PIKES PEAK BATHOLITH WORKSHOP

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A workshop on the Pikes Peak batholith was held at Trinity University, Jan. 22-23, 1993. The participants, representing eight of the consortium's institutions, included ten students who worked on the Pikes Peak project during the summer of 1992, six faculty, and one guest speaker. The goals of the workshop included (a) presentation of petrologic and geochemical data which had been acquired by students for rocks collected from the batholith last summer, (b) discussion of generalized models for anorogenic magmatism and which model(s) seems most appropriate for the origin of the Pikes Peak batholith, and (c) familiarizing workshop participants with the utilization of Macintosh computer software in the presentation and interpretation of petrologic and geochemical data.

Workshop participants arrived in San Antonio during Thursday evening, Jan. 21. The group met for breakfast early Friday morning at the hotel where everyone was housed, then headed to Trinity for a brief tour of the campus and the Geology Department. The formal activities of the workshop were kicked off with a seminar given by the guest speaker, J. Lawford Anderson (Univ. of Southern California). His talk, "Mid-Proterozoic anorogenic plutonic perforation of North America and Planet Earth", was an excellent overview of anorogenic magmatism. The topics ranged from the unusual mineralogy and geochemistry of anorogenic granitoids to the observation that anorogenic granites are limited to Proterozoic-age crust and time periods representing pauses between orogenic, crust-forming events. The presentation included at least one specific topic of interest for each student on the Pikes Peak project, but also included "big picture" aspects of anorogenic magmatism.

After Anderson's seminar and related questions/discussions, the group reconvened for student research progress reports. Each student spoke for approximately ten minutes about their project's goals, the methods employed, results to date, and current (tentative?) interpretations. Between individual progress reports (and throughout the weekend), the group discussed possible directions individuals might take in the collection of additional data and/or the modelling and interpretation of data. Topics of discussion ranged from specific concerns (e.g., estimation of Fe^{2+}/Fe^{3+} ratios in samples for which only Fe_2O_3 contents were determined; selection of appropriate source compositions in modelling crustal anatexis) to questions dealing with the origin of the batholith on a large scale (e.g., are the gabbros generated by partial melting of depleted or enriched mantle?).

The progress reports (and lunch) were followed by a session held in one of Trinity's computer classrooms. Use of the facilities allowed video projection of a Macintosh computer monitor screen onto a wall-sized format. Diane Smith gave a presentation on the utilization of various types of software packages (EXCEL, CRICKETGRAPH, CANVAS) in plotting and modelling geochemical data. EXCEL "plotting templates" and "modelling worksheets" were discussed and demonstrated. All EXCEL files produced for the workshop were copied onto diskettes for participants to take back to their home institutions; the files included templates for plotting rare earth diagrams and "spiderplots", and worksheets for calculating trace element variations produced during partial melting of mantle sources and crustal sources, binary (magma) mixing, and fractional crystallization (with or without assimilation) of mafic to felsic magmas. Each of the templates and worksheets was demonstrated, but it was emphasized that many other types of plotting or modelling files can be generated with a basic spreadsheet package such as EXCEL, depending on the interests and needs of the individual worker. It was also shown how trace element abundances calculated from any of the modelling worksheets can be copied into a plotting program (e.g., CRICKETGRAPH) and directly compared with observed trace element contents in the rocks under investigation on various petrologic diagrams. Lastly, workshop participants were shown how to copy CRICKETGRAPH "rough" plots and paste them into a drawing program (e.g., CANVAS, MacDRAW) in order to refine them into publication quality figures. The computer-methods session ended late Friday afternoon; the group later reassembled for dinner at Lòs Barrios, a local restaurant well known for its Mexican cuisine.

