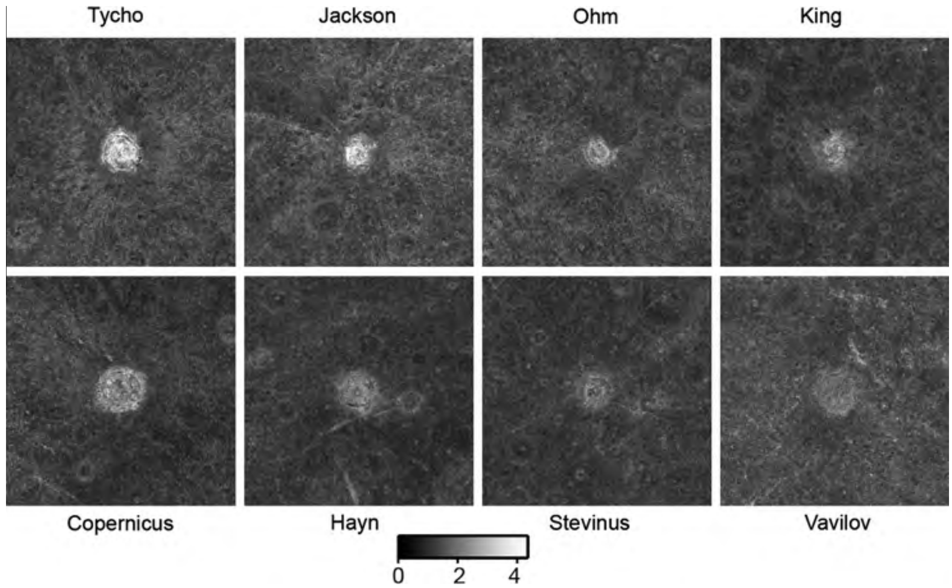

Fig. 9. Roughness maps of selected young impact craters, 115 m baseline, local equirectangular projections; brighter shades denote higher roughness. The roughness scale is the same for all maps. Each map is 550 × 550 km. These maps were created with 16 pixels per degree sampling, R_{pix} = 1.9 km.

We interpret these systematic variations in general roughness as the effect of crater age: when a crater ages, it accumulates small impacts, the regolith layer thickens, and regolith gardening mutes hectometer-scale roughness.

Absolute ages of Tycho (∼95 Ma) and Copernicus (∼800 Ma) are thought to be known from sample data (see discussion by Stöffler and Ryder, 2001). The densities of superposed craters (Hiesinger et al., 2012) are well consistent with the age ratio. They are also consistent with the putative absolute ages, assuming the chronology of Neukum et al. (2001), if the superposed craters are counted on proximal ejecta (see detailed discussion by Hiesinger et al. (2012)). Under the same assumption and limitations, van der Bogert et al. (2010) obtained a ∼150 Ma age for Jackson. Our observation that Copernicus is noticeably smoother than Tycho and Jackson is consistent with its noticeably older age.

The chronology of Neukum et al. (2001) yields a formation rate of 1.55×10^{-10} km^{-1} Ma^{-1} for large craters $D > 70$ km. This gives one crater per τ_{70} = 171 Ma for the entire Moon. Assuming Poisson statistics of cratering, the 95 Ma $\approx 0.56\tau_{70}$ age is consistent with Tycho being the youngest $D > 70$ km crater on the Moon. On the other hand, the probability that there are two or more craters of 95 Ma or younger, is rather low, ∼11%; thus, if we agree to inferences at the traditional 84% confidence level ("one sigma"), Tycho should be the youngest among $D > 70$ km craters. Similarly, the 150 Ma $\approx 0.88\tau_{70}$ age of Jackson is still consistent with it being the second youngest, while the probability that there are three or more craters of 150 Ma or younger is 6%, and thus Jackson is likely to be the second youngest. This is consistent with Tycho and Jackson being rougher than all other craters in Fig. 9. Our roughness ranking places Copernicus 5th after Ohm ($r = 2.5$) and King ($r = 2.4$), which is perfectly consistent with its age of 800 Ma $\approx 4.7\tau_{70}$. In summary, all known age constraints are consistent with the decrease of crater roughness with time.

4.2. Roughness rays and other lineaments

The roughness map (Figs. 2 and 3) shows a number of long, rough (relatively bright in the map) lineaments; some of them form conspicuous ray systems associated with large young craters. The most prominent ray systems are associated with three large craters, Tycho, Ohm, and Jackson. As we discussed above (Section 4.1), these craters are the youngest craters of their size on the entire Moon. Roughness rays associated with them are long, the longest of them exceeding ∼1500 km (∼50° of arc) from their craters. Some other Copernican-age craters (like Copernicus and a number of smaller rough craters) have less pronounced systems of shorter and less prominent radial roughness lineaments.

All craters with radial roughness lineaments have systems of bright (high albedo) rays. The bright ray systems of Tycho, Ohm, and Jackson are the most prominent albedo ray systems. The well-defined roughness rays of these three craters generally coincide with their high-albedo rays. However, not all distinctive albedo rays seen on the Moon have noticeable roughness expressions.

Long roughness rays are generally straight (following great circles). Roughness is not uniform along roughness rays: they are comprised of irregular, relatively smoother and rougher segments. In the distal parts of the long rays, the roughest segments have $r \approx 1.5$–1.7 and correspond to clusters of impact craters, interpreted to be secondaries from the central crater. It is possible that the entire roughness signature of the distal parts of the roughness rays is caused by the secondaries. This suggestion, however, is very difficult to prove: our measure of roughness is sensitive to background topography, which is not readily apparent in visual inspection of the images. Many obvious clusters of secondary craters do not have a noticeable roughness signature.

A consistent explanation of these observations is aging due to regolith gardening. The newly-formed clusters of secondaries have an initially prominent roughness expression and form roughness rays. With time, processes associated with regolith gardening smooths the craters; the clusters gradually become parts of the equilibrated topographic pattern, and their roughness expression fades away. "Rough" secondary clusters are associated only with the largest craters, because smaller craters produce smaller secondaries that are too small to affect topography at the 115 m baseline.

There are roughness lineaments that are not parts of roughness ray systems and do not have any apparent association with large impact craters. The most prominent features of this type are situated at the north-eastern limb of the Moon (Fig. 10) and are rougher ($r \approx 1.7$–1.9) than crater-associated roughness rays. They coincide with unusually dense elongated clusters of hectometer- and decameter-scale craters (Fig. 11; note that only hectometer-scale craters are resolved on this image; overabundant decameter-scale craters