FLORIDA INTERNATIONAL UNIVERSITY

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PROPOSAL FOR THESIS

MASTER OF SCIENCE IN EARTH SCIENCE

COLLEGE OF ARTS AND SCIENCES

DEPARTMENT OF EARTH SCIENCE

Kevin Chau

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I propose to the Major Professor and to the Committee Members a study of the following topic to be conducted in partial fulfillment of the requirements for the degree of Master of Science in Earth Science: **A MINERALOGICAL INVESTIGATION OF THE PALSIADES SILL**.

Abstract

The process of igneous differentiation is perhaps the single most important factor controlling the nature of erupted lavas. Unfortunately, it is nearly impossible to observe it in action. The best approach to understand the process is to study the solidified subsurface magma chambers where the magmas were differentiated prior to eruption. A classic example of such an intrusion is the Palisades Sill in New York and New Jersey. By obtaining quantitative data on the mineral chemistry of the mineral phases in the sill, this study aims to both answer old questions concerning the sill and apply the knowledge gained to the understanding of magmatic differentiation in large intrusions.

Introduction

The Palisades Sill (Figure 1) has long been the focus of much attention due to its potential contributions to the understanding of igneous differentiation. Its significance is further amplified by its ideal accessibility and quality of exposure. The presence of an olivine-rich layer near the sill's base is arguably its most noteworthy feature. As such, several workers have concentrated their efforts throughout the last century in attempts to properly understand the intrusion's origin. Unfortunately, none of the current theories satisfactorily explain all aspects of the sill.

The first workers (Lewis, 1907, 1908a, b; Bowen, 1928; Walker 1940, 1952, 1956) arrived at the conclusion that the olivine-rich layer near the bottom of the sill was a result of mineral fractionation and settling, touting it as a textbook example of fractionation-produced cumulates. This idea continues to persist, though it is now clear that the sill's history is much more complex. Walker (1969a, b) conducted a thorough investigation on the Palisades Sill using whole-rock geochemistry along a vertical transect. He found evidence of two magma pulses, the first of which was responsible for the olivine-rich layer. A similar follow-up study was conducted by Shirley (1987) in which it was reported that no less than three pulses, probably four, had taken place. He believed the olivine-rich zone to be the result of one of the later magmatic injections. Husch's (1990) study stated that heterogeneity along the strike of the sill was the result of lateral flow, which he claimed played as important a role in the observed properties as differentiation. The author also concluded that the olivine-rich layer could not have come from the same parent magma as the rest of the sill because (1) mass-balance calculations did not allow the two bodies to be in equilibrium, and (2) the olivine crystals were not sufficiently dense to be able to sink through the magma in the calculated solidification time. Gorring and Naslund (1995) used whole rock elemental data to confirm the conclusions reached by Husch (1990) and Shirley (1987). Dickson and Philpotts (2000, 2002) proposed the idea of detachment and settling of the upper cooling front to account for the region below the sandwich horizon being significantly thicker than the region above the sandwich horizon.

Figure 1. The Palisades Sill

Currently, there is no viable explanation for the existence of the olivine-rich layer. Determining the source(s) for the magma(s) is a problem that has not been solved. A powerful tool that has not been utilized by any workers is a detailed study of mineral chemistry in the sill. Consequently, I propose to seal the glaring gap in the understanding of the Palisades Sill by conducting a quantitative study of the mineral assemblages of the intrusion.

Geological Background

The Palisades Sill is a diabase intrusion approximately 200 Ma in age (Erickson and Kulp, 1961; Dallmeyer, 1975; Dunning and Hodych, 1990). Its outcrop rises prominently along the Hudson River from Staten Island, NY north through a significant portion of New Jersey, after which it crosses the state line back into New York up to Haverstraw, where it makes a sharp turn westward and disappears under Pomona (Figure 2); it is worth noting that at this turn the intrusion cuts along strata, making it a dike in this section (Walker, 1969a). It is believed that the Watchung Mountain basalts to the west are the volcanic expression of the same magma that solidified into the Palisades Sill. These magmas were injected into the sandstones and arkoses of the Newark Basin, a rift basin

