CREVASSED CRATERS ON MARS: DETECTION OF ANCIENT VOLATILE RICH CRUST. H. Sato\textsuperscript{1,2}, D. Baratoux\textsuperscript{2}, K. Kurita\textsuperscript{1}, \textsuperscript{1}Earthquake Research Institute, University of Tokyo, 1-1-1, Yayoi, Bunkyo-ku Tokyo, Japan (hsato@eri.u-tokyo.ac.jp), \textsuperscript{2}Observatoire Midi-Pyrénées, UMR 5562 CNRS et Université Paul Sabatier, Laboratoire, Dynamique Terrestre et Planétaire, 14, Avenue Edouard Belin, 31400 Toulouse, France (baratoux@dtp.obs-mip.fr).

Introduction: Xanthe Terra region on Mars is known as a site of most drastic evolution related to the formations of extensive chaotic terrains and multiple outflow channels. Chaotic terrains are thought to have been the source of gigantic flooded water \cite{1,2}, and several models which fundamentally consider the chaotic terrain as a site of disruption of the aquifer in consequence of groundwater emanation, have been proposed \cite{3,4,5,6,7,8,9,10}.

Here we present geomorphological evidences which show the evolution of chaotic terrains and their association with the presence and distribution of subsurface volatiles. We examined a particular type of craters, which are called here crevassed craters (Fig.1) which dominantly exist inside and around the chaotic terrains. Crevassed craters have been already examined by several studies \cite{11,12,8}. In \cite{11} they were described and interpreted as a kind of thermokarst consequently formed by permafrost melting over the intruded magmatic body. Recently the morphology of chaotic terrains and outflow channels was again examined \cite{8}. It was suggested that the crevassed craters resulted from localization of ground water paths through connected fractures systems related to the impacts. We report here new statistical observations on (1) crevassed crater sizes distribution and (2) crevassed craters excavation and present depths. These observations lead us to conclude about the presence of a critical depth for the formation crater crevasses over-all the region. In consequence, we propose a volatile distribution in the Martian crust at the time of outflow channels event which explains the crevassed craters characteristics. We also suggest plausible models for the crevasses formation within the craters.

Method: The studied area spreads over 30°S to 30°N in latitude and 300°E to 360°E in longitude (Fig.2), around Xanthe terra region which mainly consists of chaotic terrains, outflow channels, and cratered highlands \cite{13}. For the morphological analysis, Viking MDIM 2.1 mosaic image, MGS MOC images, Mars Odyssey THEMIS IR-day images, and MOLA MEGDRs digital elevation model were used. For each crevassed and non crevassed craters larger than few kilometers, the location, diameter, floor depth, deepest crevasse depth, and background elevation were measured. The state of degradation of each craters was noted from the inspection of visible images, whith criteria such as the prenc of ejecta, and the degree of erosion of the rim.

Results. Properties of crevassed craters. The crevassed craters have large varieties in their shape, but all of them have several discriminative shapes, for example deep crevasses, deep moat, plane top blocks, and a knobby plane inside the crater floor. These shapes are distinct from the typical degraded crater morphologies found everywhere on the Noachian terrain. The variety of their shapes are thought to be formed in a sequential process at different stages of development. In this area, we recognized 117 crevassed craters having diameter ranging about 7 to 237 km.

The crevassed craters are clustered and mostly found in the periphery of chaos (Fig.2). Inside this area, however, they are geographically intermixed with normal type craters which are not crevassed. Some non-crevassed craters are young and have fresh morphologies. We report that numerous craters older than the outflow channel events are also not crevassed. The histogram of diameters of crevassed and non-crevassed old craters shows an increasing proportion of crevassed craters at larger diameter (Fig.3). Investigating the maximum depth inside the crevasses, several craters have crevasse elevations 2~3 times deeper than the original cavity as estimated from the empirical relationships from \cite{14}(h=0.36D^{0.49}). Some crevasses affected the sedimentary material infilling the crater but also extended through the basement below the floor of the crater after its formation (cf. Fig.1).

