I work to understand the geological, geodynamic, and climatic processes that shape planetary landscapes. My research interests focus on answering the following questions: a) how do erosion histories vary as a function of time and space? and b) how can we constrain and deconvolve the driving forces which shape landscape evolution? I tackle these problems by combining field studies (e.g. geological and digital mapping), laboratory techniques (e.g. organic geochemistry, cosmogenic dating), remote sensing data (e.g. satellite and UAV), and theory (e.g. inverse and forward modeling of fluvial erosion). The effects of water on a paleo-landscape are important markers of past climatic environment and have significant potential to further our understanding of the climate evolution and habitability of Mars. Importantly, many of the geomorphic features observed on Mars are either uncommon or poorly understood on Earth. A deeper understanding of these key features will help shed light on the controlling processes which are occurring on both planetary surfaces. This proposal summarises my plans to use integrative approaches on both terrestrial and martian systems to pursue work on planetary fluvial systems at the University of Texas at Austin with Dr. Tim Goudge.

The precise distribution in space and time of liquid water on Mars remains unresolved, despite an increasing base of observational data about its influence on geological materials. Key questions that need to be answered are what environmental conditions can generate and maintain fluvial erosion, how long would it take to create observed paleochannels, and what are the physical and chemical characteristics of the substrate? The wide variety of erosional landforms observed on Mars, which range between dendritic valley networks, amphitheatre-headed canyons, and large outflow channels, attest to a complex erosional history. In order to understand the relative importance between competing erosional processes (e.g. progressive vs. megaflooding, or groundwater vs. precipitation-fed) in martian landscape evolution, similar landscapes can be studied and analysed on Earth. This proposal discusses potential projects on Martian fluvial systems in addition to constraining the hydrology of lake overflow flood events on early Mars.

The extensive paleo lake database in Goudge et al. (2016) provides many opportunities to explore surface run-off on Mars both as a function of space and time. During my studentship at the University of Chicago, I mapped and analysed a small database of Amazonian–Hesperian alluvial fans on Mars. Importantly, many craters (e.g. Roddy, Saheki) contain extensive incision of the crater rims, as well as large alluvial fan deposits on the crater floor. These crater rim channels can be modelled using detachment-limited processes, and their longitudinal profiles provide important information on the controlling processes during floods. I used measured metrics of channels and fan deposits to determine formation timescales using transport-limited processes, which suggest they flooded very intermittently and within similar timescales. Using such models for outburst channels could provide rough constraints on erosion/formation times, and whether the timescales are significantly geologically variable. In addition to this, longitudinal profiles of channels (which feed paleo-lakes) contain important features (e.g. knickzones) which record base-level changes and could provide quantitative insights on lake level changes on Mars.

The potential for fieldwork in terrestrial analog systems (e.g. Hawaii, Iceland) where basaltic and/or arid provinces are undergoing fluvial incision can be used as analogs for the martian system. Studying and monitoring discharges, channel morphologies, and longitudinal profiles, combined with detailed geological and stratigraphic mapping, can provide important constraints on dominant processes. An important advancement to understanding these would be to sample eroded surfaces to constrain erosion rates. For example, last summer I planned and undertook fieldwork in northeast Iceland, where I collected a suite of basalt samples from erosional terraces along the Jökulsá á Fjöllum river. Using mineral separation techniques and the mass spectrometer at the Noble Gas Lab at Caltech, I obtained surface exposure ages from Helium-3 concentrations. Combined with a centimeter-scale digital elevation model of the canyon which I built using UAV (drone) photogrammetry, these ages were used to determine the velocity of waterfall retreat on timescales of hundreds to thousands of years. These measurements indicate that the current model of Icelandic canyon formation, which invokes megafloods to generate the large waterfalls, is incorrect. Instead forward modelling of canyon topography calibrated by the new surface exposure ages suggest progressive knickzone retreat dominated the canyon's erosional history during the Holocene. Further, the canyon contains ample evidence for groundwater springs which form amphitheatre-headed scarps, as well as abundant historical, stratigraphic, and geomorphological evidence for rare megaflooding. Iceland is almost completely covered by datable rock and provides an excellent opportunity to expand this type of quantitative analyses to determine erosion rates at a range of spatial and temporal scales, as well as relative rates of erosion from progressive, flooding, and groundwater erosion on basaltic provinces. Importantly, erosion rates measured in the field can be used to calibrate models of 3D landscape evolution (e.g. Landlab, Badlands), which can be used to quantitatively back out the history of water on Mars. Understanding the relative importance of progressive erosion and megaflooding (e.g. Channeled Scablands) informs discrete outburst floods models, helping us constrain erosional mechanisms during lake overflow events.

Finally, a common martian feature termed martian sinuous ridges (i.e. inverted relief channels which have resisted subsequent erosion) can also be studied on Earth (e.g. Utah). These exhumed features provide important morphometric and stratigraphic details which, combined with detailed in-situ UAV mapping, could easily be used to generate cm-scale DEMs of several km-long channel systems to estimate more precise paleohydrology and formation times with a variety of sediment transport models (e.g. Manning & Meyer-Peter Mueller equations). In conclusion, field study sites (e.g. Utah, Iceland, etc.) including high resolution UAV mapping provide unique circumstances which allow us to closely match important features preserved on the present-day martian surface. Combining these with global databases of paleolakes, field-derived erosion rates, and calibrated 2- and 3-D landscape evolution models, would allow us to unravel the early geologic history of water on Mars.

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