DARK STREAK FEATURES IN MONGOLIA AS TERRESTRIAL ANALOGUES OF RECURRENT SLOPE LINEAE ON MARS M. Nakamura[1,2], Y. Sekine[1], K. Fukushi[3], N. Hasebe[3], D. Davaadorj[4], Y. Takahashi[2], H. Hasegawa[5], T. Ogura[6], K. Morida[3], [1]Earth-Life Sci. Inst., Tokyo Inst. Tech., [2]Dept. Earth Planet. Sci., Univ. Tokyo, [3]Inst. Nat. Environ. Tech., Kanazawa Univ., [4]Dept. Geograph., Nation. Univ. Mongolia, [5]Faculty Sci. Tech., Kochi Univ., [6]Dept. Soc.-Cul. Environ. Sci., Univ. Tokyo

Introduction: Recurrent Slope Lineae (RSL) are dark, narrow features that appear and lengthen on steep (~30°) slopes in warm seasons and fade in cold seasons of Mars [1,2,3]. Although the formation mechanism of RSL is still in debate, several processes have been proposed, including liquid brine flows triggered by melting of subsurface ice (wet processes) [4,5], and granular flows (dry processes) [2,6]. However, neither wet nor dry processes can explain all of the observables of RSL. In especially, the wet processes seem to be inconsistent with the absence of absorptions due to liquid water on RSL and the fact that RSL appear only on steep slopes [2].

A bottleneck that makes the formation mechanism remain unclear is that RSL have been investigated mainly through remote-sensing data of Mars. Here, we report similar dark streak features on Earth in cold, arid areas of central Mongolia. We conduct geological survey for the terrestrial RSL analogue sites to construct the high-resolution three-dimensional structure and to analyze soil samples. Based on the formation mechanism of the terrestrial RSL analogues, we discuss the formation of RSL on current Mars, especially aiming to explain the absence of absorption of liquid water and the fact that RSL appear only on steep slopes in the context of the wet processes of RSL formation.

Dark streak features in Mongolia: We first searched for RSL-like dark, narrow features over Earth's surface using Google Earth satellite images. We focused on arid or semi-arid areas because of less vegetation, which include Namib, Atacama, and Gobi deserts. Among these areas, we find RSL-like dark streak features only in cold and arid, southern part of Khangai Mountains in central Mongolia (Fig. 1), where discontinuous permafrost and underground ice melt seasonally [7]. Comparing the satellite images taken at different times, we find that dark streak features in this area show seasonal variation similar to RSL on Mars; namely, the streaks appear in summer and fade in winter. Although the slope angles of the terrestrial analogues (~10° or greater) are shallow, the observed similarities in morphology and seasonal activity (Fig. 1) suggests that the streak features in Mongolia can be promising terrestrial analogues of RSL on Mars.

Geological survey & analyses: We then conducted geological survey for two sites of the terrestrial RSL analogues found in Mongolia in the end of August 2018. One (termed, the site-BH) is located at 10-km north of Bayankhongor at altitude of 2060 m from the sea level, and the other (termed, the site-GB) is located at 25-km north of Gurvanbulag at altitude of 2630 m from the sea level. Owing to high elevation of the site-GB, a mean surface temperature at the site-GB (~4ºC) in the end of August was significantly lower than that at the site-BH (~10ºC). At both of the sites, dark streak features were found on the slopes during the survey from visual images taken by an unmanned aerial vehicle (i.e., a drone). By analyzing the visual images taken by the drone with a software of PhotoScan, a three-dimensional topographic structure was constructed at each site with a spatial/vertical resolution of 2–9 cm. A flow accumulation analysis was performed for the obtained topographic structure using a software of QGIS.

In the geological survey, we measured water contents of soils on site on and outside the dark streak features. The mineralogical compositions and grain size distributions were measured for the collected soil samples. During the survey, no water flow was observed at the site-BH, whereas water flow occurred on the slopes at the site-GB possibly due to melting of underground ice (see below). Velocity, depth, and width of the water flow were also measured on site at the site-GB. The chemical composition of the collected water was measured with ICP-AES.

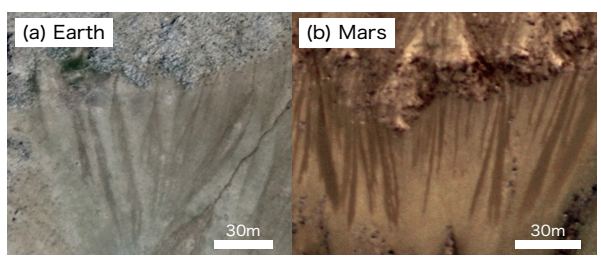

Figure 1. (a) Dark streak features at the site-BH in central Mongolia (Google Earth image). (b) Recurrent Slope Lineae (RSL) in Newton Crater, Mars. Portion of image ESP_023045_1380.

