BUILDING A 3-D MODEL OF THERMAL EROSION BY TURBULENT LAVA AT RAGLAN, CAPE SMITH BELT, NEW QUÉBEC, CANADA.
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Introduction: The Proterozoic Raglan Formation of the Cape Smith Belt, New Québec, Canada comprises two regionally mappable members [1]: a lower *Cross Lake Member* comprising local peridotite-wehrlite facies and more abundant gabbro facies, interpreted to represent channelized sheet flows or very high-level sills, and a *Katinniq Member*, comprising mesocumulate peridotite facies, interpreted to represent a system of lava channels or the remnants of a single long sinuous, meandering submarine komatiitic basalt lava channel [2, 3, 1, 4]. The *Katinniq Member* in the type locality has a true thickness of the order of 100 m and a true width of the order of 500 m. As in other areas within the Raglan Formation, it comprises multiple units, each of which is 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 (Fig. 1).

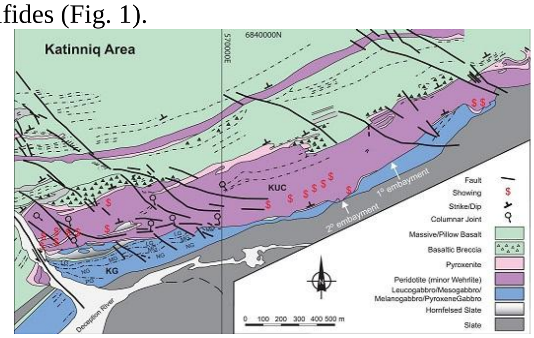

Figure 1: Geological map of the Katinniq area. KG = Katinniq Gabbro, KUC = Katinniq Ultramafic Complex. Concave (1°) and re-entrant (2°) embayments are shown (from [1]).

This set of embayments is best interpreted to have been produced by thermal erosion [5, 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 forms [6]. This is a complex erosional environment where lava eroded at the tops, bottoms, and sides of the channel, through underlying gabbro, and then burrowed laterally into underlying sediment [1]. 3-D magnetic inversion models indicate that the units are continuous in the subsurface, which has been confirmed by deep stratigraphic drilling, suggesting that they may represent long linear lava conduits analogous to the sinuous rilles on Mars, Venus, and the Moon [7]. If this interpretation is correct, it is important to assess how channel bank erosion relates to the previously-discussed erosion at the channel bed. It is clear that a 2-D or better 3-D model is required in order to explain the observed erosional features at Raglan.

Our new model builds on the 1.5-D *Williams et al.* [8, 4] model of thermal erosion by turbulently flowing lava. This model accounts for the physical and geochemical evolution of the lava with increasing downstream distances from the source. It calculates erosion rates and depths in the vertical direction with increasing downstream 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.

OpenFOAM is a C++ library of applications - solvers and utilities – the former of which solves a specific problem in continuum mechanics, and the latter of which performs tasks that involve data manipulation and algebraic calculations. This Computational Fluid Dynamics (CFD) finite volume software is extremely versatile because users have the freedom to 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.

We herein describe how to build a new 3-D model of thermal erosion by turbulently flowing lava at Raglan. Why is this work proposed now? Several studies suggest that mechanical erosion by lava has a greater role in channel-tube formation than previously thought, under certain circumstances. I want to test this hypothesis by first creating a model of thermal erosion. While not ruling out that mechanical erosion could play a dominant role in eroding lava substrates and channel banks, I intend to test the hypothesis that this may not be a necessary requirement. At a later stage, a mechanical erosion component will be added to the model for the purpose of quantifying this contribution. We will then distinguish between mechanical and thermal erosion by investigating the model results when substrate properties change. The Raglan channel, with both sediment and gabbro substrates, has both mechanically weak and strong substrates, making it a critical test case. Last, but not least, erosion by these komatiitic basalt lavas is a key component for the formation of the magmatic sulfide ore deposits associated with the other rocks. A better understanding of these erosional processes will better constrain the mode and time of emplacement for such ore deposits as well. Finally, model results will be validated against the geochemical and field data obtained for the Raglan region [1]. This 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.

Flow modeling: The motion of an incompressible fluid – like a turbulent lava flow – can be described by the Navier-Stokes momentum equations in the x, y, and z direction. Flow is investigated in steady conditions and the 3 momentum equations are Reynolds-averaged (time-averaging), a methodology that preserves the general flow trend along the channel centerline but does not account for the rapid and localized fluctuations within the flow, which define turbulent motion. Also, time-averaging introduces new unknowns into the system of equations (Reynolds stresses), which must be modeled in an attempt to describe the kinetic and dissipative effects of turbulence. The Reynolds stresses are approximated here by using a "k-ε" model, which 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.

A 3-D energy equation will be solved simultaneously, including several effects introduced by *Williams et al.* [8]. Lava temperature will change in three dimensions due to the incorporation of eroded substrate, crystallization, and heat flux across the top, bottom, and sides of the lava flow. The 3-D erosion rate of the lava substrate accounts for bed as well as bank erosion, and is a function of temperature variations only. The lava substrate temperature and properties will remain constant in time and space [9, 10 and refs therein]). The contamination of the lava by assimilated substrate, which is accounted for in the *Williams et al.* [8] model, will also be tracked here by a conservation of concentration equation. 3-D erosion rate will be calculated from the model results and used to predict geometric evolution of the substrate over which lava flows travel.

References: [1] Lesher C. M. (2007) *Geol. Ass. Canada, Sp. Pub., 5,* 351-386. [2] Watts T. and Osmond R. (1999) *Guidebook 2, Mineral Explor. Res. Centre,* Laurentian Univ., Sudbury, 181-186. [3] Green A. H. and Dupras N. (1999) *Guidebook 2, Mineral Explor. Res. Centre,* Laurentian Univ., Sudbury, 187-190. [4] Williams D. A. et al. (2011) Mineralium Deposita, http://www.springerlink.com/content/0436726705122523/. [5] Lesher C. M. (1989) *Rev. Econ. Geol., 4,* 45-102. [6] Jarvis R. A. (1995) *JGR, 100,* 10127-10140. [7] Williams D. A. et al. (1999) *Geol. Ass. Canada, Short Course Vol., 13,* 367-412. [8] Williams D. A. et al. (1998) *JGR, 103,* 27533-27549. [9] Huppert H. E. and Sparks R. S. J. (1984) *Nature, 309,* 19-22. [10] Huppert H. E. and Sparks R. S. J. (1985) *J. Petrol., 26,* 694-725.