The group met for early breakfast Saturday morning, and returned to Trinity for a "work session". No formal presentations were given on Saturday, rather, the day was dedicated to hands-on experience with Macintosh computers and the software methods outlined on Friday. Prior to the workshop, students had sent all major and trace element analyses thus far acquired to D. Smith at Trinity. The data were compiled into a master EXCEL file which was used throughout the workshop. During the workshop, the Pikes Peak database was expanded to include any new data that had been collected, and individuals created subfiles containing information for their specific samples. The group also used Saturday to examine enigmatic thin sections in order to identify "mystery" minerals and/or textures. Students consulted with Prof. Anderson about their individual research projects, and also met with the project co-directors (Noblett, Wobus, and Smith) to discuss specific research goals. Products of the day's efforts included (1) an EXCEL database containing major and trace element data collected for ~100 samples from the Pikes Peak batholith (of which everyone received a copy), (2) experience for all workshop participants with using Macintosh computer methods in the manipulation and interpretation of petrologic/geochemical data (including plotting of variation diagrams and modelling of processes such as partial melting and crystal fractionation), (3) identification of problematic minerals/textures in some thin sections under study, and (4) rough outlines for abstracts to be submitted to the Keck Symposium volume. Possibly the best outcome was the renewed inspiration to return home and attack research problems with new insights and hypotheses to test. Prof. Anderson was a tremendous resource -- his knowledge, enthusiasm for the project, and suggestions for future directions were plentiful and freely given. It was an intense, busy day and everyone wished we had more to follow.

About seven in the evening, the group adjourned and gathered at Diane Smith's home for pizza and socializing. Besides continuing conversations about research, we also renewed old friendships and repeated tall tales from the summer field work. The consensus was that the workshop was a success -- it provided the opportunity for the research group to reassemble and discuss petrogenetic problems associated with anorogenic magmatism in general, and for students to gain input regarding their individual projects. Participants later returned to the hotel, and departed San Antonio on Sunday, Jan. 24.

ALKALIC INTRUSIVE CENTERS, PIKES PEAK BATHOLITH, COLORADO

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ALKALIC INTRUSIVE CENTERS, PIKES PEAK BATHOLITH, COLORADO

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Introduction

The Proterozoic Pikes Peak Granite (1080 Ma) is exposed along the Front Range and Rampart Range from about the latitude of Colorado Springs north to Castle Rock; the granite is visible in outcrop for 65 kilometers west of Colorado Springs with a total surface exposure of about 3840 square kilometers (Figure 1). The Pikes Peak batholith is a complex pluton composed mostly of granite and granodiorite but containing more than a half dozen late-stage alkalic intrusive centers with compositions ranging from gabbro to syenite to fayalite granite and riebeckite granite.

At the Keck winter workshop on the Pikes Peak granite, Professor Lawford Anderson from the University of Southern California, held forth eloquently on the significance of this batholith. The Proterozoic 'red' granites represent a unique event in earth history as part of the anorogenic association of anorthosites, charnockites and granites. Anderson suggested that these plutons formed between "pulses" of orogeny and production of new crust during the Proterozoic and that this new, "juvenile" crust is the source rock for the anorogenic granitic magmas. Due to thermal instability, the underlying mantle, isolated from orogenic or subduction processes, might rise adiabatically to the base of this crust and through a variety of assimilation -fractional crystallization processes (AFC) yield these anorogenic granites. Such an event could occur only in newly formed continental crust and thus studies of the origin of anorogenic granites like the Pikes Peak batholith acquire significance in their ability to shed light on this process.

Geologic Setting

The Pikes Peak batholith is widely cited as an example of anorogenic granitic magmatism (Barker and others, 1975). This conclusion is based on the lack of internal deformation, the absence of contemporaneous tectonic boundaries in the region, and the presence of several late alkalic intrusive centers which are similar to those produced during crustal doming, extension and rifting in other parts of the world (e.g., New England, Nigeria).

