Petrology and Geochemistry of the Southern Shatter Zone, Cadillac Mountain Intrusive Complex, Mount Desert Island, Maine

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Introduction

The shatter zone, first named by Chapman (1962), is an intrusive breccia of large proportions that borders the Cadillac Mountain Pluton (CMP) to the north, east, and south. Wiebe (1992, 1993), Wiebe and Chapman (1993), and Seaman and Ramsey (1992) have published geochemical, petrographic, and isotopic data on the granite which comprises the main body of the pluton. Wiebe has also cursorily examined the igneous matrix of the shatter zone; however, no comprehensive study has examined this aspect of the CMP. The purpose of this study is first to provide a characterization of the igneous component of this brecciated zone and secondly to consider the reasons behind the shatter zone's unique petrographic and geochemical character. This study focuses on the southern rim of the pluton. Holden (this vol.) has studied the eastern shatter zone and its transition into the typical granite of the CMP.

Field Relations

Samples were taken and field relations noted at five localities along the southern margin of the pluton, listed here from west to east: Northeast Harbor, Bracy Cove, Western Point, Otter Point and Great Head. The focus was on the igneous matrix of the intrusive breccia zone, but xenolith lithology and characteristics were noted as well.

Xenoliths which range in size from centimeters to tens of meters can be found in varying concentrations within the shatter zone. These are comprised of metasedimentary, metavolcanic, and metagabbroic rocks of the Bar Harbor Formation and possibly the Cranberry Island Volcanic Series. Sharp contacts between xenoliths and igneous matrix indicate minimal assimilation of country rock. On the basis of megascopic description and field relations, the matrix was divided into two categories:

Medium-grained Matrix (MGM): The predominant igneous component of the shatter zone, the MGM varies both in mineralogy and grain size. Nearest to homogeneous CMG, the MGM takes the form of a cumulate layer, in which xenoliths are rare and generally smaller than those deeper within the shatter zone. Further away from the main body of the pluton the matrix becomes consistently medium-grained and homogeneous, and xenoliths are more plentiful.

Fine-grained injections (FGI): These were found at all five localities, and ranged in size up to 10 meters in diameter. FGI are consistently leucocratic and fine-grained. Contacts between MGM and FGI are soft, and xenocrysts of the first can be seen within the second. Complete crystallization of the MGM had not occurred before the injection of the fine-grained material. Xenoliths within the MGM are often arranged concentrically around FGI, indicating deformation of a liquid or crystal mush as the FGI were emplaced. Xenoliths found within FGI have stringers of medium-grained material around them. This implies that the medium-grained material was first injected into the country rock, breaking it into xenoliths, and this process was followed by emplacement of the FGI. One mafic dike was also sampled. An amphibole-rich reaction rim, chilled margins within the dike, and deformation of xenoliths within surrounding matrix indicate that this dike was emplaced prior to complete crystallization of surrounding magma.

Petrography

Thirty-seven samples were cut for the purpose of petrographic work. Excluding the FGI, certain mineralogical and textural trends can be traced moving from within the shatter zone into typical CMG. The Cadillac Mountain Granite itself is a perthitic, A-type granite, with mineral assemblage typical of A-types: hornblende, minor biotite, sphene, apatite, and fluorite.

1) Samples deepest within the shatter zone are two-feldspar, with interstitial biotite being the dominant mafic mineral. These samples often also contained amphibole, but in minor amounts. Other accessory minerals associated with this deep shatter zone matrix are sphene, zircon, and opaques

2) In four of the five localitites there is an intermediate zone comprised of cumulate plagioclase. Euhedral plagioclase crystals in a touching framework make up the bulk of this matrix type, although K-feldspar is also present in minor amounts. The dominant mafic component varies from site to site from interstitial biotite to interstitial amphibole. Clinopyroxene and minor fayalite are also present in some of these cumulates.

3) Finally, before merging with typical Cadillac Mountain granite, the shatter zone matrix becomes dominated by ternary feldspars with both interstitial amphibole and biotite, and minor altered clinopyroxene. Feldspars in these border zone rocks typically exhibit plagioclase cores within the ternary feldspar rims. These rocks also contain minor amounts of clinopyroxene, biotite, and fayalite. Some of these samples are almost completely granophyric, but with evidence of medium-sized feldspar grain boundaries still intact. One other textural variation of interest is the

appearance of "radiating fringe" in some of the feldspars in this final group. Inclusion free feldspars are rimmed by granophyric feldspar-quartz intergrowths, indicating some disequilibrium event, in the same manner as the plagioclase-cored perthitic feldspars mentioned above. This matrix type grades into typical Cadillac Mountain Granite.

