STRUCTURAL CONTROLS ON ISLAND AQUIFERS AND COASTAL SALT WATER INTRUSION, VINALHAVEN, MAINE

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INTRODUCTION

Vinalhaven island, located in Penobscot Bay, Maine, consists primarily of a large granitic pluton of Devonian age. The island supports a seasonally fluctuating population. Continuing development and tourism has lead to concerns of the sustainability of the island's aquifer, primarily concerning salt-water intrusion along coastal areas. Although the majority of the island consists of fine-grained and coarse-grained granite, there are also significant areas of coastline that are dominated by a variety of mafic and hybrid units. Given the non-porous nature of the island's bedrock, the freshwater lens of the aquifer is believed to exist almost exclusively in fractures. These fractures appear to be conduits for saltwater intrusion in coastal areas. So far, the study of these fractures on Vinalhaven in relation to ground water supplies has been limited. This project attempts to study the orientation and nature of fractures along the lithologically diverse southern coast of the island, and search for insights into possible structural controls on the coastal aquifers.

SITE GEOLOGY

The study site consists of an approximately 1.5 kilometer long stretch of the southern coastline of Vinalhaven island, between Round Neck to the west and Clam Cove to the east. An unnamed point was dubbed "BenTre Point" on the eastern boundary (Fig. 1). The area has been described in previous studies as the "Magma mingling layer" of the Vinalhaven pluton (Rhodes, 1999) and as such has very complex geology. There are six major lithologies present in this area. Fine and coarse grained granites common to the island are abundant throughout much of the site. BenTre Point and the surrounding areas is exclusively gabbros. Round Neck, as well as several outcrops in Cove 1 (Fig. 1) are dominated by a unit of "gabbroic pillows" that have intruded into a white fine grained granite (Rhodes, 1999). Granitic porphyry is also present, primarily outcropping on the point between Cove 1 and Cove 2. Finally, there are units of an intermediate granitic hybrid sequence. Metamorphosed blocks of stoped country rock are also present in the pluton, however these do not appear to form a significant part of the bedrock.

All lithologies exhibit some degree of fracturing, although there is significant difference in fracture density. Evidence of both plastic and brittle faulting/fracturing is present.

METHODS

Prior to this study, fracture mapping of the project site consisted only of photolinaments determined from aerial photographs. As such it was necessary to find and map out the major fractures and faults on the site. Many smaller scale fractures were also measured. Specifically, an effort was made to find good sites representing each of the lithological units. These sites were sketched closely, collecting the fracture orientation. All fracture orientations