More than 90 percent, by volume, of the exposed rocks in the Pikes Peak batholith are typical hornblende- and biotite granites and granodiorites with textures varying from inequigranular to porphyritic, fine-grained equigranular to pegmatitic. Hutchinson (1960, 1976) mapped primary flow structures in the batholith (based on planar parallelism of feldspars, flow layers, parallelism of xenoliths, long dimensions of feldspar, biotite, and quartz mosaics) and primary fracture systems (based on cross-joints normal to lineation, a-c normal to planar-flow structures, longitudinal joints parallel to planar flow sturctures, marginal fissures filled with aplite or pegmatite). His studies revealed three major intrusive channels within the main batholith. Since these centers are at different but overlapping altitudes, Hutchinson was able to create a three-dimensional model of the main batholith with a vertical relief of over two kilometers.

However, it is the unusual late-stage intrusive centers, which comprise only about 10 percent of the exposed batholith, which led earlier workers to hypothesize a complex, mantle-derived anorogenic origin for the Pikes Peak batholith. Wobus (1976) described two chemically distinct trends within this group of small plutons. A potassic trend, exemplified by the Windy Point and other late fine-grained granites, is found in plutons on Pikes Peak and in the Rampart Range, at West Creek and Lake George, and near Tarryall. These were interpreted as late-stage, rapidly-cooled variants of the Pikes Peak Granite. A sodic trend, recognized by compositions ranging from gabbro to syenite, fayalite granite and riebeckite granite, is found in seven small intrusive centers in the batholith. Four of these centers show ring dike-like patterns.

Geochemical analyses of samples from a few of these centers were used to propose a model for the origin of the Pikes batholith (Barker and others, 1975, 1976). Barker and others argued that mantle-derived alkali olivine basalt magma interacted with a lower crust that was depleted in K_2O due to generation of large volumes of granitic magmas during two previous Proterozoic events (1700 Ma Boulder Creek event and 1400 Ma Silver Plume event). The soda-enriched rocks of the alkalic centers were believed to be derived from those contaminated magmas. This model has been widely cited in the literature as one explanation for such rocks; however, his model was based primarily on major-element data. Trace element and isotopic compositions corroborated the model but were obtained for only a few of the alkalic centers.

