Table 3
General comparison of the three crater morphologies.

	Excess ejecta craters	Perched craters	Pedestal craters
Typical crater diameter	5–18 km	3–23 km	<0.5–6 km
Typical ejecta/pedestal thickness	27–108 m, with a mean of ~50 m	35–140 m	20–110 m, with a mean of 46 m
Ejecta type/texture	Usually DLE with a rough rocky texture	SLE or DLE with a subdued rough texture	No ejecta or SLE with a smooth texture
Distribution	Tens of known examples, present at mid latitudes in both hemispheres	Hundreds of known examples, present at mid latitudes in both hemispheres	2300 + known examples, present at mid latitudes in both hemispheres
Age	Late Amazonian	Late Hesperian to Early Amazonian	Most are Late Amazonian, but some examples are Hesperian

the ice-rich paleodeposits in the southern hemisphere were thinner and not as geographically widespread. In other words, although southern hemisphere ice-rich deposits may have accumulated just as frequently as those in the northern hemisphere, the southern hemisphere deposits may not have reached the same thicknesses, may have sublimated more quickly, and/or may have been much more constrained to localized regions.

8. Discussion

The comparison of EE, Pr, and Pd yields some striking similarities as well as some key distinguishing traits (Table 3). This survey expands on the previous understanding of EE and Pr, both in terms of their geographic extents (Fig. 10) and physical sizes (Fig. 9). This information, in conjunction with prior detailed Pd studies, provides the necessary context from which we can draw a more comprehensive analysis of the potential relationship between these morphologies. In terms of physical size (Fig. 9), the survey does show that EE and Pr can occur at smaller diameters than found in previous measurements by Black and Stewart (2008) and Boyce et al. (2005). We measured one EE that was 1.5 km in diameter, and some of the Pd that are less than 2 km in diameter qualify as Pr. However, the majority of EE tend to be greater than 5 km, and the majority of Pr are greater than 3 km. We were unable to find any new examples of EE or Pr that exceeded the size of the largest examples identified by Black and Stewart (2008) and Boyce et al. (2005), respectively; nonetheless, their studies showed that both of these morphologies can reach approximately 20 km in diameter. Pd, on the other hand, can be much smaller, with many examples less than 1 km in diameter. In addition, Pd generally do not exceed 6 km.

If we combine this outline of the diameter ranges with the fact that each morphology exhibits almost identical excess ejecta/pedestal thicknesses (Fig. 3), with averages around 50 m in all cases, then the data suggest that morphologic variations are initially based on excavation depth relative to the thickness of the ice-rich target layer; each morphology protects/insulates the same layer thickness, but the size of the impactor (and possibly other characteristics including impact velocity, impact angle, and target material strength) determines the crater depth. If the impact penetrates through the ice-rich material and excavates regolith, it creates a significant ejecta deposit. If not, it can result in a smooth armored pedestal that has a minimal ejecta deposit, or lacks ejecta altogether (Fig. 8).

This interpretation is supported by both the geographic distribution and morphologic characteristics of EE, Pr, and Pd. Specifically, the fact that the morphologies are all located in the same geographic regions within the same restricted latitudinal bands in mid to high latitudes (Fig. 10) supports the interpretation that they all require the same target material, which appears to accumulate in response to a climate-related mechanism. Our expansion of the EE and Pr surveys into the southern hemisphere shows that they occur where Pd are present. This confirms that the highest concentrations of each crater type occur in the same regions in both hemispheres. What would cause the much larger population of Pd craters? Given the fact that smaller impacts occur more frequently based on the size–frequency distribution of the impactor population, one would expect that the Pd population would grow most rapidly during periods when the ice-rich material was emplaced.

From a morphological perspective, the smoothness of pedestal surfaces, and the fact that most lack ejecta, is consistent with induration of a flat paleodeposit. Most of the ejecta would have been icy material given the thickness of the ice-rich deposit and the shallow excavation depths of small impacts. This ice-rich ejecta would have sublimated when the intercrater terrain sublimated and deflated. Regarding EE and Pr, the presence of DLE, radial striations, and rough surface textures suggests the presence of rocky material included in the ejecta, which must have been sourced from the underlying regolith. This requires that the impacts penetrated through the entire icy surface layer.

The ages of these morphologies, with EE being necessarily young (Amazonian) and Pr being usually older (Late Hesperian to Early Amazonian) suggests a possible evolution from EE to Pr. These two morphologies are located in the same geographic regions, and have the same diameter size ranges and ejecta characteristics. There are also many more Pr than EE (Fig. 10). These data suggest that EE are able to maintain the ice-rich content in their ejecta for geologically long timescales, on the order of tens to hundreds of millions of years. As EE age and become degraded, their crater interiors become infilled, and they become Pr (Fig. 2). The absence of fresh Pr and degraded EE supports the interpretation that at least some EE transform into Pr as they are mantled and eroded. Pd, being primarily young but having some old examples, experience a unique age progression that involves erosion of the pedestal from the scarp back to the crater rim through sublimation pitting along the margin (Kadish et al., 2010).

9. Conclusions

This study establishes associations between three distinctive crater morphologies (Table 3) that were previously studied independently. Through the assessment of excess ejecta craters (Black and Stewart, 2008), perched craters (Boyce et al., 2005; Meresse et al., 2006), and pedestal craters (Arvidson et al., 1976; Barlow et al., 2000; Kadish et al., 2009), we have established significant evidence for a genetic relationship between the crater types. Our expansion of previous surveys reveals that EE and Pr are present in the southern hemisphere in the same geographic locations as Pd. We have also shown that, in rare cases, EE and Pd can be smaller than the examples identified by previous studies.

These new survey results, in conjunction with the direct comparison of each morphology, lead us to conclude that:

(1) EE and Pr are genetically related, and are likely to have formed from the same general mechanism – ejecta armoring of an icy substrate (Fig. 8). The primary difference between