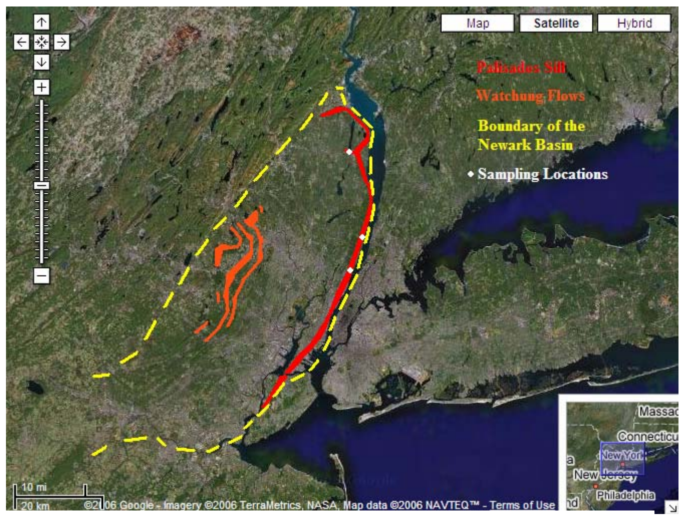

Figure 2. Location map of the Palisades Sill (red). The Newark Basin is outlined in yellow, and the Watchung Mountains are orange.

associated with the separation of Pangaea and the opening of the Atlantic Ocean (Walker, 1969a).

Recently, the Palisades Sill has been grouped with the other gabbroic and basaltic rocks of a Large Igneous Province (LIP), the Central Atlantic Magmatic Province, or CAMP (Leitch et al, 1998; Marzoli et al, 1999; McHone, 2000; Janney and Castillo, 2001). Whether the eruption of such volumes of basaltic lava was the result of a mantle plume (Leitch et al, 1998; Marzoli et al, 1999; Janney and Castillo, 2001) or a more passive cause (McHone, 2000) is still hotly debated. What is known is that the remaining exposures believed to have been part of CAMP are found along the eastern coast of North America, in the Atlas Mountains of northwestern Africa, and in Brazil in South America (Figure 3). Current estimates put CAMP as possibly the largest known LIP, at least in terms of area; it was approximately 5000 km across, 3 x 10^5 km^2 in area, and 6 x 10^4 km^3 in volume (Marzoli et al., 1999). One of the more intriguing CAMP features is the fact that after plate reconstruction, the dike swarms found on the three continents radiate from

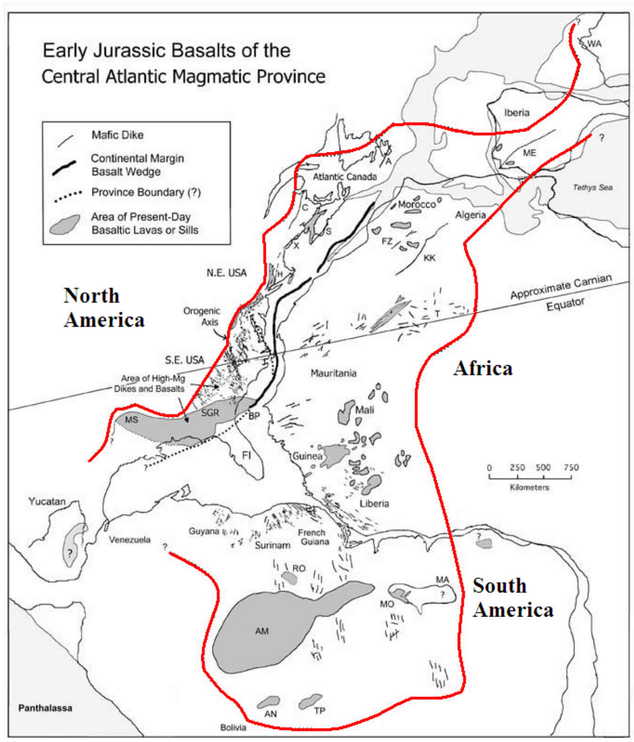

Figure 3. Estimated extent of the Central Atlantic Magmatic Province (red outline) with North America, South America, and Africa as they were when they were part of Pangaea (Adapted from CAMP Website, McHone)

