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Spatial, temporal, mineralogical, and compositional variations in Mesozoic kimberlitic magmatism in New York State

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ABSTRACT

Mesozoic kimberlitic magmatism was geographically widespread across central New York State, and nearly 90 distinct intrusions have been discovered since the first "serpentinite body" was described over 175 years ago. Most of the intrusions are narrow (<30 cm wide), near vertical, north–south oriented dikes, although three larger, irregular diatremes are also known. Previous studies assumed that all of the intrusions were genetically and temporally related, and often examined only a small sub-set of the intrusions. By combining modern samples with historic samples in the collections of the New York State Museum and Hamilton College, we were able to obtain detailed mineralogical and geochemical data on samples from 27 distinct intrusions.

The intrusions can be divided into four distinct groups on the basis of both mineralogy and geochemistry, and previously published radiometric age dates suggest that these four groups may also have distinct emplacement ages. Group A intrusions are exposed on the western margin of Cayuga Lake near Ithaca, and are characterized by olivine and phlogopite macrocrysts in a serpentine and phlogopite-rich matrix. These intrusions are relatively Ti-rich and contain abundant perovskite grains in the groundmass that yielded U–Pb crystallization ages of ~146 Ma (Heaman and Kjarsgaard, 2000). Group B intrusions are exposed over a relatively large area surrounding Ithaca, and are characterized by having a diverse macrocryst assemblage that includes pyrope, diopside, and spinel in addition to olivine and phlogopite. These intrusions are the most incompatible and REE enriched, and are chemically similar to the Kirkland Lake kimberlites in eastern Ontario. Intrusion ages for this group cluster between 125 and 110 Ma. Group C intrusions are all found within the city of Syracuse, and are similar to the Group B intrusions in both mineralogy and chemistry. They appear to be somewhat older, with intrusion ages of 135–125 Ma. Finally, Group D intrusions are geographically distant from the other three groups, being exposed in East Canada Creek nearly 100 km east of the Syracuse dikes. They are characterized mineralogically by abundant olivine and sparse, but large, phlogopite macrocrysts, and chemically by having the lowest incompatible element and rare earth element (REE) concentrations, and the highest $^{87}Sr/^{86}Sr$ ratios. Intrusion ages for these dikes are poorly constrained, but appear to be contemporaneous with, or slightly older than, the ~146 Ma Group A intrusions.

All of the kimberlitic intrusions in central New York State have initial Sr and Nd isotope ratios close to bulk earth. This fact, combined with the observed macrocryst assemblages and incompatible trace element ratios, indicates that these magmas were derived primarily from an asthenospheric, garnet lherzolite source. Episodic intrusion of small volume, volatile-rich kimberlitic magmas into the Paleozoic sedimentary platform rocks of central New York appears to have occurred along ancient crustal structures that were reactivated by the far field stresses related to the opening of the North Atlantic Ocean.

1. Introduction

Magmatism was widespread in northeastern North America during the Mesozoic, and dominated by three distinct episodes and styles of activity (Fig. 1): 1) extensive tholeiitic basalt flows and sills of the Circum-Atlantic Magmatic Province (CAMP) (~200 Ma) (Kontak, 2008; Marzoli et al., 2011; Murphy et al., 2011); 2) shallow, relatively small, alkalic intrusions of the Monteregian Hills and larger New England–Quebec Province (~130–110 Ma) (Eby, 1987; McHone and Butler, 1984); and 3) larger, dominantly granitic to syenitic intrusions of the White Mountain Magma Series (200–155 and 130–110 Ma) (Eby et al., 1992; McHone, 1996). Small volume, ultramafic and ultrapotassic intrusions are also widespread in the region, but they have not been as extensively studied, and their petrogenesis is poorly understood. These intrusions provide the only direct evidence of the

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nature of the mantle underlying eastern North America, and are an important part of the tectonic and magmatic history of the region.

The rocks of this study lie within a broad belt of mica-bearing ultramafic intrusions that runs along the western flank of the Appalachian Mountains from Alabama north into Ontario and Quebec. While these rocks exhibit a wide range of mineral assemblages and textures, all have been referred to as kimberlites by previous researchers (e.g. Basu and Rubury, 1980; Bikerman, 1997; Bolivar, 1976; Meyer, 1976).

Currently, there are two theories that have been put forth to explain the origin of the kimberlitic rocks in New York State: 1) they are part of a chain of small, alkaline intrusions in eastern North America related to passage of the North American plate over the Great Meteor hot spot (Heaman and Kjarsgaard, 2000); or 2) they are part of a belt of kimberlitic intrusions along the western flanks of the Appalachian Mountains that were intruded along old structures that were reactivated by crustal extension related to rifting and opening of the Atlantic Basin (Parrish and Lavin, 1982).

This paper presents the results of the first comprehensive study of the kimberlitic rocks of New York State. The goals of the study are: 1) to identify and document mineralogical and chemical variations within and between intrusions, 2) to identify any spatial or temporal patterns in the distribution of these rocks, and 3) to constrain the conditions and tectonic setting under which these rocks formed.

