985; Miller et al., 1988).

The distribution of Pahrump Group rocks in a northwest-trending belt 150 km long and 60 km wide led Wright et al. (1976) to interpret the Pahrump basin as an aulocogen, characterized by episodic, long-lived subsidence. However, the principal evidence for syndepositional normal faulting occurs in the middle to upper part of the Kingston Peak Formation where scarp-derived fanglomerates have been noted (Miller, 1985; Walker et al., 1986). It is significant that the fanglomerate contains clasts of all the stratigraphically underlying formations, including the diabase sills of the Crystal Spring Formation. The facies of the Crystal Spring or Beck Spring Formations do not show convincing evidence for syndepositional normal faulting, and Roberts (1976) noted "remarkable persistence" of facies within the lower half of the Crystal Spring Formation. Finally, when the significant Tertiary extension that characterizes the Death Valley region is restored (Wernicke et al., 1988; Levy and Christie-Blick, 1989), the corrected length of the "basin" might have been 60% of its present value, and its geometry more equant than elongate. Such relations suggest perhaps that the Crystal Spring and Beck Spring Formations are remnants of a cratonic cover sequence that was disrupted during block faulting associated with deposition of the middle to upper Kingston Peak formation.

SAMPLE LOCATIONS AND DESCRIPTION

The Middle Proterozoic sills in the southwestern United States typically are medium- to coarse-grained diabases or olivine diabases with well-developed subophitic texture (Hammond, 1990). In many sills, primary clinopyroxene and plagioclase have been altered to an assemblage consisting of hornblende + sericite ± actinolite ± chlorite ± biotite (Hammond, 1990). Diabase sills in the Pahrump Group are restricted to the Crystal Spring Formation and have not been observed in stratigraphically higher units (Wright, 1968; Wright et al., 1976). The sills are up to 450 m thick, and contact skarns are commonly developed where the sills intrude adjacent to carbonate beds (Roberts, 1976; Hammond, 1986; Wright, 1968). Wright (1968) and Hammond (1986) suggested that Crystal Spring Formation sediments may have been wet and unconsolidated at the time of sill intrusion.

Two diabase sills that intrude the Crystal Spring Formation were selected for a U-Pb baddeleyite study. The first sample (54-1014, 1.35 kg) is from an ~80-m-thick medium- to coarse-grained gabbroic part of a sill that intrudes the lower Crystal Spring Formation exposed at the Saratoga Springs rest stop at the southern end of the Black Mountains (Fig. 1; hereafter referred to as the Saratoga Springs sill). The second sample (LH91-1, 12.68 kg) was collected from a sill in the northwest part of the Kingston Range, about 1 km east of Crystal Spring and about 50 km east of the Saratoga Springs locality (Fig. 1; hereafter referred to as the Kingston Range sill). This sill is gabbroic, ~50 m thick, and the sample site is an irregularly shaped, coarse-grained to pegmatitic zone located ~10 m below the top of the sill.

U-Pb RESULTS

The procedures for separating baddeleyite from rock samples, isolating U and Pb from baddeleyite, and analyzing the isotopic composition of these purified elements on a VG354 mass spectrometer are documented elsewhere (Heaman and Machado, 1991). Error estimation for individual analyses was calculated by propagating all known sources of uncertainty; errors are listed at 1σ in Table 1. Regression lines and age uncertainties (2σ) were calculated by using the program of Davis (1982). The decay constants for ^{238}U ($1.551\,25 \times 10^{-10}$) and ^{235}U ($9.848\,5 \times 10^{-10}$) and the isotopic composition of U ($^{238}U/^{235}U$ = 137.88) are the values determined by Jaffey et al. (1971).

