The Mount Scott Intrusive Suite, Wichita Mountains, Oklahoma

Jonathan D. Price

Department of Chemistry, Geosciences, and Physics, Midwestern State University, 3410 Taft Boulevard, Wichita Falls, Texas, 76308. jonathan.price@mwsu.edu. ph. (940) 397-4288.

ABSTRACT

In the last 50 years the Mount Scott Granite and three other granite bodies—the Rush Lake Granite, the Medicine Park Granite, and the Saddle Mountain Granite—have been characterized and mapped as separate lithodemic units within the eastern Wichita Mountains of southwestern Oklahoma. These are part of the Wichita Granite Group (WGG), products of felsic magmatism during Eocambrian rifting of the Southern Oklahoma Aulacogen. Like all members of the WGG, these are pink-to-red A-type alkali feldspar granites. Each is porphyritic and wholly or partially granophyric, as are other WGG members. These units, however, share contact and compositional relationships that suggest a common reservoir in the crust that ultimately fed shallow (locally subvolcanic) tabular plutonic bodies, and that each constitutes part of the multi-lobed Mount Scott Intrusive Suite.

Using the voluminous Mount Scott Granite as a parent composition, the other three granite bodies are reasonably modeled as products of major-element crystal fractionation. The results, collaborated by trace-element trends, suggest that two daughter liquids formed through plagioclase and hornblende crystallization. One daughter fraction produced the Medicine Park Granite and part of the Rush Lake Granite, the second daughter fraction produced the remainder of the Rush Lake Granite. Compositional parameters indicate the site of fractionation was 7 to 8 km deep in the crust. Contact relationships indicate that these early liquids rose to intrude a shallow horizon 1 to 2 km below the surface. These early fractions were quickly followed by the magma that gave rise to the Mount Scott Granite. The relatively brief interval separating emplacement of these magma fractions may have provided the heat necessary to give the Mount Scott Granite its distinctive rounded (rapakivi) feldspar phenocrysts. Following emplacement, the Mount Scott Granite magma underwent further fractionation of small amounts of hornblende and alkali feldspar near its top to produce a liquid that gave rise to the Saddle Mountain Granite.

INTRODUCTION

Nearly half a century has passed since Clifford A. Merritt recognized the Mount Scott Granite as a distinctive unit based on its petrographic characteristics (Merritt, 1965). His paper is a classic examination of this well-exposed Cambrian granite in the eastern Wichita Mountains, southwestern Oklahoma. His careful examination arose from the exhaustive seminal study of Oklahoma's crystalline rocks undertaken with William E. Ham and Roger E. Denison (Ham et al., 1964) published the previous year. Ham et al. (1964) examined the rocks of the Wichita Mountains as the surface exposure of earliest Cambrian magmatism preserved in the Oklahoma basement. Whereas Ham et al. (1964) discussed group-level relationships, such as the Wichita Granite Group (WGG), Merritt (1965) focused solely on the Mount Scott Granite, previously mapped as the Lugert Granite, a similar WGG unit. New petrographic and chemical data, in part acquired for the Ham et al. (1964) study, permitted Merritt to concretely separate the two granites and begin to infer differences in their origins.

Merritt's study separated the Lugert Granite petrographically and geographically from the Mount Scott Granite. The latter is characterized by rounded alkali feldspar phenocrysts and enclaves of mafic minerals, features not seen in the Lugert Granite. Merritt's Mount Scott Granite included outcrops of medium-grained porphyritic granite in the Eastern Wichita Mountains, whereas those in the west remained mapped as Lugert Granite, as shown on his geologic map (Merritt, 1965, p. 266). He designated as mixed Lugert – Mt. Scott those exposures in the Raggedy Mountains, now south of Tom Steed Reservoir (constructed in 1975). Subsequent efforts definitively included these outcrops as Mount Scott Granite (Gilbert, 1982; Myers et al., 1981; Powell et al., 1980). Additionally, the area Merritt mapped as "Mt. Scott Granite" includes several exposures of granite that deviate from an "ovoid + enclave-"

bearing criterion. Later workers noted three other porphyritic granites that possess neither rounded phenocrysts nor mafic enclaves. The Saddle Mountain Granite was initially identified as a rhyolite (Havens, 1977; Merritt, 1967), but later as granite (Gilbert, 1986). The Medicine Park Granite was separated by Merritt (1967) and others (Gilbert, 1982, 1986; Merritt, 1967; Myers et al., 1981). The Rush Lake Granite, originally mapped as a subunit of the Mount Scott Granite (Myers et al., 1981), was distinguished by subsequent mapping efforts (Price, 1998; Stanley et al., 2005).

The nature of the intrusion events that produced these granites provides insight on the nature of the Southern Oklahoma Aulacogen and granitic magmatism in general. Merritt (1965) suggested a complex, multi-event intrusion for the Mount Scott Granite, citing subtle differences in chemistry and texture within the granite outcrops covered by his map. The currently mapped Mount Scott Granite (now strictly the ovoid + enclave rock) presumably removes much of the variation. With the exception of minor volumes adjacent to gabbros, the currently mapped granite is compositional homogenous, arguing for its origin as a single intrusion. The same assessment applies to the Medicine Park and Saddle Mountain Granites. The Rush Lake Granite exhibits minor compositional variation, but these variations reflect no more than two separated intrusions. As explored in this paper, all of these granites reveal features indicating they are spatially and compositionally related and roughly contemporaneous. The Mount Scott and the adjacent Medicine Park, Rush Lake, and Saddle Mountain Granites may constitute a complex, multi-event intrusive suite; granites from individual intrusions closely related in time, space, and composition.

Using new mapping and geochemical data, this paper explores the interconnections of these granites, a makes the case for a comagmatic origin for the Mount Scott, Medicine Park, Rush Lake, and Saddle Mountain Granites, building on previously defined relationships (Weaver and Gilbert, 1986). Furthermore, the paper will establish that these four units form a series of related and nearly contemporaneous intrusive events that formed the Mount Scott Intrusive Suite.

Nomenclature

This paper attempts to precisely employ terminology used in the characterization of intrusions. I use the term “pluton” as follows: a spatially-localized intrusion or agglomeration of largely concordant individual intrusions. Pluton, in this sense, closely approximates the intrusive equivalent of a consanguineous volcanic series in which an extrusive center erupts the evolved contents of a single magma chamber as one or more eruptive products.

To be clear—the individual granite units (e.g., the Mount Scott Granite) are lithodemic only, i.e., they are mappable as separate units based on easily-observed characteristics. It is admittedly confusing to employ the Mount Scott name to both a lithodemic unit and an intrusive suite (made of four lithodemic units). But doing so maintains consistency with previous work that has utilized Mount Scott as the type locality *and* the location that best defines the voluminous intrusion.

Like a volcano, the morphology and distribution of the igneous rocks in an intrusive suite depends on the compositional properties and driving pressures of the magmas from which they solidify. Plutonic intrusions, however, must also displace dense solid rock, so their geometry is also strongly affected by the structural integrity of the intruded crust. This paper uses “sheet” or “tabular body” to denote an intrusion with lateral dimensions that are greater than its thickness, exhibiting concordant to sub-concordant geometries and having an observable floor. The terms “sill” and “laccolith” are similar (and the former has been used in previous discussions of the plutonic bodies of the WGG). Sill typically implies intrusion into layered strata and a laccolith implies a demonstrably domed upper intrusive contact (Neuendorf et al., 2011). Sills, laccoliths, tabular bodies, and sheet plutons all may arise from similar crustal mechanics and emplacement processes (e.g., Hogan et al., 1998; Román-Berdiel, 1999; Vigneresse, 2004).

This paper will describe the Mount Scott Intrusive Suite as a shallowly-emplaced (epizonal) sheet pluton or tabular body composed of four lithodemic units: the Mount Scott Granite, the Rush Lake Granite, the Medicine Park Granite, and the Saddle Mountain Granite.

Regional geologic framework

The rocks that form the Mount Scott Intrusive Suite make up a significant part of the Wichita Mountains of southwestern Oklahoma (Fig. 1). The rocky promontories and rounded hills of this region are the exposed part of the Wichita Igneous province, a collection of mostly bimodal intrusive and extrusive lithologies (Ham et al., 1964; Hanson et al., 2012; Hogan and Gilbert, 1998; Myers et al., 1981; Powell et al., 1980; Soreghan et al., 2012). These lithologies represent magmatism associated with the formation of the Southern Oklahoma Aulacogen (SOA), late-Proterozoic to earliest Paleozoic continental rifting of the Pannotian supercontinent (Hoffman, 1974; Hogan and Gilbert, 1998; Keller and Stephenson, 2007).

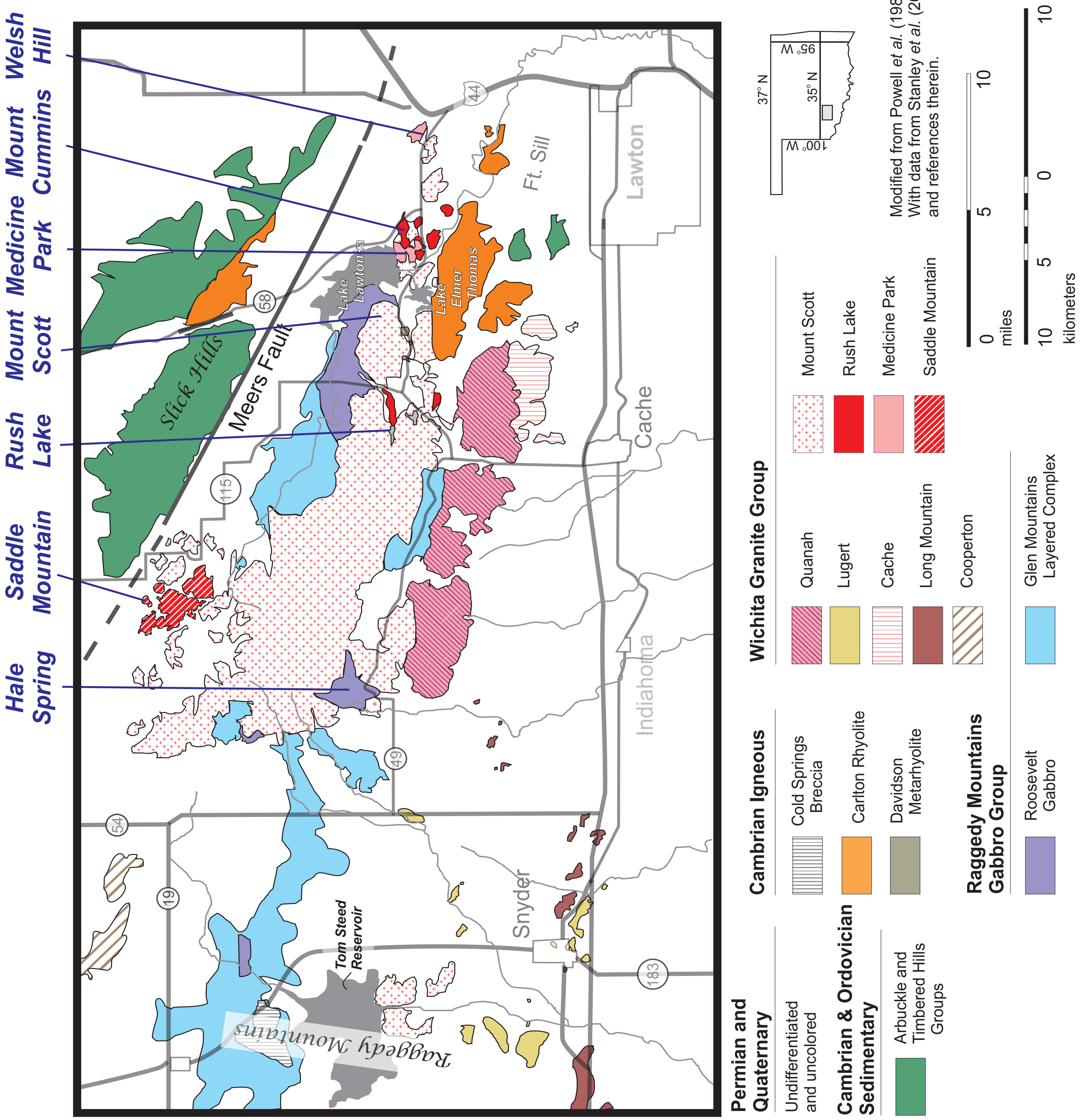


Figure 1. Map of the igneous units exposed in the eastern Wichita Mountains, southwestern Oklahoma. Locations for contact diagram (Figure 7) and descriptions in text are labeled at the top of the map.