a central point (Leitch et al, 1998). This indicated to some (Leitch et al, 1998) that a plume had significantly uplifted the lithosphere above it to cause radial fractures, which in turn would have facilitated the outpouring of large volumes of lava. The counter argument by Beutel et al (2005) was that massive post-orogenic instabilities caused the supercontinental crust to deform and fracture, still releasing the CAMP lavas.

If the Palisades Sill were part of a much larger province, one would expect to see similarities in other formations. Indeed, basalts and diabases on the three continents are all of roughly similar compositions, straddling both the olivine tholeiite and quartz tholeiite fields (Ragland et al, 1968; Bertrand et al, 1982). Additionally, isotopic dating of CAMP rocks consistently yields ages of 200 ± 2 Ma (Marzoli et al., 1999; Hames et al., 2000; Beutel et al., 2005). The discovery of diabase sills with olivine-rich zones near their bases in the Atlas Mountains (Bertrand et al., 1982) is an exciting development in the ongoing quest to decipher the origin of the Palisades Sill. It is important to note that the Atlas and Anti-Atlas Mountains are orogenized Triassic rift basins (Bertrand et al, 1982), African analogs of the North American Triassic basins; before the opening of the Atlantic Ocean, the two sets of rift basins faced each other.

Proposed Research and Objectives

The ultimate goal of this research is to use systematically collected data from samples along a transect of the sill to interpret the differentiation processes that operate within a tholeiitic intrusion. Most lavas undergo significant changes from their original compositions via the combined effects of fractionation and differentiation occur in subsurface magma chambers. It is ideal then to study these magma chambers in order to understand these processes at work.

The Palisades Sill is a classic example of an intrusion whose magma is a highly evolved tholeiite, which is an ideal site to investigate igneous differentiation. Furthermore, there is the ongoing argument as to the role of crystal settling in the olivine-rich zone and the number of magmatic pulses constituting the sill. Mineral chemistry best records changes in equilibrium to the system; I therefore intend to use EPMA to quantify the mineral phases found in the Palisades Sill rocks in order to answer these questions.

By comparing Mg# and NiO content, a detailed look at the olivine grains from the olivine-rich zone would constrain the number of olivine populations present and, in turn, help deduce the number of magma pulses involved. Preliminary optical analyses revealed a strong presence of orthopyroxene in all of the samples; coupled with clinopyroxene, probe data of these phases could serve as a useful addition to the interpretation in the form of a geobarometer. Likewise, analysis of the iron oxide mineral chemistries would be helpful as geothermometers. An overall sense of compositional trends for each phase throughout the sill would provide a broader picture of magmatic behavior from the onset of crystallization (the chill margins) to the solidification of the last pockets of melt (the sandwich horizon).

With the completion of this project, it is expected that not only will some questions on the Palisades Sill be answered, but perhaps more importantly, a better understanding of how large intrusions and subsurface magmatic processes behave will be achieved.

Methodology

Samples were carefully collected from the sill by myself in August of 2006 and by Dr. Richard Naslund of SUNY Binghamton in 1990; Dr. Naslund has shared with me part of his collection. With thin sections having been made from the samples, the first step is to make a detailed petrographic study of each of the sections. Afterward, following a carbon-coating of the slides, quantitative analyses will be obtained for each mineral phase found in the thin sections through the use of EPMA data from the JEOL 8900R housed in FCAEM.

Summary

The Palisades Sill is a classic subject in the field of petrology. Yet, with so much focus centered on it, there is much is has yet to reveal. This project aims to investigate a major asset in studying igneous rocks, that of mineral chemistry, and extend that information to achieve a better understanding of the process of igneous differentiation. Through the use of detailed optical studies, quantitative analysis of the mineral phases, and careful interpretation of that data, the goals laid out in this study will be achieved.

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