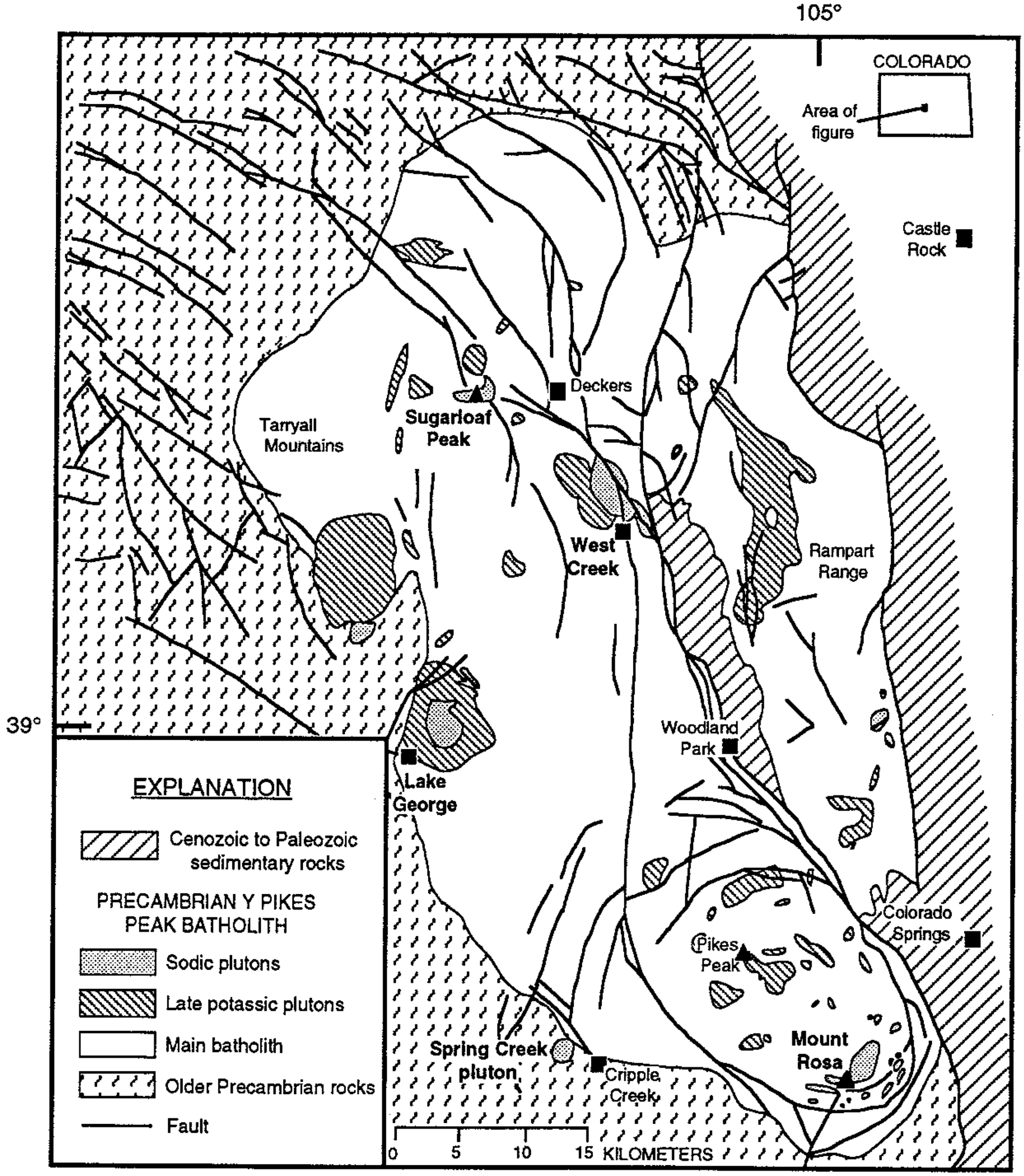

Figure 1. Geologic index map of the Pikes Peak batholith showing locations of sodic and late potassic plutons. From Bryant and Wobus (1975) and Scott and others (1976).

The Keck project students and faculty made field observations and sampled extensively in all the alkalic centers and in the associated granitic rocks. The geochemical data they generated include major, minor, trace element and isotopic compositions from all the major rock types involved. At the winter workshop, students began developing computer models to test Barker et al.'s and other hypotheses for the origin of magmas emplaced in the batholith. Fractional crystallization, combined assimilation-fractional crystallization (AFC), and partial melting processes were evaluated with the geochemical data collected during this project.

Student Projects

Four students elected to study the rock types found in the sodic centers. With the exception of one previously unmapped center (Sugarloaf), field work for these projects consisted of careful sampling from several centers, along with observations of contacts and textures, but not re-mapping. Collection of coarse-grained plutonic samples presented some challenges because unweathered samples needed to be at least twenty times larger than the largest grain size to ensure homogeneity in the splits of powders for geochemical analysis.

Chase Davis pursued gabbro and syenite occurrences from the Lake George, Tarryall and Spring Creek plutons. The gabbros are mantle-derived rocks which provide a starting point for tests of AFC origins for the rest of the sodic trend rocks. Preliminary data show these gabbros are fairly evolved with low Mg-numbers and are unlikely to be direct products of melting from the mantle. **Rachel Beane** studied the syenites of the Sugarloaf pluton. Sugarloaf was the only center not mapped by U.S.G.S. workers so Rachel first focussed on defining the textural variants and rock types in the Sugarloaf pluton. If Barker and others' hypothesis is correct, the geochemical data should show derivation from the gabbros and links to the fayalite granites via AFC processes. **Ben Saltoun** studied the fayalite granites, primarily from the Mount Rosa body. His first goal was to sort out terminology because these rocks actually varied in composition from syenites to granites. His geochemical data will test the continuity from Rachel's syenite compositions to the final step in the sodic series of riebeckite granite. **Greg Kay** worked on the Na-amphibole (riebeckite) granites in the Mount Rosa body. A wide variety of textural variants need to be explained. His geochemical data provide the final point for testing the continuity of the sodic series.