The Glen Mountains Layered Complex (GMLC) represents the earliest magmatism recorded in the aulacogen as exposed in the Wichita Mountains. This is a voluminous layered mid-crustal intrusion of anorthosite, anorthositic gabbro, and troctolite. The GMLC is overlain by the Carlton Rhyolite Group, the contact between them records a period of uplift and erosion. Thus, the boundary is an unconformity that is marking a hiatus between early and late stages of magmatism (Gilbert, 1983; Ham et al., 1964; Myers et al., 1981; Powell et al., 1980). In addition to the rhyolite that is found extensively on the surface and in the subsurface of southern Oklahoma (Ham et al., 1964; Hanson et al., 2012; Puckett et al., 2011; Puckett et al., this guidebook), felsic magmatism during this latter stage also produced tabular bodies of alkali-feldspar granite. These tabular bodies are located at or near the unconformity (Hogan and Gilbert, 1997; Hogan et al., 1998; Myers et al., 1981). Post-GMLC mafic magmatism is also represented by the Roosevelt Gabbro plutons, formed volumetrically minor diabase dikes, and basaltic rocks found in the subsurface (Hanson et al., 2012; Puckett, 2012; Puckett et al., 2011).

Following the cessation of magmatism, a deep basin formed in the Late Cambrian and continuing through the Mississippian (Miall and Blakey, 2008). The igneous rocks were buried beneath 4-5 km of Paleozoic sediments now exposed in the northern Wichita Mountains (Slick Hills) and to the southeast in the Arbuckle Mountains. These Paleozoic rocks also comprise much of southern Oklahoma's subsurface. Pennsylvanian uplift of the Ancestral Rocky Mountains, following the trend of the aulacogen, locally removed the overlying sedimentary cover on the uplifted blocks (Soreghan et al., 2012). By the early Permian, the igneous rocks of the Wichita Mountains were exposed to erosion and weathering, producing many of the landforms largely observed in the modern topography (Gilbert, 1982). An influx of Permian clastic sediments, including locally derived Post Oak Conglomerate, buried these mountains (Al-Shaieb et al., 1980). Sporadic burial may have continued into the early Tertiary. Recent regional uplift eroded this cover, exposing the Permian landforms, and permitting limited modifications of the paleotopography. Generally, erosion increases to the southeast producing extensive exposures of the igneous rocks in that direction; the northwesternmost exposures tend to be inselbergs and isolated chains of peaks separated by Permian and Quaternary cover.

The well-exposed eastern Wichita Mountains' contact relationships preserve considerable insight into the complexities of the granitic intrusions. The Mount Scott Granite is one of the best-exposed units in the region, exhibiting visible contacts with three other similar granite units, the Medicine Park, the Rush Lake, and the Saddle Mountain Granites.

Characteristics of the magmatic units

This paper describes the four lithodemic units that formed the Mount Scott Intrusive Suite: the Saddle Mountain Granite, the Medicine Park Granite, the Rush Lake Granite, and the Mount Scott Granite. The latter unit is the most voluminous on the basis of exposure and likely represents the bulk of the intrusive suite. It is also the best characterized of the units. Highly weathered exposures are typical in the Wichita Mountains, but there are several localities of "fresh" Mount Scott Granite, where it has been exposed in barrow pits, quarries, and road cuts. Additional fresh material for the Mount Scott includes core from a shallow drill hole, spudded in the granite and drilled to a depth of 87.5 m (Price et al., 1998). This unit has been the subject of intense scrutiny since Merritt (1965) and numerous subsequent efforts contributed information about the processes that gave rise to the granite (Gilbert, 1982; Hogan and Gilbert, 1995; Hogan et al., 2000; Hogan et al., 1998; Merritt, 1967; Myers et al., 1981; Powell et al., 1980; Price et al., 1996; Price et al., 1999; Price et al., 1998). The other granite units are less exposed, have fewer "fresh" sampling localities, and have largely avoided in-depth scrutiny, but there are sufficient data for evaluation and comparison.

The Mount Scott Granite

The Mount Scott Granite is a pink to brick-red alkali-feldspar granite with mafic enclaves and 2 to 3 mm gray ovoid phenocrysts of alkali feldspar set in a variably granophyric matrix with minor plagioclase, amphibole, biotite and accessories minerals (Fig. 2A). Although petrographically medium grained, finely interspersed granophyre make it appear micro-granitic to the unaided eye. The color index of the granite is low (4 to 6 vol.% mafic crystals), and ovoid feldspar phenocrysts are dark-gray color in fresh samples. Mafic phases include ferroedenitic hornblende and Fe-rich biotite (Hogan and Gilbert, 1995) altered to chlorite and clays. The rock also contains hematite and minor ilmenite, and drill-core materials from depths greater than 28 m have unaltered magnetite (Price et al., 1998). Accessory phases of zircon + apatite ± titanite ± fluorite ± allanite occur in glomerocrysts of mafic minerals and oxides and as inclusions within the feldspar phenocrysts and the mafic minerals.

The characteristic ovoid crystals consist of two populations of alkali feldspar, one sodic (Or_{10-15}) and the other

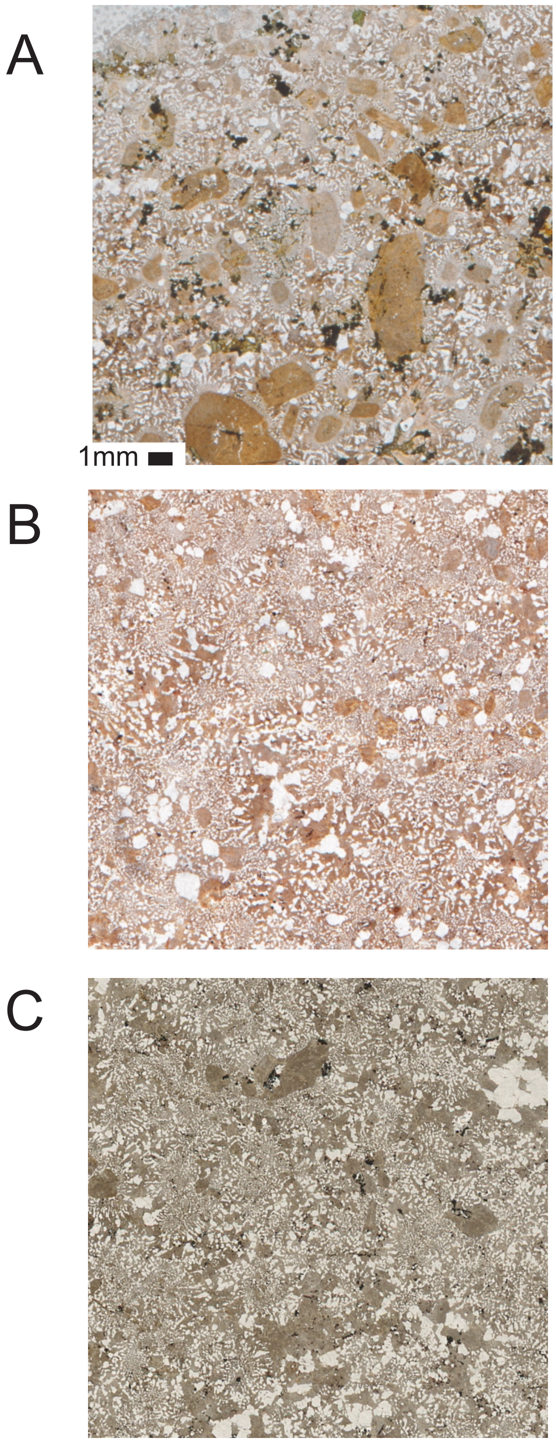


Figure 2. Plane polarized light photomicrographs of three of the granite units in the Mount Scott Intrusive Suite. A.) the Mount Scott Granite, exhibiting rounded phenocrysts (ovoids) partially mantled by fine to medium granophyre. B.) The Rush Lake Granite, with smaller, angular feldspar phenocrysts and dense granophyre. C.) The Medicine Park Granite, with a darker hue but similar texture to the Rush Lake Granite.

relatively potassic (Or_{50-65}). These precipitated as a solvus pair during early crystallization of the magma (Price, 1998; Price et al., 1996); the ovoid shape resulting from decompression-induced resorption during ascent from an early crystallization depth of 7 to 8 km to the emplacement depth at the GMLC-Carlton Rhyolite Group unconformity, estimated to be about 1 km at the time of the intrusion. Decompression adjustment of feldspar equilibria also resulted in epitaxial overgrowth of plagioclase on the resorbed ovoid crystals, particularly evident in granophyre-poor samples within the Mount Scott Granite.

Quartz phenocrysts in many samples from the Mount Scott Granite contain relatively low- titanium cores exhibiting sharp boundaries with the rims. The quartz crystals are not optically zoned, but electron-microprobe analysis (EMPA) and cathodoluminescence (CL) imaging reveal that these phenocrysts are compositionally zoned (Fig. 3). Quartz grains in the Mount Scott Granite emit dominantly blue CL, resulting from electron-induced Ti emission where Ti substitutes for Si in the lattice. The intensity of the blue CL, which correlates to Ti concentration, varies greatly from phenocryst core to rim. Cores exhibit subtle fine oscillatory zoning with an overall diminished intensity, correlating with low Ti concentrations (40 to 60 ppm) as determined by EMPA. A sharp (4- micron) boundary separates the cores from rims with stronger CL intensity and correspondingly elevated Ti concentrations (100 to 200 ppm). Many rims also exhibit zoning with rimward-decreasing CL intensity and Ti concentration. The CL intensities and Ti concentrations of non-phenocrystic quartz (including granophyre) is comparable to that of the rims (Price, 2011).

The Mount Scott Granite exhibits a variation in granophyre concentration that Merritt (1965) noted. Granophyre is an intergrowth texture of feldspar and quartz (Fig. 4) observed in shallowly emplaced A-type granites (Morgan and London, 2012). The granite ranges from granophyric to allotriomorphic granular in texture. There is a slight decrease in the amount of quartz with decreasing granophyric content—the quartz mode drops from 25% in samples with no discernible granophyre (completely allotriomorphic granular) to 20% where granophyric texture exceeds 90% of the matrix (Price, 2013). The ovoids serve as the dominant nucleation site for granophyre, but smaller phenocrystic quartz may also be mantled by granophyre.

