USING THE OPENFOAM C++ LIBRARY OF APPLICATIONS TO SIMULATE FLOW OF TURBULENT LAVA AT RAGLAN, CAPE SMITH BELT, NEW QUÉBEC, CANADA. V. Cataldo[1], D. A. Williams[1] and M. W. Schmeeckle[2], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, 85287-1404 (Vincenzo.Cataldo@asu.edu); [2]School of Geographical Sciences and Urban Planning, Arizona State University, Tempe, AZ, 85287-5302.

Introduction: Located in the eastern part of the Cape Smith Belt, the Proterozoic Raglan Formation of New Québec, Canada comprises a lower *Cross Lake Member* and a *Katinniq Member* [1]. The lower member is represented by local peridotite-wehrlite facies and more abundant gabbro facies, interpreted to be channelized sheet flows or very high-level sills, whereas the *Katinniq Member*, comprises mesocumulate peridotite facies – a system of lava channels or the remnants of a long sinuous, meandering submarine komatiitic basalt lava channel [1, - 4], extending for at least 20 km and possibly up to 50 km in length [3]. Both 3-D magnetic inversion models and deep stratigraphic drilling suggest that the individual channels may represent long lava conduits analogous to the sinuous rilles on Mars, Venus, and the Moon [5 and Fig. 1 a, b].

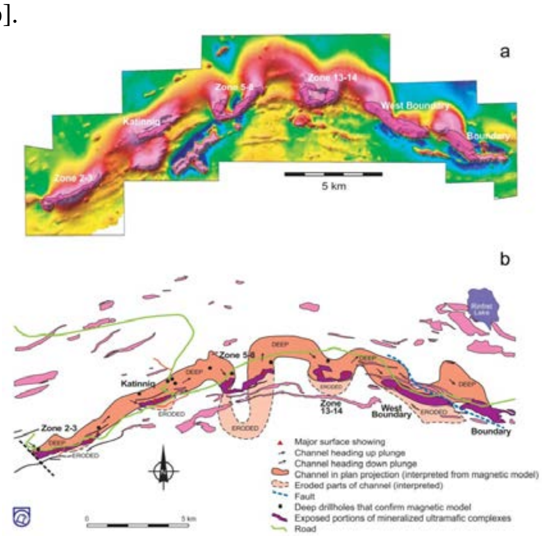

Figure 1: a) Magnetic map of the Raglan block. Red and blue colors indicate areas of high and low magnetic susceptibility, re spectively; (b) Meandering lava channel exploration model for the Raglan mineralized ultramafic complexes (from [1]).

True thickness and width of the *Katinniq Member* are of the order of 100 m and 500 m, respectively, but individual units within it are 10-50 m thick. Importantly, the system appears to have been initially extrusive and later became laterally erosive [1]. The *Katinniq Member* progressively cuts downward through a <10-m thick horizon of sediments and gabbros, forming a broad, concave, V-shaped embayment with numerous smaller hourglass-shaped, re-entrant embayments that typically localize Fe-Ni-Cu sulfides.

All embayments are best interpreted to have been produced by thermal erosion by the lava [6, 1]. Erosional downcutting forms a concave, V-shaped cross section as long as the lava remains above the ground level; but when it sinks below ground level, undercutting occurs and an hour-glass, re-entrant channel cross section develops [7]. Moreover, the erosional processes seem to have played a key role in the formation of the mineralized deposits found within the rocks. A better understanding of these erosional processes will better constrain the mode and time of emplacement for not only the lavas but also the ore deposits as well.

We created a 3-D model of thermal erosion by turbulently flowing lava in an attempt to assess how channel bank erosion relates to erosion at the channel bed, a scenario that cannot be explored by the 1.5-D model of *Williams et al*. [8]. The rigorous *Williams et al*. model of thermal erosion by turbulent lava accounts for both the physical and geochemical evolution of the lava with increasing downstream distance from the source. It calculates erosion rates and depths at the channel bed with increasing distances over time. Erosion rates increase with increasing incision velocities into the substrate and increasing flow temperature. Other parameters affecting the total amount of erosion obtained are the convective heat transfer coefficient in the flow and the energy required to melt the substrate. The new model uses the resources made available by OpenFOAM, a C++ library of applications called solvers and utilities. Solvers enable simulation of specific problems in the area of Computational Fluid Dynamics (CFD), whereas utilities are designed to perform simple pre-and post-processing tasks like those involved in mesh generation. The OpenFOAM finite volume software is extremely versatile because users can create their own solvers and utilities or modify existing ones. Finally it allows for grid design that can be tailored to the scenario of interest.

Final model results will be validated against the geochemical and field data obtained for the Raglan region [1]. This operation is essential in order to assess if the modeled lava contamination, dimension of erosion and corresponding eruption volumes and durations are consistent with current interpretations of the Raglan flows.

The 3-D model: The motion of a turbulent lava flow – an incompressible fluid – can be described by the Navier-Stokes momentum equations in the x, y, and z direction. The process of time-averaging - inherent in turbulent modeling - introduces two new unknowns (Reynolds stresses) into the system of equations, which are approximated by using a "k-ε" model that contains two additional transport equations. The k expression quantifies the turbulent kinetic energy that is produced, convected, and diffused within the flow, whereas the ε equation approximates turbulent dissipation.

The simpleFoam solver – available in the OpenFOAM library – is well-suited for the purpose of modeling turbulent, incompressible flow. The most important input parameters of the flow are velocity and pressure. Flow is investigated in steady conditions. Importantly, no initial temperature is specified, a severe limitation for the purpose of modeling turbulently flowing lava.

Modifying the simpleFoam solver. To solve the temperature limitation inherent in the chosen solver, we coupled a 3-D temperature model to simpleFoam. The model contains an expression for heat flux which displays a turbulent diffusivity term. Equating this expression to the heat flux expression adopted in the ablation problem (heat conduction) described by *Ozisik* [9] enabled determination of the steady-rate advance (erosion rate) of the lava/substrate interface over the entire channel boundary. The lava/substrate interface is assumed to be at the fusion temperature so that there is no temperature gradient in the solid phase and no heat is removed from the flowing lava to keep the substrate temperature at its melting value.

As the flow temperature decreases, flow viscosity increases to the point at which the crystallization of olivine crystals commences. We derived a 3-D expression that allows calculation of the latent heat released within the flowing lava as a result of olivine crystals growth. The latent heat is assumed to be constant (i.e., not temperature-dependent), hence the new expression is the 3-D equivalent of that adopted by *Williams et al*. [8].

Designing two lava channel grids. Using the mesh-generating utility available in OpenFOAM, we designed two rectangular channel grids. The two lava channels are 200 m and 500 m wide, and 10 m and 20 m thick, respectively [4]. An identical value of channel length for the two channels (1,000 m) is considered at this stage.

The newly-found expressions are part of a written program code. Results of the current investigation will be presented at this meeting.

Work in progress: At the current stage of development, the model does not account for the geochemical evolution of the lava with decreasing temperature. The contamination of the lava by assimilated substrate, which is accounted for in the *Williams et al*. [8] model, will also be tracked by a conservation of concentration equation. Also, the newly calculated erosion rates will be used to predict geometric evolution of the substrate over which lava flows travel.

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