CRYOVOLCANISM ON PLUTO. D.P. Cruikshank[a*], O.M.Umurhan[a], R.A. Beyer[a], B. Schmitt[b], J.T. Keane[c], K.D. Runyon[d], D. Atri[e,f], O.L. White[a], I. Matsuyama[g], J.M. Moore[a], W.B. McKinnon[h], S.A. Sandford[a], K.N. Singer[i], W.M. Grundy[j], C.M. Dalle Ore[a,k], J.C. Cook[l], T. Bertrand[a], S.A. Stern[i], C.B. Olkin[i], H.A. Weaver[d], L.A. Young[i], J.R. Spencer[i], C.M. Lisse[d], Y.J. Pendleton[a], F. Scipioni[a,k], R.P. Binzel[m], A.M. Earle[m], S.J. Robbins[i], G.R. Gladstone[n], P.M.Schenk[o], R.J. Cartwright[a,k], K. Ennico[a]. *Affiliations:* [a]NASA Ames Research Center, [b]Université Grenoble Alpes, [c]Caltech, [d]Applied Physics Lab., [e]New York University Abu Dhabi, [f]Blue Marble Space Inst. Seattle, [g]LPL, Univ. Arizona, [h]Washington Univ., [i]SWRI Boulder, [j]Lowell Observatory, [k]SETI Institute, [l]Pinhead Institute, Teluride CO, [m]MIT, [n]SWRI San Antonio, [o]LPI, Houston. *e-mail: Dale.P.Cruikshank@nasa.gov.

Introduction: Several structures on Pluto's surface seen in the images and supported by spectroscopic data from the New Horizons spacecraft appear to have originated by cryovolcanic processes. The pronounced constructional edifices known as Piccard Mons and Wright Mons south of Sputnik Planitia exhibit high relief and deep central pits, and may be cryovolcanic in origin [1]. In the broad arc west of Sputnik Planitia, some tectonic fractures and graben structures appear to be conduits through which cryolavas have emerged onto the surface from one or more subsurface reservoirs. Crustal fractures comprising the Virgil Fossae complex, which cuts through the north rim of Elliot crater, are seen in New Horizons data as sources of a cryolava consisting of H_2O containing NH_3 or an ammoniated compound, and that is strongly colored by a red-orange pigment (Fig. 1). The pigment is regarded as a tholin, a complex organic component that can be synthesized in the laboratory by energetic processing (UV, charged-particle, and thermal) of hydrocarbons and other C- and N-bearing molecules, and probably occurs in fluids in Pluto's subsurface reservoirs (see also [2]).

In Fig. 2, the distribution of the NH_3 spectral signature is shown, with high concentration within the main trough of Virgil Fossae and decreasing concentration with distance from the trough. From the spectral band at ~2.2 µm attributed to NH_3 in some form, we are unable to distinguish among an ammonia hydrate (NH_3•$n$$H_2O$), an ammoniated salt (e.g., NH_4Cl), and, although unlikely, pure NH_3 in H_2O. Ammonia can be destroyed by UV radiation and charged-particle radiolysis. Accordingly, Cruikshank et al. [2] evaluated the effects of the potential destructive forces at Pluto and estimated that the ammoniated H_2O was emplaced sometime in the broad timeframe $\sim10^5$ to 10^9 y ago, but in any case not on the primordial surface of the planet.

Additional Evidence of Cryovolcanism: North of Virgil Fossae is another fault complex in Viking Terra that exhibits evidence of cryovolcanic flooding. In the section of a major graben trough running from northwest to southeast there is a ~100-km reach that is mostly filled with colored material presumed to be tholin carried in the fluid that erupted onto the surface. An adjacent 28-km crater has been embayed with the same material. At the southeast extremity of the trough, there are three, possibly four, narrow troughs or faults about 40-50 km long, and the same colored material appears to have ponded at the distal ends of at least two of them (Fig. 2). The smooth upper surface of both the crater and the filled fossa trough suggest that the filling material was originally a fluid. In support of this view, elevation transects across the region and the topographic features (Figs. 3,4) show that the upper surface of the fossa fill and that of the crater lie at the same depth (~1 km) below the local mean datum.

