FIELD AND MICROSTRUCTURAL ANALYSIS OF A DIKE SWARM AND A DEFORMED COMPOSITE DIKE IN THE VINALHAVEN INTRUSIVE COMPLEX, MAINE

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INTRODUCTION

The Vinalhaven Intrusive Complex located in Mid-Coast Maine represents a well-preserved bimodal intrusion with both granitic and gabbroic components (Mitchell and Rhodes, 1989). The intrusion was constructed through a series of successive felsic and mafic inputs over the course of 0.5 to 1.0 million years (Hawkins and Wiebe, unpublished U-Pb data, Wiebe and Hawkins, 2003). Within this well-exposed intrusive complex, detailed field and petrographic studies of a dike swarm and a deformed composite dike provide an opportunity to further refine its construction history.

FIELD RELATIONSHIPS

A prominent dike swarm is located at Smith Point, on the southern part of Vinalhaven Island directly south-west of the ferry terminal (Fig. 1). The majority of Smith Point (approximately 200 m2) consists of coarse-grained granite with fine-grained granite dikes (approximately 5 – 1500 cm in width) cutting through it. The western side of the point includes a composite dike along with porphyry and gabbro sections (Fig. 2).
Gradational contacts between the gabbro and porphyry and the porphyry and coarse-grained granite sections of Smith Point are marked by commingling and disaggregated crystals along the edges of the rock units. These observations correspond with prior studies (Wiebe et al., 2004) of the gabbro, porphyry, and granite units of the Vinalhaven Intrusive Complex which identified their contemporaneous emplacement. Sharp contacts exist between all fine-grained granite dikes and the surrounding host rock. These sharp contacts of the fine-grained granite dikes with chilled margins indicate emplacement after the coarse-grained granite, gabbro, and porphyry had solidified. As such, samples were obtained from the fine-grained granite dikes in order to evaluate whether the dike swarm underwent magmatic or solid state deformation. Nine samples were obtained for detailed petrographic and microstructural analysis (Fig. 2). Samples included fine-grained granite dikes, contacts between fine-grained granite dikes and coarse-grained granite chamber material, and contacts between fine-grained granite dikes and porphyritic chamber material.

Mafic pillows within granite (composite dikes) have been observed (Hawkins and Wiebe, 2004, Wiebe et al., 2001) at several places on Vinalhaven. The mafic pillows show some hybridization with apparent plagioclase xenocrysts derived from the granite matrix. Chilled margins are apparent within the mafic pillows with grains ranging in size from fine to aphanitic with movement out from center. A detailed map (5 m x 8 m) of one location, Arey Neck, was made where the mafic pillows and granite appear to be more deformed than in other places (Fig. 3a). Field and microstructural analyses are presented here to help determine whether the deformation was during the solid state or with melt present.

Figure 1. Location of mapped sites in relation to southern Vinalhaven and the State of Maine. State of Maine topography map and enlarged portion of the Vinalhaven 1:24,000 quadrangle map sourced from MEGIS library.

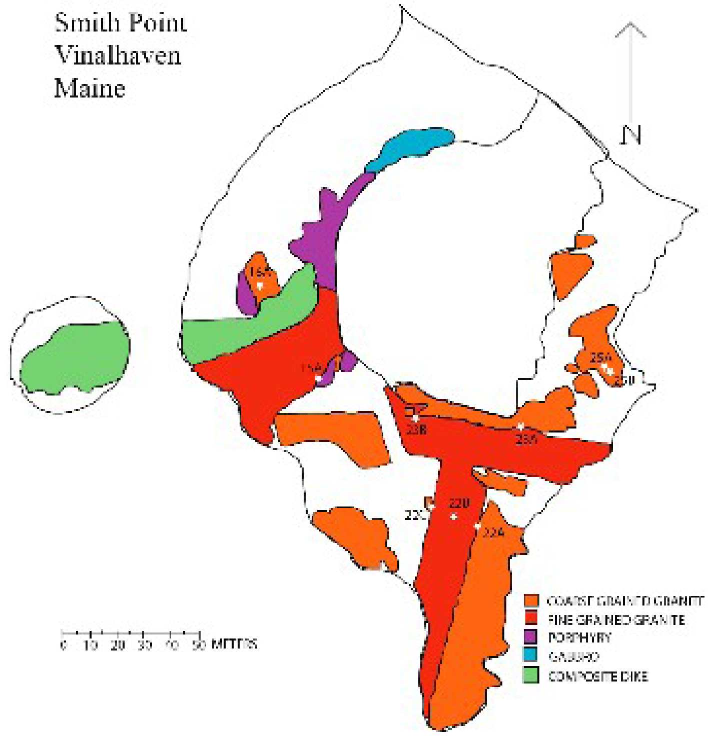

Figure 2. Geologic map of the Smith Point region of the Vinalhaven Intrusive Complex. Rock type indicated by color and defined in key located in lower right hand corner. Sample locations are marked by stars with reference numbers.

