volcanism is similar. Although peripheral ponded mare units do occur downrange in Crisium (Mare Spumans, Undarum, Anguis), these units can be correlated with impacts by hypervelocity decapitated projectile fragments from the Crisium impactor [3]. We interpret these fundamental similarities between Crisium and Orientale to be common signatures of basin formation at oblique impact angles, whereas the observed differences are attributed to variations in cavity collapse as a function of impact angle.

Discussion: As discussed by [3,5,6], smaller complex craters (20–100 km) with asymmetric ejecta patterns typically exhibit offset central peaks and more extensive wall slumps uprange, reflecting the distinctive asymmetry of crater profiles for oblique impacts. Similarly, the differences in basin appearance between Crisium and Orientale provide insight into the effects of impact angle on cavity collapse during basin formation. First, the progression from discontinuous concentric troughs in the Crisium massif ring to a split massif ring at Orientale is consistent with increasing failure of the transient cavity rim at higher impact angles. In addition, the outer Crisium scarp is lower than the Cordillera scarp, whereas the inner Crisium massifs are much higher than the inner Rook massifs. These topographic differences also support greater slumping during cavity collapse with increased impact angles. Even the changing expression of the innermost ring structures (from a mare bench ~200 m high in Crisium [16] to a combination of scarps and massifs in Orientale [8]) may reflect such variations in basin collapse, if the relation of rim failure to interior uplift resembles that observed in smaller terrestrial craters [17].

Second, the greater restriction of uprange peripheral volcanism in Orientale also can be related to greater cavity collapse. If reduced cavity collapse indicates reduced cavity equilibration, isostatic uplift after the impact should increase with decreasing impact angle. Since flexural stresses during such uplift are tensile at depth outside the basin region [7], conditions for structurally controlled dike formation will then depend on impact angle. For a given basin size, therefore, basins formed by highly oblique impacts should induce greater flexural stresses than higher-angle impacts; hence, magma columns should be more likely to reach the surface along peripheral basin faults resulting from lower-angle impacts.

Third, the greater prominance of the basin scarps uprange of both Crisium and Orientale may reflect the asymmetry of oblique impact cavities. In the ring tectonic model of basin scarp formation [18,19], the outer scarp reflects lithospheric failure over mantle flow into the collapsing cavity. For an axisymmetric flow field, therefore, the basin scarp should be equally well developed around the basin periphery. The uprange offset in deepest projectile penetration at low impact angles [1], however, should modify the pressure gradients driving mantle flow during cavity collapse. Since both wall slopes and cavity depths are reduced downrange [1], the volume of mantle flow into an oblique transient cavity may be predominantly derived from beneath the basin rim uprange. In addition, since projectile failure should reduce the energy of later (downrange) cavity excavation in an oblique impact, peak shock pressures also should be centered closer to the point of initial contact (uprange); thus shock disruption and acoustic fluidization could be enhanced uprange of the transient cavity.

The observed settings of the peripheral mare units in Crisium and Orientale provide further support for the inferred asymmetry of cavity collapse. Although tectonically controlled mare units consistently develop along uprange scarps in Crisium and Orientale, peripheral volcanism downrange of Crisium apparently requires intersection of the ring fault with an impact structure. This observation suggests that magma column heights are greatest uprange of Crisium and Orientale, which is consistent with greater scarp failure in these regions. In addition, however, the uprange offset in oblique impacts of the mantle uplift and deepest impactor penetration could produce such an asymmetry by shifting the mantle melt reservoirs uprange and by shifting the center of basin uplift and the associated flexural stress fields.

