VOlCANIC LANDFORMS IN HYDRAOTES CHAOS: THE ROLE OF MAGMATISM IN THE CHAOTIC TERRAINS FORMATION. S. Meresse*, F. Costard¹, N. Mangold¹, P. Masson¹ and G. Neukum¹, and the HRSC team. ¹UMR 8148, IDES, Université Paris-Sud, Bât. 509, 91405 Orsay cedex, France, sandrine.meresse@u-psud.fr. ²Institut für Geologische Wissenschaften, Freien Universität, Berlin, Germany.

Introduction: The chaos are commonly described as broad and deep depressions containing irregular mesas and knobs of varying sizes. These depressions may be explained by collapse of the ancient cratered highland material [1] and lie at 1 to 7 km below the surrounding, few undisturbed terrains.

The origin of the collapses, and hence the chaotic terrains is still uncertain. Varied geologic scenarios have been proposed and principally include magma-ice interactions with melting of the cryosphere [2,3] release of liquid carbon dioxide or gas hydrate [4,5] and catastrophic release of groundwater from confined aquifers or subterranean caverns, which is the principal mechanism proposed [1,6,7,8].

We have investigated the geometric and morphologic characteristics of the chaotic terrains located east of Valles Marineris with the MOLA and HRSC data to better constrain the formation of these chaos as well as their relation with the outflow channels. Our study area extends from 20°S to 20°N and 305°E to 350°E. It contains the main chaos and four major outflow channels source area, Shalbatana Vallis, Simud Vallis, Tiu Vallis and Ares Vallis. The observation is principally focused on Hydraotes chaos which contains possible volcanic cones.

Hydraotes chaos, a complex depression: Hydraotes Chaos seems to be a singular chaos with unique characteristics. It is the deepest and most developed depression located in the middle of our study area, from 4°S to 4°N and 321°E to 328°E (Fig. 1). This chaos is nowadays placed at the junction of three channels: two major outflows, Simud and Tiu Vallis which flow out of it and a channel coming from Aurorae Chaos which flows into. The chaos is delimited by large scarps but contrary to the other chaos, it is composed principally of mesas separated by narrow valleys. The mesas are extremely developed and large. They are lower than the surrounding plateau and they have disorganized summital slopes. The second remarkable feature is the presence, at the mouth of the south channel of a large, deep and smooth plain.

Small pitted cones: High Resolution Stereo Camera (HRSC) images of Hydraotes (Figs. 2 and 4) have revealed with precision the presence of numerous cones with summit pits on the floor of the chaos. About forty cones have been observed but the distribution, the shape and size of these cones are not uniform across the chaos. Three major morphologic types of pitted cones are recognized in the depression (Fig. 1).

Figure 1. Mosaic of THEMIS IR images of Hydraotes Chaos. The black points show the location of the relatively pristine pitted cones. The white point represents the potential eroded pitted cones. A point can represented cluster of cones. Locations of figures 2 and 3 are shown by open boxes.

A dozen of large (mean diameter of 1500 m) and relatively pristine cones are located on the deep, youthful and smooth surface in the south of the chaos (Figs. 1 white box, 2). We name them basin cones in the following. They are often arranged in small groups of two or three cones spaced of about 5 km. The other cones were identified in the narrow valleys separating the low mesas and are defined as valley cones (Fig. 4). They tend to be more isolated and have lower sizes but they are also relatively fresh. Finally, a third type is found on the edge of the south basin floor (white point in Fig. 1). They are potential small eroded cones with raised-rim morphology. All the cones are observed on the deepest part of the chaos between ~4200 to ~4800
m in the valleys and –4900 to –5100 m in the southern smooth basin floor.

The basin cones are the larger cones observable in the chaos. They have all rounded shape, regular size and bowl-like summit pits. Although they have similar morphologies, they display distinct features. Two cones are surrounded by deposits presenting rough surface (Figs. 2, black arrows, and 3a). The deposits of the northern cone are relatively circular and symmetrical around the cone while the deposits around the southern cone are asymmetric and look thicker. In both cases, the deposits do not seem to disrupt or erode the cones suggesting that they predate them. Therefore the rough deposits observed around the Hydraotes cones might be lava flows. The images show also a cone with multiple craters (Fig 3b) which belongs to a cluster of three cones. Finally, the last unusual feature is an alignment of three cones visible on figure 3c. The valley cones have also rounded morphology but they do not display other distinct features.

Size information has been derived for the basin and valley cones, examined in HRSC and THEMIS visible images. The measured geometric parameters include the basal diameter, the crater diameter defined as the rim-to-rim distance and the crater/base diameter ratio. The basin cones have minimum and maximum diameters of 1100 and 1860 m. The majority of the cones have diameters around 1300-1500 m. All have summit craters with diameter ranging from 300 to 760 m. The crater/base ratio has a peak in its distribution at 0.3 with a mean value of 0.33. The valley cones are much smaller than the south cones with basal diameters ranging from 350 to 700 m (and a mean value of about 500 m). The diameter of the summit craters is included between 120 and 240 m. That represents a mean crater base/ratio of 0.34 which is the same value as the larger cones.

Heights have been only derived for the 12 basin cones in the south from MOLA data. HRSC DEM has been also used for the topographic information in order to check the measurements made on MOLA data. The height of the basin cones is relatively important from 145 to 245 m in the MOLA data and 170 to 250 m in the HRSC data.
Potential terrestrial and Martian analogs. The presence of small pitted cones on Mars was first recognized from analysis of Viking Orbiter imagery [9]. They have been essentially observed on the northern plains, (e.g. Acidalia Planitia, Amazonis Planitia, Cydonia mensae), and near the volcanic region of Elysium, particularly in Isidis and Cerberus plains [9,10,11,12]. A variety of origins have been suggested for the cones in these northern plains, including volcanic, ground-ice and sedimentary processes.