Emily Giambalvo noted the unusual compositions of the amphiboles throughout the Pikes Peak batholith. She sampled rocks from several of the alkalic plutons including West Creek, Sugarloaf and Mount Rosa, and then worked with Beane and Kay to obtain SEM/EDAX compositions on the amphiboles in rocks which were also being analyzed for whole-rock geochemistry. Emily has characterized the amphibole chemistry and showed that many of the old microscope identifications of riebeckite are incorrect. Her data will also allow approximations for distribution coefficients of trace elements between amphibole and whole rock compositions that will refine fractionation models.

Jill Douglass undertook the study of Rb-Sr and Sm-Nd isotope systematics representing the spectrum of compositions in the Pikes Peak batholith. She collected isotopic data from 16 carefully screened samples which were also analyzed for major and trace elements by other students. The data (in combination with additional Pikes Peak data provided by Dan Unruh of the U.S.G.S.) are crucial in evaluating magma-crust interactions and the geochemical nature of source rocks in the mantle and/or crust.

Jen Stewart selected a group of intermediate composition rocks to study. These granodiorites contain biotite and hornblende as well as megacrysts of labradorite. The latter have been inferred to be relicts from lower crust anorthosite, a lithology which is commonly associated with anorogenic granites and may possibly be related to a small body of anorthosite in the Spring Creek pluton.

Britta Gustavson studied the Windy Point granite, a fine-grained variant of the potassic portion of the batholith which occurs throughout the exposed area of rocks, often forming resistant knobs such as the summit of Pikes Peak itself. Geochemical analysis of these rocks provides the standard for comparison of the sodic suite trend against the potassic trend. Britta's data may reveal the relationship between these rocks and the coarse-grained granites that characterize the bulk of the batholith.

Sami Goldman studied a series of unusual lamprophyric dikes located around the south margin of the Mount Rosa center. Her field observations constrained several of these as Pikes Peak in age while other dikes in the region may be younger. These rocks are the most primitive yet found in the batholith and are essential in understanding the nature of the underlying mantle and interaction of mantle-derived melts with crust.

Marnie Sturm undertook a study of the overall geochemical trends in the batholith. Other workers have shown that there are several geochemical varieties of "A-type" granites found around the world (e.g., Eby, 1992), and for some, their geochemistries correlate with tectonic setting. Marnie will compare major and trace element data for the Pikes Peak rocks with other global occurrences of A-type granitoids on various types of discrimination diagrams in order to establish geochemical characteristics of the Pikes Peak batholith in the overall scheme of A-type (and anorogenic) granites.

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Field Relations, Petrology and Geochemistry of Sugarloaf Complex , Pikes Peak Batholith, Colorado

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Sugarloaf is one of seven sodic intrusive centers that lie within or adjacent to the 1,040-m.y.-old Pikes Peak Batholith in central Colorado. Major element and modal analyses from six centers have previously been published: Lake George, Tarryall and Rampart Range by R.A. Wobus (1976), and West Creek/Deckers, Mt. Rosa and Cripple Creek by Barker and others (1975). This study presents field relations, petrography, and major and trace element analyses for the seventh intrusive center.

FIELD RELATIONS

Sugarloaf is a north-north west trending pluton of syenite (1x3 km) located in the Green Mountain 7 1/2-minute quadrangle (T9S, R71W). Outcrops and float were used to determine the contact between the syenite and the Pikes Peak granite. The contact was plotted on a forty-foot contour interval topographic map using an altimeter and Brunton compass (figure 1). Granite with abundant milky quartz, found in the south west portion of the map area, suggests local shearing and later mineralization.

Four textures of syenite were identified: fine, medium, coarse and pegmatitic syenite. The various textures of syenite were not mappable and generally occured throughout Sugarloaf. The fine grained syenite appears to cut the medium and coarse grained syenite in several places. Much of the syenite was weathered; the freshest samples were found near the top of Sugarloaf. Samples of syenite were also taken from a Jefferson County Highway 126 roadcut approximately three miles to the east of Sugarloaf (T9S, R70W).