Conclusions: Variations in impact angle can produce differences in the appearance of multiring impact basins. Comparison of Orientale to the more oblique impact structure at Crisium also suggests that these differences primarily reflect the degree of cavity collapse. The relative changes in massif ring topography, basin scarp relief, and the distribution of peripheral mare units are consistent with a reduction in degree of cavity collapse with decreasing impact angle. The prominent uprange basin scarps and the restriction of tectonically derived peripheral mare units along uprange ring structures also may indicate an uprange enhancement of failure during cavity collapse. Finally, although basin ring faults appear to be preferred pathways for mare volcanism [16,20–22], fault-controlled peripheral mare volcanism occurs most readily uprange of an oblique impact; elsewhere such volcanism apparently requires superposition of an impact structure on the ring fault.

References: [1] Gault D. E. and Wedekind J. A. (1978) *Proc. LPSC 9th*, 3843–3875. [2] Schultz P. H. and Gault D. E. (1990) *GSA Spec. Pap. 247*, 239–261. [3] Schultz P. H. and Gault D. E. (1991) *LPSC XXII*, 1195–1196. [4] Schultz P. H. and Gault D. E. (1991) *Meteoritics, 26*, 392–393. [5] Schultz P. H., this volume. [6] Schultz P. H. (1992) *LPSC XXIII*, 1231–1232. [7] Wichman R. W. and Schultz P. H. (1992) *LPSC XXIII*, 1521–1522. [8] Wilhelms D. E. (1987) *U.S. Geol. Surv. Prof. Pap. 1348*. [9] Müller P. M. and Sjogren W. L. (1969) *Appl. Mech. Rev., 22*, 955–959. [10] Müller P. M. et al. (1974) *Moon, 10*, 195–205. [11] Sjogren W. L. and Smith J. C. (1976) *Proc. LSC 7th*, 2639–2648. [12] Howard K. A. et al. (1974) *Rev. Geophys. Space Phys., 12*, 309–327. [13] Casella C. J. and Binder A. B. (1972) *U.S. Geol. Surv. Map I-707*. [14] Olson A. B. and Wilhelms D. E. (1974) *U.S. Geol. Surv. Map I-837*. [15] Schultz P. H. (1979) *Proc. Conf. Lunar Highlands Crust*, 141–142. [16] Head J. W. et al. (1978) *Mare Crisium: The View from Luna 24*, 43–74. [17] Croft S. K. (1981) *Multi-Ring Basins, Proc. LPSC 12A* (P. Schultz and R. Merrill, eds.), 227–258, Pergamon, New York. [18] Melosh H. J. and McKinnon W. B. (1978) *GRL, 5*, 985–988. [19] Melosh H. J. (1982) *JGR, 87*, 1880–1890. [20] Head J. W. (1976) *Rev. Geophys. Space Phys., 14*, 265–300. [21] Greeley R. (1976) *Proc. LSC 7th*, 2747–2759. [22] Schultz P. H. and Glicken H. (1979) *JGR, 84*, 8033–8047.

S83-46 N93-10195 475251

SELF-ORGANIZED ROCK TEXTURES AND MULTIRING STRUCTURE IN THE DUOLUN CRATER. Wu Siben and Zhang Jiayun, Institute of Mineral Deposits, Chinese Academy of Geological Science, Beijing 100037, China.

AA 374113

The Duolun impact crater is a multiring basin located 200 km north of Beijing [1,2]. From the center to the edge of the crater there are innermost rim, inner ring, outer rim, and outermost ring. The 5-km-diameter raised innermost rim, 80 to 150 m above the surrounding plain, is located in the cratering center and consists of volcanic rock (andesite, etc.). The prominent 70-km-diameter ring, which is encircled by the Luan river, the Shandian river, and their tributaries, is a peripheral trough now occupied by the Lower Cretaceous coal-bearing formation, etc. The 82-km-diameter outer rim, 200 to 250 m above the plain, consists of Archean metamorphic rocks (quartzite, schist), lower Permian limestone and impact melt, which may indicate the boundary of excavation. The 170-km-diameter outermost ring is marked by monomict megablock breccia.

