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Review Article

Coastal to deep-marine geomorphic classification: A standardised framework and review of terms to support globally consistent mapping

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ABSTRACT

Marine and coastal geomorphology is inherently interdisciplinary, involving the interpretation of landforms shaped by overlapping hydrodynamic, sedimentary, tectonic, and biogenic processes across diverse physiographic settings. As the United Nations Decade of Ocean Science drives the collection of information to address ocean challenges, geomorphic data is becoming an increasingly critical baseline resource to support evidence-based decision-making. Standardised, inter-jurisdictional geomorphic frameworks enable consistent terminology across scales. Though marine sub-discipline lexicons are generally well established, seabed geomorphology mapping encompasses terminological nuances that can hinder analysts working across disciplinary boundaries.

To address these challenges, the International Seabed Geomorphology Mapping Working Group (ISGM) developed a comprehensive classification framework using an Ocean Best Practice process that incorporates science-community input. This two-part approach separates morphological mapping (Part 1) from geomorphic interpretation (Part 2), constraining the uncertainty inherent to stratigraphic interpretation to a second step. In Part 1, 40 bathymetric shapes are defined using standardised Morphology Feature terms. In Part 2, a hierarchical framework and glossary of 400 terms across 11 overlapping classes assigns geomorphic interpretation. The framework supports classification from *Setting/Process* through *basic geomorphic units* (BGU), *types* (BGU-T) and *sub-types* (BGU-sT), allowing users to tailor classification to available data quality and application needs.

Implementation is supported by open-access, machine-readable digital vocabularies, which standardise established terms without redefining them, and GIS tools. Applied examples demonstrate utility across global datasets. By integrating existing terminology into a standardised hierarchy, the ISGM approach provides the first cross-class geomorphic framework capable of supporting consistent terminology from global to local scales.

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1. Introduction

The rapid expansion of the Ocean Economy during the United Nations Decade of Ocean Science (2021–2030; UNESCO, 2021) is accelerating seabed data acquisition, with new bathymetric data coverage annually exceeding 3% of the total global seafloor area (Wölfl et al., 2019; Niyazi et al., 2025a, 2025b). This global demand for seabed data is reflected in a proliferation of global, multinational, and regional mapping programs such as Seabed 2030 (Mayer et al., 2018), EMODnet (Europe), MAREANO (Norway: https://www.mareano.no/en), INFOMAR (Ireland: https://www.infomar.ie/) and AusSeabed (Australia: http://www.ausseabed.gov.au/). The data from these programs are being used to underpin geomorphology maps that integrate seabed shape with sedimentological, stratigraphic and biological data to interpret the origin of seabed units. By synthesising complex geologic and environmental information these maps, and their derivatives, serve as critical input layers for mapping and decision-support workflows (e.g. Mellett et al., 2015; Coughlan et al., 2020; Peters et al., 2020; Guinan et al., 2021). These workflows guide infrastructure siting and resource management by balancing ecological, technical, and regulatory considerations (Griffiths and Martin, 2017; Micallef et al., 2018; Coughlan et al., 2020). They can also inform nautical charting (e.g., UK HO, 2022) and underpin predictive models of habitat distribution (e.g. Harris and Baker, 2011, 2020; Huang et al., 2011, 2014; Thums et al., 2017; Wilson et al., 2007; Wright and Heyman, 2008; Wong et al., 2025).

Despite their broad utility, the full potential of marine geomorphology maps can be limited by inconsistent terminology and classification schemes. Challenges for nomenclature are amplified in the marine realm, where interpretations are primarily based on remotely acquired acoustic and geophysical data, and where landforms may include inherited components formed under different palaeoenvironmental conditions; dynamic sedimentary and oceanographic processes reshape the seabed; and diverse geomorphic processes often intersect. Given the inherent ambiguity in interpreting seabed geomorphology, classification systems that accommodate uncertainty while providing terminological consistency can enhance comparability between datasets and interpretations, supporting more informed and integrated decision-making. Central to the framework presented here is the formal definition and structuring of geomorphic terminology into open access digital vocabularies (Wells et al., 2025a, b, c, d).

While terrestrial geomorphology has developed gradually as a science over more than a century (Chorley et al., 1964, 1973), marine geomorphology remains a frontier discipline. Interpretation in the marine realm is complicated by indirect observation methods, topographies that are often partly inherited from palaeoenvironmental conditions and tectonic processes, and the interaction of relict and modern sedimentary strata with oceanographic dynamics across a wide range of spatial scales. The urgent task is to develop a standardised classification framework for broad international use, ensuring that the surge in seabed data acquisition translates into persistent maps that are interoperable across disciplines and jurisdictions. This urgency is heightened as nations move rapidly to assess geomorphic features linked to associated resources within and beyond their jurisdictions.

