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The Paleoproterozoic Marathon Large Igneous Province: New evidence for a 2.1 Ga long-lived mantle plume event along the southern margin of the North American Superior Province

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Abstract

Three Paleoproterozoic diabase dyke swarms, the Marathon, Kapuskasing and Fort Frances, which outcrop around the northern margin of Lake Superior, radiate from a focal region south of the lake. U–Pb dating shows that the Marathon and Kapuskasing swarms range in age between 2126 and 2101 Ma, and the Fort Frances between 2076 and 2067 Ma. The convergence of the dyke swarms to a common focal area and the lack of apparent polar wander during the time interval 2125–2067 Ma, suggest that a single, periodically active, plume was responsible. This 60 m.y. period of magmatism, manifest over an area of at least 400,000 km^2, is designated as the Marathon Large Igneous Province. Only a single magnetic field reversal has been recognized throughout the 60 m.y. of plume activity. This observation, together with U–Pb geochronology, has helped to place dykes within each swarm in a chronological order based on their magnetic polarity. For the dyke population as a whole, older dykes tend to show more enriched and more fractionated incompatible trace element patterns compared to younger ones, a result which suggests that the Marathon, Kapuskasing and Fort Frances swarms are genetically related and underwent a secular reduction both in the degree of crustal contamination and/or depth of mantle melting over the course of plume activity. A similar geochemical relationship has also been found for the 2171–2166 Ma Biscotasing swarm but determining whether it is a common feature of plume development must await further study.

Keywords: Paleoproterozoic; Dyke swarm; U–Pb geochronology; Paleomagnetism; Geochemistry; Mantle plume; Large Igneous Province

1. Introduction

Archean cratons are surviving fragments of presumably more extensive terrains. Transecting these cratons are Proterozoic dyke swarms, of variable extent, trend and age, which are thought to represent preserved remnants of major rifting events. The most direct evidence for the timing of break-up along a given margin of a craton is provided by the age of dyke swarms that radiate from that margin (Halls, 1982; Ernst and Buchan, 1997, 2004). It has been suggested that precise U–Pb dating of Proterozoic swarms could be used to "bar code" cratons, thus helping to identify cratons that were once joined (Bleeker, 2004; Bleeker and Ernst, 2006). In addition, paleomagnetism of mafic dyke swarms provides constraints on the geometry of reconstructed cratons.

The Marathon dykes occur at the western fringe of a host of dykes from different swarms whose trends gradually change eastwards from NS to ENE toward the Kapuskasing Structural Zone (KZ), a fault-bounded belt of mainly Archean lower crustal gneisses that was uplifted at ∼2 Ga (Fig. 1). Representatives of the Marathon swarm have not previously been found farther east toward the KZ. If some of the ENE-trending dykes in this area are Marathon in age, they would define a large radiating swarm converging to the south, thus establishing the location of a major mantle plume source as well as a rifted margin of the Superior Province.

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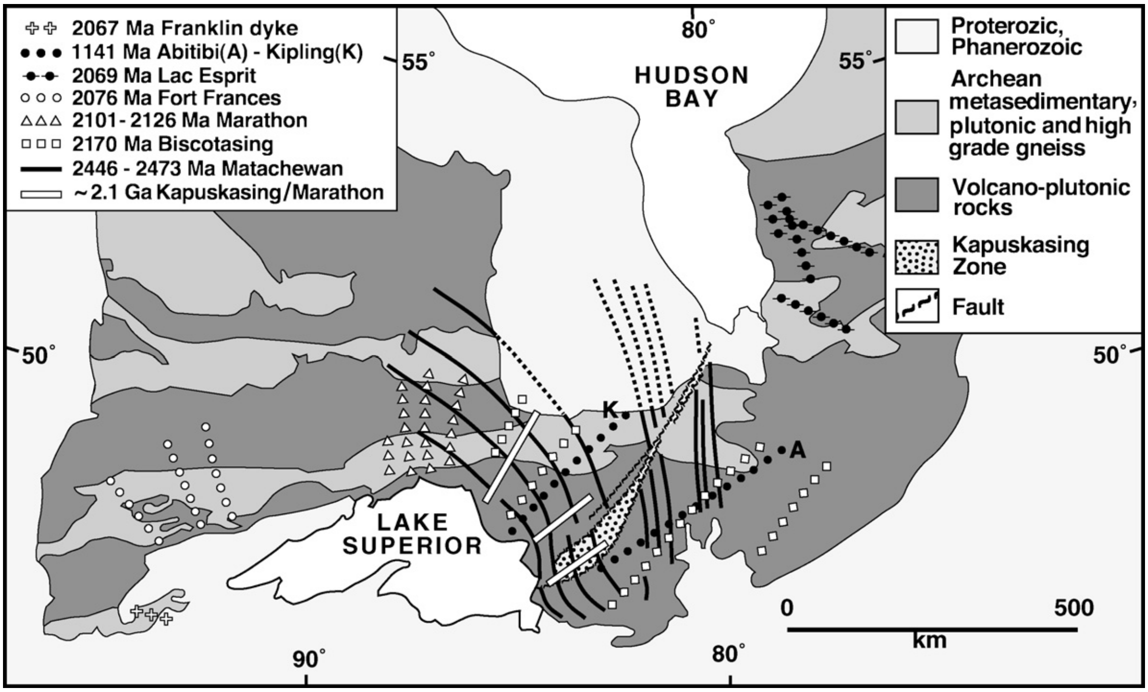