Six samples of the composite dike were obtained for petrographic analysis (Fig. 3b). Samples included porphyry, deformed porphyry under mafic blocks, contacts between porphyry and mafic dikes, and porphyry surrounding mafic pillows.

[Figure 3.]

Figure 3a. Mapped area of Arey Neck outcrop. Photo taken looking North with David Hawkins for scale.

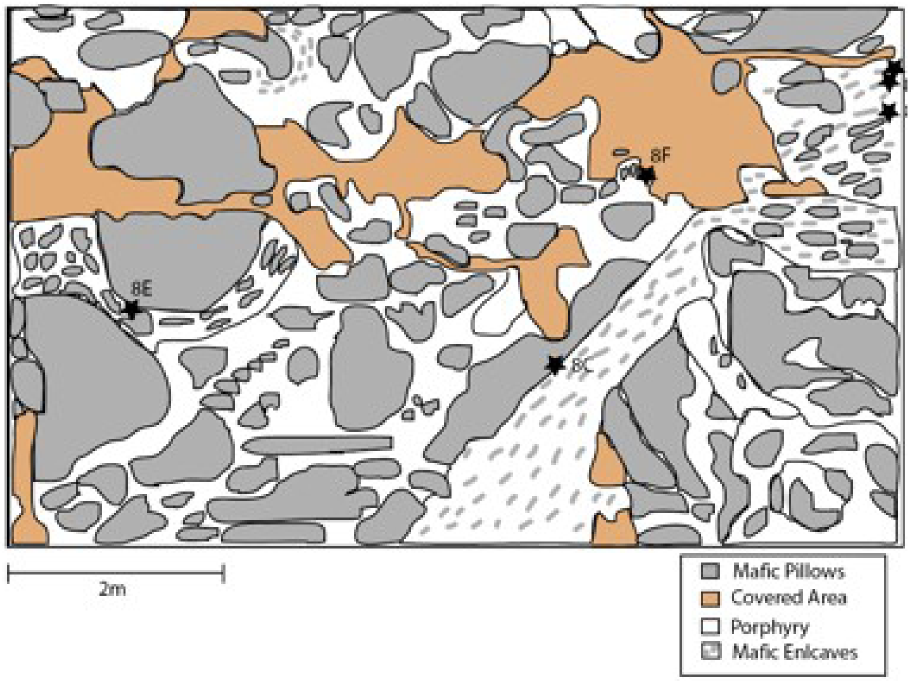

Figure 3b. Map of rock relationships and sample locations at the Arey Neck outcrop.

PETROGRPHIC OBSERVATIONS

Smith Point

A fine-grained granite dike (181°, 25° E) located on the southern tip of Smith Point was analyzed for signs of magmatic and solid state deformation. The dike is a fine-grained hypidiomorphic equigranular aphyric to sparsely porphyritic biotite granite with alkali feldspar (orthoclare) phenocrysts up to 12 mm in length. Deformation twins are apparent in plagioclase grains. These multiple twins are formed through shear of the crystal lattice resulting in a series of dislocations and are easily distinguished from the growth twins by their lenticular appearance (e.g., Blenkinsop 2000, Vernon 2004). Patches of plagioclase are intergrown with vermicular quartz in places giving it a myrmekitic texture. Exsolution, in the form of tartan twinning, is apparent in the orthoclase grains and embayments are observable within some quartz grains. Consertal textures (Janousek et al., 2004), represented by numerous subgrains, are observable in both quartz and feldspar grains within the samples as well.