Fine-grained injections (FGI). Omitted from the above description are the FGI which can be found at each locality. These are in general very fine-grained and leucocratic. Felpspars range from predominantly plagioclase, to equal parts plagioclase and alkali feldspar, to perthitic. Amphibole is the predominant and in most cases sole mafic mineral; in two Great Head samples, biotite is also present. One FGI from Western Point and one from Otter Point contain clinopyroxene as well. Mafics, especially amphibole, are generally poikilitic within the FGI. Xenocrysts or "glomerocrysts" of foreign material were found in eight of ten samples of FGI. These glomerocrysts contain considerably larger grains of quartz, alkali feldspar and plagioclase, as well as mafics which include amphibole, biotite, and clinopyroxene. These inclusions are cognate as defined by Shelley (1993). The one basalt dike found at Great Head is predominantly plagioclase, with clinopyroxene, biotite, and amphibole in descending order of concentration.

Textures within the FGI range from felsitic to granophyric, and indicate extremely rapid crystallization and undercooling. The mineralogy and texture of the glomerocrysts and megacrysts are similar to that of medium-grained matrix rocks near the FGI. One sample, OP-8A, shows a contact between medium-grained matrix and FGI, and xenocrysts of the former can be found in the latter. The FGI have textures typical of hypabyssal rocks, and were probably extremely near the surface during crystallization. In the field they resemble the "silicic blobs" within the CMG as described by Wiebe (in press).

Geochemistry

Major and trace element whole rock chemistry was determined for seventeen samples using X-ray fluorescence and inductively coupled plasma techniques at Franklin and Marshall College. INAA analysis by XRAL Laboratories in Ann Arbor, Michigan was used to determine additional trace elements (Hf, Ta, Th, and U) and REEs of nine of the seventeen samples.

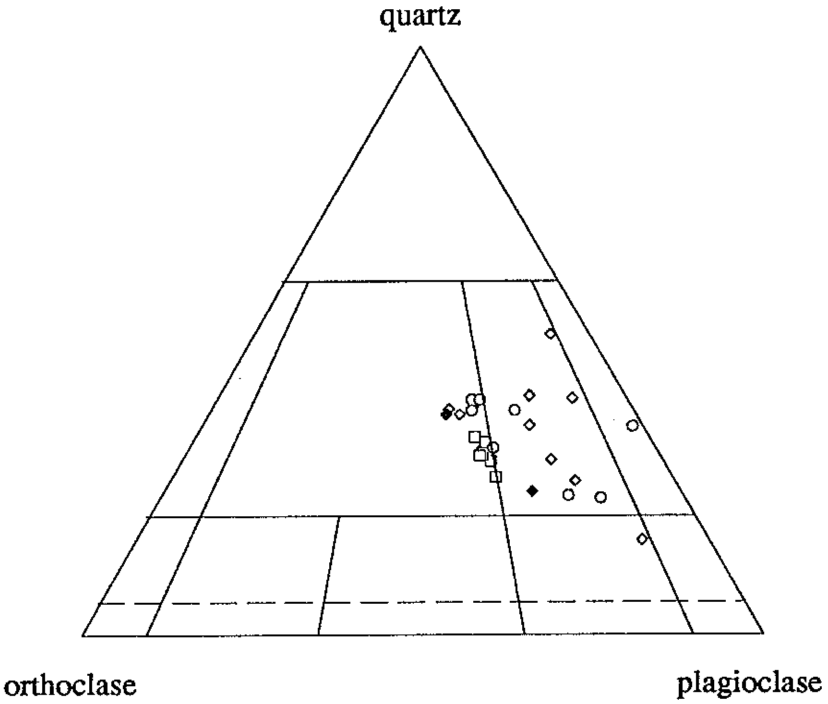

fig. 1. Q-Or-Pl normative plot of shatter zone matrix (open circles), Cadillac Mountain Granite (open squares), fine-grained shatter zone injections (open diamonds), and silicic blobs in CMG (closed diamonds).

