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Ongonite and topazite dikes in the Flying W ranch area, Tonto basin, Arizona

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ABSTRACT

Topaz-rich ongonite and topazite dikes cut rocks of the Proterozoic Alder Group in the Flying W ranch area, 12 km west of Young, Arizona. The main ongonite dike, composed dominantly of quartz, topaz, and sodic plagioclase, is mineralogically similar to ongonites described from Mongolia and the Transbaikal region of the USSR. The topazite dikes, composed predominantly of quartz and topaz, are mineralogically and compositionally similar to topazite from the New England district, New South Wales, Australia. The two types of dikes in the Flying W ranch area grade into each other over a few meters. This is the first reported occurrence of either of these rock types in North America, and their first reported occurrence together.

Field, textural, mineralogical, and geochemical evidence suggests a dominantly magmatic genesis for both ongonite and topazite dikes. This evidence includes crosscutting relations with Alder Group rocks, chilled and flow-foliated dike margins, xenoliths of Alder Group rocks along dike margins, and dike topaz with an igneous texture and geochemical signature.

The melts that formed these dikes are believed to be extreme differentiates of an F-rich granitic magma. The paucity of aplitic and pegmatitic textures in the dike rocks indicates that the melts were relatively "dry" (not accompanied by an immiscible fluid phase) upon their emplacement as dikes. Crystallization was, however, accompanied by the exsolution of a late fluid phase that altered surrounding Alder Group rocks. These fluids, enriched in Be, F, B, K, and Na, formed two areas of significant alteration and mineralization referred to as the Breadpan and Dysart areas. The discovery of acicular blue beryl in zones altered to tourmaline, quartz, alkali feldspar, and fluorite prompted exploration of both areas in the early 1960s.

Topaz was discovered in a unit of the Alder Group in the 1950s. The topaz occurs with quartz, sericite, and fluorite as microveinlets cutting metamorphosed rhyolite tuff and nearby rocks. It is considered to be a product of the mineralizing event above, rather than a primary, vapor-phase mineral.

Dike emplacement and associated mineralization appears to have occurred after the Mazatzal orogeny (1715 Ma) and before the deposition of Apache Group rocks (1100 Ma).

INTRODUCTION

In the Flying W ranch area, Proterozoic Alder Group rocks host a series of topaz-rich dikes and associated Be-F mineralization. The area is located 12 km west of Young and 26 km southeast of Payson, Arizona, in the Tonto basin, a part of Arizona's Transition zone (Pierce, 1985; see Fig. 1).

Beryllium mineralization, in the form of blue, acicular beryl, was discovered at two localities in the Flying W ranch area (Breadpan and Dysart areas, see Fig. 2) in the early 1960s (Smith, 1962; Meeves, 1966). At a third location, here referred to as the Spring Creek locality (see Fig. 2), L. T. Silver discovered minute grains of topaz ($Al_2SiO_4(F,OH)_2$) in heavy-mineral separates from a metarhyolite unit (Flying W rhyolite) in the Alder Group (cited in Conway, 1976). The occurrence of topaz in seemingly unaltered rhyolite and the proximity of this rhyolite to Be-F mineralization led Burt et al. (1982) to suggest that the Flying W rhyolite might be a Precambrian analogue to Tertiary topaz rhyolites of the western United States and Mexico (Christiansen et al., 1983, 1986). A recognized problem with this proposal was the fact that topaz in the Flying W Formation occurs in a metamorphosed rhyolitic tuff, whereas topaz in Tertiary topaz rhyolites is nearly always found in lava.

This study was initiated to determine the origin of the topaz in the Flying W rhyolite. The discovery of topaz-rich dikes in both the Dysart and Breadpan areas prompted expansion of this study to include the petrogenesis of the dikes and their relation to mineralization.

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Fig. 1. Location map of study area showing Arizona's physiographic provinces (redrawn from Pierce, 1985).

ROCK UNITS

Alder Group

Both the Be-F mineralization and topaz-rich dikes in the Flying W ranch area are contained within the two lowermost members of the Alder Group, the Breadpan and Flying W Formations. These two formations consist of metamorphosed volcanic and clastic sedimentary rocks that exhibit near-vertical dips and are, as a rule, well-foliated. Metamorphism and deformation of these rocks took place during the Mazatzal orogeny (Wilson, 1939), between 1660 and 1715 Ma (Silver, 1964).

Rocks of the Alder Group were first mapped, and formations and units first named, by R. G. Gastil (1954). More detailed descriptions of these rocks can be found in Gastil (1958), Conway (1976), and Sherlock (1986).

Breadpan Formation. The Breadpan Formation, named by Conway (1976) for extensive exposures in Breadpan Canyon and previously referred to as the Alder Formation (Gastil, 1954), is composed entirely of meta–clastic rocks finer than cobble conglomerate (Conway, 1976). In Breadpan Canyon and vicinity (see Fig. 2), the formation consists predominantly of purple to gray phyllite (composed largely of sericite), interbedded with metagraywacke and meta–pebble conglomerate. Small (0.5 to 3 m wide), discontinuous, metamorphosed pegmatitic lenses composed of quartz and K-feldspar are also common. These lithologic units (and to a lesser extent the pegmatite lenses) exhibit a well-developed, steeply dipping foliation trending approximately N60°E across the map area.

Nonfoliated, unmineralized quartz veins, ranging in width from less than a few centimeters to greater than 4 m, occur throughout the Breadpan Formation, but do not appear to be directly related to the Be or F mineralization.

Thin-section examination of phyllite from the Breadpan Formation shows that the degree of metamorphism of these rocks corresponds to the chlorite zone of the greenschist facies (Jackson, 1970). No minerals that would indicate a higher grade of regional metamorphism have been found in any Alder Group rocks, nor are there any visible signs of contact metamorphism to a hornfels by a buried pluton.

Flying W Formation. The Flying W Formation, also host to the beryllium-fluorine mineralization in the area, conformably overlies the Breadpan Formation. It ranges in thickness from 100 to 400 m and consists of interbedded basaltic lavas and pyroclastic rocks, rhyolitic tuff, andesitic lava, and coarse conglomerates. Deformation-produced foliation is either weak or absent in these units. A measured columnar section (Fig. 3) was taken from outcrops on the west side of Spring Creek, 1 km north-northwest of the Flying W ranch house (see Fig. 2).

The lower to middle third (70–100 m) of the Flying W Formation (Fig. 3) consists of the Flying W rhyolite, a massive tuffaceous unit. The apparent age (U-Pb zircon) of this unit (L. T. Silver, cited in Conway, 1976) is 1715(15) Ma. This is the only date available for rocks in the study area. The heavy-mineral separates used in this dating process also yielded abundant, minute topaz. The occurrence of topaz was confirmed by R. G. Gastil (pers. comm., 1985), who discovered (but did not report) topaz in heavy-mineral separates from the same unit in the mid-1950s (see Gastil, 1954, 1958). Topaz was not identified in hand specimen nor in this section, and the origin of the topaz remained unknown.

Ongonite and topazite dikes

A series of aphanitic, topaz-rich, felsic dikes have been discovered in the map area near both the Breadpan and Dysart beryllium claims (Kortemeier and Burt, 1985; see Fig. 2). These dikes are narrow (less than 5 m), steeply dipping bodies that are fairly continuous and well-exposed along their strike lengths of from 250 m to 2.4 km. The interiors of the dikes are white, fine-grained, and granular. This massive interior rock weathers to a sandy grus. Along the margins of the dikes, in a zone that is generally 2–8 cm wide, the dike is pink, extremely fine-grained, and flow-banded (Fig. 4). This dense, very fine-grained zone exhibits conchoidal fracture. Locally, the dike interiors have a purple tint when freshly broken due to disseminated fluorite. This color disappears on weathering.