We have processed New Horizons LEISA spectral images of this crater-fossa complex and find the spectral signature of NH_3 that is similar or greater in strength than found previously in the Virgil Fossae region [3]. As in the case of Virgil Fossae, the colored H_2O ice appears to have emerged onto the surface from multiple sources in the same general vicinity, some in craters and some associated with surface fissures. The Virgil Fossae exposures and the exposures in Viking Terra presented here, as well as other patches of red-colored H_2O seen in other locations along the broad arc of structurally modified terrain west of Sputnik Planum point to an origin in Pluto's subsurface. The view reached in the present investigation is that surface fractures in the bedrock, which is presumed to be H_2O ice, create pathways for internal water-rich fluids at some relatively shallow depth to reach the surface. That fluid also carries one or more ammonium components, the red material of presumed organic composition, and most likely other chemical components not identified in our data. In the case of Virgil Fossae, Cruikshank et al. [2] have presented evidence for an explosive cryovolcanic component to the effusion of the cryolava, although in the Viking Terra fossa-crater complex, it is unclear if the fluid was debouched only along the faults defining the main fossa trench or if there is an explosive component of the emplacement.

As in the case of Virgil Fossae, the presence of the ammonium signature in the filling material in the fossa and crater in Viking Terra is an indicator of the relative youth of its emplacement, and suggests that water-rich fluid existed late in Pluto's history, and may still be present in shallow reservoirs accessible to fractures and areas of structural weakness in the planet's crust.

References: [1] Singer, K. et al. 2018. Cryovolcanism on Pluto and comparison to features across the Solar System. *42nd COSPAR Scientific Assembly*, Pasadena, CA. [2] Cruikshank, D. P. et al. 2019. Prebiotic chemistry of Pluto. *Astrobiology* 19 (No. 7). [3] Cruikshank, D. P. et al. 2019. Recent cryovolcanism in Virgil Fossae on Pluto. *Icarus* (in press). [4] Dalle Ore, C. M. et al. 2019. Detection of ammonia on Pluto's surface in a region of geologically recent tectonism. *Sci. Adv.* (in press).

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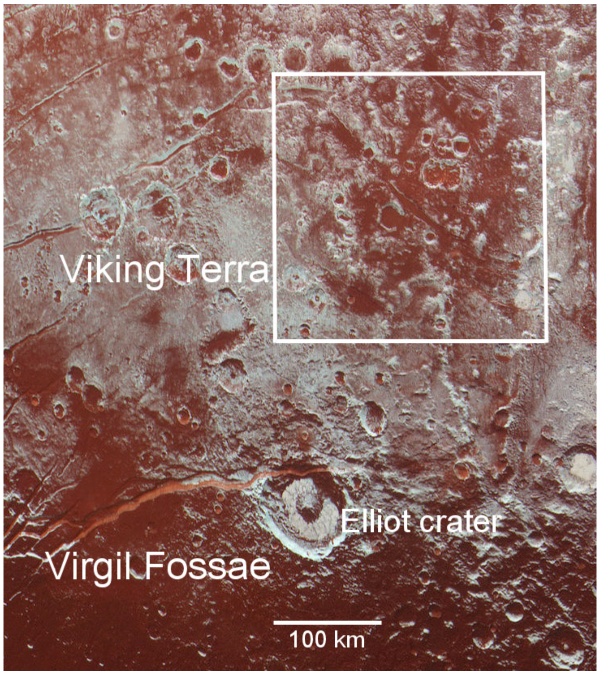

Fig. 1. Virgil Fossae and Elliot crater. Distinct red color in fossa trough and surroundings represent the ammoniated H_2O that carries the red chromophore. The white frame denotes the region in Viking Terra with the flooded trench and embayed crater.