Major Element Chemistry. CIPW norms of MGM, FGI, CMG, and silicic intrusions within the CMG were calculated from major element chemistry (CMG and silicic intrusion data from Wiebe, in press). The results are shown in Figure 1. Normative values for MGM and FGI vary little, and together form a trend from minimum melt compostion in the granite field to more plagioclase rich compostions. CMG and silicic intrusions form the more potassic components of this trend. Three MGM samples lie within the granodiorite field, and one (BC-6B) within the tonalite field. Sample GH-7.5, a mafic dike, plots in the quartz monzodiorite field, following the same trend as the more silicic samples. Harker variation diagrams plotting major element oxides versus silica for MGM and FGI show decreasing trends in Al_2O_3, total FeO, MnO, MgO, and P_2O_5 with increasing silica. K_2O shows an initial increase with increasing silica, then followed by a decreasing trend between 74 and 80% silica. Cadillac Mountain Granite samples plot in the middle of these trends, perhaps indicating a differentiation trend or that the CMG is the product of a mixing of two end products. Silica values for MGM ranges from 68.0 to 78.3 percent. FGI range in silica from 68.4 to 78.6 weight percent. Both of these greatly exceed the range of the actual CMG, which is about 72% to 75% silica (Wiebe, in press).

Trace Element Chemistry. Trace element data reveal that shatter zone rocks are especially enriched in Ba, Th, and Ta relative to MORB, as well as Zr, Hf, Y, and Yb (fig. 2). The latter group of elements tends to go into accessory phases, especially in granites. Shatter zone rocks are depleted in P, Ti, Sc, and Cr. The sharp troughs at P and Ti could be the result of apatite and ilmenite fractionation, respectively. Overall, there is a general trend toward LIL enrichment and depletion in the compatible elements of mafic rocks, as would be expected among granitoids.

Chondrite-normalized REE plots indicate in general a gently sloping trend which is enriched overall in REE and slightly more so in LREE. Eu anomalies indicate high variation in plagioclase fractionation. Anomalies are positive for plagioclase-rich cumulates and negative for plagioclase-poor fractionated MGM and FGI (fig. 3).

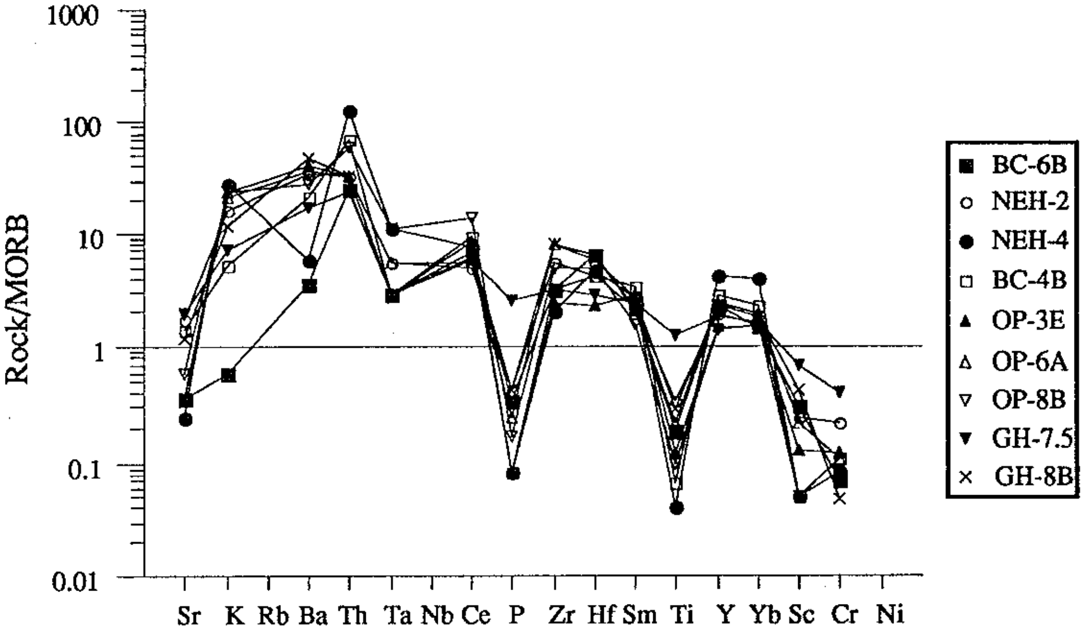

fig. 2. Pearce plot (spiderdiagram) of samples normalized to MORB.