Xenoliths of surrounding rocks are common in the marginal zones of the dikes (see Fig. 8), and the contacts of the dikes with the xenoliths and with surrounding country rocks are sharp (Fig. 4). Visible contact meta-

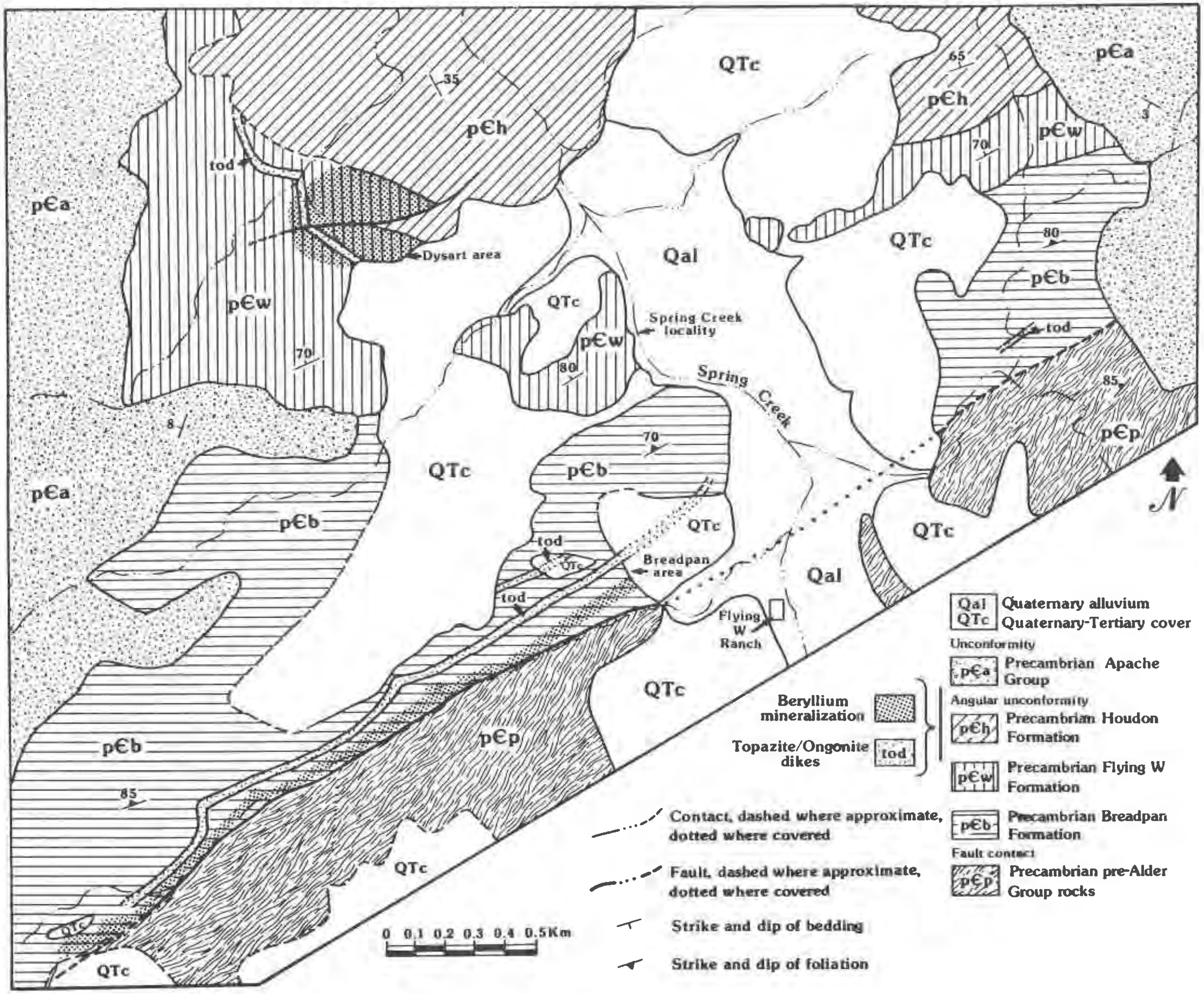

Fig. 2. Geologic map of the Flying W ranch area, Gila County, Arizona (mapping by W.T.K.).

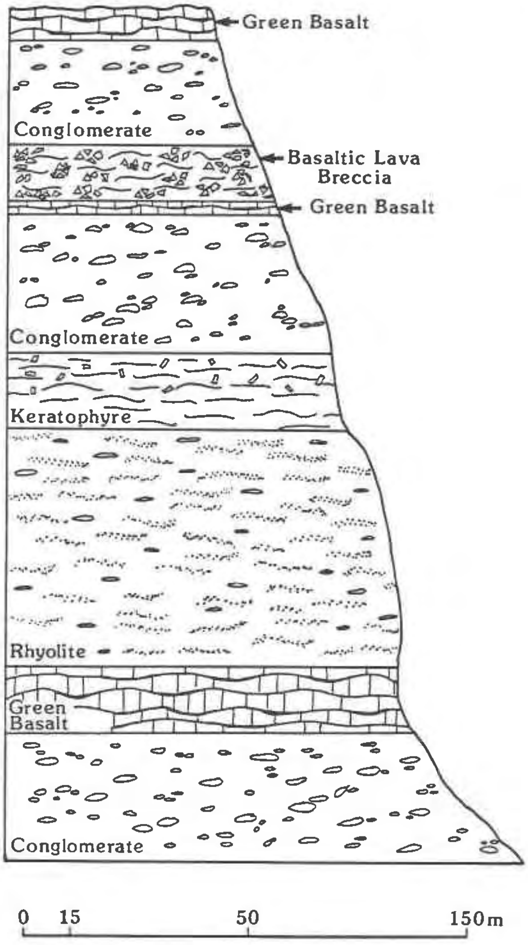

Fig. 3. Measured columnar section of the Flying W Formation, Spring Creek locality.

Fig. 4. Photograph of flow-foliated Breadpan dike margin. Note dike's sharp contact with country rock. Width of dike shown is about 20 cm.

morphism of the country rock either consists of minor sericitization in a zone less than 2 cm wide or is absent.

The dikes are texturally homogeneous; no differentiated aplitic and pegmatitic phases are present. In thin section, the dikes are either fine-grained porphyritic or aphanitic, with grain sizes rarely exceeding 1 mm. No evidence of postemplacement metamorphism is present; i.e., deformation-produced foliation is absent, veining and fracturing of the rocks are minor, and, in thin section, quartz grains are unstrained. Vein-controlled hydrothermal alteration also appears to be absent.

The extremely leucocratic dikes in the Flying W ranch area show a striking textural resemblance to ongonite dikes described from Mongolia and the Transbaikal region of the USSR (Kovalenko et al., 1971, 1975; Kovalenko and Kovalenko, 1976) and discussed below. Mineralogically, the dikes can be divided into two groups: those consisting predominantly of quartz and topaz, with variable mica (referred to as topazite) and those consisting predominantly of quartz, topaz, and albitic plagioclase, with variable mica (referred to as ongonite). These dikes are described individually below.

Topazite dikes of Breadpan Canyon. Two dikes have been discovered on the northwest slope of Breadpan Canyon. The first to be discovered, here called the Breadpan dike, is also the most elongated; it crops out over a strike length of approximately 2.4 km (Fig. 2). The Breadpan dike is 1.5 to 2.0 m wide, trends approximately N45°E, and dips approximately 54°NW. This orientation is subparallel to the N60°E, 70°NW orientation of the Breadpan phyllite in the area. On an outcrop scale, however, the Breadpan dike clearly cuts across and warps the slaty foliation. Contact metamorphism of the phyllites by the Breadpan dike is limited to a zone of sericitization less than 2.5 cm wide.

In thin section (Fig. 5), the Breadpan dike consists predominantly of two minerals, fine-grained (<1 mm) anhedral quartz (70%) and finer-grained (<0.7 mm) blocky to prismatic topaz (30%). White mica is locally abundant (up to 15%), and its texture appears to be primary. Fluorite, visible in hand specimen, is also present locally as individual cubes or as granular aggregates. Opaque minerals are extremely rare. Toward the western end of the Breadpan dike, the dike rock contains minor quantities of unaltered plagioclase, either as phenocrysts in the fine-grained, quartz-topaz groundmass or as grains intergrown with equigranular quartz and topaz.

Major- and trace-element analyses of four samples of the Breadpan dike topazite (samples containing no feldspar) are given in Table 1. In confirmation of the petrographic observations, the rock contains unusually high SiO_2 (71–86%) and Al_2O_3 (8–21%) and is relatively lacking in all other major elements. F, at or above 2% (the upper detection limit was set at 20000 ppm by the analyst), is high owing to the abundant topaz. The rock is enriched in Sr and Ta, and depleted in Rb, Be, Y, Nb, and Mo relative to peralkaline rhyolites, topaz rhyolites, and ongonites (see Christiansen et al., 1983).

A second dike, located approximately 100 m upslope from the Breadpan dike, is similar to the Breadpan dike in all but two respects: (1) the second dike is exposed on only one hillside, providing approximately 250 m of horizontal exposure (compared with 2.4 km of exposure on the Breadpan dike), and (2) weathered, limonite-replaced pyrite cubes occur locally in the border zone of the second dike. No pyrite has been observed in the Breadpan dike.

These two dikes, the Breadpan dike and its less elongate neighbor, are geochemically and mineralogically similar to rocks referred to as "topazite" by Eadington and Nashar (1978) and Eadington (1983). A complete discussion of topazites is given below.

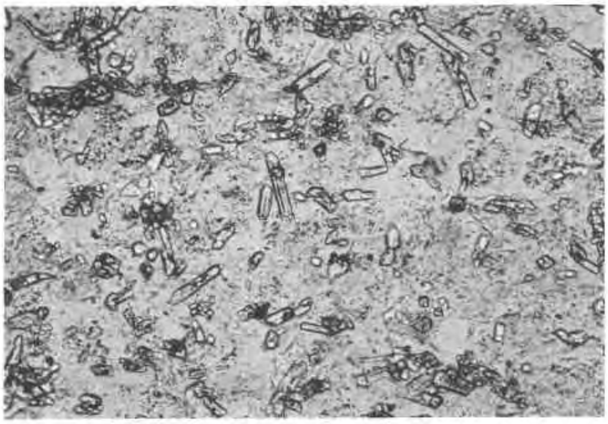

Fig. 5. Photomicrograph of Breadpan dike, central zone. Note acicular, high-relief topaz. Remainder of rock is composed of larger, anhedral quartz. Plane-polarized light. Field of view about 700 μm across.