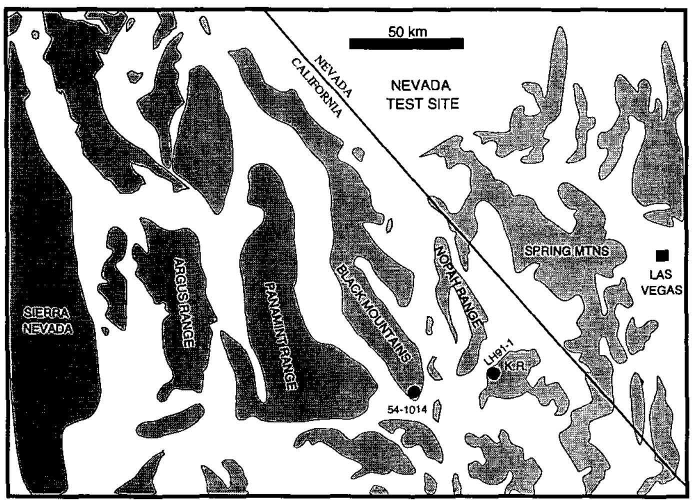

Figure 1. Location of diabase sills collected in this study. Sample 54-1014, southern end of Black Mountains; sample LH91-1, northwest Kingston Range. K.R. = Kingston Range.

Baddeleyite recovered from the Saratoga Springs sill occurs as tiny (40–80 μm), light yellow blades that commonly contain fractures and turbidity (interpreted as alteration related). In addition, many baddeleyite crystals are coated with a sporadic development of botryoidal zircon growth that likely formed during recent, low-temperature fluid interaction. This zircon growth, which is best revealed through scanning electron microscope backscatter imaging, rarely forms complete rims on baddeleyite and is unlike the metamorphic zircon found in coronitic gabbros (Davidson and van Breemen, 1988).

The U-Pb results for three baddeleyite fractions from this sill are presented in Table 1 (fractions 1–3) and Figure 2. All three fractions contain abundant U (477–549 ppm) and together define a discordia line with an upper-intercept age of 1069 ±3 Ma and a lower-intercept age of 65 Ma. These fractions are unusually discordant for baddeleyite (11%–19% along the best-fit regression line), indicating significant Pb loss in baddeleyite or, more likely, growth of young zircon (ca. 65 Ma) as a coating on the surface of the baddeleyite. Nevertheless, the upper-intercept age is interpreted as a good estimate for the time of sill emplacement.

The Kingston Range sill produced abundant euhedral, light yellow baddeleyite blades. The baddeleyite population in this sample has a slightly larger range in grain size (40–100 μm), contains abundant U (55–634 ppm), and commonly contains fractures, turbidity, and only minor zircon growth on the crystal faces. The U-Pb results for three baddeleyite fractions (4–6 in Table 1) are shown in Figure 2. The least discordant fraction (6) corresponds to the least magnetic grains with negligible visible turbidity. These three fractions are between 3.8% and 8.7% discordant and yield a slightly older upper-intercept age of 1087 ±3 Ma, interpreted as the time of sill emplacement.

DISCUSSION

Timing of Pahrump Group Deposition

The U-Pb baddeleyite age results obtained for two diabase sills that intrude the Pahrump Group indicate that sill emplacement occurred be-

TABLE 1. U-Pb BADDELEYITE RESULTS FOR PAHRUMP GROUP GABBRO SILLS

			Concentration			Atomic ratios+					Apparent age (Ma)			
Fraction no.	Description*	Weight (μg)	U (ppm)	Pb (ppm)	Common Pb (pg)	$^{206}Pb/^{204}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	disc.# (%)
Saratoga Springs sill (54-1014)														
1	3M, (30)	10	549	83	26	2610	0.0393	0.15438 ±22	1.5926 ±21	0.07482 ±5	925	967	1064	14.0
2	1M, (33)	8	477	71	29	1309	0.0418	0.14746 ±22	1.5168 ±23	0.07460 ±4	887	937	1058	17.3
3	1M, (94)	31	488	79	117	1460	0.0387	0.16248 ±15	1.6760 ±16	0.07481 ±2	971	1000	1064	9.4
Kingston Range sill (LH91-1)														
4	3M, (35)	15	600	100	35	2942	0.0301	0.17219 ±24	1.7875 ±24	0.07529 ±6	1024	1041	1076	5.2
5	3M, (115)	50	634	105	62	5733	0.0353	0.17132 ±65	1.7746 ±67	0.07512 ±7	1019	1036	1072	5.3
6	1M, (17)	29	545	93	24	8045	0.0260	0.17831 ±13	1.8561 ±14	0.07549 ±2	1058	1066	1082	2.4

