GLOBAL DISTRIBUTION OF MARS ANALOGUE, POTENTIALLY HABITABLE PHREATOMAGMATIC ENVIRONMENTS. C. H. Ryan[1,2*], M. E. Schmidt[3], and R. L. Flemming[1,2]; [1]Department of Earth Sciences and [2]Institute for Earth and Space Exploration, Western University, London, ON, Canada (*email: cryan73@uwo.ca); [3]Department of Earth Sciences, Brock University, St. Catharines, ON, Canada.

Introduction: Mafic phreatomagmatic environments may have been critical for the origin and early proliferation of life on Earth since 3.5 Ga, as well as key habitable environments on Mars [1, 2]. Phreatomagmatic structures include tuff cones, tuff rings, and maars that form by explosive magma-water interactions, either through exposure of the magma to groundwater or eruption in shallow lacustrine or oceanic settings. Such environments represent the intersection of multiple relevant Martian crustal processes: mafic volcanism, hydrothermal alteration, and extant liquid ground or surface water [3–7]. Phreatomagmatic structures have been potentially identified *in situ* by the Spirit rover [8, 9] and in orbital imagery [4, 10], underscoring their importance as Mars analogues.

Previous work has focused on characterizing the phreatomagmatic features of the Fort Rock Volcanic Field (FRVF) in Oregon, USA [11] and Upsal Hogback (UH) in Nevada, USA [12] with regards to their relevance as Mars analogues. These researchers also discovered putative biogenic alteration (PBA) in variably palagonitized basaltic glass samples. The PBA at these locations have morphologies similar to biogenic alteration textures in sea floor basaltic glass [13–15] and impact glass from the Reis impact structure in Germany [16].

Studying geologically recent phreatomagmatic features allows us to closely investigate the geochemical and mineralogical micro-environments that are crucial to microbial habitability, without the influence of long-term geological alteration. Our continued investigations into these environments, termed here as relevant volcanic fields (RVFs), is critical to our understanding of Martian and early Earth habitability. We have therefore created a database of RVFs on Earth for use as a basis for further study and field campaigns, to better explore the range of RVFs and their significance as Mars analogues.

Methods: We used the Smithsonian Institution Global Volcanism Program's Pleistocene Volcanoes List [17] to develop our database. We screened it for entries with the following features: cone, explosion crater, maar, pyroclastic cone, volcanic field, unknown, tuff cone, and tuff ring.

These features were then explored on Google Earth, where we studied the satellite imagery and topography of the volcanic features at each site to determine whether they could be classified as tuff cones, tuff rings, or maars, based on morphology described in [18, 19] (*e.g.* crater:base diameter ratio, proximity to current or former body of water, exposed yellowish material). Additional screening was based on composition, age, presence of water-rock interaction during or immediately after eruption, and associated water provenance.

Results: We have identified 30 RVFs distributed globally, including FRVF and UH (Fig. 1). While RVFs are found around the world, there are clear trends in their locations. Ten sites in the western USA and Mexico, one in Argentina, and three in Uganda and Tanzania are associated with continental rift/basin-and-range environments where the crust has thinned, allowing upwelling of the mafic mantle. Two sites: Hawai'i (USA) and Iceland are linked to mantle plumes. Eight RVFs in South Korea, the Philippines, and New Zealand are located along the Pacific Ring of Fire where subduction has caused melting of the overlying lithosphere. Below, we give details of two example sites: Llancanelo and Western Snake River Plain (WSRP).

Llancanelo: The Llancanelo Volcanic Field (Fig. 2[A]) is a Plio-Pleistocene volcanic complex with scoria cones, tuff cones and rings, and extensive lava flows in Mendoza, Argentina, east of the back arc of the Andes [20]. Their composition is olivine alkali basalt. Cone structures including lapilli tuff and tuff with deformed beds, impact sags, slump textures, ripples, and other soft deformational features indicate the presence of ground and/or shallow surface water interacting with ascending magma. Surrounding and inter-bedded sediments are lacustrine in origin. Alteration of residual glass in the wet surge bed deposits has formed palagonite, cristobalite, analcime, natrolite, chabazite, calcite, smectite, nontronite, saponite, and montmorillonite. Palagonitization of the tuff has formed hard, erosion-resistant beds.