Table 1. Major- and trace-element analyses of rocks from the Breadpan and Dysart dikes, Arizona, of ongonite from Mongolia, and of topazite from New South Wales, Australia

							Topazites	
	6101	6103	6107	6109	693	Ongonite	A	B
SiO_2	79.76	86.93	71.00	79.02	75.54	70.78	73.40	81.10
Al_2O_3	15.48	8.65	21.30	17.77	18.09	16.78	20.80	15.80
Fe_2O_3	0.50	0.40	0.47	0.38	0.67	0.27	0.00	—
FeO	0.18	0.18	0.12	0.04	0.21	0.26	0.56	0.40
MnO	0.01	0.01	<0.01	<0.01	0.02	0.18	0.02	0.01
MgO	0.14	0.11	0.29	0.03	0.07	0.20	0.00	0.17
CaO	0.07	0.07	0.26	<0.01	0.42	0.34	0.00	0.14
Li_2O	—	—	—	—	—	0.42	—	—
Na_2O	0.04	0.17	0.01	<0.01	4.32	5.24	<0.01	0.01
K_2O	0.32	0.34	1.74	0.07	0.41	3.31	0.04	0.10
TiO_2	0.04	0.02	0.02	0.02	0.02	—	0.02	0.03
P_2O_5	0.33	0.21	0.22	0.22	0.07	0.07	—	—
F	>20000	16500	>20000	>20000	19000	19900	65500	46000
Rb	32	45	115	12	263	1876	—	—
Sr	255	86	138	113	152	20	—	—
Ba	56	<50	<50	<50	1200	25	—	—
Nb	48	34	47	23	103	69	—	—
Ta	159	179	133	77.5	1.5	67	—	—
Y	<1	<1	<1	<1	<1	—	—	—
Li	76	79	51	22	327	—	10	—
Be	3	6	2	<1	2	19.2	—	—
Sn	55	73	47	29	102	37	4	15
W	14	10	15	13	11	—	130	400
Mo	<1	<1	<1	<1	<1	—	6	6
Zr	54	116	74	57	40	66	50	60
Hf	16	32	18	16	9	10.7	—	—
U	12	18	11	5.2	3.1	—	—	—
Th	23.2	12	9.1	6.6	11	—	—	—
Rb/Sr	0.13	0.52	0.83	0.11	1.7	93.8	—	—
K/Rb	81	66	134	50	14.1	15.1	—	—
Nb/Ta	0.3	0.19	0.35	0.30	0.94	1.01	—	—
Zr/Hf	3.4	3.6	4.1	3.6	4.5	6.1	—	—

Note: samples 6101, 6103, 6107, and 6109 are Breadpan dike topazite; 6101 and 6109 are from the coarse, interior zone, 6103 and 6107 are from the marginal, banded zone. Sample 693 is Dysart dike ongonite, marginal zone. Oxides, Be, Li, and Mo analyzed by the direct current plasma method; F by specific ion; Rb, Sr, Nb, Y, and Sn by XRF; Mo, Ba, Hf, Ta, W, Th, and U by neutron activation. All analyses are by Bondar-Clegg, Lakewood, Colorado; analytical error not specified. Ongonite is from the Ongon-Heierhan district, Mongolia (from Kovalenko and Kovalenko, 1976) and topazites are from the New England district, Australia (from Eadington and Nashar, 1978). Oxides in wt%; trace elements in ppm.

Fig. 6. Photomicrograph of elongate, radiating topaz grains, Dysart dike. Plane-polarized light. Field of view about 700 μm across.

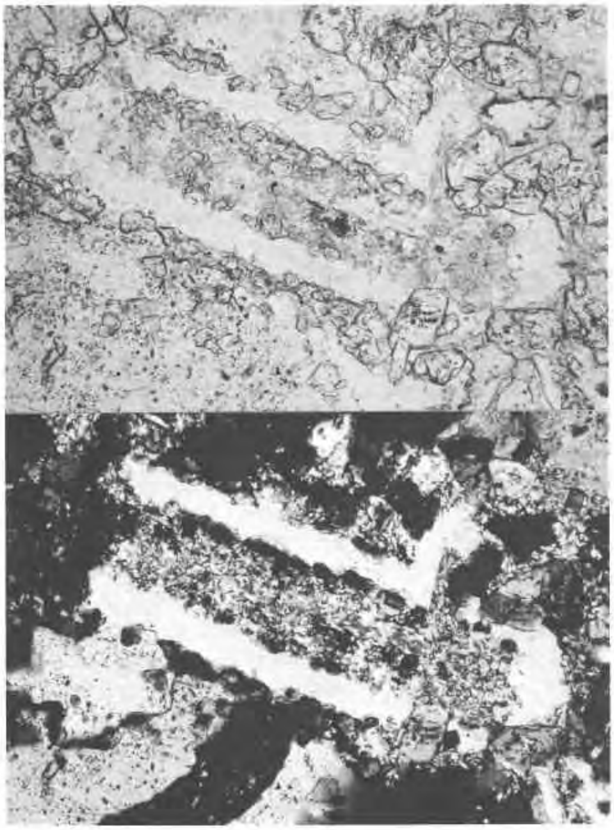

Fig. 7. Photomicrographs of relict plagioclase grain, Dysart dike. Replacement of plagioclase here is by quartz, sericite, and topaz. Top, plane-polarized light. Bottom, crossed nicols. Field of view about 700 μm across.

The Dysart ongonite dike. A third major dike was discovered approximately 2 km northwest of the Flying W ranch house and 1 km west of Spring Creek. This dike, here named the Dysart dike, intrudes conglomerates and basalts of the Flying W Formation (Fig. 2). The dike is 4 to 5 m wide and crops out over a strike length of approximately 700 m. It has an orientation of N10°W, 55°NE and clearly cuts across the N50°E, 80°NW foliation of the Flying W units. An 8- to 15-cm-wide dikelet, exposed for approximately 6 m along strike and located 21 m east of the main dike, trends N35°W, or almost perpendicular to the foliation of the country rock.

Approximately 300 m south of the northern end of the Dysart dike, small pyrite cubes (less than 5 mm and partially replaced by limonite) are abundant in both marginal and central dike material.

In thin section, the Dysart dike is composed of approximately 40% anhedral quartz, 30% topaz, and 30% albite. White mica and fluorite are present locally, but together constitute less than 5% of the rock. The topaz grains, here up to 0.7 mm long, occur as blocky or prismatic grains or as glomeroporphyritic, radiating crystals displaying excellent basal cleavage (Fig. 6). The albite grains are subhedral to anhedral and appear to be partly resorbed. The upper northern end of the Dysart dike contains only quartz, topaz, and variable white mica; plagioclase is noticeably absent. In a transition zone exposed on a steep slope between upper plagioclase-barren and lower plagioclase-bearing dike rock, relict plagioclase grains are now altered to quartz, sericite, and variable topaz (Fig. 7). In fluorite-rich areas in this transition zone, plagioclase has been altered to the assemblage fluorite, sericite, and quartz.

A geochemical analysis of a sample of Dysart dike ongonite is given in Table 1 (sample 693). The Dysart dike resembles the Breadpan dike in its high content of SiO_2 (75.5%) and Al_2O_3; the presence of abundant albite adds appreciable Na_2O to the analysis. F is again approximately 2% owing to the high content of topaz. Compared to peralkaline rhyolites, topaz rhyolites, and ongonites (see Christiansen et al., 1983), this rock has high concentrations of Sr, Li, Sn, and Ta, and low Be, U, Y, Mo, and Zr values. The Dysart dike is mineralogically and geochemically similar to ongonites described by Kovalenko and Kovalenko (1976) and below.

Dikelet east of Spring Creek. One very narrow (<15 cm), short (outcrop <15 m) dike has been discovered cutting Breadpan slate in a small canyon on the east side of Spring Creek, approximately 1.3 km northeast of the Flying W ranch house (see Fig. 2). Where sampled, the dikelet is 3.5 cm wide and flow-banded from margin to margin. Small xenoliths of the surrounding slate are present in this dikelet and locally distort the flow banding (Fig. 8).

In thin section; this dikelet is porphyritic, with an extremely fine-grained, flow-foliated groundmass consisting of approximately 25% topaz and 75% quartz (+ plagioclase?). Euhedral to subhedral quartz, subhedral to anhedral plagioclase, microperthitic alkali feldspar, and muscovite occur as phenocrysts in this dikelet. This is the only recognized occurrence of potassic feldspar in the dike rocks of the Flying W ranch area. The presence of both plagioclase and microperthitic feldspar makes this dikelet very similar to Mongolian ongonites.

