

Towards a Methodological Validation of Digital Terrain Models as a Potential Impact Criterion

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1. Motivation: DTMs at the centre of crater screening

High-resolution digital terrain models (DTMs/DEMs) have become indispensable for crater mapping and geomorphological screening on Earth and other planetary bodies.

- Global elevation products (TanDEM-X, Copernicus DEM) enable systematic identification of circular landforms
- Automated crater detection and ML-based screening are increasingly applied in planetary science
- On Earth, the diagnostic status of morphology-only DEM evidence remains unresolved
- Impact confirmation still requires established shock-metamorphic and geochemical criteria (French & Koeberl 2010)

2. The core problem: Morphological equifinality and false positives

A central difficulty in terrestrial crater identification is morphological equifinality: similar circular depressions can arise from fundamentally different processes. On Earth, crater-like landforms are produced not only by hypervelocity impacts but also by:

- Karst collapse dolines and flooded sinkholes,
- Glacial kettle holes in moraine landscapes,
- Volcanic maars and diatreme structures,
- Anthropogenic excavation pits, quarries, and reservoirs,
- Mining subsidence features and historical extraction depressions,
- Bomb and artillery crater fields.

These analogue classes constitute systematic false positives for any morphology-based screening criterion. Consequently, circularity, rim-like topography, or DEM pattern similarity cannot function as independent diagnostic indicators without rigorous benchmarking against hard-negative controls (French and Koeberl 2010, 152–168).

3. Objective: From qualitative pattern recognition to benchmark validation

This contribution outlines a reproducible validation framework for testing whether DTM-derived morphometry can serve as a supplementary impact criterion.

- Key question: Can morphometric parameters discriminate impacts from hard-negative analogues?
- Focus is methodological validation, not proposal of new candidate structures
- Benchmark calibration is required to quantify false-positive rates

4. Benchmark positives: Gold-standard confirmation evidence

Validation requires a strict gold standard dataset.

- Positives must be independently confirmed impact craters
- Diagnostic evidence includes PDFs, shatter cones, melt rocks, geochemical signatures
- Morphology-only candidate structures cannot serve as benchmarks
- Earth Impact Database provides established confirmed reference cases
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5. Hard-negative controls: Terrestrial analogue classes

The decisive terrestrial stress test is comparison against non-impact analogues.

- Karst depressions and sinkholes
- Glacial circular landforms
- Anthropogenic pits and quarries
- Explosive/bomb crater fields

Controls must be matched by diameter bin, relief context, and DEM resolution tier.

Key refs:
French, B.M., & Koeberl, C. (2010). The convincing identification of terrestrial meteorite impact structures. Earth-Science Reviews, 98, 123–170.
Pike, R.J. (1980). Control of crater morphology by gravity and target type. Proc. Lunar Planet. Sci. Conf. 11, 2159–2189.
Melosh, H.J. (1989). Impact Cratering: A Geologic Process. Oxford University Press.
Stepinski, T.F., et al. (2009). Automatic crater detection on planetary surfaces. Icarus, 203, 77–87.
Silburt, A., et al. (2019). Lunar crater identification via deep learning. Icarus, 317, 27–38.

Michael A. Rappenglück & Barbara Rappenglück, ORCID: 0000-0002-1741-6315, mr@infis.org, Figures, plots, and pipeline schematic © Authors.