The average chemical composition of the Mount Scott Granite is presented in Table 1. With the exception of samples near gabbro contacts (which are excluded from the average value), the Mount Scott Granite is remarkably homogenous, particularly with respect to trace elements. Samples

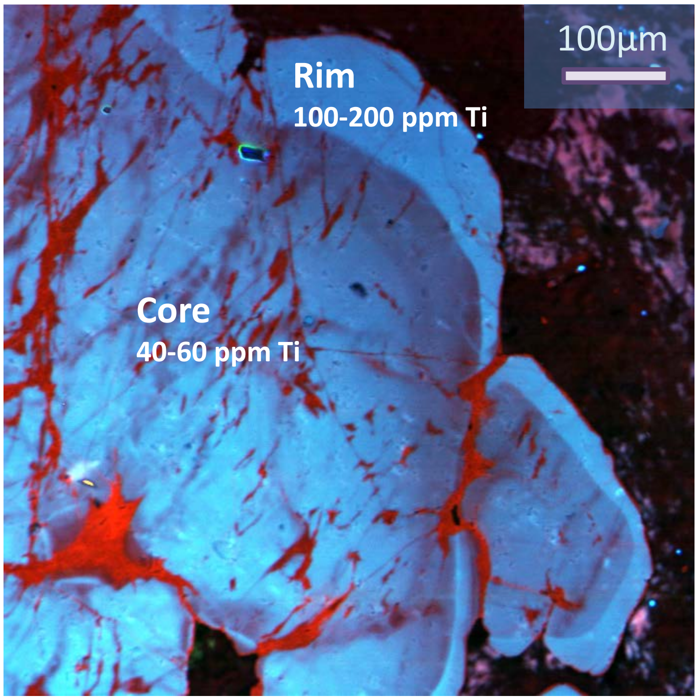


Figure 3. Compiled image of Red-Green-Blue (RGB) filtered electron-beam induced cathodoluminescent (CL) emissions on quartz in the Mount Scott Granite. Although not optically resolvable, CL reveals that quartz phenocrysts have cores that emit lower-intensity blue light and rims that emit higher-intensity blue light. A sharp boundary separates the core from the rim. Electron Microprobe Analysis (EMPA) reveals that this change is due to core-to-rim increases in Ti substituting for Si in the quartz. Red CL results from Fe emission from hematite grains, veins, disseminated particles.

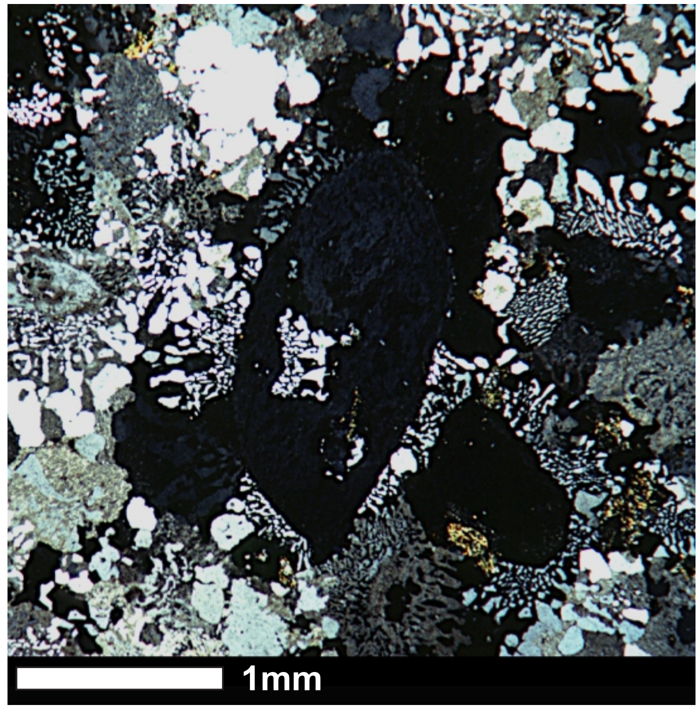


Figure 4. Cross-polarized optical micrograph of granophyric texture in Mount Scott Granite. Granophyre is the intergrowth of alkali feldspar and quartz attributed to significant magma undercooling during crystallization. All of the Mount Scott Intrusive Suite units exhibit granophyric texture, principally nucleated on feldspar and, to a lesser extent, on quartz crystals.

taken from localities 25 km apart reveal only minor differences in composition. It is low-calcium, metaluminous, and enriched in La, Y, and Yb; typical of within-plate and A-type granites (Hogan and Gilbert, 1995; Weaver and Gilbert, 1986). The normative Q-Ab-Or concentrations place it between the dry minimum and wet eutectic compositions at 400 MPa (Fig. 5). Lanthanide elements normalized to chondrite meteorite (i.e., Bulk Earth) compositions generally decrease with increasing atomic number and show a pronounced europium anomaly (Fig. 6).

Rush Lake Granite

The Rush Lake Granite is a recently defined unit, first recognized as a separate lithodemic unit in unpublished mapping in Price (1998), and incorporated into the Lawton Quadrangle 1:100 000 geologic map (Stanley et al., 2005). Price (1998) argued that the unit is texturally distinct, in part because it lacks the ovoid + enclave assemblage so common to the Mount Scott Granite. The author also noted significant geochemical differences. Prior to this new mapping, the granite was included as part of the Mount Scott Granite (Facies B) (Myers et al., 1981).

The Rush Lake Granite is red weathering to brick-red and orange. Relatively unweathered exposures are rare, as its small volume is mostly limited to valleys. It is porphyritic with mostly angular pink alkali feldspar phenocrysts surrounded by variable amounts of granophyre (Fig. 2B). Granophyre growth boundaries are well defined in coarser samples by distinctive “chains” of quartz crystals (typically < 1 mm wide and 2 to 3 cm long). The rock color index varies from 3 to 5 vol. %, and contains biotite, hornblende, and oxides, and in most samples the mafic silicates have been extensively altered to chlorite and clay minerals. Accessory minerals include apatite, fluorite, zircon, and allanite. The rock contains abundant 2 to 50 mm diameter miarolitic cavities and microscopic to 3-cm-wide quartz veins.

Compositionally, the Rush Lake Granite is a low-calcium, metaluminous, alkali feldspar granite (Table 1). Limited sampling reveals that the unit is compositionally heterogeneous, with analyses pointing to at least two chemical types. Type A is represented by a sample taken from the westernmost exposures of the granite near Rush Lake that contains relatively low amounts of Fe, Mn, Ti, and (most significantly) Ba (Table 1). It has relatively elevated SiO_2 and, at 75.8 wt.%, it is one of the most silica-rich felsic rocks within the province. It also has the greatest europium anomaly of the units considered here (Fig. 6). Type B is represented by the average of two analyses from the eastern outcrops. This type most notably contains subequal amounts of Na_2O and K_2O (Table 1).

Compared to Mount Scott Granite, Type A Rush Lake shows minor enrichment of Nb, La, and Ce. This differs from the trend exhibited by the Type B Rush Lake and Medicine Park Granites, but is similar to the Saddle Mountain Granite. Type A also shows the greatest decrease in Ba (43%) and Sr (82%) relative to the Mount Scott Granite. Type B, on the other hand, shows broad similarities in composition with the Mount Scott Granite. Generally, it is relatively enriched in K, Rb, Th but strongly depleted in Sr, and slightly depleted in Ba, the REE's, and Zn. Both types plot near the Q-Ab-Or range for the Mount Scott Granite, but type A is relatively enriched in normative quartz while type B is relatively enriched in normative albite (Fig. 5).

Table 1. Composition of the units in the Mount Scott Granite Intrusive Suite

	Mount Scott Granite Avg	Medicine Park Granite Avg	Rush Lake Granite Type A	Rush Lake Granite Type B Avg	Saddle Mtn. Granite* Avg.
Major element oxides in wt.%					
SiO_2	72.8	75.6	75.8	73.0	72.8
TiO_2	0.44	0.21	0.15	0.31	0.46
Al_2O_3	12.5	11.9	11.6	12.1	12.5
Fe_2O_3	3.54	2.35	1.87	2.76	3.88
MnO	0.08	0.02	0.01	0.02	0.08
MgO	0.35	0.05	0.06	0.26	0.38
CaO	1.22	0.45	0.28	0.63	1.11
Na_2O	3.96	3.84	3.76	4.46	3.62
K_2O	4.24	4.61	5.07	4.27	4.35
P_2O_5	0.07	0.01	0.02	0.06	0.07
LOI	0.17	n.d.	0.64	0.85	n.d.
Total	99.30	99.03	99.28	98.73	99.27
Trace elements in ppm					
Ba	1130	1080	664	963	1135
Rb	128.3	145.5	163.4	148.5	136.5
Nb	90	84	101	82	81
Ta	8	8	9	7	8
Sr	97	41	17	51	104
Zr	547	476	344	529	594
Y	109	93	81	75	107
Zn	128	48	71	99	94
La	88.6	82.9	90.9	70.2	91.5
Ce	190.7	165.9	201.5	145.3	189.0
Pr	20.5	n.d.	20.6	18.7	n.d.
Nd	97.4	88.3	91.4	77.2	91.0
Sm	21.4	20.4	17.5	17.4	20.2
Eu	3.8	2.6	1.5	2.7	3.1
Gd	20.6	n.d.	17.8	17.6	n.d.
Tb	3.3	3.0	2.8	2.6	3.0
Dy	19.5	n.d.	15.5	14.0	n.d.
Ho	4.0	n.d.	3.0	2.9	n.d.
Er	11.7	n.d.	9.1	8.5	n.d.
Tm	1.6	n.d.	1.3	1.2	n.d.
Yb	10.0	8.9	8.6	8.5	9.8
Lu	1.4	1.4	1.4	1.3	1.6
Hf	17	14	12	16	16
Th	13	15	17	15	14
F	1785	n.d.	1370	2570	n.d.

*Includes data from Weaver and Gilbert (1986, unpublished).

Medicine Park Granite

The Medicine Park Granite was first recognized by Johnson and Denison (1973) and subsequently described by Myers et al. (1981) and Gilbert and Powell (1988). The rock is pink-purple weathering to dark red, porphyritic with small angular orange-pink alkali-feldspar phenocrysts in a largely granophyric matrix (Fig. 2C). The color index is extremely low; the rock contains 1 to 2 vol.% altered mafic silicates (probable pseudomorphs after hornblende) and oxides. Myers et al. (1981) reported the rock to be "pyroxene-bearing in places;" but pyroxenes were not present in samples collected by Price (1998). Oxides are typically rounded and rimmed with a thin mantle of titanite. Other accessory phases include apatite and zircon that occur as glomerocrysts with the mafic phases. Small quartz veins (2 to 6 mm wide) are common.

The Medicine Park Granite is unique among the granites described here, because it alone contains normative corundum (1%; Myers et al., 1981). Compositionally the Medicine Park Granite is evolved with elevated concentrations of SiO_2 and Rb and relatively low amounts of CaO, P_2O_5, and mafic components.