Fig. 1. Map of the main Proterozoic dyke swarms in relation to the Kapuskasing Zone. The main dykes of interest in this paper comprise the Fort Frances, Marathon and Kapuskasing swarms.

In this paper we use an integrated approach, employing paleomagnetism, U–Pb dating and geochemistry to define the full extent of the Marathon swarm, to relate it to other dykes of similar age in the Lake Superior region, and finally, via chilled margin geochemistry, to help test models of plume development for radiating swarms.

2. Background

2.1. Integration of paleomagnetism, U–Pb geochronology and geochemistry in dyke studies

Over the time period from 600 to 3000 Ma, mafic dyke swarms, associated with continental rifting episodes, have been emplaced somewhere on earth every ~50 m.y. on average. They penetrate deep into cratonic interiors and their distal parts – remote from margins that are often sites of later collisional events – are often extremely fresh. Their excellent state of preservation, frequency of occurrence and overall basaltic composition through time make them excellent targets for the study of past continental configurations and of how certain aspects of Earth, such as the geomagnetic field, have evolved (e.g. Halls, 1982).

U–Pb dating of diabase dykes has made considerable advances in the last 20 years to the point where, due to methods for efficient recovery of baddeleyite and low-blank isotopic analysis on single micro-crystals, it is now possible to obtain age precisions of about a million years for many Precambrian diabases.

It has long been recognized that diabase dykes frequently preserve an excellent record of the magnetic field direction at the time of dyke cooling and have provided almost half of the Precambrian paleomagnetic database (http://dragon.ngu.no). Paleomagnetism can distinguish, not only dyke swarms differing in age by tens of millions of years because of their different pole positions along apparent polar wander paths, but also, on a finer age scale, dykes of opposing magnetic polarity within a given swarm. The primary nature of the paleomagnetic direction can be ascertained by using a baked contact test (Everitt and Clegg, 1962), which is considered positive if the paleomagnetic direction from dyke and baked host rocks is the same but different from that of an older magnetization in unbaked host rocks farther afield. Other indications of primary magnetization are dykes of opposite magnetic polarity in the same swarm or small differences in direction between neighbouring dykes that persist along strike (e.g. Halls, 1986). Combined with high precision U–Pb dating it is now possible to define highly precise apparent polar wander paths for inter-cratonic comparison and also the number, age and sense of polarity reversals within a given swarm.

Geochemical investigations have shown that dyke chilled margins retain a remarkably constant composition along strike for hundreds of kilometres (e.g. Kalsbeek and Taylor, 1986; Ernst and Bell, 1992), regardless of longitudinal differences in the lithology of host rock exposures. Each dyke represents a single magma injection event because neighbouring dykes of the same trend have small but distinctive differences in chemical composition that persist for tens of kilometres along strike (e.g. Halls, 1986). In this paper the geochemical results, all obtained from chilled, fine-grained rocks within about 30 cm of dyke margins, are used to identify different ages of dyke intrusion and, together with aeromagnetic data, to identify sampling sites from the same dyke whose paleomagnetic results need to be combined. In this way the dispersion of paleomagnetic directions for a population of dykes within the swarm can be used to give