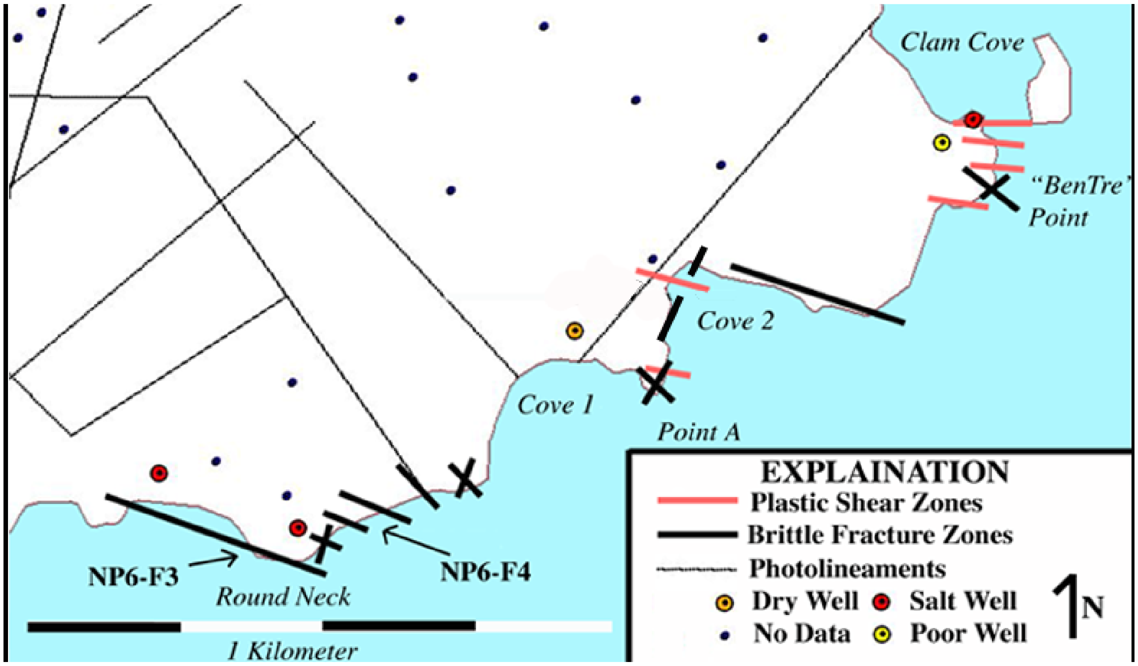

Figure 1: Map of project area. Primary orientations for brittle fracture zones are NNE-SSW and ESE-WNW. Shear zones are oriented E-W. Salt wells at Round Neck and "BenTre" Point appear to lie along fracture zones, suggesting these structures may be inlets for ocean water. Photolineaments appear to roughly correlate with mapped fractures.

were taken using a Brunton compass, and later plotted on a stereonet program. Hand samples were taken from many of the closely sketched areas, as well as from several interesting structures throughout the site. Several petrographic thin sections were taken from these hand samples.

RESULTS

Fracture Nature/Orientation

Mapping of the coastline revealed a variety of prominent fractures and possible faults throughout the site (Fig 1.) Three distinct types of post-magmatism deformation were observed, one plastic, one brittle, and some a hybrid of the two. Individual shear structures and shear zones were observed throughout the site. Several large (30m+ in length, 1m+ in width) shear zones were observed, although soil cover or submersion obscured the full magnitude of these features. BenTre Point had the greatest concentration of these features, although they were present at various locations along the entire study area (Fig 1.). Strike of these features was East-West with a near vertical dip.

Brittle fractures/joints were also observed. These structures ranged from in length from a few millimeters to over 100 meters, and were far more prolific in the study area than post-magmatic shear structures. Major brittle fractures also tended to be open more so than plastic structures. Two primary orientations were observed, striking at north-northeast-south-southwest and east-southeast-west-northwest, both dipping near vertical. Neither orientation appeared consistently to over-print the other. Several major fracture zones appeared to also include overprinted plastic deformation features, and may be re-activated fault zones. Brittle conjugate pairs were observed on both prominent orientations. Also present were irregular, low-angle fractures interpreted to be decompression jointing.

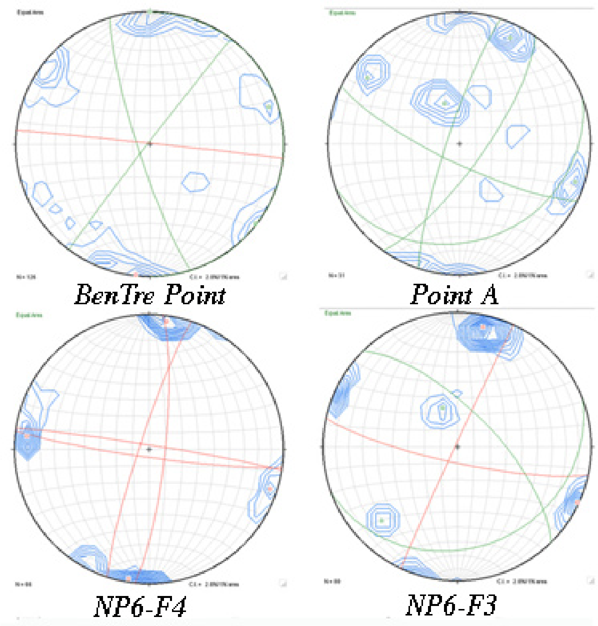

Figure 2: Selected stereonets of project site (see Fig. 1) showing primary fracture orientations. Red great circles indicate dominant fracture orientations. Three dominant fractures sets were observed. One striking NNE-SSW, one ESE-WNW, and one E-W, the latter of which represents plastically deformed shear zones.

Fracture Density vs. Lithology

Significant differences in fracture density for the various lithologies were observed. Coarse-grained granite outcrops had the lowest density of fractures with only one or two fractures per square meter. However these fractures tend to be much longer (5m+), and were consistently open and often brecciated, likely allowing significant groundwater flow. Granite hybrid outcrops were slightly more fractured than coarse-grained granites, exhibiting nearly double the fracture density. Fine-grained granites and gabbros had similar fracture densities, with several prominent fractures (<1m-5m in length) per square meter. Porphory outcrops exhibited extremely clean fractures, in some places having a dozen fractures or more per square meter. Most densely fractured were the “gabbroic pillow” units, in some places having several dozen fractures per square meter, ranging from meter to sub meter scale. In several cases, fractures not manifested in coarser rocks appeared in adjacent fine-grained units (Fig. 3).