* 3M = Frantz Isodynamic Separator magnetic split at 1.7 amps and 3° side tilt. Numbers in parentheses are the total number of grains analyzed.
+ Corrected for blank (Pb = 2pg; U = 1pg) and initial common Pb. The isotopic composition of the common Pb in excess of blank was calculated by using the model of Stacey and Kramers (1975).
# Percent discordance along a discordia line to zero age.

tween 1087 and 1069 Ma. These ages provide a minimum estimate for the depositional age of the Crystal Spring Formation. If the sediments were wet and unconsolidated at the time of sill intrusion, as suggested by Wright (1968) and Hammond (1986), the ages may approximate the time of Crystal Spring deposition.

These results provide a context for reevaluating the age and significance of other Pahrump units. Previously, all units in the Pahrump Group have been considered to be conformably stacked (e.g., Miller et al., 1988) on the basis of "interfingering" contact relations between units. However, little information (e.g., detailed bed-by-bed measured sections across contacts) is provided to support this conclusion. If the glaciogenic diamictites of the upper Kingston Peak Formation correlate with the ~700–600 Ma glacial event (Miller et al., 1988), then the Pahrump Group would represent continuous sedimentation for a span of over 350–450 m.y., an interval nearly equivalent to the Phanerozoic Eon. We find this conclusion improbable on empirical grounds (cf. Sadler, 1981) and suggest that the Pahrump Group must contain major disconformities as cautioned by Christie-Blick et al. (1988). Consequently, we suggest that the Crystal Spring and Beck Spring Formations are unrelated and constitute two distinct phases of basin development.

It is also possible that the top of the Beck Spring Formation is a substantial disconformity. A karstic surface and incised valley fill occur between the Beck Spring and overlying Kingston Peak Formations near the Jupiter Peak area of the northern Kingston Range (J. Grotzinger and N. Christie-Blick, unpublished data), and Kenny et al. (1990) presented isotopic evidence for weathering and ground-water recharge along a similar (possibly the same) subaerial exposure surface at the top of the Beck Spring Formation. Recent work by Horodyski and Mankiewicz (1990) has shown the presence of possible calcified algae in the upper Beck Spring–lower Kingston Peak Formations. The occurrence of possible calcified algae in close proximity to glaciogenic sediments indicates that the section may be on the order of about 600 Ma, an age that seems to characterize the youngest glacial episode of the late Proterozoic (Harland, 1983; Conway Morris, 1988).

Walker et al. (1986) suggested that the upper part of the Kingston Peak Formation was strongly influenced by block faulting associated with regional transtension. Evidence includes reworking of older Pahrump units (including sills) to form scarp-related fanglomerates adjacent to basin margins (Miller, 1985). We suggest that this constitutes the only strong evidence for block faulting *during* sedimentation of the Pahrump Group, and it was at this time that older stratigraphic units, originally deposited over much broader areas, were broken up and preserved in structural depressions; uplifted areas were stripped to older crystalline basement prior to deposition of the Noonday Dolomite. Adjacent to scarps, erosional detritus was shed into troughs to form the upper Kingston Peak Formation, a unit that is probably completely unrelated to underlying units of the Kingston Peak. As suggested by Walker et al. (1986), the upper Kingston Peak Formation may represent the inception of rifting that led to the ultimate development of the miogeocline. The timing estimates discussed above would constrain this rifting event to be younger than about 600 Ma, thus supporting the backstripping results that predicted continental breakup ages of about 590 Ma (Bond et al., 1984; Christie-Blick and Levy, 1989).

