Testing of an ‘amalgamated sill’ hypothesis for the origin of mafic-ultramafic layered intrusions

R.M. Latypov

School of Geosciences, University of the Witwatersrand, South Africa

E-mail: Rais.Latypov@wits.ac.za

Summary Five major lines of petrological research are proposed to rigorously test a recently emerged ‘amalgamated sill’ hypothesis for the origin of mafic-ultramafic layered intrusions.

1. Introduction and background to current research

For over a century, a classical paradigm of a magma chamber has been underpinning all studies of mafic layered intrusions. The paradigm envisages a magma chamber as a large body of the molten, long-lived, and slowly fractionating magma (‘a big magma tank’) enclosed in cold crustal rocks (Wager and Brown, 1968; Parsons, 1987; Cawthorn, 1996; Charlier et al., 2015). A key feature of this classical paradigm is that it explains readily why the rock sequences of layered intrusions – that form in a sequential stratigraphic order from the base (oldest) to the top (youngest) – are fully consistent with fractional crystallization of basaltic melts (Irvine, 1970, 1979). In the recent years, this traditional view of a magma chamber has been questioned by many geoscientists who contend that such long-lived and largely molten ‘big magma tank’ chambers are either very short-lived or never existed in the Earth’s history. One alternative to a classical view is an “amalgamated sill” hypothesis that portrays the layered intrusions as a stack of sills (crystal-rich slurries) that often invade pre-existing cumulates in a random fashion (Mungall et al., 2016; Wall et al., 2018; Scoates et al., 2021). This re-interpretation is mostly motivated by a discovery that absolute ages of zircons do not become progressively younger from the base towards the top of the layered intrusions, as it would normally be expected from the stratigraphic law of superposition. Rather, the zircon ages are out-of-sequence, i.e. they change a few times from old to young ones and backwards with moving up-section of the complexes.

2. Research questions at hand

As any new concept in science, an “amalgamated sill” hypothesis for the origin of layered intrusion needs to be subjected to rigorous testing. I propose that this testing can be done using five major approaches:

1. Field relationships between layers of cumulate rocks:

An “amalgamated sill” hypothesis predicts that the intrusive bodies should display cross-cutting relationships with both underlying and overlying layers. This feature can be employed to prove/disprove the intrusive nature of layers/units in layered intrusions.

2. Textural observations in cumulate rocks:

The zircon dating indicates that the age difference between individual sills in layered intrusions can be up to a few million years (Wall et al., 2018; Scoates et al., 2021). This implies that internal chilled margins can locally develop within a stack of incrementally intruded sheets of magma. The existence of the late-stage sills can thus be proven by chilled margins.

3. Stratigraphic chemical trends through the rock sequences:

The interpretation of the layers/units as randomly-emplaced sills implies that their mineral, whole-rock and isotopic compositions may be substantially different from the host cumulate strata of layered intrusions into which they have been intruded. This feature can thus be used for testing the sill's nature of layers/units by their chemical composition.

4. Phase equilibria-controlled crystallization sequences of layered intrusions:

The cumulate stratigraphy of most layered intrusions is consistent with a few major crystallization sequences that are expected from liquidus phase equilibria in basaltic systems (Irvine, 1970, 1979). The random emplacement of sills into pre-existing strata is expected to disturb the systematic order of phase crystallization in layered intrusions. The abrupt reversals and/or chaotic changes in crystallization sequences may therefore be used to identify the late-stage sills.

5. Isotopic zircon ages in potholes:

Some layered intrusions show potholes - roughly circular depressions in the chamber floor in which footwall rocks were removed by magmatic erosion (Latypov et al., 2016; 2019). The crosscutting relationships between the rocks in potholes allow to safely define the relative ages of the layers/zones. The absolute ages of zircons extracted from the rocks in the potholes can thus be a primary tool for proving/disproving the out-of-sequence geochronology that lies at the heart of the “amalgamated sill” hypothesis.

3. Future prospects

A “amalgamated sill” hypothesis has been developed based on the study of two world-known layered intrusions – Bushveld Complex in South Africa (Mungall et al., 2016; Scoates et al., 2021) and Stillwater Complex in Canada (Wall et al., 2018) and. In this context, the ARLIN project has a great potential to explore the validity of this new hypothesis using numerous mafic-ultramafic layered intrusions located on the Fennoscandian Shield. The research may provide an important step beyond the current state-of-the-art in theoretical and applied fields of modern igneous petrology and mineral deposit geology. This would significantly improve and strengthen the overall global position and competitiveness of Fennoscandian-based geosciences.

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