Formation mechanism of terrestrial RSL analogues: Although no water flowed during the survey, dark streak features appeared at the site-BH (Fig. 2). At the source regions of the dark streak features, small

cannels with width of ~5–10 cm and depth of ~1–2 cm are found. The upstream of the dark streaks are dented with depth < 1 cm, which becomes shallower toward the downstream. These observations suggest that erosion of surface materials would have occurred along with the dark streak features in the past. This view is supported by our results of the flow accumulation analysis for the constructed three-dimensional structure. The flow directions expected from the analysis agree with the directions of the dark streaks at the site-BH. Given that the slope angle (10–12°) at the site-BH is shallower than the angle of repose (~30°), erosion would have been caused by surface runoff, rather than granular flows.

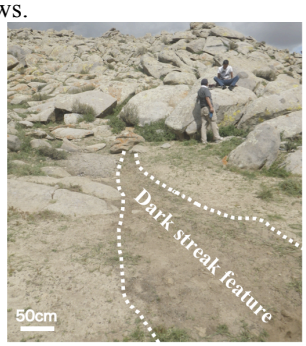

Figure 2. A close-up picture of a source region of a dark streak feature at the site-BH. The source rocks of the soils (the boulders in the upstream) are granite.

Although the dark streak features would have been formed by water erosion, darkening is not caused by the presence of liquid water. Water contents (27±9%; 1σ) in surface soils on the dark streaks at the site-BH show no significant difference from those outside the streaks (22±5%; 1σ) within errors. On the other hand, the surface of the dark streaks contains less bright sands (grain ~300–2000 μm, composed mainly of quartz and plagioclase) and more dark silts (grain ~10–200 μm, composed mainly of biotite and hornblende), compared with those outside the dark streaks. These results suggest that selective traction of the bright sand-sized grains by surface runoff results in remnant of the dark silt-sized grains on the slopes, which darkens the streak features at the site-BH.

Such selective traction of the bright sands can occur if friction velocity of water flow ranges ~10–30 mm/sec (Fig. 3), where only sand grains can move but silt-sized grains cannot [8]. At the other site of RSL analogue (i.e., the site-GB), water flow was observed along with the dark streak features during the survey. At the site-GB, water flows with ~3 mm in depth and ~10 cm in width at the velocity of ~0.1 m/sec, which corresponds to ~30 mm/sec of friction velocity. A Ca-carbonate-containing composition of the collected water (Ca^{2+}: 1.4 mM) strongly suggests that the water is derived from subsurface at the site-GB (e.g., melting of underground ice). If melting of underground ice at the site-BH induces water flow with a similar friction velocity of ~30 mm/sec, the water flow is sufficient to cause the selective traction, leaving to the dark streak features after dryness of the surface water.

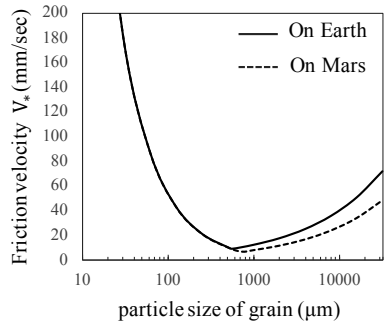

Figure 3. Relationship between threshold friction velocity of water flow and particle size of grain based on ref. [8].

Implications for RSL on Mars: Based on the formation mechanism of the terrestrial RSL analogues, we can explain the two issues in the wet processes for RSL formation on Mars; 1) no remote-sensing detection of liquid water, and 2) the fact that RSL appear only on steep slopes. At RSL sites on Mars, a thin layer of fine sands is considered to cover basaltic bedrocks on the slopes [9]. If liquid water/brine flows due to melting of underground ice, this can remove fine sands on the slopes. Consequently, dark streak features would appear on the slopes due to exposure of underlying basaltic bedrocks even after dryness of water.

Figure 3 suggests that water flow at the site-GB with ~30 mm/sec of friction velocity can also transport fine sands on Mars. To achieve this friction velocity on Mars, steeper slopes would be required due to the lower gravity than Earth. Using the Manning equation, we suggest that a slope with angle > ~25–30° would be required to achieve surface flow with this friction velocity, if the depth and width of water flow are same as those of the terrestrial analogues. Our results suggest that RSL on Mars would appear only on steep slopes due to its low gravity.

References: [1] McEwen et al. (2011) Science, 333, 740; [2] McEwen et al. (2014) Nat. Geosci., 7, 53; [3] Dundas et al. (2017) Nat. Geosci., 10, 903; [4] Stillman et al. (2016) Icarus, 265, 125; [5] Ojha et al. (2015) Nat. Geosci., 8, 829; [6] Schmidt et al. (2017) Nat. Geosci., 10, 270; [7] Szumińska (2016) Sediment. Geol. 340, 62; [8] Melosh (2011) Planetary Surface Processes, Cambridge Univ. Press, pp. 500; [9] Ruff and Christensen (2002) J. Geophys. Res., 107, 5127