Western Snake River Plain: The WSRP Volcanic Field is in southwestern Idaho, USA, through which the present-day Snake River flows (Fig. 2[B]). The area has been volcanically active since 17 Ma with several discrete periods of rhyolitic to basaltic eruptive activity, along with the formation and later draining of paleo-Lake Idaho, where water was available to interact with erupting magmas [21, 22]. The final eruptive period in the Pleistocene produced tuff cones, cinder cones, tuff rings, maars, and subaerial lava flows of tholeiitic olivine basalt composition, providing evidence of fluctuating lake water levels during this time. While many of these cones and craters have been significantly eroded by the Snake River, remnants of their structures are exposed in the walls of the Snake River Canyon, where bedded glassy tuff deposits inter-layered with lacustrine sediments, bomb sags, and soft deformational features have been observed. Alteration products include palagonitized glassy tuffs and secondary clays, calcite, zeolites, and gypsum.

Discussion: As mafic glass has been found to contain PBAs, it represents a compelling target for habitability research. Volcanic glasses are not well-preserved in the ancient geological record as they alter readily to palagonite, then clays and zeolites in the presence of water [23]. Amorphous silica materials are widespread on the surface of Mars, including at Gusev Crater [9, 24], and may have provided a habitat and energy source for opportunistic lithotrophic microbes. These RVFs provide pristine glass samples with varying levels of alteration, in which we can examine the roles of composition, mineralogy, and alteration on PBA textures.

