

¹ APM: An ArcGIS Model Builder toolbox to efficiently map and characterize pockmarks

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Software

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¹⁴ Summary

¹⁵ Pockmarks are crater-like depressions on the seafloor formed by the focused expulsion of fluids such as methane or pore water. They are important indicators of active geological processes, seabed stability, and benthic habitat distribution (Judd & Hovland, 2007). High-resolution multibeam bathymetry now allows researchers to detect thousands of these features, but manual mapping is slow and inconsistent.

²⁰ **Automatic Pockmarks Mapping (APM)** is an ArcGIS Desktop addins toolbox for Arcmap that automates the detection and morphometric characterization of seabed pockmarks. The software converts bathymetric digital elevation models into standardized geomorphological datasets through a reproducible workflow. APM is organized into three main stages: bathymetry optimization, pockmark delineation, and parameter extraction. The tool reduces operator bias and enables large-scale statistical analysis of pockmark fields while remaining accessible to users without advanced programming skills.

²⁷ Statement of need

²⁸ Manual mapping of high-resolution multibeam data is **time-consuming and subjective**, which increases the risk of errors and limits consistency in subsequent analyses (Andrews et al., 2010; Gafeira et al., 2012). While several methodologies for mapping pockmarks exist, there is a need for fast, objective, and free tools that minimize user involvement. **APM Toolbox** addresses this by providing a systematic methodology to identify, spatially delineate, and extract quantitative parameters of pockmarks regardless of the shape and size of the depression (Gafeira et al., 2018; Picard et al., 2018).

³⁵ APM addresses the need for a standardized and objective workflow that integrates directly into a widely used GIS environment. The target audience includes marine geologists, geomorphologists, environmental agencies, and graduate students who require automated tools but may not have programming expertise. By providing repeatable detection and measurement procedures, APM supports quantitative comparisons between regions and time periods.

40 State of the field

41 Several semi-automated approaches to pockmark mapping have been proposed. Script-based
42 tools such as those of Andrews et al. (2010) provide flexibility but require coding expertise.
43 GIS-based toolboxes developed by Gafeira et al. (2012) and Gafeira et al. (2018) demonstrated
44 that automated pockmark characterization is feasible within ArcGIS environments. More recent
45 work has used geomorphometric approaches to infer seabed processes from mapped depressions
46 (Picard et al., 2018).

47 APM extends this line of research with a design focused on operational usability. Unlike
48 workflows that assume flat terrain or require external dependencies, APM is packaged as a
49 self-contained toolbox that operates on sloping continental margins and complex bathymetry.
50 The software incorporates a robust irregularity filtering strategy derived from geomorphometric
51 principles and emphasizes a hybrid approach combining automation with expert validation.
52 This design choice reflects a “build vs. contribute” decision: APM was developed to solve
53 practical limitations encountered in institutional workflows where existing tools could not be
54 directly integrated or adapted.

55 Software design

56 APM is implemented using ArcGIS Model Builder in a modular architecture that prioritizes
57 transparency and reproducibility. The visual workflow allows users to inspect every processing
58 step and adapt parameters to their datasets without modifying source code.

59 The pipeline consists of three components:

- 60 ▪ **Optimization stage:** Digital elevation models are smoothed using focal statistics to
61 suppress acquisition noise and avoid false detections during terrain analysis.
- 62 ▪ **Feature delineation:** Pockmark rims are identified using the Bathymetric Position Index
63 (BPI) (Lundblad et al., 2006). A selective manual cleaning step is intentionally preserved
64 to allow expert interpretation when natural depressions overlap with anthropogenic
65 artifacts.
- 66 ▪ **Geomorphometric engine:** The toolbox extracts geometric descriptors including area,
67 depth, volume, eccentricity, and orientation. Orientation is computed using a longest-axis
68 method consistent with previous geomorphometric studies (Picard et al., 2018), enabling
69 interpretation of bottom current influence.

70 This architecture reflects a deliberate trade-off: while lower-level code could achieve marginal
71 speed improvements, the chosen design maximizes accessibility, auditability, and long-term
72 maintainability.