Outside the innermost rim and near the cratering center there are some lobes of imbricate ground surge consisting of volcanic rocks or impact melt. The ground surges appear to be a lot of festoons consisting of a series of arclike ridges with steep outer slopes and gentle inner slopes. The incline of the ridge has a centripetal gradual decrease up to apparent disappearance. The outer edge of the ground surges forms an incomplete ring peak of 18-22 km diameter. The phenomenon indicates that the ground surges are products of oscillatory uplift near the cratering center.

Recently we have found some self-organized textures [3] or chaos phenomena in shock-metamorphic rocks from the Duolun impact crater, such as turbulence in matrices of impact glass, oscillatory zoning, or chemical chaos of spherulites in spherulitic splashed breccia, fractal wavy textures or self-similar wavy textures with varied scaling in impact glass, and crystallite beams shaped like Lorentz strange attractor. The rare phenomena indicate that the shock-metamorphic rocks from Duolun crater are formed far from equilibirum. If it is considerable that impact cratering generates momentarily under high-pressure and superhigh-temperature, occurrence of those chaos phenomena in shock-metamorphic rocks is not surprising.

This research is supported by NSF of China, and by the Chinese Foundation for Development of Geological Sciences and Techniques.

References: [1] Siben W. (1987) *LPS XVIII*, 920–921. [2] Siben W. (1989) *Meteoritics, 24*, 342–343. [3] Ortolova P. J. (1990) *Earth Sci. Rev., 29*, 3–8.

GEOCHEMICAL ASPECT OF IMPACT CRATERING: STUDIES IN VERNADSKY INSTITUTE. O. I. Yakovlev and A. T. Basilevsky, Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Science, Moscow.

Studies of the geochemical effects of impact cratering at the Vernadsky Institute in collaboration with the Institute of Dynamics of Geospheres, Moscow State University, Leningrad State University, and some other institutions were fulfilled by several approaches.

At the initial stage, three approaches were used: (1) experimental studies of high-temperature vaporization of geological materials (basalts, granites, and so on) in vacuum that was considered as a model of behavior of impact melt and vapor; (2) search of impact-induced geochemical effects in the rock from terrestrial impact craters; and (3) studies of samples of lunar regolith.

The first approach resulted in the conclusion that even at not very high temperatures a selective vaporization of geologic materials occurs and may lead to noticeable changes in elements' contents and ratios. This effect is controlled by the volatilities of individual elements and compounds (sequences of volatilities were determined) as well as their interactions, e.g., realized through the so-called basicity-acidity effect known in igneous petrology.

The second approach resulted in the conclusion that geochemical effects that might be predicted from the experiments and theoretical work are seen in some impact melts, but these observations are not reliable enough and one of the major problems is the uncertainty in estimation of the preimpact target composition.

The third approach was successful in finding such predictable impact-induced effects as partial loss of alkalis, Si, and Fe from regolith and some components of highland breccia.

The next stage of the studies included experiments on quasi-equilibrium vaporization of geological material in Knudsen cells. This study gave reliable data on forms of occurrence of rock-forming elements in the vapor phase, their fugacities, and time-and-temperature sequences of the elements' vaporization, which confirmed, in general, the earlier results from vacuum vaporization experiments. These results provided significant progress in understanding the geochemical effects of impact cratering, but it is evident that impact-induced vaporization is very fast and not equilibrium.

This is why recently a series of experiments using the light gas gun were made. The results show that even at a rather low velocity of impact (5 to 6 km/s) the silicate material involved in the shock displays effects of melting and partial vaporization. It is interesting that with this fast and unequilibrium process the associations of vaporized elements may differ drastically from those that resulted from the slow quasiequilibrium process. For example, refractory U and Th vaporize quite easily. Effects of redox reaction between the materials of target and projectile were found.

The mentioned experimental data show that at small (laboratory experiments) scale geochemical effects do occur in high-velocity impacts. But their role in large-scale natural processes such as heavy bombardment at the early stages of planetary evolution should be clarified in future studies.