ALTERATION AND MINERALIZATION

Three areas of alteration and mineralization in the Flying W ranch area are discussed below. Two of these, the Breadpan and Dysart areas, were prospected for beryllium in the early 1960s. The third area, located along Spring Creek and here referred to as the Spring Creek locality (see Fig. 2), is not strongly mineralized in beryllium, but is the locality where topaz was discovered in heavy-mineral separates from the Flying W rhyolite (Conway, 1976). Weak alteration (fluorite or tourmaline or both with sericite along veinlets) occurs throughout the study area. The mineral-resource potential of this area and the nearby Hells Gate Wilderness Area is discussed in Conway et al. (1983).

Breadpan area

In Breadpan Canyon, beryllium mineralization is hosted by Breadpan Formation phyllites. The mineralization involves pervasive alteration and veining of the country rock in a zone approximately 1.5 m to 12 m wide and extending for approximately 2 km parallel to the foliation of the host rocks (see Fig. 2). Beryllium exploration in this area included surface sampling, trenching, and drilling over the strike length of the mineralized zone. The beryllium grade is referred to as "marginal," and no production is recorded (Smith, 1962).

The alteration assemblage in the Breadpan area is composed predominantly of black, fine-grained tourmaline and pink to white K-feldspar, with subordinate fluorite, quartz, chlorite, calcite, sericite, beryl, and specular hematite. Alteration in the Breadpan area is weakest along the margins of the mineralized zone and intensifies toward the center. Along the margins, the Breadpan slate has been sericitized and feldspathized, producing a light-colored, coarse-grained phyllite. Stronger alteration has created a finely banded rock composed of layers of the light-colored, coarse-grained phyllite separated by tourmaline-rich layers that are oriented parallel to the original foliation. In the center of the mineralized area, the most intense alteration has caused the original slate to be completely replaced by alkali feldspars, with or without tourmaline and chlorite. This core area is also cut by veinlets of tourmaline, calcite, and fluorite. Beryl occurs as aggregates of small (<3 mm), blue grains intimately associated with pink alkali feldspar, black tourmaline, brown carbonate, and clear quartz.

The altered and mineralized zone is located approximately 45 m downslope from the Breadpan dike, yet the intervening country rock is completely unaltered. Evidently the F, Be, and B-rich mineralizing fluids were localized by fractures parallel to the foliation and arose from depth, rather than directly from the adjacent dike.

Fig. 8. Photograph of dikelet east of Spring Creek. Note xenolith-rich margin.

Dysart area

In the Dysart area (Fig. 2), beryllium mineralization is hosted by Flying W Formation conglomerates and basalts. The younger Houdon Formation quartzite, which occurs in this area in both fault and conformable contact with the Flying W rocks (Fig. 2), does not appear to host mineralization. Claims were staked in early 1960s by the same group that conducted the exploratory trenching and drilling in the Breadpan area (Smith, 1962). Four to five pits were excavated, but no further exploration was attempted.

The country rock surrounding the Dysart dike is strongly altered, especially on the hanging-wall side of the dike to the northeast. The alteration assemblage is dominated by tourmaline, fluorite, and quartz, with subordinate K-feldspar, sericite, beryl, and topaz. The alteration appears to have commenced with feldspathization, sericitization, and silicification as in the Breadpan area. Thereafter, mineralization in the two areas diverged. In the Dysart area, the second stage consisted of brecciation of the country rock and deposition of tourmaline and fluorite (with or without quartz and sericite) as the supporting matrix for the previously altered clasts (see Fig. 9). A third stage consisted of fracturing of the breccia, followed by veining by tourmaline + fluorite + quartz + beryl. The beryl mineralization represents the final pulse of fracture filling; beryl usually occurs as dark blue, elongate, radiating crys-

Fig. 9. Photograph of tourmaline- and fluorite-supported breccia, Dysart area. Clasts are composed of silicified and feldspathized Flying W conglomerate. Small quartz vein at base of rock.

Fig. 10. Photograph of blue beryl on tourmaline-fluorite-quartz vein, Dysart area.

tals up to 2.5 cm in length (Fig. 10) on fractures having an approximate orientation of N20°E, 25°NE.

The mineralization in the Dysart area is more pervasive than that in the Breadpan area. The Flying W units in the Dysart area are only weakly foliated, so that mineralizing fluids tended not to be controlled by the orientation of the host rocks (in contrast to the Breadpan area) and, instead, brecciated the competent Flying W units.

Spring Creek locality

The outcrop of Flying W units located 1 km north-northwest of (downstream from) the Flying W ranch house, on the western bank of Spring Creek, is here referred to as the Spring Creek locality (Fig. 2). The beryllium mineralization in this area is hosted by Flying W rhyolite, conglomerate, and basaltic breccia units. The mineralization and alteration in this area, neither pervasive nor intense, consists of small veins and coated fractures locally surrounded by narrow, weakly altered zones. The alteration assemblage includes quartz, tourmaline, sericite, topaz, fluorite, and beryl.

Macroscopic evidence of alteration-mineralization at the Spring Creek location includes fluorite on fractures in the Flying W rhyolite and overlying conglomerate, veinlets of tourmaline, quartz, sericite, and topaz in nearby outcrops of Flying W basaltic lava breccia, and veinlets of tourmaline, quartz, and beryl along fractures in Flying W conglomerate outcrops. These last veinlets appear identical to the beryl-bearing veinlets in the Dysart area.

In the Flying W rhyolite, the altered and veined rock is bleached to a pink or white color, with pervasive microveinlets containing quartz, topaz, sericite, and fluorite. In thin section, these veinlets contain topaz and sericite along the margins, with quartz and minor fluorite in the center. The pink to white, bleached areas surrounding these microveinlets contain primary plagioclase grains altered to sericite plus topaz.

DISCUSSION

Origin of topaz in Flying W rhyolite

In the Spring Creek area, topaz is found only in visibly altered samples, either as an alteration product of plagioclase or in veinlets of quartz, white mica, and topaz (a common greisen assemblage). In thin section, 15 relatively fresh, unaltered, dense, dark red Flying W rhyolite samples contained no topaz. These facts indicate that the topaz in the Flying W rhyolite formed as a secondary hydrothermal mineral. There is no evidence that the topaz formed as the product of vapor-phase crystallization from a F-rich lava (Kortemeier and Burt, 1986). The Flying W rhyolite is, therefore, not a Precambrian analogue of Tertiary topaz rhyolites (as hypothesized by Burt et al., 1982).

Origin of ongonite and topazite dikes

The Breadpan dike was first described (Meeves, 1966) as a "fluorite-bearing sandstone." This designation may have been based on the rock's fine grain size, abundance of quartz, and friable weathered appearance. It has also been suggested to us verbally that these dikes represent greisen veins or greisen replacement of more normal granitic dikes. Nevertheless, the evidence supporting a primary magmatic origin is substantial and includes (1) crosscutting relationships with country rocks, (2) chilled margins along contacts with country rocks, (3) flow foliation along dike margins, (4) flow lineations on dike margins, (5) inclusions of country rock (entrained xenoliths) along dike margins, and (6) abundant topaz without replacement textures and with an igneous geochemical signature. These features are discussed individually below.

Crosscutting relationships with country rocks. Both the Breadpan and Dysart dikes show definite crosscutting relationships with the rocks they intrude. The Dysart dike cuts across the contact between the Flying W conglomerate and the Flying W basalt. The Breadpan dike, oriented approximately parallel to the surrounding Breadpan Formation, locally contorts and cuts across the foliation.

Chilled margins. Margins of the Breadpan and Dysart dikes exhibit a much finer grain size (0.01 mm) as compared with the interiors (grains up to 1 mm). The chilling effect of the country rock on the dikes can be observed in the space of a single thin section taken at the dike–country rock contact (Fig. 11). Grain size doubles from the contact to a point less than 1 cm inside the dike.