The possible terrestrial analogs for a volcanic origin are exclusively primary volcanic cones. The different types are cinder cones [13], tuff cones [12] and rootless cones, also called pseudocraters [10,11,12]. Cinder cones are volcanic cones built almost entirely of loose volcanic fragments like pumice, pyroclastics, or tephra. They are steep conical hills formed above a vent and usually grow up in groups, often occurring on the flanks of stratovolcanoes and large shield volcanoes. Terrestrial cinder cones rarely rise more than 300-500 m. Tuff cones or rings form when ascending magma interacts with groundwater or standing water. This explosive eruption may usually shallow asymmetric ring of indurated tuff. Finally, rootless cones, which is the most mentioned terrestrial analog, are formed by the interaction of lava flows with surface or near-surface water. Rootless cones principally occur in several areas of Iceland including the Myvatn and Alftaver districts [11,12]. They exhibit a wide range of morphologies, from large, broad-cratered cones, to smaller- and steeper cones [12].

Some authors have proposed non-volcanic processes for the formation of the Martian cones. Burr et al., [14] have interpreted the conical forms with rimmed summit depressions in the Cerberus plains as pingos or collapsing pingos. However, this features observed principally in Athabasca Valles are flatter and more irregular in their forms than the other Martian pitted cones. Tanaka [15] and Farrand et al. [16] have proposed mud volcanoes and deposition around geysers and/or springs as terrestrial analogs.

Synthesis and discussion. The discovery of small rounded cones with summit pit on the floor of Hydraotes chaos provide new clue on the chaotic terrain formation. The analyses have revealed that a non volcanic interpretation of the Hydraotes cones origin is inconclusive. The sizes and the morphology of the pingos, often showing radial extension cracks, are inconsistent with the cones observed in the chaos. The lack of periglacial features on the floor of Hydraotes argues also against the pingos as analogs. The other analog often mentioned is the mud volcanoes. The term “mud-volcano” generally is applied to a more or less violent eruption or surfaces extrusion of watery mud or clay. The principal reason why we do not favor a mud volcano origin for the Hydraotes cones is the large morphologic and geometric variability of the mud volcanoes on earth.

After examining various cones morphologies, we conclude that the primary volcanic cones are the most potential analogs to the Hydraotes cones. This observation involve that magmatic or volcanic activity occurs during the chaos formation. The last point to clarify is the nature of the Hydraotes cones and so the type of volcanism implicated in their formation. Three origins are indeed possible for the cones including: (1) explosive eruptions from a vent where the magma is interacting with groundwater producing thus tuff cones, (2) simple eruption of volcanic fragments from a vent in the ground at the origin of cinder cones and (3) lava flow running over a water-satured surface and causing hydrovolcanic explosions. These phreatic eruptions build up crater-like forms called rootless cones or pseudocraters. The morphometric analyses have shown that these three types of cones have different sizes but relatively comparable crater/base ratios. However, because terrestrial tuff cones generally have asymmetric and low rims, this process is less likely. Finally, the distinction between rootless cones and cinder cones is more difficult to establish.

We can not totally exclude the rootless cones hypothesis. Indeed, the traces of possible large lava flow have been discovered on the floor of Hydraotes but the cones identified on the basin floor are not exclusively restricted to the lava flow. Moreover the
geometric parameters of the rootless cones are closer to those of the northern cones, especially with Amazonis Planititia. The distribution of the cones observed in Iceland and in northern lowland show large cones field where the cones are close to each other. On hydraotes, the cones or small groups of cone are opposite more than 4 km away from each other. So we do not favor rootless cones as potential terrestrial analog for the Hydrotees cones.

Criteria suggestive of cinder cones include: (1) the greatest correlation in sizes and crater/base ratio with the hydrotees cones, (2) distinctive features like multiple cones often observed on terrestrial cinder cones, and (3) the presence of a rough mantle around two cones suggestive of surrounding lava flows. Symmetrical cones including associated lava flow is a typical feature of terrestrial cinder cones as we can observed on S.P. crater in the San Francisco volcanic field [17]. Cinder cones are also characterized by their steeply angled sides, with mean slopes similar to the Hydrotees cones, and conical shapes. The principal argument against cinder cones is link to their spatial distribution. On Earth, they are expected to be found on the flanks of pre-existing volcanoes but cinder cones are also found in flat-lying volcanic fields notably in the San Francisco Volcanic Field.

The volcanic cones are observed on the basin floor, therefore they formed after the chaos was already formed and evolved close to its current shape. It is almost impossible to date the small cones individually, but we can expect they formed late in the chaos history. A question can remain on the role of this late volcanism on the chaos formation. These cones might be uncorrelated to a volcanism that created the chaos, and thus there is no proof that a volcanism occurred before the basin subsided. Moreover, the fact that they formed just here, at the lowest part of the basin is certainly not a coincidence and might sign the last volcanic process of a previous history in which volcanic activity occurred at the same location earlier.

Conclusions: Hydrotees is the deepest chaos of the chaotic terrains area. We propose that the central part of Hydrotees have undergone multiple collapses. Thus, the lower crustal thickness has probably allowed magmatic rise along fault system resulting in tardy volcanic activity. The volcanism is expressed by the cinder cones. Magnetic activity probably allowed the discharge of ground water by rupture of confined aquifers or magma-ice interactions.