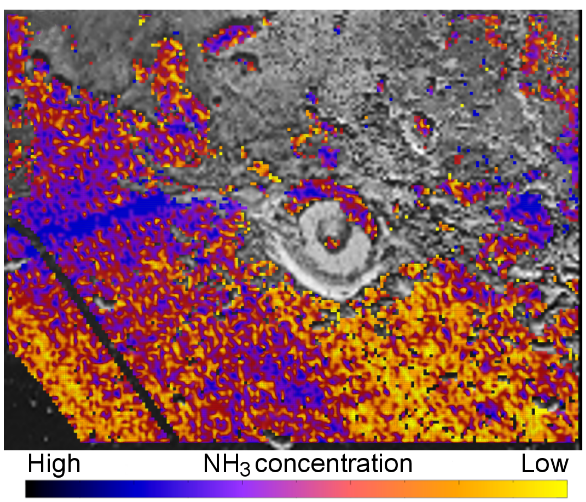

Fig. 2. Distribution of NH_3 in the Virgil Fossae region, showing concentration (arbitrary units) derived from the strength of the spectral absorption band attributed to an ammonia hydrate or an ammoniated salt [3,4]. Gray regions of the image show no absorption of H_2O or NH_3, and appear to be largely covered with CH_4 frost or ice.

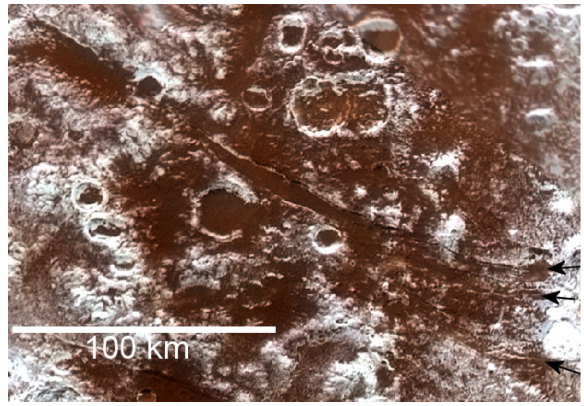

Fig. 3. Filled fossa trough and embayed crater in Viking Terra. Filling material is H_2O ice with the spectral signature of ammonia, and also carries the orange-brown chromophore. Black arrows (lower right) indicate ponded material at the distal ends of fractures or graben troughs.

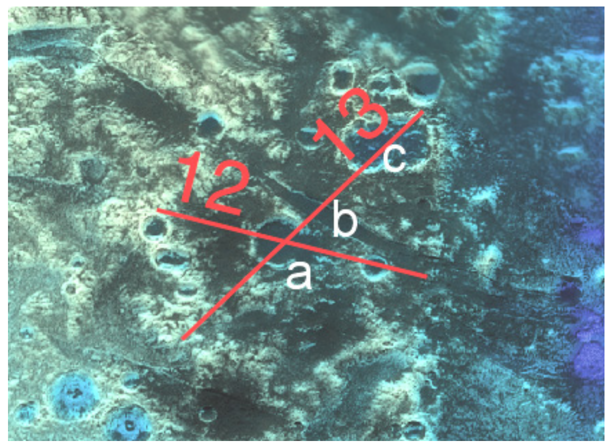

Fig. 4. Positions of elevation transects across the fossa trough, embayed crater, and surroundings.

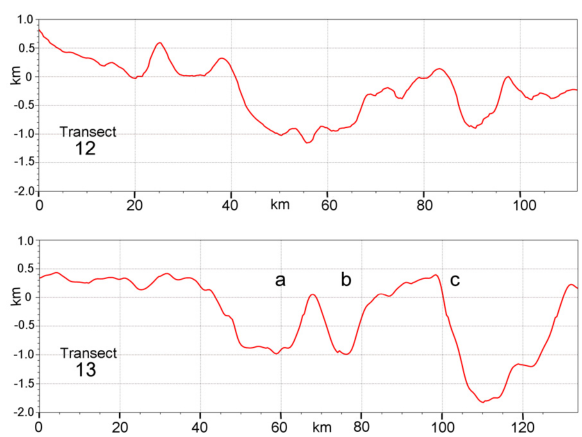

Fig. 5. Elevation profiles along transects shown in Fig. 4.