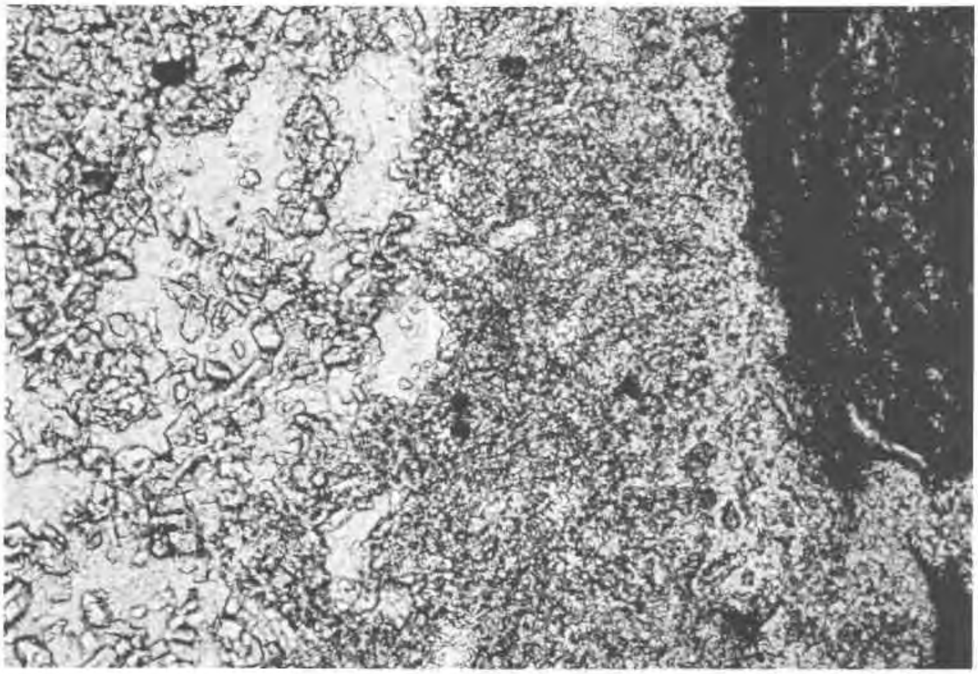

Fig. 11. Photomicrograph of chilled margin, Breadpan dike. Darker, higher-relief grains are topaz. Remaining grains are quartz. Plane-polarized light. Field of view about 700 μm across.

Flow foliation. The margins of all dike bodies exhibit a pronounced flow-foliated texture. In hand specimen, the foliated appearance is due to pink and white color-banding parallel to the contact of the dike and country rock (Fig. 4). This banding occurs both as linear zones, or as highly contorted zones (Fig. 12). In thin section, it is evident that the foliation is caused by segregation of quartz (white) and topaz (pink) into distinct zones parallel to the margins (Fig. 13). The prismatic topaz grains in these zones are oriented parallel to the margins of the rock and to the flow foliation; they are not oriented perpendicular to the dike–country rock contact as would be expected if this color and mineral zoning represented banding in a fracture-filling hydrothermal vein. This parallel orientation would likewise not be expected of secondary topaz replacing other minerals.

Flow lineations. Lineations observed on the flow-foliated margins of the Breadpan and Dysart dikes (Breadpan lineations: plunge 54°, bearing N6°E, Dysart lineations: 39°, N68°E) indicate intrusion of a viscous fluid (magma) and indicate that this magma was intruded upward rather than horizontally. These lineations therefore suggest that the igneous body from which the dike magma emanated lies beneath the study area rather than some distance away from it laterally.

Inclusions of country rock (xenoliths). The Breadpan dike, the Dysart dike, and the dikelet east of Spring Creek all contain entrained pieces of country rock along their margins (see Fig. 8). The inclusions are completely supported by the enveloping dike rock. Flow foliation present at the margins of the dikes is distorted around these xenoliths. A thin section of an inclusion from the Breadpan dike shows alteration of the xenolith to sericite.

Topaz without replacement textures. The majority of the topaz in the dikes of the Flying W ranch area occurs as small, acicular grains (Fig. 5) or as elongate, radiating grains (Fig. 6). This is in contrast to topaz textures in hydrothermally altered rocks such as the Mount Bischoff, Tasmania and East Kemptville, Nova Scotia tin greisens (Groves et al., 1972; Richardson, 1985; Chatterjee, et al., 1985), the Henderson porphyry molybdenum deposit, Colorado (Wallace et al., 1978; Seedorff, 1985), and the Mount Pleasant porphyry tin-tungsten deposit, New Brunswick (Pouliot et al., 1978; Parrish, 1982). Topaz in these rocks occurs as masses of anhedral grains often replacing other phases. Acicular groundmass topaz, which also occurs in igneous ongonite dikes from Mongolia (Kovalenko and Kovalenko, 1976; see discussion below) appears to be the product of magmatic rather than hydrothermal processes.

Topaz with an igneous geochemical signature. Until recently, topaz was generally accepted to be primarily the product of postmagmatic pneumatolytic processes such as greisenization or vapor-phase crystallization (Eadington and Nashar, 1978; Clarke, 1981). Fluid-inclusion and experimental studies (Kovalenko and Kovalenko, 1976; Eadington and Nashar, 1978) indicate that topaz can also form under magmatic conditions as a liquidus phase (see the ongonite and topazite discussions below). The occurrence of abundant topaz in these dikes, therefore, does not preclude a magmatic origin.

In an ion-microprobe study of topaz from different en-

Fig. 12. Photograph of contorted flow foliation, Breadpan dike.

vironments, Hervig et al. (1987) discovered that concentrations of Li and B in topaz vary considerably depending on the geologic environment in which the topaz grew. Topaz samples from six topaz rhyolites, five pegmatites, and four hydrothermal greisens were analyzed. (Single samples of topaz from a metamorphic rock, an xenolith of granite in rhyolite, and a porphyry molybdenum deposit were also analyzed and are included in Fig. 14, but will not be discussed here.) Topaz crystals from rhyolites are about 100 times richer in Li than are those from hydrothermal greisens or pegmatitic rocks. B is also highest in rhyolitic topaz, but the variation between the different geologic environments is less pronounced than that created by the Li values.

It is assumed that the variations in bulk composition of the various rock types are not responsible for the Li and B results: pegmatites are enriched in B and Li, yet topaz from pegmatites shows low concentrations of both elements. Hervig et al. (1987) proposed that variations in temperature, pressure, cooling rate, and growth medium may cause the variations in Li and B concentrations. Relatively high-temperature, low-pressure, rapidly cooled magmatic rocks such as rhyolites tend to have greater substitution of B and Li in topaz than more slowly cooled, low-temperature, high-pressure, aqueous-phase-present rocks such as pegmatites and greisen veins and replacements.

Ion-microprobe analyses of topaz free of replacement textures from the Dysart ongonite dike, Flying W ranch area, show striking similarities to rhyolitic topaz analyses, with relatively high concentrations of both Li and B. When plotted on a Li-B concentration diagram with rhyolitic, hydrothermal, and pegmatitic topaz, topaz from the Dysart ongonite falls well within the rhyolitic topaz field (analysis 16, Fig. 14). Topaz from a specimen of Breadpan dike topazite (analysis 17, Fig. 14) is somewhat lower in Li and B, but still lies well outside the greisen and pegmatite fields of other analyses. This evidence suggests that topaz in the dike rocks from the Flying W ranch area was quenched from magmatic conditions, rather than recrystallized under lower-temperature hydrothermal conditions.

The features described above indicate that the dikes were emplaced and crystallized as magmatic bodies. Nevertheless, some areas of these bodies have evidently undergone syn- or postmagmatic alteration. Quartz veinlets, fluorite "blebs," and zones altered to sericite, quartz, fluorite, and topaz (where the topaz occurs as masses of anhedral grains), all suggest that the dikes have locally been affected by hydrothermal fluids. These fluids presumably were released late in the crystallization history of the dikes or underlying intrusive body (Kovalenko and Kovalenko, 1976, 1984). Intrusion of the dike-forming magma along steeply dipping planes (as indicated by the present dike orientations and the presence of near-vertical flow lineations along the margins of the dikes) could have been followed by "streaming" of late-stage fluids up the dike, causing the observed alteration.

Relationship of mineralization to dike emplacement

The three mineralized zones studied in the Flying W ranch area (the Breadpan, Dysart, and Spring Creek) share a common alteration assemblage that consists predominantly of quartz, tourmaline, fluorite, sericite, beryl, and topaz. Differences among the areas appear to be due to variations in the physical and chemical properties of the country rock and of the mineralizing fluids. The two most extensive areas of alteration and mineralization (Breadpan and Dysart areas) are both close to ongonite or topazite dikes, whereas the area of minor alteration and mineralization (Spring Creek) lies 600 m from an observed dike (see Fig. 2). On the basis of these field observations, mineralization and dike emplacement were closely associated, and the extent of mineralization is related to distance from a dike. Fluids given off by the dikes and their parent igneous body evidently altered and mineralized the surrounding (or nearby) country rock. More fluids than those given off by the dikes themselves are needed to account for the two main areas of mineralization and also to account for the occurrence of weak alteration throughout the study area, including the east side of Spring Creek.

Age of dike emplacement and associated mineralization

Given that the emplacement of the ongonite and topazite dikes was related to the mineralization, the age of these two events should be comparable. Both the dikes and the mineralization affect Breadpan Formation and Flying W Formation rocks, dated at 1715 Ma (Conway, 1976). The dikes also cut across the foliation of these rocks and therefore postdate the Mazatzal orogeny, estimated to have occurred in the interval 1660–1715 Ma (Silver, 1964). These data indicate that the maximum age of the dikes and associated mineralization is about 1715 Ma.