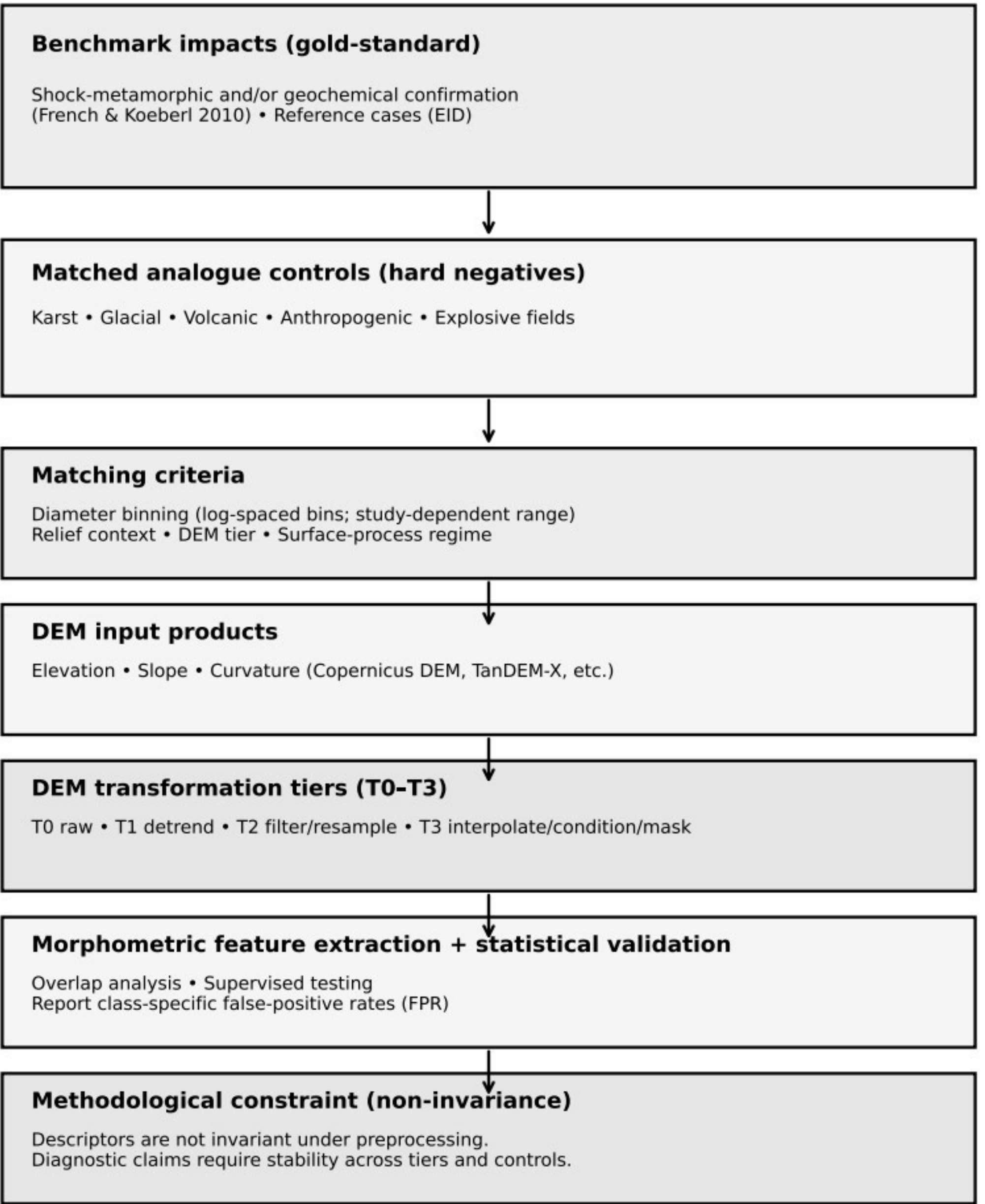


Fig. 1. Benchmark control validation pipeline with explicit DEM transformation tiers (T0–T3).