Despite differences, the Medicine Park Granite is similar to the Mount Scott Granite and falls on the quartz-enriched end of the same range of normative Q-Ab-Or. It is relatively enriched in K, Rb, Th but strongly depleted in Sr, and slightly depleted in Ba, the REE's, and Zn, making

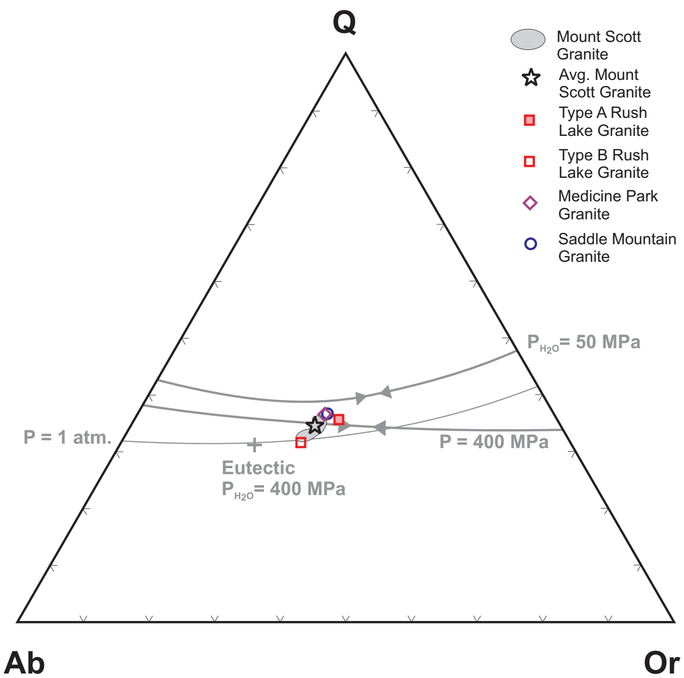


Figure 5. Q-Ab-Or plot for the granite units in the Mount Scott Intrusive Suite. Data fall within a small area on the plot, illustrating the compositional similarity among these rocks. Boundary curves from Steiner et al. (1975) shown for reference.

much of its composition virtually identical to Type B Rush Lake Granite. It occurs in contact with the Type B Rush Lake Granite and can be discriminated from it by its low color index and purple hue.

Saddle Mountain Granite

The Saddle Mountain Granite has been previously described in Gilbert (1986). This is a dark red, dense, and porphyritic granophyric granite that grades into spherulitic texture to the north. Phenocrysts are alkali feldspar and quartz, with lesser hornblende and biotite in the matrix (Myers et al., 1981).

The geochemistry of the Saddle Mountain Granite are documented in Gilbert and Myers (1986) and Weaver and Gilbert (1986), and their data is employed in this study. Generally, the granite is low-calcium, metaluminous, and enriched in La, Y, and Yb. It is identical to the Medicine Park Granite in normative Q-Ab-Or (Fig. 5). Overall, it is nearly chemically indistinguishable from the Mount Scott Granite. It has a slightly deeper europium anomaly (Fig. 6) and slightly elevated Sr and Zr.

Exposures and contact relationships

The units of the intrusive suite and their contacts are locally covered by Permian and recent sediments but are reasonably well exposed throughout the eastern Wichita Mountains. Most exposures are highly weathered, and they are all medium grained porphyritic red granites, making field discrimination a challenging exercise. However, with care the contacts between units can be observed and are reasonably informative. These contacts appear to be intrusive in nature and are not post-magmatic faults.

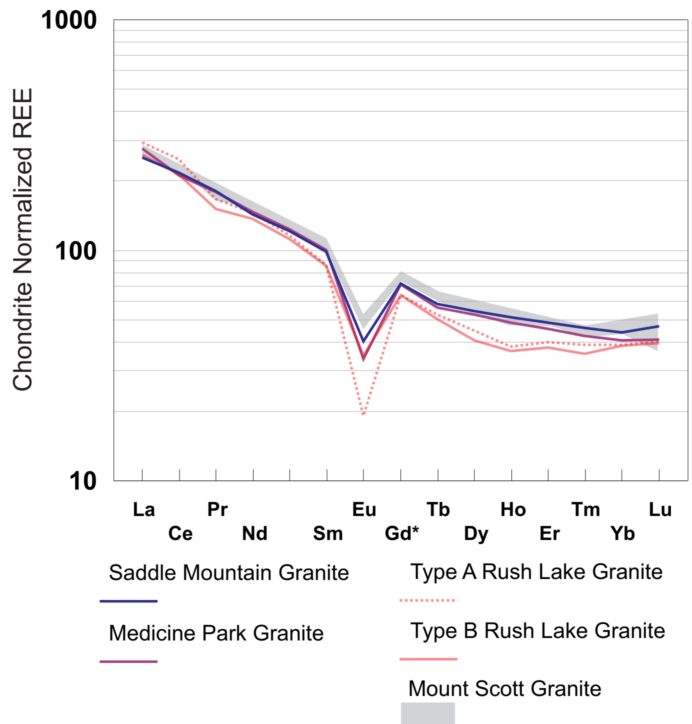


Figure 6. Rare-earth element diagram for the units of the Mount Scott Intrusive Suite. Although all units exhibit similar trends, there is an overall depletion in all elements and a development of the Eu anomaly with the Saddle Mountain Granite, to the Medicine Park Granite, to the Rush Lake Granite. This trend might indicate increasing amounts of plagioclase fractionation. Values normalized to chondrite analyses of Nakamura (1974).

Much of the exposure of the intrusive suite is on public lands. The bulk is within the boundaries of the Wichita Mountains Wildlife Refuge (WMWR), and a small amount is within those of the Great Plains State Park, immediately south of Lake Tom Steed. The intrusive suite's easternmost exposures are on the hills just west of I-44, Welsh Hill (Fig.

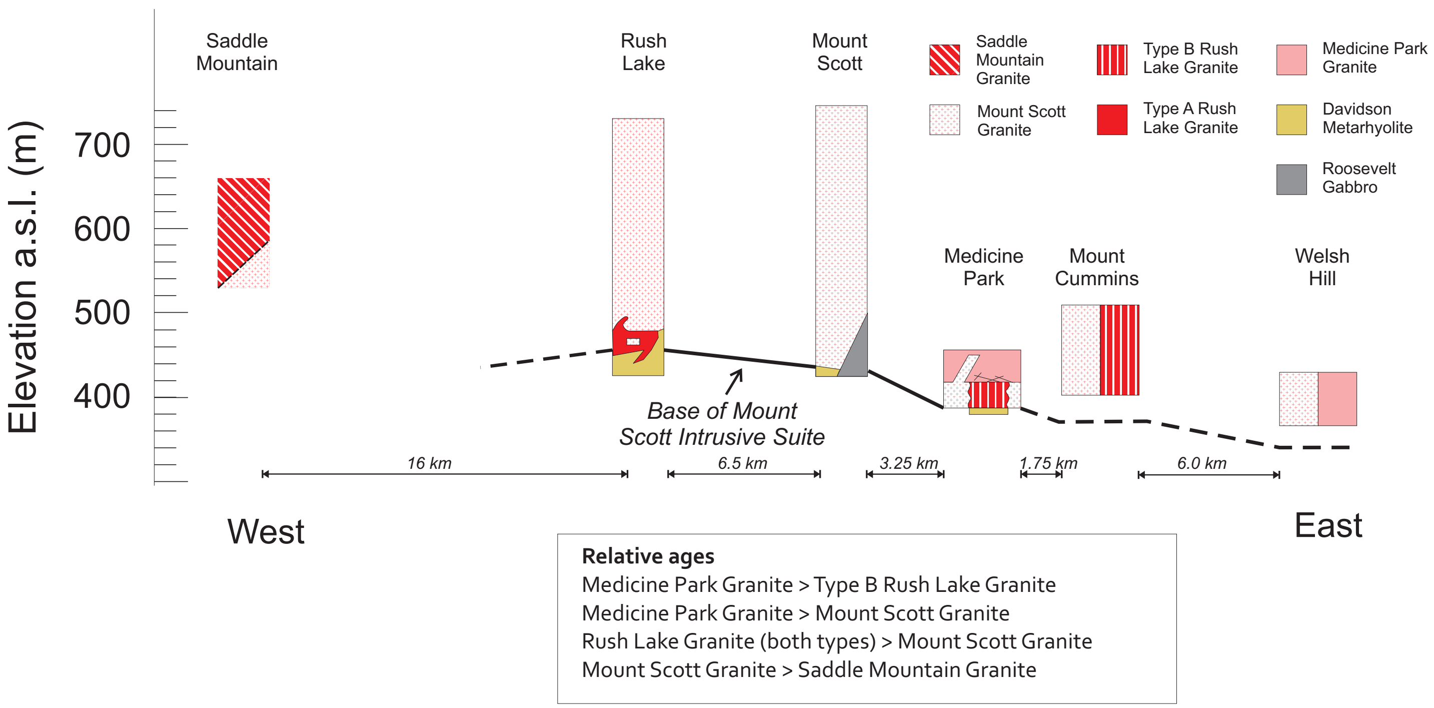


Figure 7. Columns outlining the general elevation relationships of exposures among the Mount Scott, Rush Lake, Medicine Park, and Saddle Mountain Granites, and adjacent lithologies along a west to east traverse in the eastern Wichita Mountains. Locations are noted at the top of Figure 1. The Saddle Mountain is minimally exposed near its type locality; it grades into the Mount Scott Granite at what is likely the top of the intrusive suite. The Davidson Metarhyolite underlies the intrusive suite at Rush Lake, Mount Scott, and the Medicine Park. It is the likely floor of the intrusive suite. At Rush Lake, the Rush Lake Granite intrudes the Davidson and incorporates it as xenoliths, and underlies the Mount Scott Granite, and their contacts are interdigitating. Further east, all of the units of the intrusive suite seemingly share the same horizon of emplacement. Mount Scott Granite dikes intrude the Medicine Park Granite, suggesting that is older than the former.

1). Here and to the immediate west, the Mount Scott Granite is interspersed with the Type B Rush Lake and Medicine Park Granites. The Permian (Leonardian) Post Oak conglomerate partially covers this exposure, as does modern alluvium and soil.

Starting at the southern base of its type locality, the Mount Scott Granite is uninterruptedly exposed along the northern range of peaks to just beyond the western boundary of the WMWR. The Type A Rush Lake Granite is also exposed near the base of Mount Scott west to Rush Lake (Fig. 1), but the exposures are sporadic. The Rush Lake contacts the Davidson Metarhyolite, a hornfels that may represent the floor immediately under the intrusive suite. Both units form the eastern lowlands which are partially mantled by Permian sediments. The Rush Lake Granite's furthest west exposures are adjacent to but not covered by Rush Lake (reconnaissance of the reservoir floor, drained in 2011 for dam repair, found only Mount Scott Granite in the lake bottom). The Mount Scott and Rush Lake Granites (particularly the latter) are locally covered by Post Oak Conglomerate, boulders, and a few thin soils. Exposures of the Mount Scott Granite terminate west of the refuge at a relatively abrupt change from mountainous to plains topography. Most of Mount Scott Granite at this boundary is in contact with Permian sedimentary strata that overlie members of the RMGG. Two embayments of RMGG occur at the western and southwestern edge of this boundary. The southwestern embayment, known as the Hale Spring Area (Fig. 1), has been the subject of detailed study (McLean and Stearns, 1986; Price et al., 1998), including scientific drilling and sampling from the Smith Quarry, one of the original type localities of Merritt (1965).

The Mount Scott Granite is almost continuous to its northernmost exposures, which occur 4 km east of the intersection of state highways 19 and 54. Much of the northern part of the exposed Mount Scott Intrusive Suite is partially covered by Permian strata and recent detritus, and exposures are limited to rugged inselbergs. The Saddle

Mountain Granite crops out 10 km further to the east based on mapping by Powell et al. (1980) and Gilbert (1986). There is no Mount Scott-Saddle Mountain contact *per se*. It changes texture from spherulitic in the north to granophyric in the south, and grades into Mount Scott Granite (Gilbert, 1986). To the southeast, the northern margin of Mount Scott Granite overlies the Raggedy Mountains Gabbro Group (RMGG). The northern margin of the intrusive suite is as much as 17 km from the southern one, where it contacts the Quanah Granite, the GMLC, and the Carlton Rhyolite and Davidson Metarhyolite.