A minimum age for the intrusive and mineralizing ac-

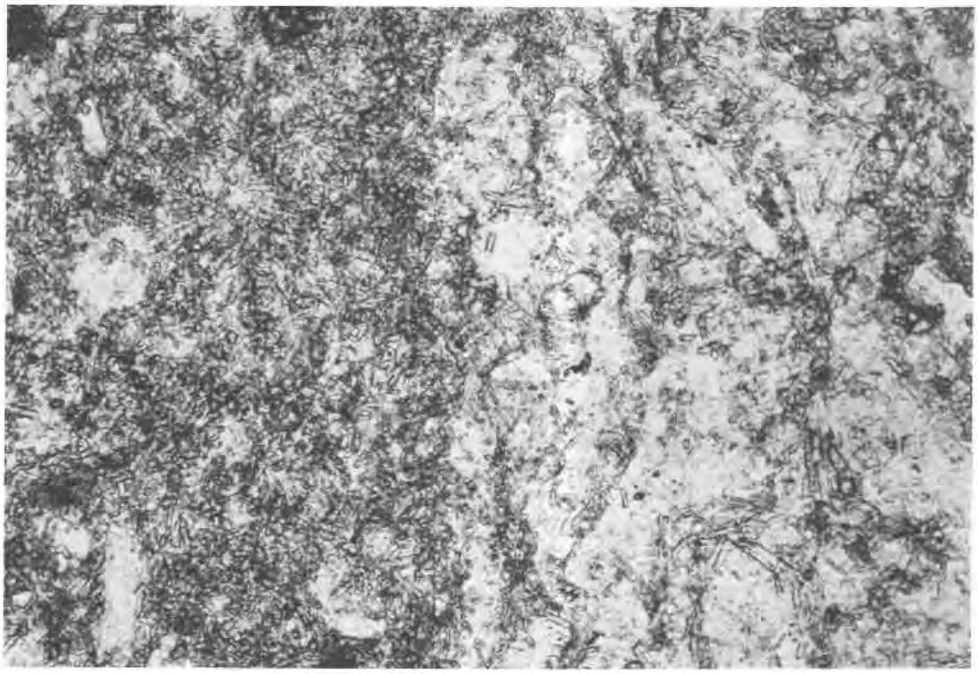

Fig. 13. Photomicrograph of flow-foliated margin of Dysart dike. Note abundance of topaz in zone on left, abundance of quartz on right. The segregation of topaz and quartz into discrete zones parallel to dike margins gives the rock a banded appearance in hand specimen. Plane-polarized light. Field of view about 700 μm across.

tivity is more difficult to determine. Apache Group rocks, deposited within the interval 1500 to 1100 Ma (Livingston and Damon, 1968; Silver et al., 1977a, 1977b; Shafiqullah et al., 1980) are present at several locations in the field area and at one location lie not more than 250 m from Dysart dike outcrops (see Fig. 2). The dike, however, pinches out before reaching the contact with the younger Precambrian rocks, and therefore its relative age is not indicated. A similar problem exists at the westernmost end of the Breadpan dike, where Apache Group rocks crop out approximately 400 m west of the last outcrop of the dike.

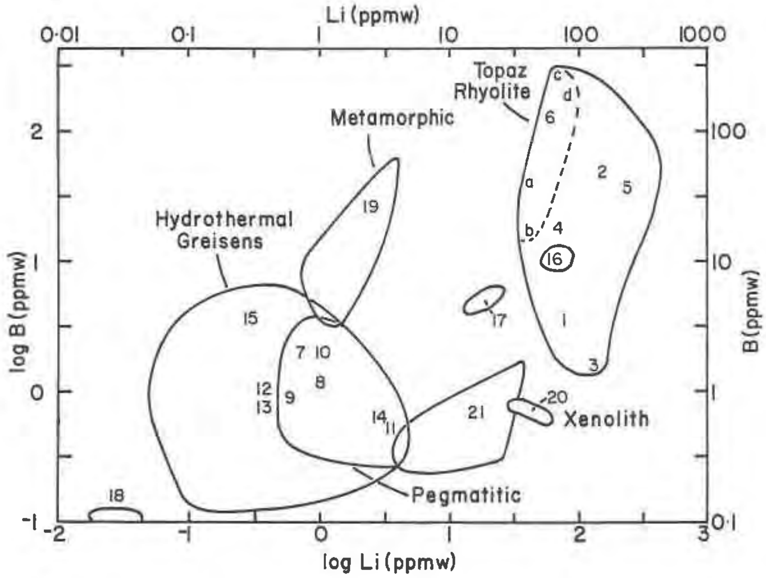

Fig. 14. Li vs. B diagram from ion-microprobe analyses of topaz from different geologic environments (from Hervig et al., 1987). The Dysart dike ongonite sample is area 16, the Breadpan dike topazite is area 17, and the topazite from N.S.W., Australia, is area 18.

The mineralization may be more revealing. In the northeastern part of the map area (Fig. 2), Breadpan and Flying W Formation rocks are veined and altered in the same manner as rocks described from the Spring Creek locality. Overlying these rocks and separated from them by an angular unconformity is a conglomerate of the Apache Group. Veined and altered Alder Group rocks occur immediately below the unconformity, but no veining or alteration is apparent in the conglomerate above. This evidence, combined with the lack of dikes cutting the Apache Group rocks, suggests that the age of the ongonite and topazite dikes and associated mineralization is greater than that of the Apache Group rocks.

From the above arguments, the age of the dikes and mineralization probably falls within the interval 1715 to 1100 Ma. This activity may have been contemporaneous with the intrusion of 1410–1460 Ma anorogenic, F-rich granites (Silver, 1968; Silver et al., 1977a, 1977b) such as the Ruin and Lawler Peak intrusions. Nevertheless, a younger (e.g., Tertiary) age cannot definitely be excluded.

Comparison of Flying W dikes to other rock types

The dikes in the Flying W ranch area represent types of igneous rocks that have not previously been described in North America. They have some of the textural features commonly attributed to fine-grained aplite dikes, yet the dikes of the Flying W ranch area are not truly aplitic, or allotriomorphic-granular in texture. A true aplitic texture consists of equal-sized grains, with no grains better formed than others (Shand, 1969, p. 185). Rocks from the Flying W area dikes are better described as fine-grained porphyritic; distinctions in grain size between groundmass and phenocrystic phases are easily made, and the habit of the individual minerals varies from euhedral to anhedral.

The dikes of the Flying W ranch area also differ from typical aplitic dikes by their lack of associated pegmatitic fabrics. Pegmatites and aplites are believed to be generated in the same geologic environment and are often intimately associated (Hatch et al., 1972, p. 222; Williams et al., 1982, p. 178). The lack of associated pegmatitic fabric in the Flying W area dikes indicates either that (1) the dike-forming magma was relatively "dry" (did not contain an immiscible fluid phase) at the time of emplacement or (2) a high level of intrusion and subsequently low lithostatic pressures led to the loss of any immiscible fluid phase at the time of dike emplacement (or the dikes simply cooled very rapidly). In any case, the Flying W dikes do not represent typical dikes of aplite-pegmatite affinity.

Mineralogically, dikes of the Flying W ranch area are similar to tin-bearing greisens such as occur in Cornwall, England (Exley and Stone, 1964; Hosking, 1964). Greisens are formally defined as pneumatolytically altered granite rocks (or surrounding country rocks) composed largely of quartz, mica, tourmaline, and topaz (Johannsen, 1932, p. 5; Williams et al., 1982, p. 172; Bates and Jackson, 1987, p. 290). Convincing evidence of replacement is usually present, such as aggregates of white mica after feldspar (Hatch et al., 1972, p. 223), partial rims of topaz around quartz phenocrysts, or topaz pseudomorphs after feldspar (Groves et al., 1972, p. 195–197). In contrast to the situation in the Flying W area, greisens are commonly associated with and localized along sets of hydrothermal veins.

The topazite and ongonite dikes share some important similarities with topaz rhyolites: both rock types are believed to be produced by extreme differentiation of granitic magma, and both rock types may be associated with beryllium-fluorine mineralization (Bikun, 1980; Burt et al., 1982; Burt and Sheridan, 1986). Nevertheless, the dikes of the Flying W ranch area appear to be more highly differentiated than topaz rhyolites (their relatively high Sr content may be due to contamination by wall rocks, as discussed below).

Two rock types strikingly similar to those of the Flying W ranch area are ongonites, described from Mongolia and the Transbaikal region of the USSR (Kovalenko et al., 1971; Kovalenko et al., 1975; Kovalenko and Kovalenko, 1976), and topazites (sometimes called silexites), described from the New England district, New South Wales, Australia (Eadington and Nashar, 1978; Eadington, 1983; Kleeman, 1985). These two rock types are described below.

Ongonites. Ongonites are defined (Kovalenko et al., 1971) as the aphanitic, vitrophyric, or phenocrystic subvolcanic analogue of rare-metal Li-F granites. Kovalenko et al. (1971, 1975) and Kovalenko and Kovalenko (1976) describe ongonites in Mongolia and the Transbaikal region of the USSR as topaz-bearing "quartz keratophyres" that form subvolcanic dikes and stocks, as well as lava flows. Ongonite dikes from the type locality, the Ongon-Heierhan tungsten belt in central Mongolia, are described below in a condensed extract from an unpublished English translation of Kovalenko and Kovalenko (1976).