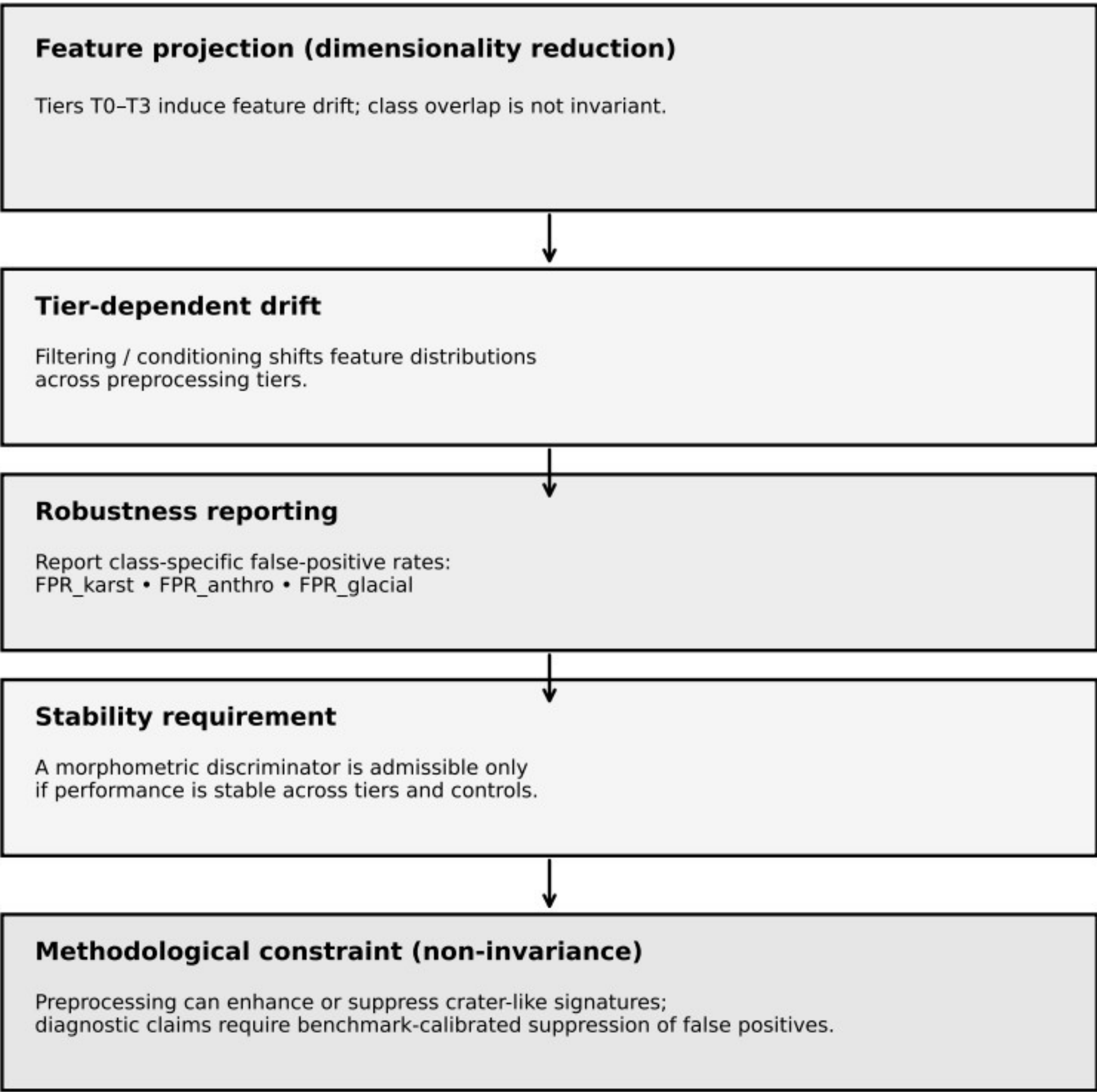
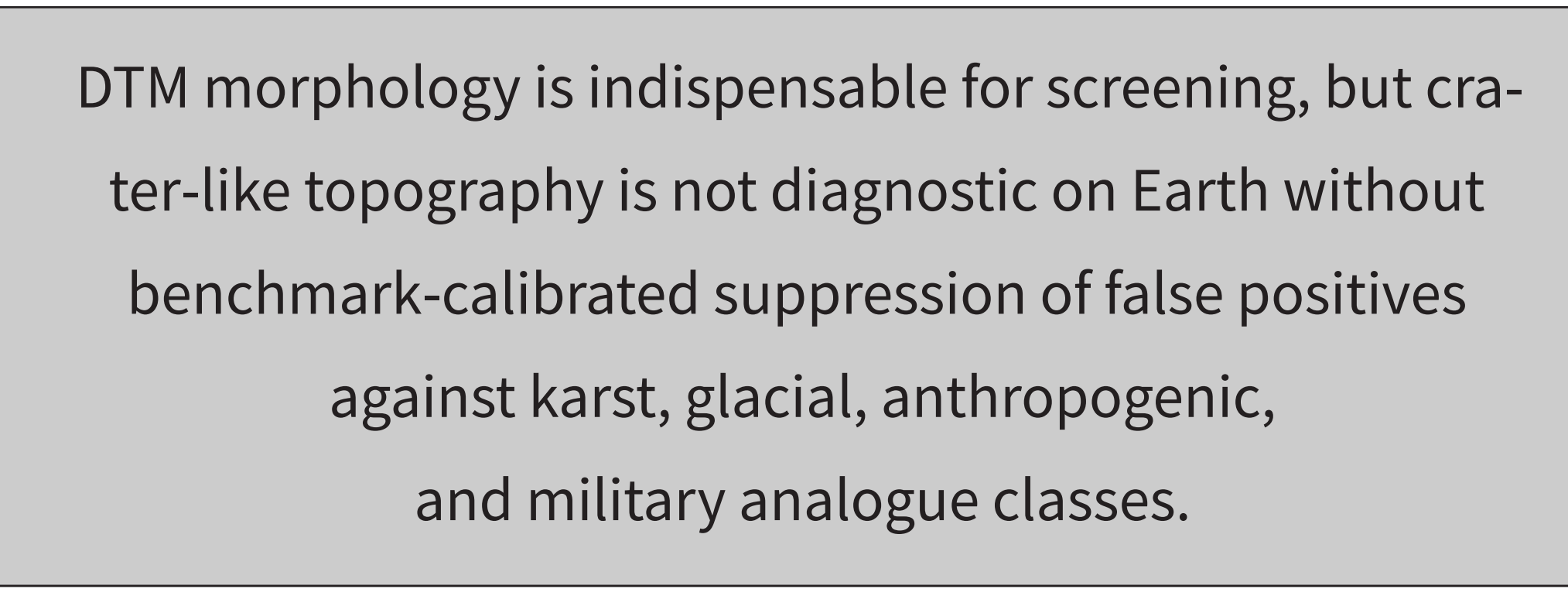