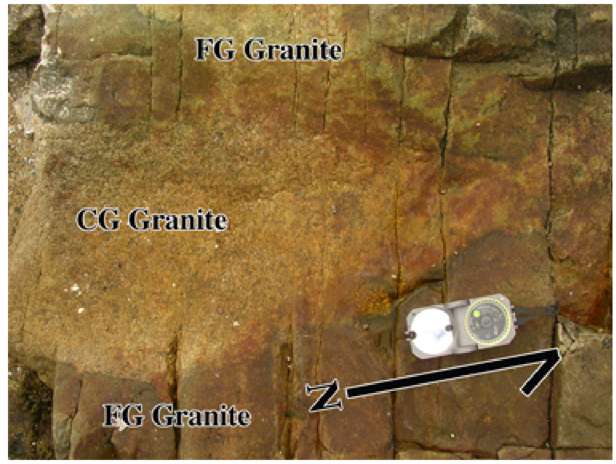

Figure 3: Example of a fine-grained/coarse-grained granite contact. Note the well developed fractures in the FG granite that disappear when entering CG granite. Also note the resulting higher density of fractures in the FG granite, which may lead to increased capacity to carry groundwater.

Thin Sections

An analysis of thin sections taken from prominent fracture areas revealed frequent evidence of water flow through small-scale fractures. Brittle micro-fractures running parallel to the major fracture orientations in sampled lithologies showed oxidation/alteration. Samples from smaller plastically deformed features also showed evidence of oxidation and fluid flow.

Thin sections from a major plastic deformation zone (NP6-F2, BenTre Point) exhibited features suggesting multiple fluid flow events (Fig. 4). Alteration zones visible in hand sample were revealed under magnification to consist primarily of chlorite. Chlorite crystals were aligned perpendicular to the fracture surface, indicating widening of the fracture during formation. Quartz veining was also frequently observed, appearing within chlorite veins suggesting a secondary event of silica-rich fluid. Significant open cavities were also observed within chlorite veins, apparently due to dissolution from later fluid flow. Cross-cutting relationships with magmatic veins suggests little displacement.

