Origin of Pit Chains in the Floor of Lunar Copernican Craters —Example of Crater Copernicus, Aristarchus and Tycho. Zhiyong Xiao[1] and Zuoxun Zeng[1, 2] , Ning Ding[1] , Hu Caizhi[1] China University of Geosciences, Wuhan,430074, P.R.China, [2] Huazhong Tectonomechanical Research Center, Wuhan 430074, P.R.China, xiaobeary@yahoo.com.cn

Introduction: Copernican is the youngest lunar geologic age which begins from ~1 billion years ago. The majority craters with integrated and bright ray system were formed during this time, such as crater Tycho, Aristarchus, Kepler, Copernicus, et al.

There is much research about crater chains which are rayed from the main impact craters and cracks across the crater floor. However, few people have ever taken notice of the pit chains in the floor of Copernican craters. Although the craters in these pit chains are less than 100m in diameter and the length of the pit chains are just ~2km, the morphology of the pit chains are still maintained clearly (Fig.1). Pit chains with smooth surroundings which are developed in the floor of the Copernican craters are rarely observed. The origin of the pit chains has never been discussed before. In the 1960s, the Lunar Obiter (LO) spacecrafts were launched to get high resolution images of the lunar surface to pick landing sites for Apollo. Crater Copernicus and Aristarchus in Oceanus Procellarum and crater Tycho in the mountain area of lunar surface were covered perfectly by the LO. It's possible to study the detailed morphology of the pit chains in the floor of the Copernican craters using these images.

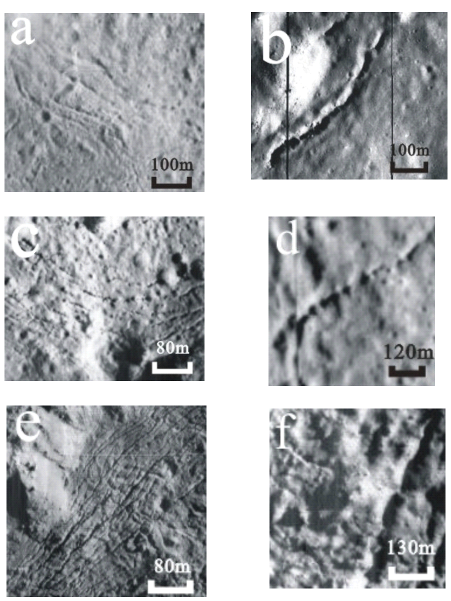

Fig.1 The ICFPCs and RCFPCs in Copernicus, Aristarchus and Tycho. a ,c, e are RCFPCs in the up three craters respectively; b, d , f are ICFPCs in the craters respectively.

ICFPCs and RCFPCs in Copernican Craters: There are many pit chains at the inner crater floor of these craters. They are named as Inner Crater Floor Pit Chains (ICFPCs). The ICFPCs are vastly developed in the floor of Copernicus and relatively less in Aristarchus, fewer in Tycho. They are usually ~50m wide and ~2km long (Fig. 1), most of them laid orderless in the relatively flat areas of the crater floor.

There are many pit chains developed around the inner crater floor of the Copernican craters (Round Crater Floor Pit Chains, RCFPCs) too. The morphology of them is especially clear in crater Aristarchus and Tycho (Fig 1.c, 1.e). Comparing to the ICFPCs, the RCFPCs in the Copernican craters are narrower but longer. The RCFPCs are located circularly around the inner crater floor and many of them are arranged in nearly parallel groups. It's noticeable that in crater Copernicus, the morphology of the RCFPCs is not that clear (Fig1.a). In Tycho, the RCFPCs are just like trenches along part of the inner crater floor (Fig 1.e).

Formation Mechanism of the ICFPCs and RCFPCs:

1. Formation of the RCFPCs

The modification process of the crater floor after the impact is derived from the igneous intrusion and topographic relaxation, in which the igneous intrusion plays the most prominent function [1]. It is a slow process which may be existed for a long time after the impact. Wichman and Schultz (1995) proposed a pistol model to demonstrate the mechanism of the igneous intrusion [1]. In this theory, there is a magma chamber under the crater floor. With the uplift of the chamber (laccolith), the crater floor will be lifted. Referring to the W-shape of the crater floor, we believe that during the lifting process, in one aspect, central peaks will be formed in the center of the craters; in another aspect, circular high angle normal faults will be formed along the border of the crater floor as a result of the tension effect of the central uplift, especially in the low gravity and low atmosphere pressure environment on lunar surface. This model is called the igneous intrusion model or the laccolith uplift model (Fig.2).