Another extensive outcrop of Mount Scott Granite is in the central Wichita Mountains (Raggedy Mountains) south of Lake Tom Steed in and adjacent to Great Plains State Park. These outcrops are largely isolated and surrounded by Permian strata.

Based on the exposures described above, the intrusive suite, dominated by the Mount Scott Granite, is exposed for a distance 55 km east to west, (25 km of which is continuous) and nearly continuously for 17 km north to south. The total exposed surface area is 240 square km. Exposures suggest a thickness of at least 0.5 km, and there is no evidence to suggest a substantially thicker geometry. Merritt (1965) notes that Mount Scott Granite-like materials were encountered in the subsurface both north and south of the exposed rocks. Additionally, the roof is not preserved and the top of the suite has been eroded. Thus, the above dimensions slightly underestimate the size of the body. The exposures however indicate that the intrusive suite was thin but laterally extensive.

The Mount Scott Granite overlies the GMLC, much of the Roosevelt Gabbros, the Type A Rush Lake Granite, the Davidson Metarhyolite, and the lowermost Carlton Rhyolite Group. It roughly shares the same horizon with the upper part of the Sandy Creek Gabbro (Roosevelt Gabbro), the Quanah Granite, the Type B Rush Lake Granite, and much of the Medicine Park Granite. It is also locally below the Medicine Park Granite and beneath the Saddle Mountain Granite. Generally speaking, the Medicine Park and Rush Lake Granites are along the floor of the intrusive suite even with the base of the Mount Scott Granite. The Saddle Mountain Granite is in the uppermost parts of the intrusive suite.

Figure 7 illustrates the exposure elevations and the contact relationships of the intrusive suite, from Saddle Mountain to Welsh Hill (Fig. 1). As mentioned above, the contact between the Mount Scott and Saddle Mountain granites is gradational, but the latter is exposed at relatively higher elevations in the Saddle Mountain region. The Rush Lake, Medicine Park, and Mount Scott Granites exhibit considerable complexity where exposed in the easternmost Wichita Mountains. The contact geometries near the town of Medicine Park are perhaps the most complex (Figure 8). Topographical relationships that suggest these three granites intruded along the same horizon near the base of the intrusive suite.

Within the Mount Scott Intrusive Suite, exposures of contacts between the Rush Lake (both types) Granite and the Mount Scott Granite indicate that the Rush Lake Granite predates more voluminous unit, but not by much time. Exposures at Rush Lake reveal a non-diffuse, but convoluted, interdigitating boundary between the Mount Scott and Type A Rush Lake Granites. Exposures at Medicine Park and Mount Cummins reveal a gradual, diffuse contact between the Mount Scott and Type B Rush Lake Granites. At all three localities, the Mount Scott Granite contains xenoliths and stoped blocks of the Rush Lake Granite near the contacts.

The Medicine Park Granite appears to predate the Mount Scott and Rush Lake Granites. Both fine as they approach their respective contacts with the Medicine Park Granite. Additionally, a fine-grained Mount Scott Granite dike intrudes the Medicine Park Granite. Contacts between the Medicine Park Granite and the Mount Scott Granite are always sharp and subplanar.

At present, the Mount Scott Granite is the only suite unit with an absolute age at 533.4 ± 1.7 Ma, zircon (Wright et al., 1996). Given evidence that the time span for magmatism is likely to be short (Price et al., 2012), it is also likely that any differences in radiometric dates for the other units of the intrusive suite would be insignificant. Contact relationships provide the best evidence for timing of the intrusions, and they indicate that the Mount Scott Granite and Rush Lake Granite are younger than the Medicine Park Granite, and that the Mount Scott Granite is younger than the Rush Lake Granite.

Compositional relationships

The four units share many compositional characteristics while exhibiting a few small but important distinctions. In terms of incompatible elements, the Mount Scott and the Saddle Mountain Granites are the most primitive, having low SiO_2 and Rb and high FeO + MgO (Weaver and Gilbert, 1986). The Type A Rush Lake Granite is slightly more evolved than the Mount Scott Granite, and the Type B Rush Lake and Medicine Park Granites are the most evolved of the series. Lanthanide-element plots normalized to chondrite (Nakamura, 1974) illustrate both depletion of rare-earth elements and an increased Eu anomaly for the Saddle Mountain, the Medicine Park, and the Rush Lake (both types) Granites relative the Mount Scott Granite (Figure 6).

The similar composition and texture and the close proximity of the four units suggests a possible genetic relationship. Weaver and Gilbert (1986) previously suggested such a relationship among the Medicine Park, Saddle Mountain, and Mount Scott Granites. The nature of this relationship and the relationship of these three units with the Rush Lake Granite is potentially constrainable through mass-balance modeling.

The incompatible-element relationships, coupled with the field data, suggest that the Medicine Park, Rush Lake, and Saddle Mountain granite units formed from magmas that arose as daughter products through crystal fractionation. Given its substantially greater volume and more primitive composition, the Mount Scott Granite represents a likely parental magma. This granite, although largely homogeneous, exhibits limited compositional variation best seen in the trace elements (e.g., Ba, Rb, Sr). Trace element plots of the Medicine Park, the Rush Lake, and the Saddle Mountain Granites fall along trends that point to the Mount Scott Granite samples with low Rb. Therefore, fractional crystallization relationship would reasonably start with a parent magma similar to low-Rb Mount Scott Granite.

Modeling assumes that the processes resulting in the magmas that formed the Rush Lake and Medicine Park Granites occurred prior to the ascent of these bodies and the Mount Scott Granite, a sequence consistent with contact relationships. Processes that produced the Saddle Mountain Granite occurred following emplacement of the Mount Scott Granite, which is also consistent. Descriptions of pre- and post-ascent fractionation follow.

Major Element Modeling

Least squares models (e.g., Wright and Doherty, 1970) of major-element fractionation were applied using the low-Rb Mount Scott Granite composition as a parent. The model used compositional data for the feldspars, amphiboles, biotites, oxides, titanites, and apatites from the Mount Scott Granite. Liquids were then calculated from the degree of fractionation to crystals following Mount Scott Granite crystals + liquid = Low-Rb Mount Scott Granite. Three potential liquids were modeled using the following compositions: I) average Medicine Park Granite, II) Type A Rush Lake Granite, and III) Saddle Mountain Granite. The Type B Rush Lake Granite approximates the compositional parameters of the Medicine Park Granite and is adequately modeled using liquid I. Liquids I and II are products of pre-ascent fractionation, liquid III is a post-ascent product.

Pre-ascent liquids would result from the fractionation of early-forming minerals (phenocrysts and other pre-emplacement phases). In the Mount Scott Granite, prior work has established a pre-ascent assemblage of Ksp + Pl + Qtz + Hbl +Ttn (Hogan and Gilbert, 1995; Price, 1998, 2013; Price et al., 2012; Price et al., 1996). Oxide populations could be early as well. Of these phases, plagioclase is absent and hornblende concentrations are diminished in both the Medicine Park and Rush Lake Granites.

The models indicate the Rush Lake and Medicine Park Granites are related through fractional crystallization of mostly hornblende and plagioclase (Table 2). Modeling for the liquid that gave rise to the Medicine Park Granite (I) requires 6.4 wt.% crystallization of plagioclase, 5.9 wt.% hornblende and 0.6 wt.% titanite. This produces a reasonable fit (sum of the squared residuals (Σr^2) = 0.388) with discrepancies in Na_2O contributing 71% the squared

Table 2. Major element fractionation models (least squares). All values are in weight percent.

	P	I	II	III
	Low-Rb Mount Scott Granite	Medicine Park Granite	Type A Rush Lake Granite	Saddle Mtn. Granite
Liquid		88.4	82.7	92.4
Hbl		5.9	7.3	2.6
Ab				5.8
Pl		6.4	10.6	
Ttn		0.6	0.8	0.4
Ap				0.6
Mt				0.9
Bt				
		Calculated Parent		
SiO_2	72.8	72.8	72.8	72.8
TiO_2	0.47	0.47	0.44	0.45
Al_2O_3	12.5	12.2	12.3	12.6
Fe_2O_3	3.72	3.75	3.72	3.72
MnO	0.09	0.04	0.01	0.05
MgO	0.29	0.28	0.29	0.23
CaO	1.29	1.25	1.33	1.33
Na_2O	3.96	4.48	4.28	3.80
K_2O	4.17	4.12	4.25	4.14
P_2O_5	0.08	-0.03	-0.07	0.28
Σ res^2		0.39	0.17	0.08

Figure 8. Panoramic photograph of the region east of the town of Medicine Park showing the approximate locations of the contacts between the Medicine Park Granite, the Rush Lake Granite, and the Mount Scott Granite. The gen-

residual values. A better fit results from added (dissolved in) albite. Modeling the Type A Rush Lake Granite (II) as a daughter product results in 10.6 wt.% crystallization of plagioclase, 7.3 wt.% crystallization of hornblende, and 0.8 wt.% titanite, with a reasonable fit ($\Sigma r^2 = 0.171$). Na_2O is again the greatest source of squared residuals (57%). As above the fit is improved if albite is added into the parent composition.

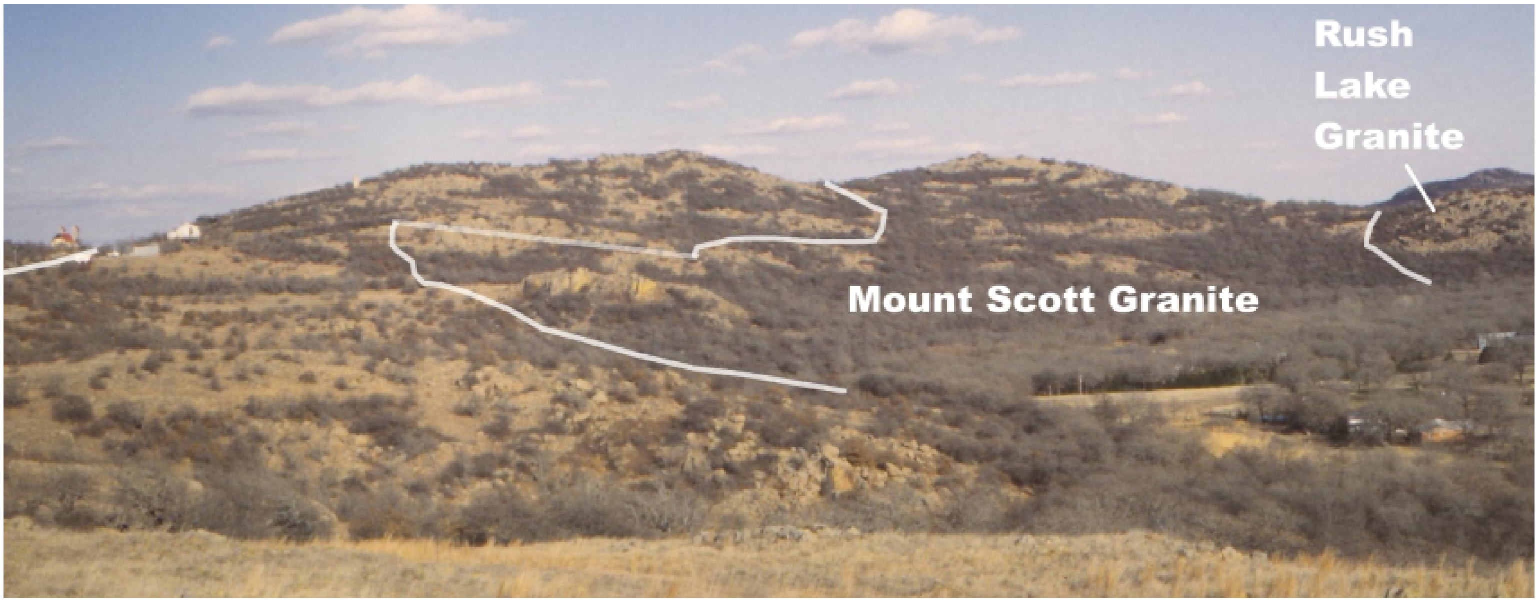
All pre-ascent fractionation models indicate increasing Na_2O, even if one employs other Mount Scott Granite compositions for the parent. The reason for this is unclear. Liquids I and II may have acquired Na_2O through Ab assimilation. Plagioclase assimilation seems likely as ascent would have traversed the anorthositic rocks of the GMLC en route to the emplacement level. However, the liquids require the addition of roughly 0.5 wt.% Na_2O, requiring 19% incorporation of GMLC feldspars based on the compositions documented in Powell and Phelps (1977). And any acquired plagioclase would have to completely dissolve into the melt and/or diffuse into the feldspars, as plagioclase is not present in either the Rush Lake or Medicine Park Granites. This seems unlikely given the heat budget of the magma. So addition of Ab could not arise solely through the addition of GMLC feldspars. Alternatively, the discrepancy may reflect incorporation of albitic feldspar from an unknown source. It could also arise from an inadequate parental composition and/or incorrectly assuming alkali contents of the Rush Lake and Medicine Park Granites are representative of their respective magmas. Late-stage SiO_2 loss might affect the alkali content of the granites. Quartz veins are a prominent, but volumetrically minor feature (<1 vol.%) in these units. Veins could indicate late volatile scavenging or post-crystallization leaching of SiO_2 if they are sourced from their host. While this might be plausible for the granites derived from liquid I, the elevated SiO_2 of the Type A Rush Lake Granite precludes significant SiO_2 loss.