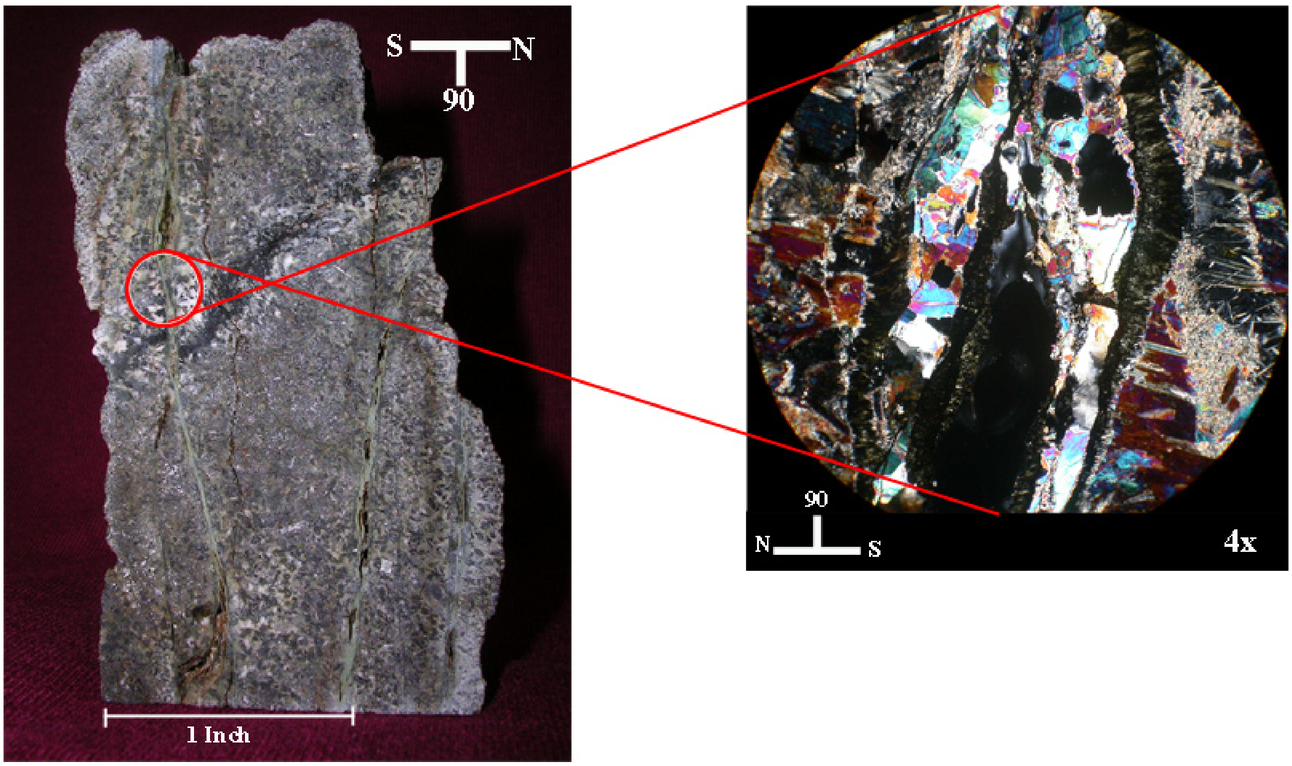

Figure 4: Comparison of hand sample and thin section from shear zone at BenTre point. Both quartz and chlorite veining suggests two sources of fluid during vein formation. Subsequent dissolution of chlorite by modern groundwater flow indicates the shear zone is a conduit for water flow and possible saltwater intrusion.

DISCUSSION & CONCLUSIONS

Based upon initial field mapping, at least two major deformation events affected the project site. One, an apparently older, plastic deformation event, definitely post-magmatism given observed cross-cutting relationships of magmatic structures. Thin sections from deformation zones at BenTre Point suggest two separate fluid flow events. The primary event resulted in chlorite formation, likely from alteration of the surrounding gabbro, with a secondary silica-rich fluid of unknown origin. Modern water flow appears to have subsequently altered these features.

At least one secondary, brittle event post-dates the plastic deformation. The presence of conjugate sets of fractures suggests the nature of this deformation was compressional. High angle, north-northeast striking water-bearing fractures have been observed in igneous rocks on the Maine coastline by Hansen, et al. (1999), which may correlate with the NNE-SSW fracture orientation observed. In a municipal survey of groundwater supply on Vinalhaven, Gerber (1989) observed two prominent fracture sets, a one primarily striking northeast-southwest, and with a strong secondary orientation running northwest-southeast. This correlates with the two prominent northeast-southwest, and southeast-northwest sets observed in this study. Gerber also notes that faults/fracture zones can be important bedrock aquifers if structural deformation is sufficient to create a zone of crushed rock. If intersecting with ocean water these zones can be a conduit for saltwater intrusion.

Photolineaments in the project area were too sparse to make definitive conclusions as to their usefulness in predicting fracture patterns. However, Gerber (1999) found a strong correlation between photolineaments and dominant fracture orientation in the Folly Pond area of Vinalhaven. At least one photolineament at the project site was found to coincide with a prominent fracture zone striking southeast-northwest.

Evidence for structural links to salt-water intrusion at the project site comes from prominent fracture zones, which, when plotted inland, intersect known saltwater wells (Fig. 1). Two salt wells, one at the Gordon residence at Round Neck, and another at BenTre Point, lie on mapped brittle and plastic deformation zones. This is not a statistically significant number of wells, however. Further investigation of coastal salt wells in the region would be needed to make definitive conclusions on the influence of local fractures on salt-water intrusion.

Fracture density throughout the project site appears to be linked to lithology and grain size of the bedrock. Finer grained units exhibit denser, more frequent fractures, while coarse grained units, specifically the coarse grained granite, exhibit less frequent, but larger fractures. Small-scale structures have been found to influence groundwater flow, however this effect is diminished in massive rocks (Williams, 2003) such as the granite that makes up the majority of the island. Therefore, differences in groundwater flow between coarse grained and fine-grained granites may be negligible inland. However coastally fine grained granites may be more prone to saltwater intrusion given the greater observed fracture density. Likewise, highly fractured lithologies, specifically the "gabbroic pillow" unit, may have significant effects locally but are unlikely to have strong influence inland given the unit's infrequent occurrence over the island.

FUTURE WORK

Future work on this project should focus on four key points with the goals of better understanding the occurrence of salt-water intrusion and improving the prediction of contamination-prone well sites. One, continued mapping of the southern coast of Vinalhaven should be conducted to further study the influence of lithology on fracture density. Two, a wider study of wells along the southern coastline should be taken, with special focus on the wells relationship to lithology and possible local structural features (e.g. intersecting fractures present at Round Neck and BenTre Point). Three, further attempts should be made to confirm or rule out the correlation of photo-lineaments to major fracture zones so that these features may be used to guide future surveys. Four, sites should be sought out to investigate the influence of dikes, unit contacts, and other features that may also serve as groundwater conduits.

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