lands are significantly lower than for hectometer-scale roughness. A few examples are shown in Fig. 13. While entire craters are rough at the hectometer scale (Fig. 9), at the kilometer scale only the rims and walls are distinctive. It is interesting that a large melt pool in the northern part of the Copernicus floor is very rough at the hectometer scale (Fig. 9), while it is as smooth as typical maria at the kilometer scale (Fig. 13).

The youngest, Copernican-age craters are distinctively rougher than older craters at the shorter, 0.46 km baseline; at longer baselines, a similar difference still exists, but it is not so pronounced. The latter makes these craters bluish in the color composites (Figs. 4 and 5). It appears as if the roughness systematically decreases with age, more rapidly at shorter baselines, and more slowly at longer baselines. The majority of large distinctively rough craters have been mapped as Copernican, Eratosthenian or Late Imbrian by Wilhelms (1987). There are some exceptions; for example, Compton (Fig. 13) was mapped as Early Imbrian. On the basis of its roughness signature we would suggest that it postdates the Orientale basin and formed in the Late Imbrian.

It is clearly seen in Fig. 13 that rough craters are surrounded by rings of relatively smoother proximal ejecta, while farther from the craters their distal ejecta becomes rougher. Tycho (Fig. 9) and the majority of smaller Copernican craters have a similar ring in the hectometer-scale map. The scale of topographic features responsible for the relatively smoother proximal ejecta and the relatively rougher distal ejecta is probably proportional to crater size.

On the basis of detailed analysis of images, we interpret the difference being due to the proximal zone of interaction and flow of emplaced ejecta, often coated with impact melt veneers (e.g., Hawke and Head, 1977), while the rougher outer annulus forms where the radial decrease in ejecta density begins to expose individual chains of ejecta that form steeper-sided secondary crater chains. The radial nature of the bright outer annulus (Fig. 13) supports this interpretation.

Outside younger craters and Orientale ejecta, the roughness of the highlands at 0.48 km baseline does not show significant variations. On the 1.8 km baseline roughness map the highlands are covered with a low-contrast pattern of circles, obviously, old (pre-Orientale) craters. In some sense, this pattern should be considered as spurious noise, which results from the fact that this longest baseline is comparable to the sliding window size.

5.2. Volcanic plains

All mare surfaces are smoother than the highland surfaces, as discussed in Section 3. There are roughness variations within maria; they are, however, not readily seen in Figs. 1, 4, and 5 because the stretch is chosen to show the whole dynamic range of roughness. Fig. 14 shows the global km-scale roughness map (analogous to Figs. 4 and 5) stretched to better show the roughness variations in maria. The roughness contrast between maria and highlands is higher at longer baselines, and this is why all mare surfaces are blue in the color composite map (Fig. 14).

The roughness maps reveal the tectonic fabric of the maria, mostly in the form of wrinkle ridges; their east–west segments often appear rougher than north–south segments because of the anisotropy of our roughness measure (discussed in Section 2.3). The few-kilometer-size craters appear as bright (rough) dots. Ejecta of somewhat larger craters appear bluish in the color composite (Fig. 4) because they are not distinctive at longer baselines.

There are significant variations in the background kilometer-scale roughness of the maria. They do not correlate with the variations of hectometer-scale roughness. For example, the division of Mare Humorum into rougher and smoother parts seen in Fig. 2 does not appear in Fig. 14. In contrast to what is observed at the hectometer scale, at the kilometer scale Mare Tranquillitatis is systematically rougher than Mare Serenitatis.

The latter difference is a part of the obvious trend that older maria (Hiesinger et al., 2011) tend to be rougher than younger maria. A similar trend has been observed on Mars (Kreslavsky and Head, 2000): a wide range of kilometer-scale roughness spans various volcanic plains from the smoothest and youngest Cerberus Plains in Elysium Planitia (e.g., Vaucher et al., 2009) to the moderately smooth Late Hesperian ridged plains, to the much rougher Late Noachian ridged plains, which are still distinctively smoother than the heavily cratered highlands of Mars. Qualitative comparison of mare roughness (Fig. 14) against crater-deduced mare ages (Hiesinger et al., 2010, 2011) shows, however, that roughness is not always a function of age. In other words, it seems possible to find a pair of mare areas where the younger area is somewhat rougher, contrary to the general trend.

Some boundaries between mare units correspond to distinctive sharp contrasts in roughness, for example, the contact between Mare Tranquillitatis and Mare Serenitiatis materials mentioned above, and the contact between Late Imbrian and Eratosthenian lavas in north-central Oceanus Procellarum (Whitford-Stark and Head, 1980; Hiesinger et al., 2011). These prominent geological contacts are well known from maps of color ratios. There are some sharp roughness contacts that do not correspond to well expressed sharp color contrasts, for example, in far north-western part of Oceanus Procellarum. It is possible that these roughness contrasts reveal previously unrecognized contacts between volcanic plains of different ages, or even cryptomaria. Some contacts between mare units are overprinted by later crater ejecta, modified by tectonics, etc., and are not clearly seen in the roughness maps.

A number of light blue areas in Fig. 14 (smooth at 1.8 km baseline, rough at 0.46 km baseline) do not correspond to mare surfaces (they have a high albedo and do not have a mafic spectral signature). Some of these plain areas are cryptomaria (e.g., Antonenko et al., 1995 and references therein), for example, the typical crypto-

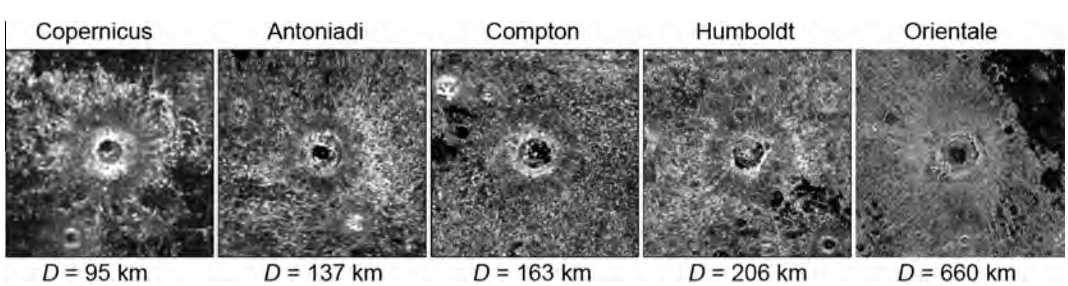

Fig. 13. Maps of kilometer-scale roughness of several large craters and basins; scales are chosen proportional to the diameters. 1.8 km baseline and local Lambert azimuthal equal-area projection for Orientale; 0.92 km baseline and local equirectangular projections for all other craters. Brighter shades denote higher roughness, and stretch is chosen individually for each map to show details; Copernicus is significantly rougher than all other objects. Crater diameters are listed according to Head et al. (2010b), Orientale basin diameter is taken equal to Outer Rook Ring diameter according to Head (1974) and Baker et al. (2012).