Arey Neck

Samples taken from the mapped portion of Arey Neck include fine-grained hypidiomorphic equigranular aphyric to sparsely porphyritic biotite granite, similar in composition to that found at Smith Point, but interwoven with apophyses, or small veins, of microcrystalline basalt. Grains are relatively equigranular and acicular within the basalt ranging in diameter from .01-.05 mm and showing a definite shape preferred orientation. The granite shows an inequigranular seriate texture with equant to elongate columnar grains ranging from .01-1 mm in diameter. Grains are subhedral to anhedral throughout the samples, with grains within the granitic component being significantly more anhedral than those found in the basaltic component. As at Smith Point consertal textures are observable in many quartz and feldspar grains within the granite, and patches of plagioclase are intergrown with vermicular quartz in places giving it a myrmekitic texture. Multiple twinning within feldspar grains is also apparent.

DISCUSSION

Smith Pt.

Petrographic observations of the fine-grained granite dike indicated that solid state or submagmatic deformation had occurred. Myrmekite, a symplectic intergrowth of quartz and plagioclase with a vermicular texture (Mackenzie and Guilford, 1994) was apparent throughout the samples (Fig. 4). Its presence signifies either deformation in the solid state or submagmatic deformation, where small amounts of magmatic fluid helped in the transport of the chemical components (e.g., Vernon and Paterson, 2002, Bozkurt and Park, 1997). Transfer of Na and Ca from the plagioclase in a fluid or through solid diffusion had to have occurred within the samples in order for the myrmekite to have formed (Vernon 2004).

In addition two forms of dynamic recrystallization indicative of deformation in the solid state are noticeable within quartz grains from the fine-grained granite dike under petrographic observation. The first, grain boundary migration, results in the movement of grain boundaries into one another within the crystal leading to the closure of the boundary and formation of a new grain with a different lattice orientation from the parent (Blenkinsop 2000). The second, subgrain rotation, causes the progressive rotation of subgrains by the movement of dislocations into subgrain walls during recovery to eventually form new grains (Blenkinsop 2000) (Fig. 4).

At temperatures below 400°-700° C quartz grains deform by slip on the (0001) planes in the direction of the a-axes and subgrains parallel to the c-axis (Vernon 2004). However, at temperatures above 400°-700° C quartz grains deform by slip on the {1010} planes along the c-axis, and subgrains parallel to (0001) planes along the a-axes (Vernon 2004). Determining whether a-slip or c-slip has operated on the grains can therefore help confine deformation temperatures. This can be accomplished by checking the orientation of the fast and slow light-vibration directions with a gypsum plate in grains with their c-axes sub-parallel to the thin-section plane (Vernon 2004). A "chessboard" subgrain pattern was observed on the quartz grains indicating both the operation of c-slip and a-slip (Fig. 4). For the samples obtained from the fine-grained granite dike the presence of c-slip indicates that deformation occurred at temperatures near the solidus implying the presence of melt indicating submagmatic deformation, while a-slip indicates solid state deformation.

Arey Neck

Field observations of Arey Neck show lenticular mafic enclaves scattered throughout the granitic matrix of the sampling area (Fig. 5). These enclaves are aligned in a magmatic flow foliation that reflects the intensity of flow in the host granite. The extension of these enclaves is achieved through rotation and alignment of their constituent minerals without plastic deformation (Patterson et al., 2004). Thin section analysis of the mafic section supported magmatic deformation mechanisms showing sub-parallel alignment of elongate euhedral feldspar and hornblende crystals that are not internally deformed. The absence of plastic deformation would be expected to occur only if a significant portion of the interstitial medium was in the melt phase and was too weak to support it.

However, looking at the granitic matrix under thin section yielded different results. Solid state deformational mechanisms were noticeable throughout the granitic sections. Porphyroclasts of K-feldspar were surrounded by fine-grained folia which anastamosed around it reflecting heterogeneous strain associated with solid state flow (Fig. 4). Furthermore, the grain-size reduction associated with the anastamosing folia extended beyond the margins of the porphyroclasts within the samples. This general grain size reduction, indicating deformation in the solid state, was the result of recrystallization that led to the formation of many micro-grains (Vernon 2000). Also, these recrystallized aggregates of quartz and feldspar show elongation and subgrain rotation. These features indicate high levels of solid state strain (Blenkinsop 2000) (Fig. 4).