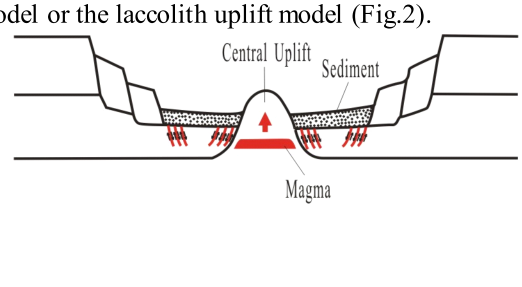

Fig. 2 Schematic diagram of crater modification by igneous intrusion. Thrusts with opposite dips will be created at each side of the central peak. Unconsolidated sediments will cover the crater floor before or after the formation of these faults (the depth of the sediments has been exaggerated). When the laccolith intrusion goes on or the existence of external driven forces, these faults will be active again and the sediments will subsidise along the faults to create pit chains.

After the impact, debris and sediments will be gathered in the crater floor, especially at the border of the crater floor and crater wall for the relatively low relief there. The circular faults will be mantled by unconsolidated materials and will be activated if there is external forces, such as impacts at close regions [2], lunar quake [3]. So pit chains will be created along these faults.

It's seems to be plausible to explain the origin of the RCFPCs in Aristarchus by the fault theory [4]. However, grooves with RCFPCs shape are just located in limited areas on the floor of crater Tycho, such as the relatively flat part of the crater floor, so does that in crater Copernicus. It's inferred that it's the formation age, the depth of debris, the strength of fault movement and the condition of magma movement that caused this difference. In one aspect, Copernicus is older than Aristarchus, so the former RCFPCs may be covered gradually by the debris and later magma movement (Fig 1.a). In another aspect, Tycho is younger than Aristarchus, so the debris may be not that deep to create pit chains with integrated morphology, and the RCFPCs are just like cracks around the crater floor (Fig 1.e).

Lava flows may create pit chain-like grooves as well. The convex of these grooves are following the direction of the lava flow. However, the convex of the RCFPCs in the floor of crater Aristarchus and Tycho is almost opposite to the traces of the lava flows from the crater wall and that in the crater floor. Besides, seeing from the LO images, the RCFPCs are not disturbed by the lava flows. As a result, it can be concluded that the RCFPCs in the three Copernican craters are formed after the activity of magma both on the crater wall and in the crater floor.

2. Formation of the ICFPCs

It sounds reasonable to explain that the ICFPCs were created by the activity of faults too. However, it seems to be some problem in this theory here: the ICFPCs are orderless and not with the same morphology as the RCFPCs. They should be circularly distributed around the central peaks, if faults underling them were created by the laccolith uplift as well. Of course it's possible that the top of the laccolith is irregular so that faults on the lunar surface are orderless; it's also possible that in the process of uplift, the laccolith is made up of blocks instead of as an integrated one and the blocks are with different uplift velocity [1] so that the uplift process of the crater floor is not uniform and the orderless distributed faults can be created. What's more, the ICFPCs in crater Tycho are much fewer than those in the other two Copernican craters. So, before the crater was formed, was the irregular topography of the impact site an issue for this difference? From the present material, we can not prove or reject any of these assumptions.

Another aspect which can not be ignored is the magma movement in the crater floor. After the impact, there would be many volcanic activities in the crater floor and lava flows will reconstruct the crater floor [5]. During the volcanic activities, lava tube collapse [6], lava fissures [7] and gas exsolution [8] may create pit craters and pit chains. However, it's hard to say that the ICFPCs were collapsed lava tubes for the absence of lava flow traces at the end of the ICFPCs; how could the small scale ICFPCs not be covered by the later refilling materials such as surrounding debris or volcanic ashes? These problems can be solved only if we can totally understand the formation process of craters, such as the duration of volcanic activities during the modification process.

Conclusion

1. In the modification process of crater formation, laccolith uplift may create circular high angle normal faults. Unconsolidated materials are depositions before or after the formation of these faults, which will mantle the faults. RCFPCs in the Copernican craters are originated from the activity of faults while the driven force of these faults may be the laccolith uplift, close impact, lunar quakes, et al.

2. The RCFPCs may be vastly developed in the floor of the early Copernican craters such as Copernicus. As time goes on, debris and depositions would fill the pits.

3. The ICFPCs may be originated from the activity of faults or from the volcanic activities.

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References: [1] Wichman W.R. and Schultz P.H. (1995) *JGR, 100*,21201-21218.[2] http://history.nasa.gov/SP-168/section3a.htm.[3] Latham G. et al. *Earth, Moon and Planets,* 4, 373-382. [4] FerrillM.B. et al. *GSA Today*,10,4-12. [5] French M.N. (1998) *LPS*, pp 26-27. [6] Xiao L. and Wang C. (2009) *Planetary and Space Sciences*, 57,685-698. [7] Brennan J.W. (1975) *The Moon*, 12, 449-461. [8] Head J.W. (2009) *EPSL,* doi: 10.1016 / j.epsl. 2009. 03. 008.