> Ongonite dikes occur 100 km southwest of Ulan Bator, Mongolia, in the Ongon-Heierhan tungsten belt approximately 10 km east of exposures of the Mesozoic Ongon-Heierhan granite massif. The ongonite dikes pinch out near the Ongon-Heierhan granite outcrops, and no relationship between the two has been discerned. Gravimetric evidence, however, places granites of Ongon-Heierhan type at a depth of approximately 600 m under the ongonite dike system. K-Ar dates of micas from both the Ongon-Heierhan massif and the ongonite dikes are early Mesozoic.
>
> The ongonite dikes, ranging in width from less than 20 cm to 2.5 m and in length from less than 100 to 450 m, cut fine-grained, weakly metamorphosed, mid-Paleozoic sandstones of the Khent series. Xenoliths of these sandstones are common along the margins of the dikes. The dikes' contacts with the wallrock and with xenoliths are extremely sharp, and neither the wallrock nor the xenoliths show signs of alteration or contact metamorphism.
>
> In outcrop, the dike rock is white and dense, with conchoidal fracture. Veinlets of quartz and sericite with tungsten and tin ore minerals cut the dikes. The texture of the dikes ranges from aphyric or glassy in a marginal chill zone 10 to 15 cm wide to porphyritic and phenocryst-rich in the centers. In general, the crystallinity tends to increase toward the center of the dikes. The

aphyric marginal zones are commonly flow-banded parallel to the contact. Contortion of the flow-banding occurs around xenoliths.

The primary minerals of ongonites are albite, potassium feldspar, and quartz. These three minerals occur both as phenocrysts and in the microcrystalline groundmass. Topaz and micas are less abundant and occur only rarely as phenocrysts. Accessory minerals include fluorite, garnet, zircon, ilmenite, columbite, tantalite, cassiterite, and pyrite. Needle-shaped, microlitic topaz crystals, less than 0.05 mm long and 0.01 mm wide, may constitute up to 10% of the groundmass of ongonites and are considered to be a characteristic feature of this rock. Along the aphyric flow-banded margins of the ongonite dikes, topaz microlites are oriented subparallel to the contacts of the dikes with the country rock and appear to "flow around" phenocrysts. These features indicate that the topaz microlites existed, if only in part, while the ongonitic magma was still molten and mobile. Segregation of these topaz microlites into discrete zones (together with oriented albite phenocrysts and alternating glassy and crystallized zones) produces the flow-banded appearance of the marginal areas of the dikes.

Postmagmatic alteration was extremely minor and did not substantially influence either the composition or the fabric of the rock.

The major-element geochemistry of a dike from the Ongon-Heierhan district, averaged from 53 analyses, is given in Table 1 (this paper). It differs markedly from that of all other magmatic rocks. Although the silica content resembles that of granites and rhyolites, the alumina value approaches that of a syenite. The high alumina is due to the significant amounts of topaz in the rock. Ongonites are also very leucocratic and contain almost no Ti (similar to alaskite). The ratio K/Na is almost always greater than 1.

The rare-element geochemistry of the ongonite dike, above, is also presented in Table 1. Relative to "average concentrations in granites," ongonites are enriched in F, Li, Rb, Tl, Be, Sn, Hf, Nb, and Ta. Concentrations of Ba, Sr, REEs, Y, and Zr are low. Low values for Li/Rb, Nb/Ta, and Zr/Hf are also characteristic. Overall, the rare-element geochemistry of these rocks is similar to that of rare-metal pegmatites and rare-metal Li-F granites.

Kovalenko and Kovalenko (1976) indicate that all of their geologic, petrologic, and geochemical data support the genesis of ongonites by magmatic processes. They considered the Ongon-Heierhan ongonite bodies to be subvolcanic and rapidly cooled, as evidenced by porphyritic textures, glassy to microcrystalline groundmass, and other features "of effusive appearance" in the ongonite bodies.

Kovalenko and Kovalenko (1976, 1984) stated that ongonites may be regarded as residual melts derived from the protracted fractional crystallization of crustally derived F-rich granitic magmas, possibly of alaskitic composition. The elevated F contents of this granitic magma would lead to Na and Al enrichment in the remaining melt (Manning, 1981; Manning et al., 1981; Pichavant and Manning, 1984; Dingwell, 1985). This F-, Na-, and Al-enriched melt from which ongonites crystallize should correspond to one of the most strongly differentiated granitic magmas possible in nature. Furthermore, its viscosity is much lower than that of a normal granitic melt (Dingwell, 1987), facilitating its intrusion as narrow dikes.

Experiments performed on the system ongonite-H_2O-HF (Kovalenko, 1979) demonstrate the feasibility of crystallizing the major minerals of ongonites (albite, microcline, quartz, topaz, and mica) from a silicate melt. Crystallization of ongonitic melts is completed at very low temperatures: 575(25) °C. If the melt contains B as well as F (as suggested by the abundant tourmaline in the veinlets near the dikes of the Flying W ranch area), its crystallization may be further depressed (to temperatures less than 500 °C: London, 1986, 1987). During the final stages of crystallization of the ongonitic magmas, the fluid phase becomes enriched in Be, W, Pb, Zn, F, B, Li, Si, and H_2O, components responsible for greisenization. The partitioning of these elements into the fluid phase at the end of crystallization helps explain the relative dearth of these elements in the ongonite bodies themselves and the abundance of these same elements in nearby rocks (i.e., Ongon-Heierhan tungsten seams; Breadpan-Dysart beryllium mineralization).

Mineralogically, the main part of the Dysart dike resembles the Ongon-Heierhan ongonites. Both dikes consist predominantly of quartz, topaz, and feldspars. Feldspar compositions differ, however, with the Ongon-Heierhan ongonite containing abundant potassium feldspar and the Dysart ongonite containing only albitic plagioclase. (K-feldspar in a dikelet on the east side of Spring Creek is mentioned above.)

Textural and outcrop characteristics of the ongonite dikes from Mongolia are strikingly similar to those of the dikes in the Flying W ranch area (see Flying W ongonite and topazite dike descriptions above). The multiple similarities between the Ongon-Heierhan dikes and the dikes of the Flying W ranch area suggest that they shared comparable magmatic, intrusive, and cooling histories. Differences between the dike systems in the two localities (i.e., higher Sr and Ba, lower Rb in the Flying W dikes compared to lower Sr and Ba, higher Rb in the Mongolian dikes) could result from differences in the initial composition of the two source magmas or differences in fractionation trends between the two magma systems, as well as differences in final mineralogy. The higher Sr and Ba in the narrow Flying W dikes could also result from contamination by metavolcanic country rocks.

Topazites. Quartz-topaz rocks from the New England district, New South Wales, Australia, occur as dikes and sills that intrude a biotite granite and siltstones of a roof pendant in the granite. Eadington and Nashar (1978) referred to these intrusives as topazites and indicated that these rocks have mineralogic, textural, and field relationships that suggest a magmatic origin. This contention was disputed by Kleeman (1985), who concluded that the quartz-topaz assemblage formed by hydrothermal replacement of late microgranite dikes and sills (i.e., by pervasive greisenization), with magmatic grain size and textures preserved.

The thickness of the topazite intrusive bodies ranges from a few centimeters to tens of meters. Boundaries with the enclosing rocks are sharp (Eadington, 1983), and where the topazite intrudes siltstones, a narrow zone of induration, silicification, or metamorphism to biotite-quartz hornfels is developed, the degree of alteration depending on the size of the intrusion.

In hand specimen, the New South Wales quartz-topaz rock resembles a quartzite, but contains 5 vol% miarolitic cavities. Quartz and topaz are the only major minerals; wolframite, muscovite, and tourmaline are minor. Euhedral to subhedral topaz crystals constitute 18–27% of the rock; the remainder is mainly quartz, which is typically anhedral.

Chemical analyses of the NSW topazite (Table 1) show extremely low alkali-metal and alkali-earth contents and high SiO_2, Al_2O_3, and F contents, as would be expected from the mineralogy.

Locally, hydrothermal alteration is believed to have affected the topazite bodies (Eadington and Nashar, 1978). In places, topaz has been replaced by white mica, and quartz grains have been recrystallized to produce a compact rock consisting primarily of quartz and mica. This altered rock often contains economic concentrations of wolframite (Eadington, 1983).