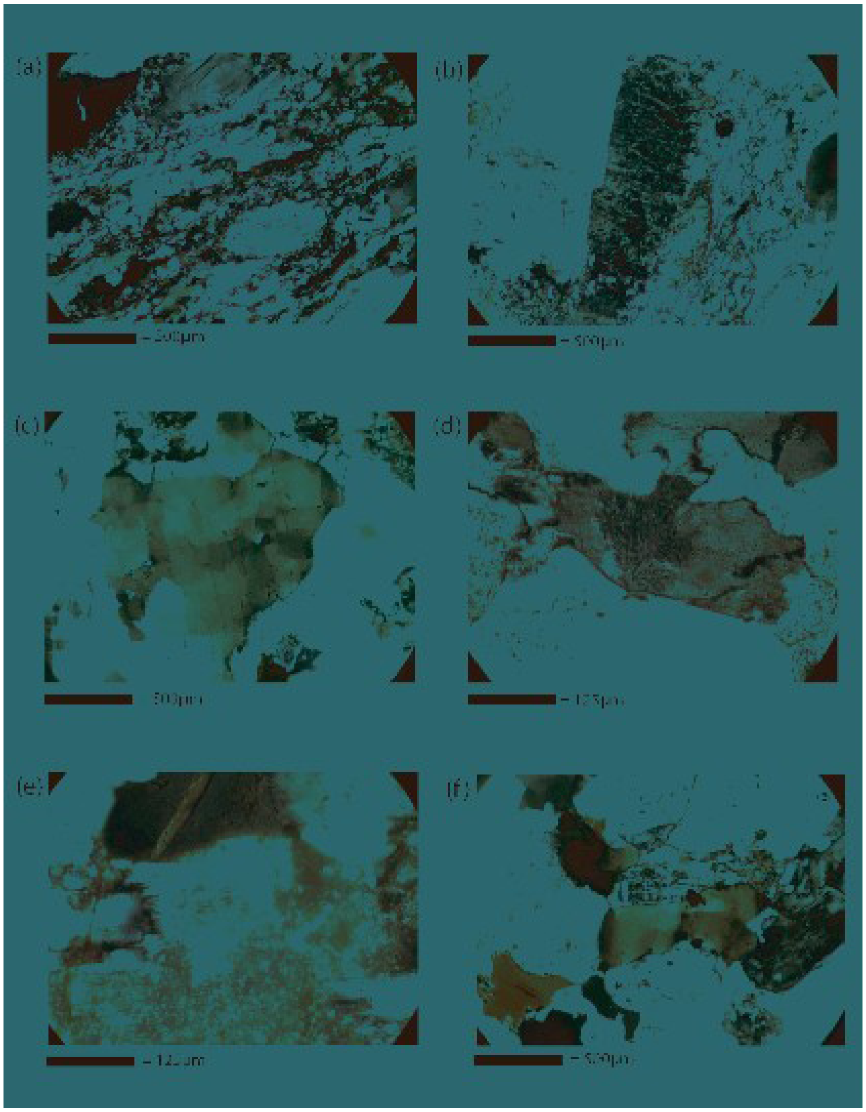

Figure 4. Photomicrographs of samples taken from Smith Point and Arey Neck: (a) recrystallized aggregates of quartz and feldspar showing solid state strain from Arey Neck. (b) Anastamosing folia surrounding feldspar porphyroclast from Arey Neck. (c) "Chessboard" subgrain pattern in quartz from Smith Point. (d) Myrmekite from Smith Point. (e) Deformation twinning in plagioclase from Smith Point. (f) Tartan twinning in orthoclase from Smith Point.

Figure 5. Lenticular mafic enclaves within a granitic matrix at Arey Neck. Rock hammer for scale.

CONCLUSIONS

Well-defined microstructural indicators can be used to differentiate between magmatic and solid state deformation using optical petrography. Unfortunately, submagmatic deformation, where flow is grain supported but melt is still present, cannot be as easily defined (Tribe and D'Lemos, 1996). Deformation mechanisms that could be thought of as reflecting solid state deformation in actuality could be representative of near-solidus, grain-supported flow (Vernon 2000). In granites general crystal habit may allow for local stress concentrations great enough to cause plastic deformation even with melt pockets present (Vernon 2000). These complications make ascertaining whether a small fraction of melt contributed to deformation at Smith Point and Arey Neck difficult. With this in mind although samples obtained from Smith Point showed several deformational mechanisms linked to strain in the solid state, submagmatic deformation cannot be ruled out. Likewise, while mafic enclaves at Arey Neck show magmatic deformation, microstructures in the granitic matrix reflect solid state deformation. Hence, while field observations of the sampled portion of Arey Neck show signs of magmatic deformation during the early stages of its construction history, microstructural analyses show that both Smith Point and Arey Neck later underwent deformation in the solid state.

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