Post-ascent fractionation would result from the late-stage crystallization of the magma. Late stage phases in the Mount Scott Granite include Ksp ± Ab + Bt + Ap ± Ttn ± Flu. Hornblende may continue crystallizing during the late stage, given the relatively elevated fluorine contents attributed to the magma (Price et al., 1999).

Modeling the Saddle Mountain Granite (III), results in a smaller amount of fractionation over a greater number of phases—2.6 wt.% hornblende, 5.8 wt.% sodic alkali feldspar, 0.4 wt.% titanite, 0.6 wt.% apatite, and 0.9 wt.% biotite. This produces an excellent fit between the calculated parent composition and the actual value ($\Sigma r^2 = 0.082$).

Trace Element Modeling

A comparison of fractionation trends in Rayleigh trace-element fractionation models supports the fractional crystallization process determined by the major-element modeling. Instead of calculating a fractionation scheme for each data point, vectors are plotted on relevant trace-el-



eral nature of the contact places Mount Scott Granite adjacent to Rush Lake Granite, and above or adjacent to the Medicine Park Granite.

ement-ratio diagrams to illustrate the trends of hornblende and plagioclase fractionation. This vector-trend analysis is preferred because 1. robust distribution coefficients (K_Ds) for this system are unavailable; 2. these rocks contain relatively small deviations in concentration, therefore small changes in K_Ds could result in significant error; and 3. the uncertainty expressed in the Na_2O concentrations within the major-element models extends to the trace-element level. In felsic systems, the distribution of elements is greatly influenced by small changes in composition and intensive parameters (Pitcher, 1993), so assessing fractionation through trace-element modeling is a limited exercise. It does however further test the conclusions of the major-element mass balance.

In figure 9, the ratios of the abundant and strongly depleted (relative to the Mount Scott Granite) elements Ba and Sr and the abundant and variably depleted elements Y and La are plotted against Rb (an index of differentiation) for these units. Distribution coefficients indicate that hornblende incorporates La over Y for increasing Rb producing a downward curve, whereas plagioclase produces the opposite. Hornblende incorporates Ba/Sr at similar amounts with Rb, whereas plagioclase shows a strong preference for Ba relative to Sr.

The Medicine Park and Rush Lake Granites largely plot between the two vectors, consistent with fractionation of both plagioclase and hornblende. However, there is discrepancy with the major-element models in the degree of fractionation. For example, the Type A Rush Lake granite is reached by fractionating 11 wt.% plagioclase, equivalent with the values predicted by the major-element model, while requiring 16 wt.% crystallization of hornblende, which is double that of the major-element prediction. This higher value is unlikely given the low concentration of hornblende in the Mount Scott Granite. Additionally, one of the Medicine Park Granite samples plots inconsistent in the Y/La and Ba/Sr models, showing an affinity for plagioclase fractionation in Ba/Sr (Fig. 9B) and an affinity for hornblende fractionation Y/La.

Model summary

Fractionation models use a common parent similar to low-Rb Mount Scott Granite. Major-element modeling yields daughter liquid I, with the composition of the Medicine Park Granite and the Type B Rush Lake Granite, though fractionation of plagioclase and hornblende with minor amounts of titanite. The Type A Rush Lake Granite could also arise through more extensive fractionation of plagioclase and hornblende from the same parent. Trace-element-variation diagrams confirm that such fractionation pathways are plausible. Rare-earth-element diagrams also point to the prominence of plagioclase fractionation as evidenced by the Rush Lake Granite and Medicine Park Granite having larger Eu anomalies than the Mount Scott Granite (Fig. 6). The Saddle Mountain Granite requires a

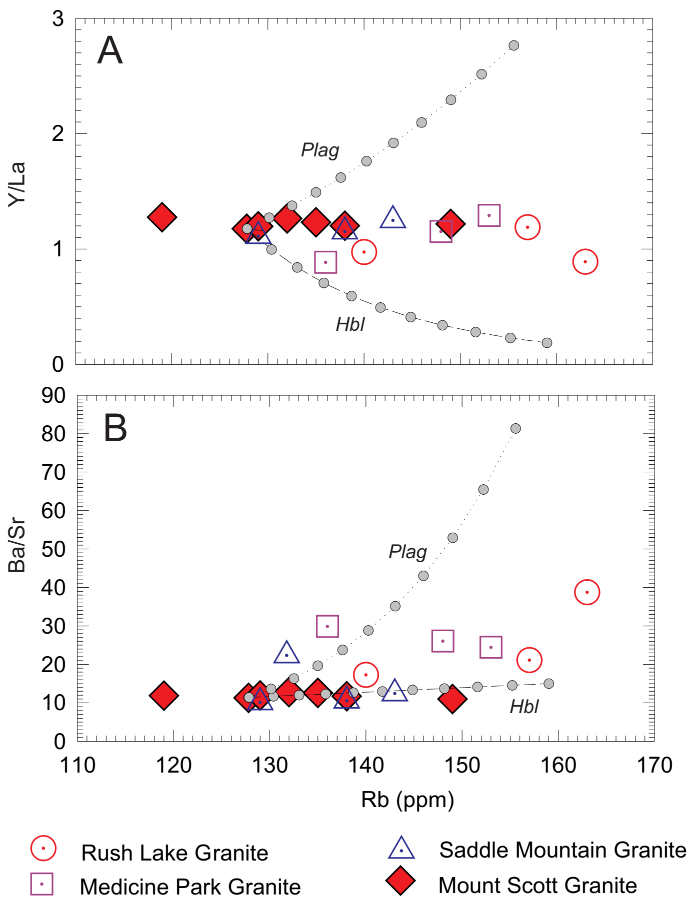


Figure 9. Plots of element ratios versus Rb for the Mount Scott Intrusive Suite. Small gray circles on curves result from Rayleigh fractionation for plagioclase (Plag) and hornblende (Hbl), each are F = 0.2% apart. Plots agree with major-element models that minor fractionation of plagioclase and hornblende produced to the Rush Lake and Medicine Park granite magmas. See text for discussion.

smaller amount of fractionation over a greater number of phases—hornblende, sodic alkali feldspar, titanite, apatite, and biotite. This is consistent with its development as a late-stage fractionate.

Discussion

The pre-ascent reservoir

Numerous studies of volcanic systems have concluded that fractional crystallization (as well as other igneous evolutionary processes) occurs within a ponded reservoir at some depth in the crust, i.e., a magma chamber. It has been argued previously that the Mount Scott Granite is the emplacement product of magma that ponded in the crust at a depth of 7 to 8 km, en route to the shallow crust from a deeper source of partial melting (Hogan and Gilbert, 1998; Hogan et al., 1998; Price et al., 1996). Mount Scott Granite alkali feldspar and quartz phenocrysts demonstrate rounding, zoning, and other features that have been related to decompression due to ascent from this reservoir to the emplacement depth. The fractional crystallization model above is consistent with pre-ascent segregation of daughter liquids in a deeper reservoir. The distribution of the fractionated daughter magmas relative to the parental magma implies that segregation occurred prior to final emplacement.

The intrusive suite therefore originates with partial crystallization at depth. Some of the early crystallizing phases of the Mount Scott Granite, principally plagioclase and hornblende, are removed from liquids I and then II in this reservoir. Other early phases, chiefly alkali feldspar, remain in these daughter liquids as well as the parent; these form the phenocrysts common to all of the units. Liquids I and II ascend first, followed by the bulk of the magma (Fig. 10).

Emplacement constraints

The Mount Scott Granite formed from a partially crystallized magma emplaced near the GMLC-Carlton Rhyolite Group boundary at a depth no greater than 2 km. Contact relationships show that the base of the intrusive suite rests on the RMGG in the west and cuts into the rhyolite in the east, firmly placing it on the unconformity. Subsurface data places the granite along a similar horizon (Merritt, 1965, 1967). The final crystallization assemblage of all four units is consistent with pressures near 50 MPa. Granophyre, common to all of the units, is attributable to an undercooling range of 50 to150 °C (Morgan and London, 2012), conditions appropriate for emplacement in the shallow crust.

The contact relationships of the units clearly suggest emplacement at this common horizon. The Rush Lake and Medicine Park Granites appear to be adjacent to and underlie the base of the Mount Scott Granite and therefore represent the lowest part of the emplacement section.