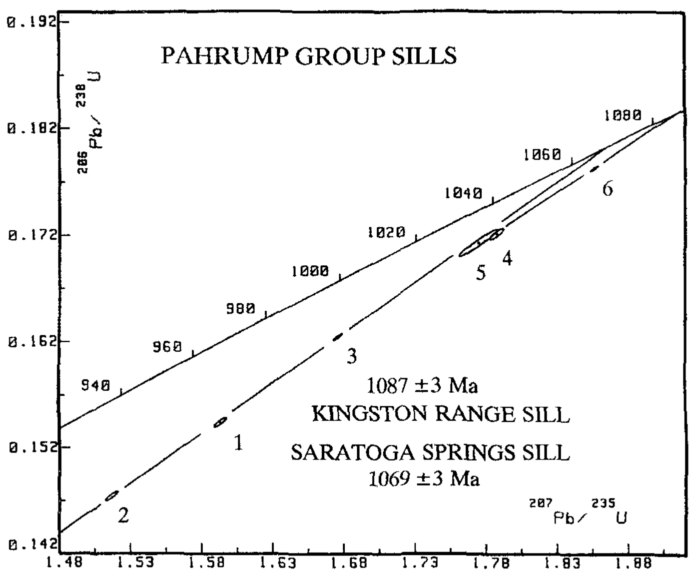

Figure 2. U-Pb concordia diagram showing baddeleyite results for two gabbro sill samples that intrude Crystal Spring Formation. Fractions 1–3 are from Saratoga Springs sill, and 4–6 are from Kingston Range sill. The 2σ error ellipses show analytical uncertainty for each analysis calculated by propagating all known sources of error.

Interregional Correlations

The Pahrump sill ages are in excellent agreement with U-Pb zircon and baddeleyite ages for the sills of central Arizona, located 450 km to the east of the Death Valley region. Silver (1978) reported U-Pb zircon ages averaging 1100 Ma in the Little Dragoon Mountains and 1120 Ma in the Sierra Ancha where the sills intrude the Apache Group. Pegmatitic gabbro from the sills of the Sierra Ancha was studied in more detail by Shastri et al. (1991), who reported U-Pb baddeleyite and zircon ages of 1100 ±2 Ma and an apatite age of 1.10 Ga. The age of the Pahrump sills is also in agreement with less precise Rb-Sr ages obtained for diabase sills that intrude the Unkar Group (1070 ±30 Ma; Elston and McKee, 1982), located in the Grand Canyon, 350 km to the east of the Death Valley region. This close age comparison supports the correlation of the Crystal Spring Formation with the Apache Group, as originally suggested by Wrucke and Shride (1972), and also with the Unkar Group. In contrast, correlation of the Pahrump Group with at least the lower part of the Belt-Purcell Supergroup is not supported by U-Pb zircon ages of 1445 ±11 and 1433 ±10 Ma for the Moyie sills in the Prichard-Aldridge sequence, British Columbia, and the Crossport C sill, Idaho, respectively (Zartman et al., 1982; Hoy, 1989). It is possible that the Crystal Spring Formation may correlate with the upper part of the Belt-Purcell, on the basis of K-Ar ages on sills that intrude the Helena Formation and are believed to be comagmatic with basaltic lavas higher up in the section (Hunt, 1962). However, there is a distinct possibility that these K-Ar ages represent reset ages and are indiscriminant (Hoy, 1989). As suggested by others (e.g., Stewart, 1972; Miller, 1985), it is likely that the Kingston Peak Formation correlates with other glaciogenic and rift-related sequences in the Cordillera and thus is of "Windermere age" and postdates the Belt-Purcell Supergroup.

Finally, the U-Pb ages for the Pahrump and Apache Group sills support the contention of Howard (1991) that, on the basis of the Pahrump-Apache correlation of Wrucke and Shride (1972), extensive, initially horizontal diabase sheets were intruded over a broad region of the southwest United States at about 1.1 Ga. Furthermore, the age of this magmatism coincides exactly with the timing of volcanism in the mid-continent rift system (1108–1087 Ma; e.g., Davis and Sutcliffe, 1985; Palmer and Davis, 1987; Davis and Paces, 1989), consistent with sill emplacement during crustal extension that occurred over a large part of North America (Wrucke, 1989; Hammond, 1990). However, the tectonic setting of the Pahrump-Apache sills is currently a controversial issue, and Howard (1991) has suggested that the uniformly subhorizontal orientation of the sills requires vertical rather than horizontal extension.

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Notes