1.1. Kimberlitic rocks of New York

1.1.1. Geographic distribution

Approximately 90 kimberlitic dikes and small diatremes have been found in New York State. Detailed information on the number of dikes in New York, their location, size, and orientation are in Bailey and Lupulescu (2007), Foster (1970), Kay and Foster (1986), and Martens (1924). The exact number of intrusions is difficult to ascertain for a number of reasons. First, the field descriptions provided by previous researchers vary in quality and specificity, and many of the earliest localities have been "lost" or buried. Second, many of the dikes are extremely small (widths of 1–3 cm) and they occur in irregular, anastomizing swarms; the criteria for identifying and counting individual dikes were not clearly described by any of the previous researchers. Finally, many of the dikes that have been given distinct names and described in the literature are undoubtedly along-strike exposures of the same dike (e.g. the Green Street, James Street, Foot Street, and Butternut Street dikes in downtown Syracuse).

Most of the kimberlitic intrusions occur within an elongate NNE–SSW area between the cities of Ithaca and Syracuse. The Montgomery County and Ogdensburg dikes are the only occurrences outside of this area. The vast majority (nearly 80) of the known intrusions are found in the vicinity of Ithaca, primarily in the ravines that feed into Cayuga Lake. The irregular spatial distribution of known kimberlitic intrusions in New York is probably due, in part, to the variable effects of glacial erosion and deposition, with the greatest number of exposures in the deep, glacially cut gorges of west-central New York. It is highly probable that many other dikes are present throughout the state but are still undiscovered, being buried by thick blankets of glacial till and/or alluvial sediment.

1.1.2. Previous work

The unusual serpentine-rich rocks of upstate New York State were first reported in 1837 in one of the earliest publications of the newly formed New York State Geological Survey (Vanuxem, 1837). This report, along with two subsequent reports (Vanuxem, 1839, 1842), contains the earliest known scientific description of kimberlitic rocks. Hunt (1858) published the first extended description and partial chemical analysis of these rocks, documenting their ultramafic character.

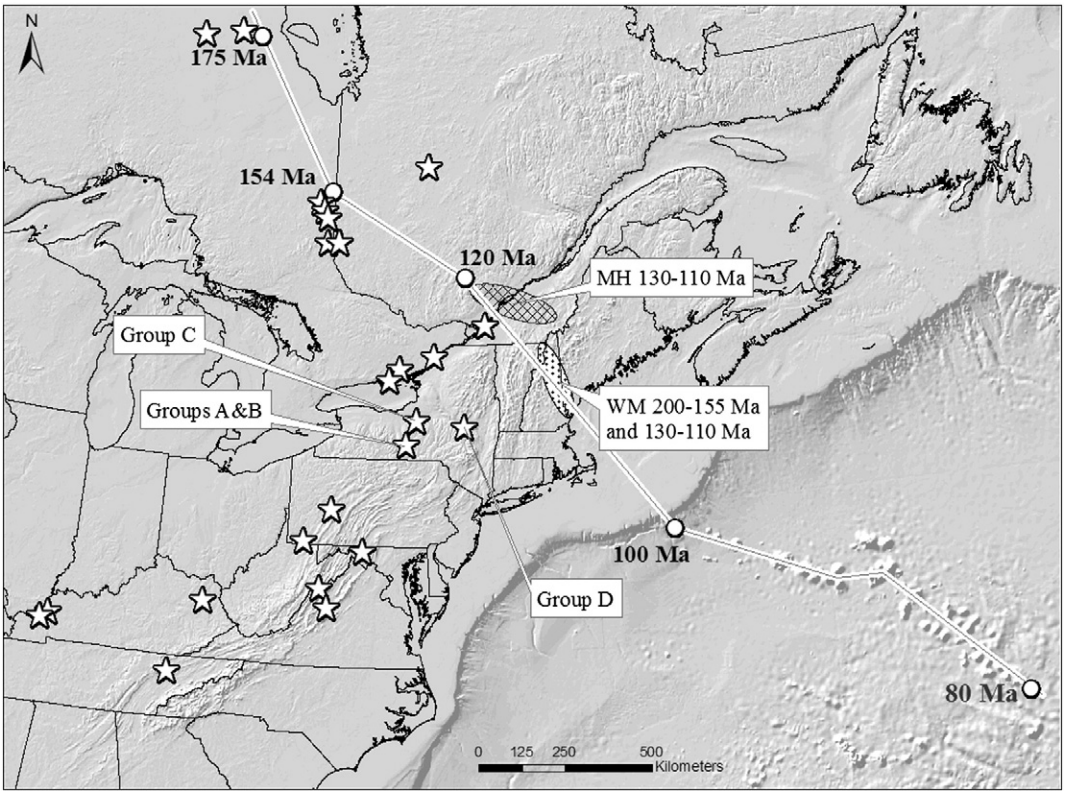

Fig. 1. Locations of Mesozoic igneous activity in northeastern North America (excluding CAMP basalts). Stars denote locations of known kimberlitic intrusions; hatched field denotes location of Monteregian Hills igneous activity; stippled field denotes location of White Mountains Magmatic Province. Line represents approximate age/location of proposed Great Meteor Hotspot track (Heaman and Kjarsgaard, 2000).