PETROGRAPHY

Point counts of four stained slabs locate the samples within the syenite range on a QAP diagram (recalculated counts: quartz <5%, plagioclase ≈20%, K-spar ≈75%). Twenty -five samples were examined in thin section. Thin section petrography showed the syenites were primarily perthite (70 - 80%), with amphiboles (10 - 20%), quartz (<5%), opaques (<5%) and trace amounts of fluorite, apatite, plagioclase and biotite.

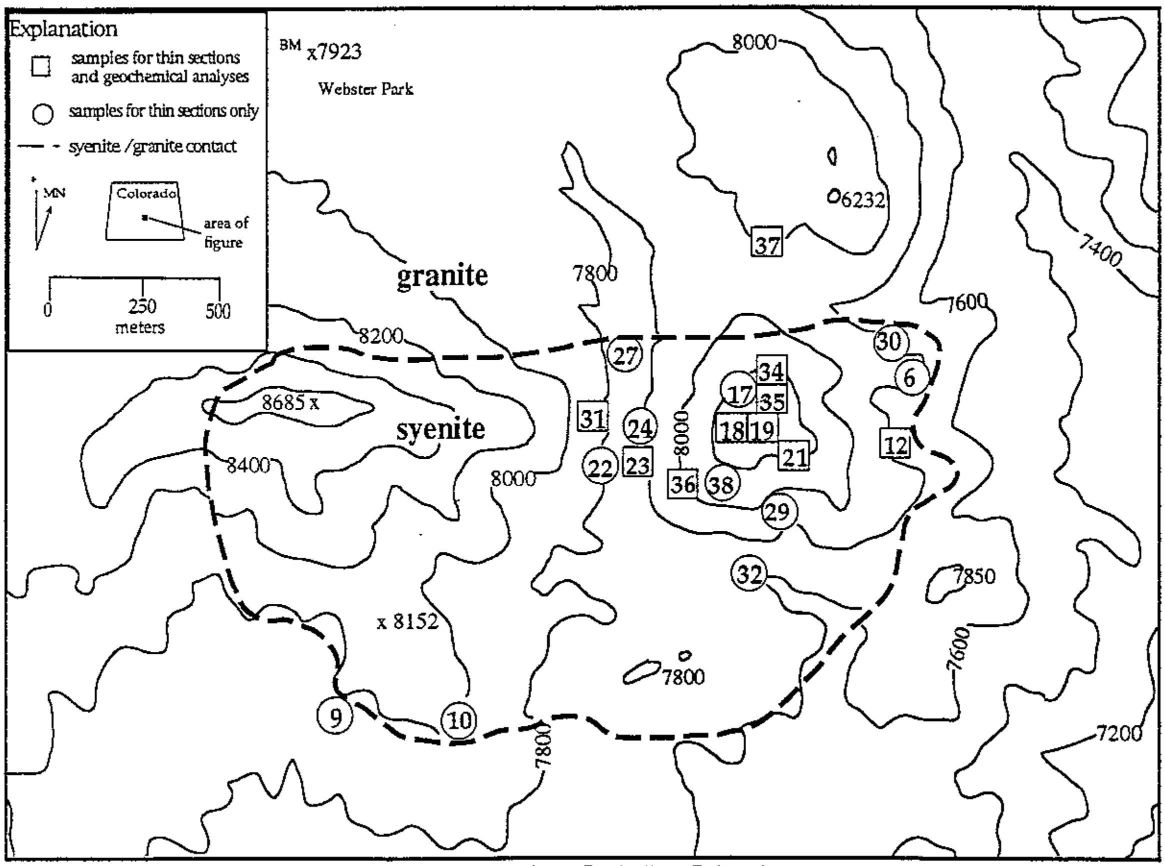

Figure 1. Map of Sugarloaf Intrusive Center, Pikes Peak Batholith, Colorado