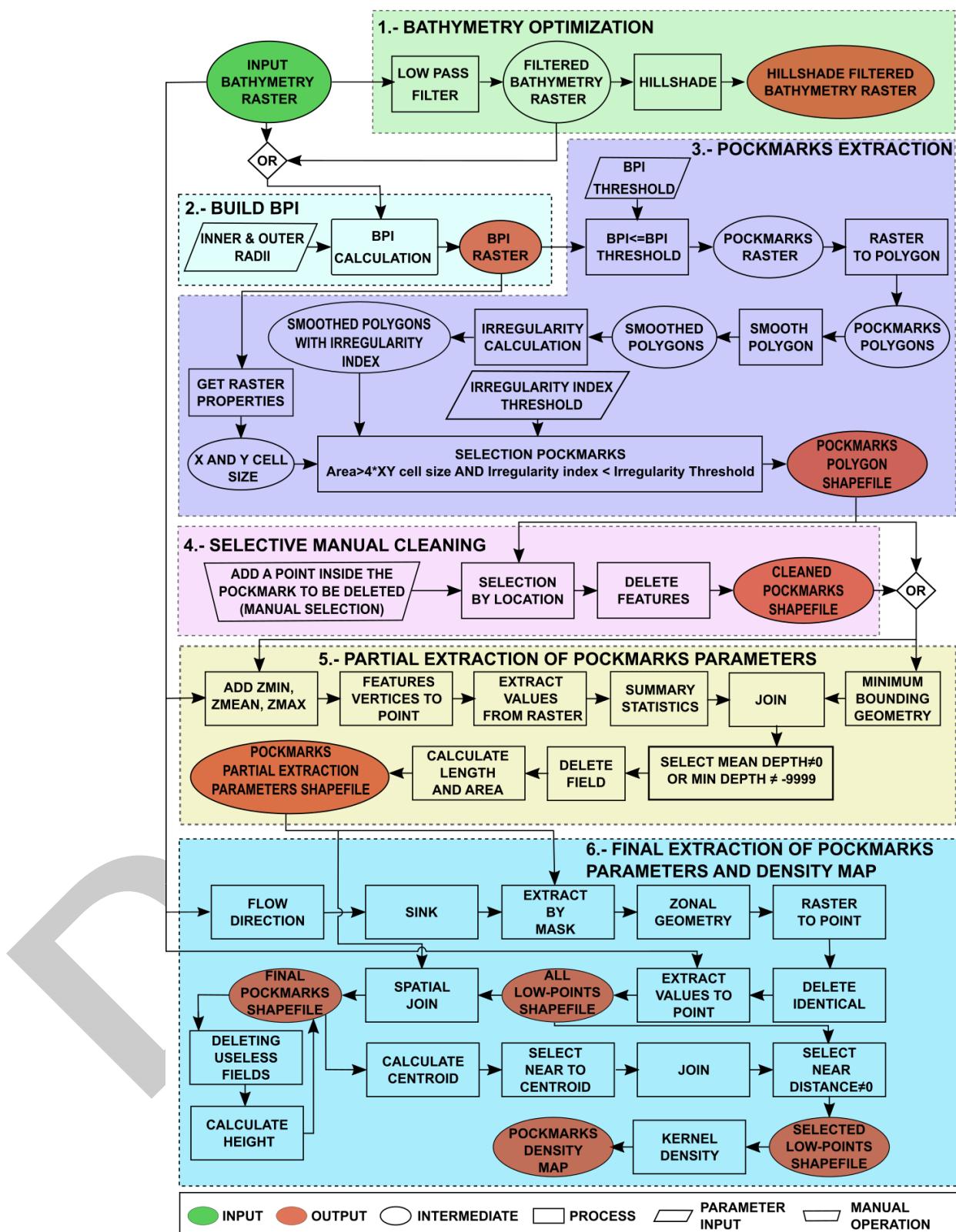


Figure 1: Flowchart illustrating the sequential stages of the automated script for pockmarks mapping. The diagram delineates distinct elements, including input data, parameter entries, processes and data outputs. Each stage is demarcated to provide a clear visual representation of the sequential workflow within the automated cartography script.

73 Research impact statement

74 APM has been applied in the **ESMARES** project (Marine Strategies in Spain, action C12A2),
75 covering diverse test areas: Guadiaro Deep Fan, Capbreton Canyon, Murcia Slope, and Mallorca
76 Channel.

77 It has been successfully employed in academic research, including the Master's thesis by
78 Sua Escobar (2025), generating standardized geomorphological layers (shapefiles and density
79 maps) for marine spatial planning. Benchmarks show APM can reduce analysis time by up
80 to 80% relative to manual workflows. By providing reproducible workflows, APM bridges raw
81 bathymetric data and high-level analyses necessary for environmental strategy and scientific
82 research.

83 The software is actively maintained in a public repository and distributed under an open license,
84 supporting community inspection, reuse, and extension.

85 AI usage disclosure

86 No generative AI tools were used in the development of APM software. This manuscript was
87 edited for structure and clarity with AI assistance, but all scientific content, geomorphological
88 interpretations, and data were provided and verified by the authors.

89 Acknowledgements

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93 Ramón Margalef cruises.

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