Given its sharp contacts in which other units fine in grain size towards the contact, the Medicine Park Granite is clearly older than the Mount Scott and the Rush Lake Granites. The dikes of Mount Scott Granite in Medicine Park Granite indicate that the latter was sufficiently cool to deform brittlely during the intrusion of the Mount Scott Granite. However, the extensive contact at Welsh Hill,

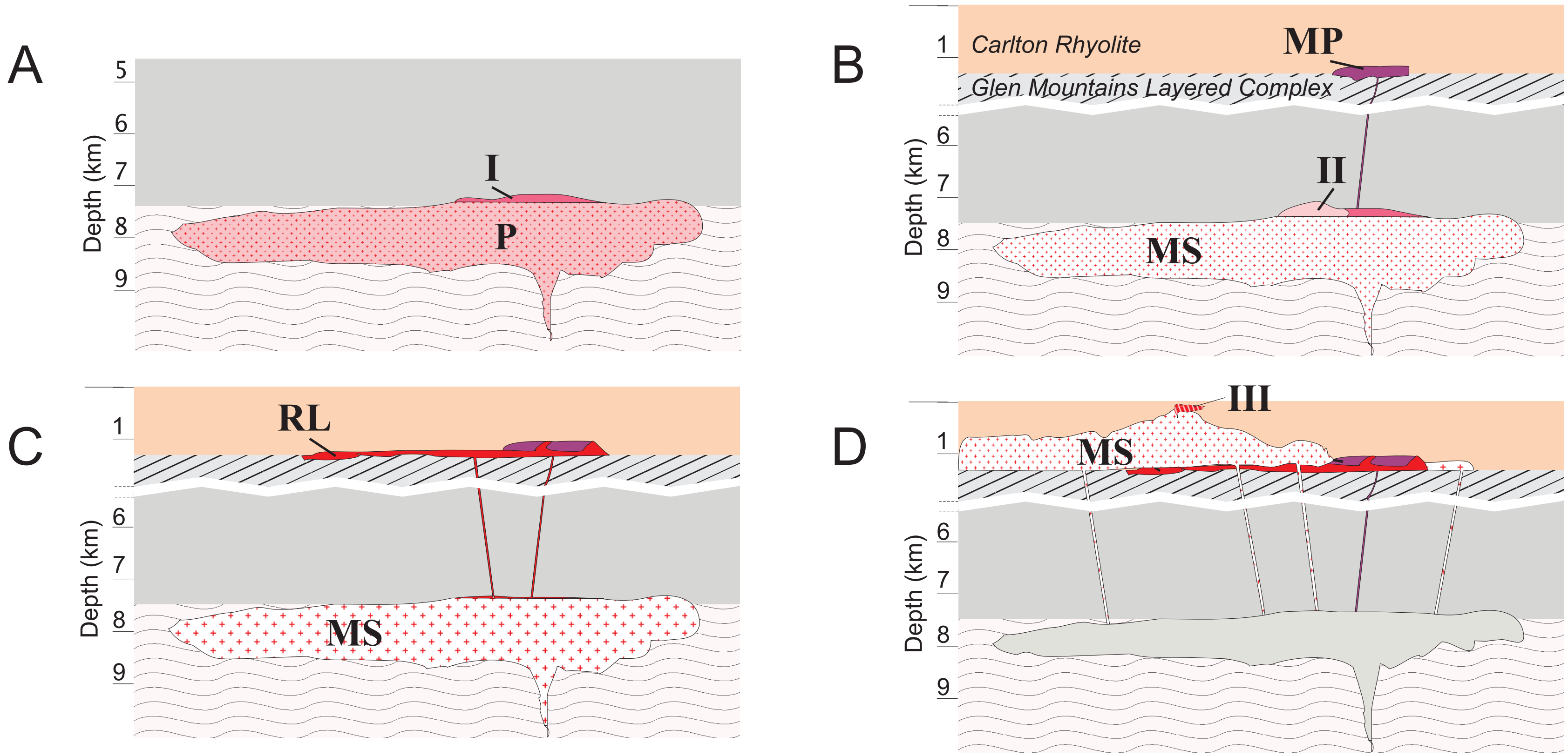


Figure 10. Development of the Mount Scott Pluton. A.) The granite parental magma (P) arrests at a depth of 7 to 8 km and begins to fractionate liquid I. B.) Some of liquid I ascends and arrests at the emplacement depth along the boundary between the Glen Mountains Layered Complex and the overlying Carlton Rhyolite. This forms the Medicine Park Granite (MP) while the parent magma (MS) produces liquid II. C.) Remainder of liquid I and all of II ascend to the same level forming the Rush Lake Granite (RL). D.) Magma MS closely follows ascent of RL magmas. This magma is emplaced at the same horizon, overrunning and shouldering aside RL to form the Mount Scott Granite. Late-stage fractionation at the emplacement level near the top of the intrusive suite forms liquid III, the Saddle Mountain Granite.

which apparently lacks a chilled margin, suggests that the Medicine Park Granite was locally warm enough to preclude chilling. The Medicine Park is oldest, but the contacts suggest a short interval separates these intrusions.

Both the diffuse and interdigitating contacts between the Rush Lake and the Mount Scott Granites indicate that both units were warm and ductile implying an even shorter hiatus between their intrusions. The Mount Scott Granite magma intruded near simultaneously with the Rush Lake Granite magma.

Following emplacement of the Mount Scott Granite magma, crystallization produced a small volume of fractioned liquid near the top of the intrusion (Liquid III). The Saddle Mountain Granite crystallized near the top of the intrusive suite. Its spherulitic texture may be a response to elevated undercooling in a shallow environment as suggested by Gilbert (1986).

Implications

For individual igneous bodies to be consanguineous, they must arise from a common parent through a segmented (two or more stage) crystallization history. The separation of more evolved products implies transport from the site of fractionation to the site of emplacement. The magmas that formed the Mount Scott Intrusive Suite may have moved up to 7 vertical kilometers. Such transport prior to final emplacement produces bodies that are distinct from examples of *in situ* granite fractionation (e.g., a zoned pluton).

In addition to statistical modeling that suggests a relationship through fractional crystallization, the Mount Scott Intrusive Suite contains additional lines of evidence that imply a segmented crystallization history. All of the units are porphyritic, with bimodal populations of feldspars and quartz that fundamentally imply two-stages of crystallization. Hornblende geobarometry calculations on samples of the Mount Scott Granite yield an average of 200 MPa, while the emplacement of the unit within the base of a volcanic pile suggests a much shallower (50 MPa) final emplacement site for the granite (Hogan and Gilbert, 1995). Rapakivi texture in the Mount Scott Granite (ovoid feldspar phenocrysts with and without plagioclase mantles) developed from ascent-related resorption of early-formed feldspar crystals (Price et al., 1996). Cathodoluminescent imaging of the Mount Scott Granite reveals zoned cores indicating a similar history for quartz phenocrysts.

This early crystallization must have been followed by rapid (but not quite simultaneous) upward movement of all the units. Magmas that ascend and emplace nearly simultaneously may physically interact (i.e., mix or mingle) in transport or during emplacement. Mixing of simultaneously emplaced magmas is documented elsewhere in the Wichita Mountains, particularly in the Cold Springs Breccia (Vadrine and Fernandez, 1986). The short transport and emplacement interval increases the potential for physical interaction, while also influencing the heat profile of the crust. An early ascending magma preheats the crust for a later one.

The small compositional differences among these magmas produced only minor differences in mineralogy. Their common emplacement conditions produced only slight differences in texture, but it is the texture that best characterizes the individual units. The Saddle Mountain Granite grades from granophyric to spherulitic. The Medicine Park Granite contains a distinctive, always fine granophyric matrix with a small number of blocky alkali feldspars. The Rush Lake Granite is largely marked by a medium grain size with phenocrysts of angular pink feldspar. And the Mount Scott Granite varies in granophyre content, but contains ovoid feldspar phenocrysts. These textural variations must arise from changes in the thermal regime during crystallization. In this case, the thermal regime imposed on each magma will be influenced by the timing interval between individual intrusions in the intrusive suite.

It is interesting to note that the alkali feldspars in the Mount Scott Granite are rounded and those in the Rush Lake and Medicine Park Granites are not. The formation of the distinctive ovoid phenocrysts in the Mount Scott Granite requires decompression with minimal cooling (Price et al., 1996), but conditions likely to persist in the shallow crust are generally unfavorable for insulating ascending magmas. This is certainly evidenced by the granophyric matrix of these rocks, the product of substantial undercooling during final crystallization after emplacement (Morgan and London, 2012). But if the Mount Scott Granite magma closely followed other intrusions, the rounded feldspars may have formed as a response to "pre-heating" of the ascent pathway.

The contact morphologies suggest that a short but significant hiatus followed intrusion the magma that formed the Medicine Park Granite. The intrusion of the volumetrically minor granite would have heated the ascent path, but given its small volume, a short hiatus may have been of sufficient length to permit a return to ambient conditions. The ascent of the Rush Lake Granite magma would see similar "cool" thermal conditions. If the Mount Scott Granite magma closely trailed that of the Rush Lake

Granite, then the elevated geotherm would reduce cooling during ascent, inducing the resorption of feldspar unseen in the prior two magmas. In other words, the distinct texture of the Mount Scott Granite may result from the intrusion of the Rush Lake Granite.

The Saddle Mountain Granite, being a post-emplacement derivative, differentiated at the top of the intrusive suite under the thermal regime (and perhaps unique volatile concentrations) there. In this sense, the Saddle Mountain Granite is similar to late-stage liquids commonly associated with plutons, typically manifested as pegmatites and aplites that back-fill fractures late in the solidification of granite bodies. Because of the proximity of the surface, the late-stage liquid in this part of the intrusive suite was injected into even shallower crust and/or erupted.

Conclusions

In the half-century that followed the initial definition of the Mount Scott Granite, careful field and geochemical studies divided it into four related lithodemic units. These are compositionally similar, but each exhibits sufficient textural differences to warrant separation. The voluminous Mount Scott Granite is best characterized by the presence of ovoid feldspars and mafic enclaves, the Rush Lake Granite by its similar granophyric texture but angular feldspar phenocrysts, the Medicine Park Granite by its finer granophyre and purple hue and angular feldspar phenocrysts, and the Saddle Mountain Granite by its gradation into a spherulitic texture. These four units represent four individual intrusive events that resulted in the construction of a single epizonal intrusive suite.

The Mount Scott Intrusive Suite contains three volumetrically minor intrusions in addition to the voluminous Mount Scott Granite. Two of these, the Medicine Park and Rush Lake Granites, can be modeled as products of pre-emplacement fractionation of small amounts of plagioclase + hornblende + oxide + titanite from low-Rb Mount Scott Granite parent. This is likely to have occurred in a "magma-chamber-like" setting at 7 to 8 km depth. The Medicine Park Granite could arise from a daughter magma (I) produced from 6.4 wt.% crystallization of plagioclase, 5.9 wt.% hornblende and 0.6 wt.% titanite. This magma ascended to the emplacement level at the unconformity marked by the GMLC and the Carlton Rhyolite Group. Intrusion of this volumetrically small batch of magma would have been followed by nearly-identical Type B Rush Lake magma (also daughter I) and by more extensive fractionation of the Type A Rush Lake Granite (daughter II). The latter requires crystallization of 10.6 wt.% plagioclase and hornblende 7.3 wt.% from a similar parent. This magma was closely followed by the intrusion of the bulk of the reservoir, a magma that cooled to form the Mount Scott Granite.

The close timing of these related units is reflected in the nature of the contacts. Chilled margins are not seen on all contacts with the Medicine Park Granite, and those between the Rush Lake and Mount Scott Granites suggest near-coincident emplacement. This close timing may have promoted the most distinctive texture in the Mount Scott Granite—the rounded feldspar phenocrysts—as the ascent of the Rush Lake Granite magma would have raised the thermal profile of the ascent path just prior to the movement of the Mount Scott Granite magma.

Following this voluminous intrusion, the uppermost portion of the Mount Scott Granite magma could produce the hypabyssal Saddle Mountain Granite by crystallizing 2.6 wt.% hornblende, 5.8 wt.% sodic alkali feldspar, 0.4 wt.% titanite, 0.6 wt.% apatite, and 0.9 wt.% biotite. Thus the Mount Scott Intrusive Suite is composed of four intrusive units that formed from both pre-ascent and post-ascent fractionation.

Acknowledgements

The author would like to thank M. Charles Gilbert of the University of Oklahoma for his many years of hard work towards understanding the geology of the Wichita Mountains, and for his guidance and support of research on the same by the author. The author also thanks John P. Hogan of the Missouri University of Science and Technology for his long-standing assistance, guidance, and insights on the Mount Scott Intrusive Suite. Additional thanks go to Richard Hanson, Matt Brueseke, Robert Puckett, Randy Keller, and Neil Suneson for organizing the field conference. And the author is deeply grateful for Neil Suneson's editorial handling of this paper.

