ASTEROIDS AND MAP PROJECTIONS: CHOICES AND COMPROMISES. P. J. Stooke[1], [1]Department of Geography, University of Western Ontario, London, Ontario, Canada N6A 5C2; pjstooke@uwo.ca

Introduction: The cartographic representation of irregularly shaped ('non-spherical') worlds (NSW) has challenged map-makers since Mariner 9 obtained images of Phobos and Deimos late in 1971. The main difficulties have been the determination of 3D shapes and the modification of conventional map projections to accommodate those shapes. This poster presents some reflections on the projection problem and various attempts to solve it, based on 35 years of efforts by many cartographers. There is no single best solution to the problem. Cartographers are best served by considering the wide variety of options now available to them, including various combinations of projection and shape model.

Shape Models: Shape modelling methods are now fairly mature, using combinations of stereoscopic imaging, control point measurement, and limb/terminator modelling, with contributions from laser altimetry where appropriate (NEAR, Hayabusa, Dawn), and the separate case of radar image inversion **[1].** But having an accurate high resolution 3D shape is only the first part of the mapping process. Any NSW can be represented by successive derivations of that shape: the actual topography, the convex hull of that topography, a best-fit or dynamically equivalent triaxial ellipsoid, or an equal volume sphere. Other compromises might be considered as well, such as smoothed topography or a surface defined by points half way between the actual surface and the convex hull, measured along radii. These derived shapes offer different advantages to cartographers when combined with map projections.

Map Projections: Map projections were traditionally derived from a sphere, or slightly modified to match an ellipsoidal model of the Earth. These projections could be applied to the Moon, Mars and other large worlds without difficulty. Phobos and Deimos represented the first challenge to this situation with images from Mariner 9 and Viking. The first map of any NSW, Phobos **[2]** ignored the shape problem (or alternatively, projected the surface of Phobos radially onto a sphere for conventional mapping), plotting features on an unmodified cylindrical projection. Soon afterwards the astronomical artist and modeller Ralph Turner created a globe of Phobos and invented a modified azimuthal projection to portray it **[3].** Since then numerous solutions to the map projection problem have been suggested. Stooke **[4]** modified azimuthal projections by treating the radius in conventional projection equations as a variable rather than a constant. His projections do not retain the properties of equivalence or conformality of conventional azimuthals. Snyder **[5]** and Bugaevsky **[6]** developed analytical solutions to preserve conventional map properties in cylindrical projections of triaxial ellipsoids. Berthoud **[7]** did the same for azimuthal projections of actual topographic surfaces. Nyrtsov **[8]** has also followed this approach for a wide variety of projections of actual shapes. Bussey and colleagues **[9]** displayed the surface of Eros as orthographic views in different orientations, and on a Simple Cylindrical global mosaic. Clark **[10]** has pioneered an approach which divides a surface along topographic highs or lows, or any other boundaries of interest, and flattens it to create global maps.

These disparate projection schemes all have unique advantages and disadvantages. Spatially variable patterns of distortion, challenging enough in projections of spheres, are exacerbated by irregularities in shape. In general, solutions which preserve or approximate equivalence or conformality when applied to NSW produce maps with irregular graticules and outlines, providing accuracy at the expense of aesthetics and interpretability. Conversely, maps which result in simple, attractive and easily interpreted graticules contain distortions which become more severe with the irregularity of the body.

Global Databases: Two basic products of any NSW mission are a digital shape model and a global photomosaic. These might be augmented with multispectral, gravity or other datasets in matching raster format. Simple Cylindrical is the obvious choice for such datasets (the memory-efficient but awkward sinusoidal projection is less accessible to many users). A few cases are appearing now (Itokawa, possibly Eros and Toutatis) where a planetocentric coordinate system is ambiguous in certain small regions. A radius can intersect the surface more than once on complex shapes. A non-centric (maybe cylindrical) coordinate system could be used, and would be easy to map on a suitable projection. One option may be Transverse Perspective Cylindrical with its axis on the long axis of the body. A special 'cap' in an azimuthal projection would show the two ends more satisfactorily. Clearly, more experiments are needed here.

Putting it all together: The use of intermediate shapes may offer advantages for mapping in some cases. Applying smoothed topography, or the convex hull of topography, to the projection may result in a map with fewer distortions than the actual topography would produce. Alternatively, it may simplify the shape of the graticule and outline, making the map more aesthetically pleasing, easier to interpret, or more readily accepted by potential users. These are issues of perception, aesthetics and functionality rather than mathematical precision, but cartography has always had to compromise between these unwilling partners.

References: **[1]** Hudson R. S. et al. (2003) *Icarus, 161*, 346–355. **[2]** Duxbury T. C. (1974) *Icarus*, *23*, 290-299. **[3]** Turner R. J. (1978), *Icarus, 33*, 116-140. **[4]** Stooke, P. J. (1998), *Can. Geog.*, *42*, 61-78. **[5]** Snyder, J. P. (1985), *Survey Review*, *28,* 130-148. **[6]** Bugaevsky, L. M. (1987), *Izvestiya Vusov.*, *4*, 79-90. **[7]** Berthoud, M. G. (2005), *Icarus*, *175*, 382-389. **[8]** Nyrtsov, M. V. et al. (2000), *Journ. Geospatial Eng.*, *2*, 45-50. **[9]** Bussey, D. B. J. et al. (2002), *Icarus*, *155*, 38-50. **[10]** Clark, C. S. (2006) *LPS XXXVII,* Abstract #1207.