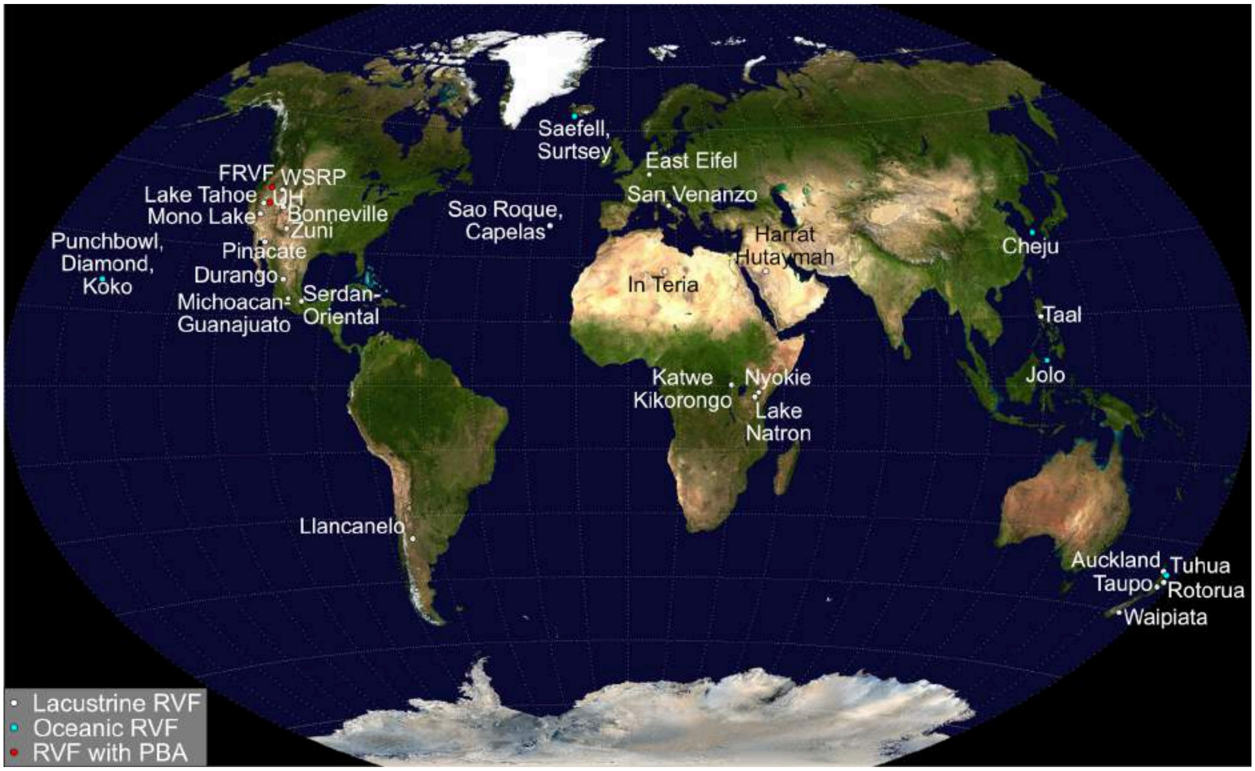

Figure 1 Global satellite mosaic map in Winkel-Tripel projection with locations of RVFs labeled. Base image from Wikimedia Commons.

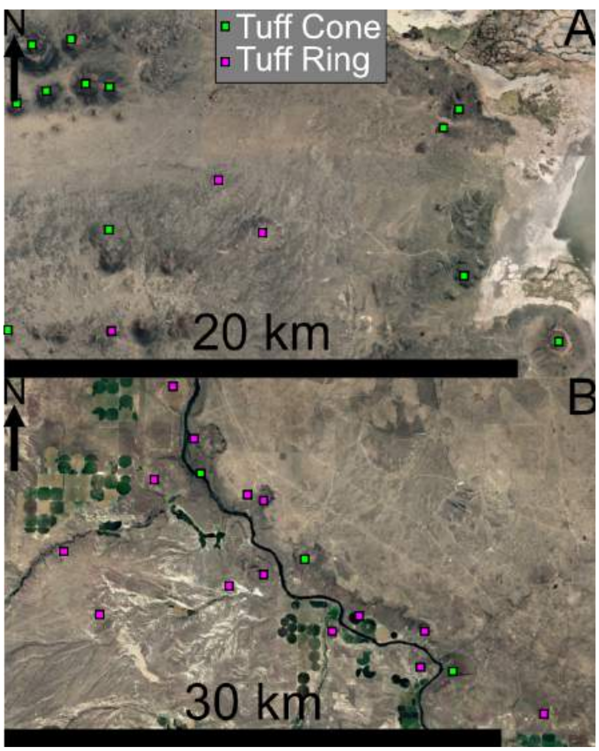

Figure 2 [A] Llancanelo Volcanic Field in Mendoza, Argentina. Llancanelo Lake is at the right edge of the image. [B] Western Snake River Plain volcanic field in Idaho, USA. The Snake River winds through the centre of the image. Images from Google Earth.

Igneous rocks observed at Columbia Hills by *Spirit* have varying compositions, from olivine-rich alkali basalts to ultramafic materials, also with varying levels of aqueous alteration [25, 26]. Alteration materials are rich in S, Cl, Br, and Fe^{3+}, most likely due to interaction with acidic waters, vapours, or brines [26, 27]. Compared to the glasses in RVFs, palagonite is not observed as an alteration product, but rather nano-phase Fe oxide [27].

Future work: Our future research will identify commonalities between RVFs in terms of geochemistry, mineralogy, and fluid composition, to determine factors affecting habitability (*i.e.* comparison with PBA-containing RVFs) and Martian analogue suitability (*i.e.* comparison with rover data from *Perseverance* and *Spirit*). We are planning a field campaign to the WSRP in 2022. We will conduct additional lab analyses, along with review of literature on other RVFs, to further support these objectives.

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