Fig. 2. Preprocessing sensitivity and robustness reporting across tiers (T0–T3)



6. Morphometric feature extraction and degradation metrics

Morphometric descriptors follow classical crater geometry and degradation concepts (Pike 1980; Melosh 1989). Relevant parameters include:

- planform circularity and ellipticity indices
- rim-to-floor relief and depth/diameter ratios
- radial elevation profile ensembles and azimuthal rim variance
- rim continuity and breach fraction measures
- curvature-based degradation proxies and infill estimates

Feature stability must be tested under preprocessing sensitivity tiers, because filtering, detrending, interpolation, and water masking can strongly amplify or suppress crater-like signatures in DEM products. Morphology is inherently multi-parameter; evaluation therefore requires an n-dimensional feature space rather than single-metric comparisons.

7. Statistical evaluation: Discrimination vs. overlap

Feature-space projections (e.g., PCA) visualise only a subset of variance and must be interpreted as reductions of an n-dimensional morphometric space.

The validation pipeline requires both exploratory and supervised testing:

- unsupervised PCA/clustering to assess feature-space overlap
- supervised classifiers (random forests, SVM, regularised regression) trained on benchmark–control datasets
- explicit reporting of class-specific false-positive rates, especially against karst and anthropogenic controls

Planetary crater detection provides methodological precedents, but terrestrial diagnostic demands are stricter because of the abundance of non-impact analogues and post-impact surface modification (Bue and Stepinski 2007; Silburt et al. 2019).

8. Expected outcomes and significance

Two scientifically constructive outcomes are possible:

- DTM morphology is indispensable for screening; however, crater-like topography is not diagnostic on Earth without benchmark-calibrated suppression of false positives.
- Restricted supplementary morphometric criteria may emerge under defined conditions, provided they demonstrate robust discrimination with low false-positive rates across analogue classes and preprocessing regimes.

In either case, benchmark-calibrated validation replaces qualitative pattern recognition with reproducible evidential practice, strengthening terrestrial impact science and clarifying the limits of morphology-only crater claims.