Fig.1 One sample of crevassed crater located at 1.2°N 334.4°E. The images are from THEMIS IR-day original mosaic (left) and MOLA 128 pix/digree grid map (right). Blocky floor formed by crevasses networks with moat inside along the crater rim are found.
To clarify the elevation difference between the original cavity of crevassed craters and the one of non-crevassed old craters, we plot the elevations of all the topographic features around one outflow channel system which originates from Valles Marineris and spreads toward Chryse Basin (Fig. 4). In order to represent our observations along the channel system, we define first a curved line following it (Fig. 2). The distance of any feature to the south-west limit of this line is defined as the length of a segment [AB] along this line. A is the most south-west point of the line, and B the perpendicular projection of the feature along the line. In order to estimate the trend of the surrounding topography, the area was divided into each 300 km along channel system. Then, the average elevations of outer uneroded Noachian plane (blue line) and lowest points of channel bottom (brown line) in each section were compared (Fig. 4). The altitude and the distance of the original cavity (dot) and the deepest crack (square) of the crevassed (red) and non-crevassed (green) old craters adjacent to the bottom line are plotted in each colored pointers with bars.

The elevations of the original cavity centers for crevassed craters were joined using a minimum curvature spline surface [15] (red line on Fig.4). The same procedure was achieved for the non-crevassed crater (green line on Fig.4). In figure 4, the profile of the spline surface for crevassed craters show a systematic lower elevation than the one for non-crevassed craters. This fact suggests that large craters with deeper original cavity are preferentially affected by the cracking process, as suspected from the crevassed and non-crevassed size distribution. The boundary which can be tracked for all region would be somewhere between the green line and red line (hatched area). The depth of this boundary is roughly constant and ranging from 1000 to 1500 m. Another remarkable point is that the channel bottom line shows up and down but keeps almost constant level of about -5000 ± 500 m and the crevasses of the crater floors seems not to extend below this depth. This particular depth is also found in the deepest point of the nearby chasmas or chaos/outflow channels, which are not connected to the main channel.

Discussion: From the existence of craters deeper than their original cavity floor, the cracking origin is supposed to be a porous weak layer extending below the large impact craters to depth of a few kms. The cracking would result from the collapse or compaction of such layers. This phenomenon occurred at preferentially larger crater and the boundary of the cracking was found in rather constant depth. Thus wide-spread...
layer of the highly porous or removable material would have existed from a depth of about 1 to 1.5 km from the surface. The lower boundary of this layer would be at constant elevation of -5 km as observed by the depth conformity of crevasses and chasmas, chaos, outflow channels.

The upper boundary depth is almost consistent with the H$_2$O melting isotherm in the equator estimated by [16] using present temperature condition. Among several boundaries in this crustal model, we suppose that the transition of the material saturated with ice and with water, rather than with ice and mostly dry material, could explain the crater floor crevasses. Indeed, this transition can be expected to reflect the most drastic change of material strength. In that case, all the porosity around and below the depth of melting isotherm in the crust must have been saturated with H$_2$O, either ice or water, at least in our studied area at the time of crevassed craters formation.

Based on these interpretations, we propose a model reflecting the distribution of H$_2$O in the martian crust at the time of crevassed craters formation (Fig.5). This structure is described using 3 units: an upper frozen layer (so called cryosphere) probably saturated with ice at depth, a middle unit saturated with liquid water and a lower rigid unit below about 5000 m in altitude which is resistant to erosion and collapse. The presence of younger non-crevassed craters in the vicinity of crevassed ones suggest that the mechanism responsible for the crevasses was not active since these impact events. Alternatively, the time scale of this process could be long enough not to affect young craters. However, the observation of craters older than the outflow channel events which are not crevassed supports the first hypothesis.