Financial support for continuing work on the Wichita Mountains and southwestern Oklahoma was provided to the author by Midwestern State University. This paper built on previous work supported by the USGS Cooperative Mapping Agreement (EDMAP) and by Eberly Chair funds at the University of Oklahoma.

REFERENCES

Al-Shaieb, Z.F., Hanson, R.E., Donovan, R.N., and Shelton, J.W., 1980, Petrology and diagenesis of sandstones in the Post Oak Formation

(Permian), southwestern Oklahoma: Journal of Sedimentary Petrology, v. 50, p. 43-50.

Gilbert, M. C., 1982, Geologic setting of the eastern Wichita Mountains, with a brief discussion of unresolved problems, *in* Gilbert, M. C., and Donovan, R. N., eds., Geology of the Eastern Wichita Mountains Southwestern Oklahoma, Oklahoma Geological Survey Guidebook 21, p. 118-119.

——, 1983, Timing and chemistry of igneous events associated with the Southern Oklahoma Aulacogen: Tectonophysics, v. 94, p. 439-455.

——, 1986, Stop 6: Saddle Mountain Granite, *in* Gilbert, M. C., ed., Petrology of the Cambrian Wichita Mountains Igneous Suite, Oklahoma Geological Survey Guidebook 23, p. 169-171.

Gilbert, M. C., and Myers, J. D., 1986, Overview of the Wichita Granite Group, *in* Gilbert, M. C., ed., Petrology of the Cambrian Wichita Mountains Igneous Suite: Oklahoma Geological Survey Guidebook 23, p. 169-171.

Gilbert, M. C., and Powell, B. N., 1988, Igneous geology of the Wichita Mountains, southwestern Oklahoma, *in* Hayward, O. T., ed., Geological Society of America Centennial Field Guide—South-Central Section, p. 93-98.

Ham, W. E., Denison, R. E., and Merritt, C. A., 1964, Basement Rocks and Structural Evolution of Southern Oklahoma: Oklahoma Geological Survey Bulletin 95, p. 302.

Hanson, R. E., Puckett R. E., Jr., Keller, G. R., Brueseke, M. E., Bulen, C. L., Mertzman, S. A., Finegan, S. A., and McCleery, D. A., 2012, Intraplate magmatism related to opening of the southern Iapetus Ocean: Cambrian Wichita igneous province in the southern Oklahoma rift zone: Lithos, v. 174, p. 57-70.

Havens, J. S., 1977, Reconnaissance of the Water Resources of the Lawton Quadrangle, Southwestern Oklahoma: Oklahoma Geological Survey Map HA-6, Sheet 1, scale 1:250,000.

Hoffman, P., 1974, Aulacogens and their genetic relation to geosynclines with a Proterozoic example from Great Slave Lake, Canada, *in* Dott, R. H., Jr., and Shaver, R. H., eds., Modern and Ancient Geosynclinal Sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication No. 19, p. 38-55.

Hogan, J. P., and Gilbert, M. C., 1995, The A-type Mount Scott Granite sheet: importance of crustal magma traps: Journal of Geophysical Research, v. 100, p. 15,779-15,792.

——, 1997, Intrusive style of A-type sheet granites in a rift environment: The Southern Oklahoma Aulacogen: Geological Society of America Special Paper 312, p. 299-311.

——, 1998, The Southern Oklahoma Aulacogen: A Cambrian analog for Mid-Proterozoic AMCG (anorthosite-mangerite-charnockite-granite) complexes?: Proceedings of the International Conference on Basement Tectonics, v. 12, p. 39-78.

Hogan, J. P., Gilbert, M. C., and Price, J. D., 2000, Crystallization of fine- and coarse-grained A-type granite sheets of the Southern Oklahoma Aulacogen, U.S.A: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 91, Parts 1-2, p. 139-150.

Hogan, J. P., Price, J. D., and Gilbert, M. C., 1998, Magma traps and driving pressure: Consequences for pluton shape and emplacement in an extensional regime: Journal of Structural Geology, v. 20, p. 1155-1168.

Johnson, K. S., and Denison, R. E., 1973, Igneous Geology of the Wichita Mountains and Economic Geology of Permian Rocks in Southwest Oklahoma: Oklahoma Geological Survey Special Publication 73-2, Guidebook for field trip 6,Geological Society of America annual meeting, Dallas, 33 p.

Keller, G. R., and Stephenson, R. A., 2007, The Southern Oklahoma and Dniepr-Donets Aulacogens: A comparative analysis: Geological Society of America Memoir 200, p. 127-143.

McLean, T. R., and Stearns, D. W., 1986, Hale Spring locality, *in* Gilbert, M. C., ed., Petrology of the Cambrian Wichita Mountains Igneous Suite: Oklahoma Geological Survey Guidebook 23, p. 172-178.

Merritt, C. A., 1965, Mt. Scott Granite, Wichita Mountains, Oklahoma: Oklahoma Geology Notes, v. 25, p. 263-272.

——, 1967, Names and relative ages of granites and rhyolites in the Wichita Mountains, Oklahoma: Oklahoma Geology Notes, v. 27, p. 45-53.

Miall, A. D., and Blakey, R. C., 2008, The Phanerozoic tectonic and sedimentary evolution of North America, *in* Miall, A. D., ed., Sedimentary Basins of the World, Volume 5: Oxford, U.K., Elsevier, p. 1-29.

Morgan, G. B., and London, D., 2012, Process of granophyre crystallization in the Long Mountain Granite, southern Oklahoma: Geological Society of America Bulletin, v. 124, p. 1251-1261.

Myers, J. D., Gilbert, M. C., and Loiselle, M. C., 1981, Geochemistry of the Cambrian Wichita Granite Group and revisions of its lithostratigraphy: Oklahoma Geology Notes, v. 41, p. 172-195.

Nakamura, N., 1974, Determination of REE, Ba, Fe, Mg, Na, and K in carbonaceous and ordinary chondrites: Geochimica et Cosmochimica Acta, v. 38, p. 757-773.

Neuendorf, K. K. E., Mehl Jr. , J. P., and Jackson, J. A., 2011, Glossary of Geology, Fifth Edition (revised), American Geological Institute, 779 p.

Pitcher, W. S., 1993, The Nature and Origin of Granite: New York, Blackie Academic and Professional, 321 p.

Powell, B. N., Gilbert, M. C., and Fischer, J. F., 1980, Lithostratigraphic classification of basement rocks of the Wichita province, Oklahoma, part I: Geological Society of America Bulletin, v. 91, p. 509-514.

Powell, B. N., and Phelps, D. W., 1977, Igneous cumulates of the Wichita province and their tectonic implications: Geology, v. 5, p. 52-56.

Price, J. D., 1998, Petrology of the Mount Scott Granite [Ph.D. thesis]: Norman, Oklahoma, University of Oklahoma, 240 p.

——, 2011, Titanium zoning in quartz: Constraints on the crystallization and cooling of the Mount Scott Granite Intrusive Suite, Southern Oklahoma Aulacogen, USA: Geological Society of America Abstracts with Programs, v. 43, no. 5, p. 202.

——, 2013, Digital image analysis of variably granophyric texture in the Mount Scott Granite, Wichita Mountains, southern Oklahoma: Geological Society of America Abstracts with Programs, v. 45, no. 3, p. 17.

Price, J. D., Gilbert, M. C., and Hogan, J. P., 2012, Regional significance of diabase dikes in the Mount Scott Granite as exposed at Lake Elmer Thomas Dam: Shale Shaker, v. 62, p. 456-474.

Price, J. D., Hogan, J. P., and Gilbert, M. C., 1996, Rapakivi texture in the Mount Scott Granite, Wichita Mountains, Oklahoma: European Journal of Mineralogy, v. 8, p. 435-451.

Price, J. D., Hogan, J. P., Gilbert, M. C., London, D., and Morgan, G. B. V, 1999, Experimental study of titanite-fluorite equilibria in the A-type Mount Scott Granite: Implications for assessing F contents of felsic magma: Geology, v. 27, p. 951-954.

Price, J. D., Hogan, J. P., Gilbert, M. C., and Payne, J. D., 1998, Surface and near-surface investigation of the alteration of the Mount Scott Granite and geometry of the Sandy Creek Gabbro pluton, Hale Spring area, Wichita Mountains: Oklahoma Proceedings of the International Conference on Basement Tectonics, v. 12, p. 79-122.

Puckett, R. E., Jr., 2012, Profiling the buried Cambrian sedimentary and bimodal igneous stratigraphy of the southern Oklahoma rift zone using basement well penetrations: Geological Society of America Abstracts with Programs, v. 44, no. 1, p. 10.

Puckett, R. E., Jr., Hanson, R. E., Eschberger, A. M., Bulen, C. L., and Brueseke, M., 2011, Using basement wells to investigate the subsurface Cambrian bimodal volcanic record in the Southern Oklahoma Aulacogen: Geological Society of America Abstracts with Programs, v. 43, no. 5, p. 651.

Román-Berdiel, T., 1999, Geometry of granite emplacement in the upper crust: Contributions of Analogue Modelling, *in* Castro, A., Fernandez, C., and Vigneresse, J. L., eds., Understanding Granites, Integrating New and Classical Techniques: Geological Society London Special Publication No. 891, p. 77-94.

Soreghan, G. S., Keller, G. R., Gilbert, M. C., Chase, C. G., and Sweet, D. E., 2012, Load-induced subsidence of the Ancestral Rocky Mountains recorded by preservation of Permian landscapes: Geosphere, v. 8, no. 3, p. 654-668.

Stanley, T. M., Miller, G. W., and Standridge, G. R., 2005, Geologic Map of the Lawton 30' x 60' Quadrangle, Caddo, Comanche, Grady, Kiowa, Stephens, and Tillman Counties, Oklahoma: Oklahoma Geological Survey, Oklahoma Geologic Quadrangle OGQ-63, scale 1:100 000.

Steiner, J. C., Jahns, R. H., and Luth, W. C., 1975, Crystallization of alkali feldspar and quartz in the haplogranite system NaAlSi3O8-KAlSi3O8-SiO2-H2O at 4 kb: Geological Society of America Bulletin, v. 86, p. 83-98.

Vadrine, D. M., and Fernandez, L. A., 1986, Geochemistry and petrology of the Cold Spring Breccia, Wichita Mountains, Oklahoma, *in* Gilbert, M. C., ed., Petrology of the Cambrian Wichita Mountains Igneous Suite: Oklahoma Geological Survey Guidebook 23, p. 117-125.

Vigneresse, J. L., 2004, A new paradigm for granite generation: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 95, p. 11-22.

Weaver, B. L., and Gilbert, M. C., 1986, Reconnaissance geochemistry of silicic igneous rocks of the Wichita Mountains: the Wichita Granite Group and the Carlton Rhyolite Group, *in* Gilbert, M. C., ed., Petrology of the Cambrian Wichita Mountains Igneous Suite: Oklahoma Geological Survey Guidebook 23, p. 117-125.

Wright, T. L., and Doherty, P. C., 1970, A linear programming and least squares computer method for solving petrologic mixing problems: Geological Society of America Bulletin, v. 81, p. 1995-2008.

Wright, J. E., Hogan, J. P., and Gilbert, M. C.,1996,. The Southern Oklahoma Aulacogen, not just another B.L.I.P.: Eos Transactions, American Geophyscial Union , v. 77, p. F845.