The granite into which the topazite bodies intrude is referred to as the Mole Granite and is one of three granite plutons within the New England batholith that host tin mineralization (Eadington, 1983). Chemical analyses of the granite show high silica values (74.1–77.3 wt%) and high concentration of the trace elements F (0.3%) and Li (80–620 ppm). In view of the intrusive relationship of the topazite into the Mole Granite and the high F contents of the granite, Eadington (1983) suggested that the topazite bodies developed as late-stage, magmatic derivatives of this granite. Partitioning of Na and K into the aqueous phase (possibly owing to high halogen concentrations: Eadington and Nashar, 1978) would leave a silicate melt enriched in Al and F that would then crystallize quartz and topaz. Studies of primary fluid inclusions in topaz from the topazite (Eadington and Nashar, 1978) indicate that crystallization of topazite from a silicate melt could occur in the temperature range of 850 to 570 °C following saturation of a granitic magma with water (second boiling) and the formation of immiscible silicate and aqueous phases. In topazites from the New England district, miarolitic textures and high porosities are evidence of an immiscible system; the cavities are thought to have been occupied by the aqueous phase at the time of crystallization.

Processes similar to those proposed for the formation of New England district topazites may be responsible for the exotic mineralogy and geochemistry of the Breadpan topazite dike in the Flying W ranch area. Compositionally, at least, these two topazite occurrences are nearly identical (Table 1). Although textural evidence of an immiscible aqueous phase in the Breadpan topazite is scarce (miarolitic cavities are few, and the porosity of the rock is low), the F-, Be-, K-, and Na-rich mineralized area in close proximity to the topazite dike suggests that an aqueous phase developed during the crystallization of the dike or its parent pluton and was lost to the surrounding country rock.

The extremely low Li and B contents in topaz from New South Wales topazite (analysis 18, Fig. 14) presumably imply that it was generated by an aqueous, rather than magmatic, fluid, at least for this sample (which represents a single coarse-grained specimen of unknown setting that was donated to D.M.B. by a visiting mining company geologist). This evidence, although it is inconclusive, supports the greisenization hypothesis of Kleeman (1985). The higher Li and B contents and distinctive textural features of topaz from the Breadpan dike topazite, on the other hand, appear to support a magmatic origin for this rock.

Relationship of topazite to ongonite

In neither the New England district nor the Ongon-Heierhan district do ongonite and topazite occur together. The occurrence of both ongonites and topazites in the Flying W ranch area therefore provides a unique opportunity to examine the relationship between these two rock types.

The transition from one rock type to the other has been observed at two localities. At the northern end of the Dysart dike, ongonite gives way to topazite; at the western end of the Breadpan dike, topazite grades into ongonite. Both transitions occur over less than 5 m. The processes producing this gradation from one rock type to another are not well understood, and information obtained from thin-section examination is inconclusive.

Observations of anhedral, partly resorbed albite phenocrysts in the ongonite of the Dysart dike suggests that early-formed albite grains were not in equilibrium with the final melt. In the feldspar-free topazite of the Dysart area, total resorption of plagioclase grains may have resulted in the partitioning of Na into an immiscible fluid phase, leaving an alkali-depleted melt to crystallize topaz and quartz. Similarly, ongonitic rock of the predominantly topazitic Breadpan dike may represent areas where equilibrium between plagioclase and melt existed to the final stages of crystallization, because the system was more closed to loss of aqueous fluids. In thin section, ongonitic rock from the Breadpan dike exhibits a fine-grained, allotriomorphic-granular texture, with interlocking quartz, plagioclase, and topaz grains. This is the only area in the dike where this equilibrium texture is so well developed.

In general, topazitic rocks have lost all of their alkali components, probably during crystallization, whereas ongonitic rocks have retained a large portion of their original Na.

Experiments on the system ongonite-H_2O-HF by Kovalenko and Kovalenko (1976) and Kovalenko (1979) and on the system granite-H_2O-HF by Glyuk and Anfilogov (1973) and Kovalenko (1978) indicate that F concentrations strongly influence the phases that crystallize. Kovalenko and Kovalenko's (1976) reconnaissance phase diagram of the system ongonite-H_2O-HF is shown in Figure 15. At low HF concentrations, the typical minerals of ongonites coexist: albite, potassium feldspar, quartz, topaz, and mica (fields I and II). At high HF concentrations, the topazite assemblage quartz + topaz crystallizes exclusively (fields X and XI), as alkalis are partitioned into the aqueous fluid.

These experiments suggest that the changes in the mineralogy of the ongonite and topazite dikes in the Flying W ranch area, in particular, the presence or absence of feldspar, may be a function of variations in HF concentrations within the dikes and in timing and degree of loss of volatiles to the country rocks.

CONCLUSIONS

Field, textural, geochemical, and mineralogical characteristics of the topaz-bearing dikes in the Flying W ranch area of the Tonto basin all support the genesis of these bodies from a magma. Several lines of evidence contradict an origin for these bodies by greisenization or veining.

The ongonite and topazite dikes of the Flying W ranch area are texturally, and, in part, mineralogically, similar to magmatically derived, subvolcanic ongonite dikes located in the Ongon-Heierhan district, Mongolia, and may share a similar magmatic, emplacement, and cooling history with these Mongolian dikes. The Dysart dike, consisting predominantly of quartz, albite, and topaz, is an ongonite. The Breadpan dike, lacking albite and consisting predominantly of quartz and topaz, is mineralogically and compositionally similar to topazite dike rocks described from the New England district, New South Wales, Australia. This occurrence of ongonite and topazite is the first of its kind in the United States and is the only recognized location in the world where the two rock types occur together.

The ongonite- and topazite-producing melts are believed to be the product of extreme fractional crystallization of an F-rich granitic source magma. Elevated F concentrations in the fractionating source magma leads to Na and Al enrichment in the remaining melt. After dike emplacement, this melt would crystallize the ongonitic phases quartz, albite, and topaz (equivalent to the Dysart dike). Extremely high HF concentrations in the magma are needed to produce topazitic compositions, for which feldspars do not crystallize, leaving quartz and topaz as the only major phases. Observed transitions from ongonite to topazite, and vice versa, may be the result of fluctuating HF concentrations within the dikes and of variations in volatile loss by the dikes as they crystallized.

The lack of coexisting pegmatitic fabrics in the dikes of the Flying W ranch area indicates that the intruding magma was originally "dry" (i.e., no immiscible fluid phase was present at the time of emplacement of the dikes). During the final stages of crystallization of the dike bodies, however, an immiscible fluid phase was lost to the surrounding Alder Group country rocks. The expulsion of this fluid phase, enriched in K, Na, F, B, and Be, contributed to the alteration and mineralization at the Breadpan, Dysart, and Spring Creek localities. The strongest alteration and mineralization occur in the Dysart and Breadpan areas, where mineralized areas and dikes are in close proximity. The alteration assemblage associated with dike emplacement includes tourmaline, quartz, fluorite, potassium feldspar, calcite, beryl, and topaz in approximate decreasing order of relative abundance.

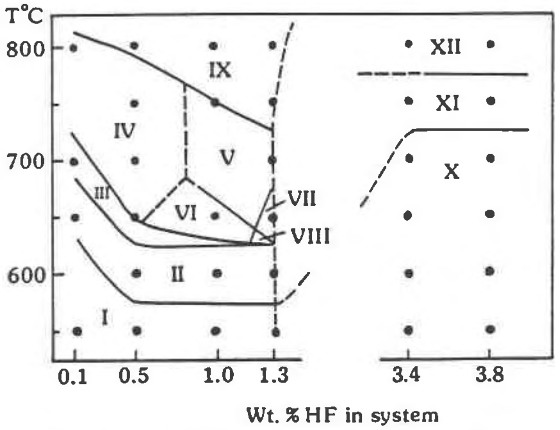

Fig. 15. Phase diagram for the system ongonite-H_2O-HF at 1000-atm pressure and fluid : rock ratio of 5:1. Dots represent analytical data points. Fields are as follows:

I. Ab + KF + Qz + Mi + Fl
II. Ab + KF + Top + Qz + Mi + M + Fl
III. Ab + KF + Qz + M + Fl
IV. Ab + M + Fl
V. Qz + M + Fl
VI. Ab + Qz + M + Fl
VII. Qz + Top + M + Fl
VIII. Qz + Top + Ab + M + Fl
IX. M + Fl
X. Qz + Top + Fl
XI. Qz + Top + M1 + M2 + Fl
XII. M1 + M2 + Fl

Abbreviations: Ab = albite; KF = potassium feldspar; Qz = quartz; Top = topaz; Mi = mica; M, M1, M2 = melt(s); Fl = fluid (from Kovalenko and Kovalenko, 1976).

Topaz in the Flying W rhyolite tuff on the west side of Spring Creek was formed as part of the alteration and mineralization associated with dike intrusion. Topaz in the rhyolite occurs as part of a typical greisen assemblage in veinlets in the rock and as an alteration product of plagioclase. There is no evidence that topaz in this unit formed during vapor-phase crystallization in the rhyolite, as is the case for topaz in Tertiary topaz rhyolites. In other words, the Flying W is not a Precambrian example of a topaz rhyolite.

Dike emplacement and associated mineralization appear to be post-Mazatzal orogeny and pre-Apache Group in age. This would imply that both dikes and mineralization were formed during the interval 1715–1100 Ma.

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