Discussion

Petrography shows textures within MGM that indicate a sudden quenching of previously slow-cooling basal CMG magma, accompanied by the injection and rapid crystallization of FGI. Major and trace element chemistry show little difference between the MGM and FGI; the two follow a single trend on Harker variation diagrams, ternary plots of quartz-plagioclase-orthoclase, and spiderdiagrams. REE plots show similar values as well, except for variable Eu anomalies (negative in FGI, no or positive anomalies in MGM). Some FGI may have originally been interstitial liquid in MGM cumulates that was released from these crystal mushes in some explosive event (the same event which caused sudden quenching and undercooling within the magma?) This explanation is problematic for FGIs in which normative plagioclase components are *higher* than those of their MGM counterparts. Some FGI may have been directly crystallized from severely undercooled magma which had not begun to crystallize, as is indicated by chemistry similar to MGM and by petrographic textures. Chemistry reveals that the FGI are not likely to be late-stage differentiates, such as the silicic blobs described by Wiebe (in press).

Major element chemistry indicates that CMG compositions fall in the middle of shatter zone matrix trends. In a broad manner, this can be explained as a result of crystal fractionation. Although petrographic textures indicate rapid crystallization at some point during shatter zone formation, the presence of cumulate textures and plagioclase and zircon accumulation in the zone indicates that some gestation period occurred marked by the absence of magma mixing. It is proposed that this period of relative rest occurred *after* convection-driven magma mixing in the main body of the pluton. The following chain of events is thus proposed for the formation of the shatter zone: as magma mixing occurred in the main body of the pluton, along the eastern and southern margins (furthest away from basaltic intrusions?) fractional crystallization was occurring due to the relative absence of convection and mixing. Distinctive mineralogy and chemistry formed in these marginal rocks. During the crystallization of these rocks, an explosive event (caused by a release of volatiles following a basaltic influx?) caused a brecciation of upper wall rocks (Bar Harbor Formation). Compaction and undercooling were processes that accompanied these events.

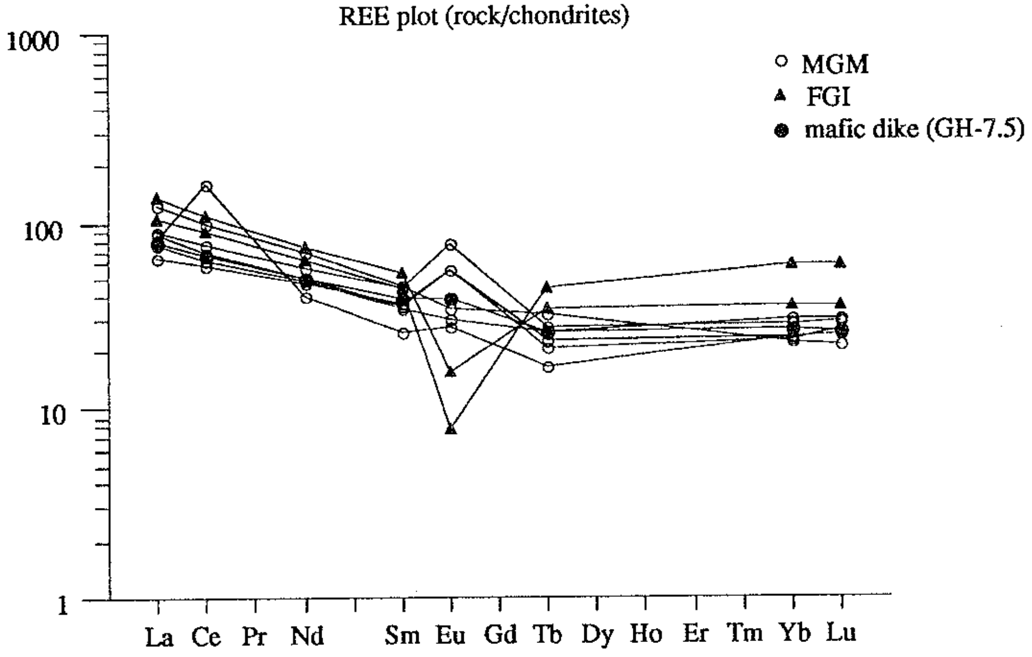

fig. 3. Rare earth element (REE) plot with samples normalized to chondrite.

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