Figures: (all maps by P. Stooke) (1) Shaded relief map of asteroid 253 Mathilde shown on an azimuthal equidistant projection of its convex hull. (2) Asteroid 243 Ida shown in various projections of its convex hull and a triaxial ellipsoid.

253 Mathilde: convex hull shape, azimuthal equidistant projection

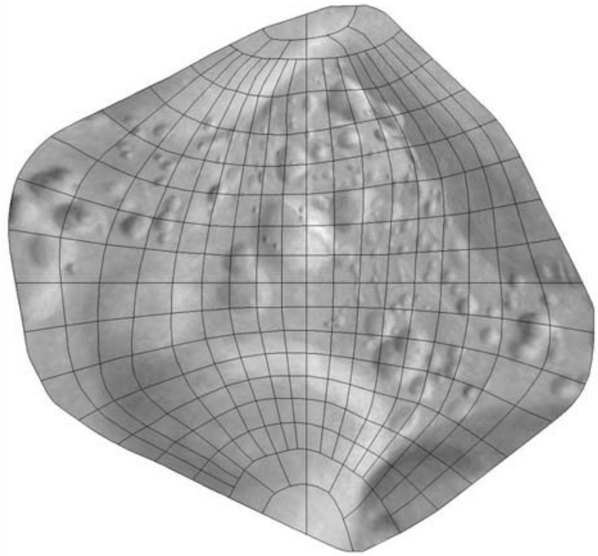
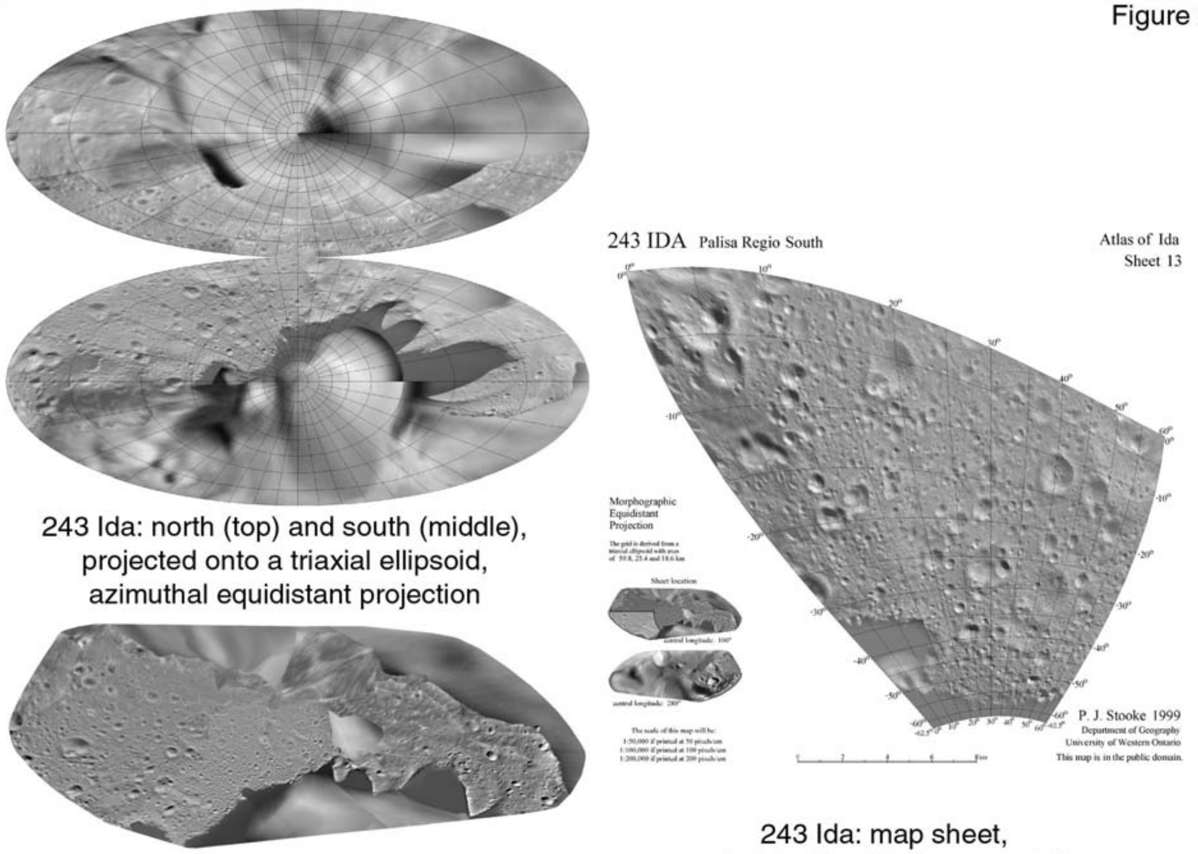


Figure 1

Figure 2



243 Ida: north (top) and south (middle), projected onto a triaxial ellipsoid, azimuthal equidistant projection

243 Ida: (bottom) convex hull shape, azimuthal equidistant projection

243 Ida: map sheet, triaxial ellipsoid shape model, azimuthal equidistant projection