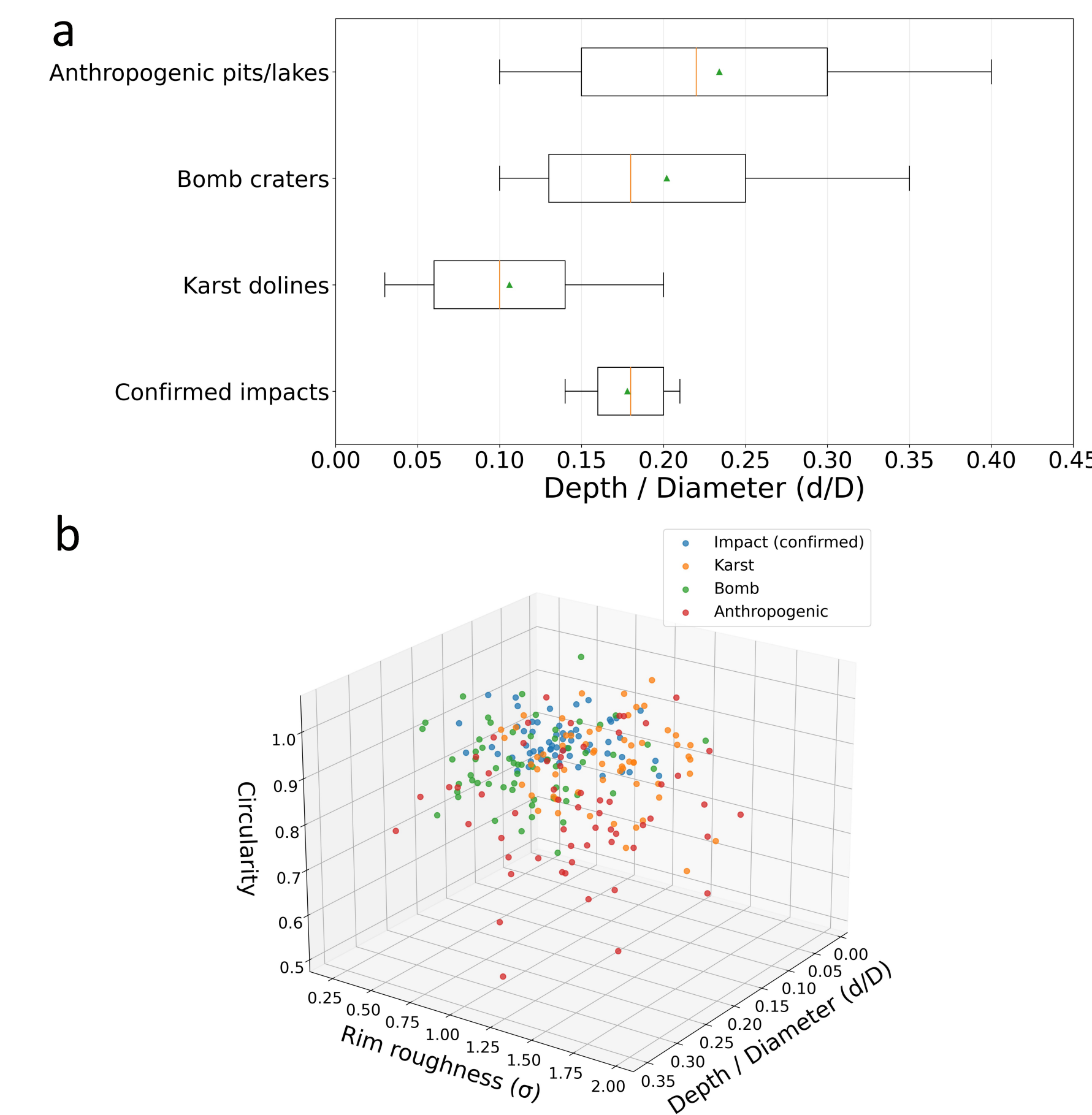


Fig. 3. Morphological Parameter Space

Crater-like depressions are characterized within a multi-parameter (n-dimensional) morphometric descriptor space (Pike, 1980; Melosh, 1989; Stepinski et al., 2009).

Descriptors commonly include geometric measures (diameter, depth, d/D, rim height and width), slope statistics, planform indices, curvature metrics, surface roughness measures, rim continuity, and degradation state.

In practice, crater morphometry routinely involves ≥10 semi-independent parameters (Pike, 1980).

Any 2D (a) or 3D (b) visualization therefore represents dimensional reduction of a higher-dimensional feature space. Morphological similarity in such projections does not establish genetic equivalence, and apparent distinctness alone is insufficient for diagnostic classification (French & Koeberl, 2010).