Seabed physiographic and geomorphic maps already underpin ocean management (e.g. Heap and Harris, 2008; Harris et al., 2014a). A widely adopted convention is the International Hydrographic Organisation's publication *B-6: Standardisation of Undersea Feature Names* (IHO, 2019: the B-6), which provides a generic system for naming seabed features. However, the B-6 scheme focuses primarily on undifferentiated morphological and physiographic terms and is not intended to capture the full diversity of causative processes that have created the physical features that occur at multiple spatial scales across the marginal to deep marine environments. Prior to the framework presented here, no inter-jurisdictional, local- to continental-scale geomorphic classification standard existed. The new framework presented herein addresses this gap by offering a consistent and scalable approach that supports scientific, management, and engineering applications. It builds on decades of research into both marine and terrestrial geomorphology and adopts and structures these vast nomenclatures to consistently classify the seabed, extending seamlessly through fluvial, coastal and marine settings to enable comparative multiscale and interdisciplinary analyses.

Formally endorsed by the United Nations Ocean Decade's Ocean Best Practice (OBP) initiative (Intergovernmental Oceanographic Commission (IOC) of UNESCO, 2023), this two-part classification framework separates the mapping of seabed Morphology (Part 1) from the geomorphic interpretation of those shapes (Part 2). It provides a consistent and interoperable structure for marine and coastal datasets and represents a global best practice for integrated marine to coastal geomorphology classification. The objectives of this paper are to describe the framework and its evolution through the OBP process, to provide an overview of the key terms and how they are structured within it, and to present international case examples that demonstrate the versatility of the approach.

2. An international Ocean Best Practice approach

The development of the classification framework presented herein has been shaped by a decade of collaboration between national geoscience agencies and marine mapping programs (Dove et al., 2016, 2020a, 2020b; Nanson et al., 2023a). These groups, working independently across jurisdictions, converged on a shared need for consistent, scalable seabed geomorphology classification resources. This manuscript reflects the results of that collaboration and synthesises the outcomes of technical reports, workshops, and ongoing implementation.

In recent years, this work has been formalised through the OBP initiative. OBP are collaboratively developed and independently reviewed standard operating procedures, manuals and guidelines that standardise the collection, processing and interpretation of marine data. OBP frameworks support a wide range of applications across diverse sectors and jurisdictions, including seabed mapping and sampling (e.g. Przeslawski et al., 2019; Picard et al., 2020; McNeil et al., 2023a; Przeslawski and Foster, 2024), and underwater noise monitoring and reporting (Robinson et al., 2014). They are also well suited to the interpretation of seabed datasets and the development of derived mapping products, such as geomorphic classification approaches.

We adopted the OBP approach to formalise a new seabed geomorphology classification scheme, following the three-phase methodology outlined by Przeslawski et al. (2023):

- Phase One – scope the need for a new OBP, and recruit a working group;
- Phase Two – develop and release the practice;
- Phase Three – revise and ratify the practice.

2.1. Phase one: identifying the need

The need for a cross-disciplinary marine and coastal geomorphology classification system was recognised by multiple national geoscience agencies over a decade ago (e.g. British Geological Survey – BGS, Geological Survey Ireland - GSI, Geological Survey of Norway - NGU: Dove et al., 2016; Geoscience Australia: Nanson and Nichol, 2018). Dove et al. (2016) proposed a two-part classification system with two discrete steps: (1) map and classify seabed morphology, then (2) interpret and assign geomorphic classes to those forms. A key benefit of this approach is the deliberate separation of the higher uncertainty that is inherent to geomorphic interpretation from more repeatable morphological delineation and classification. Adopting a two-step approach also avoids the conflation of terms between these steps (shape: Morphology; origin: geomorphology), and the premature assignment of a units origin. Nanson and Nichol (2018) later identified this two-part framework as the most suitable approach for Australian waters.

The European collaboration (Dove et al., 2016), initially led by BGS with participation from the United Kingdom, Norway, and Ireland seabed mapping programs (*MAREANO – INFOMAR – MAREMAP*), later expanded to include Geoscience Australia, forming the *International Seabed Geomorphology Mapping Working Group* (ISGM; https://www.geomorph.org/international-seabed-geomorphology-mapping-working-group/). ISGM's primary objective is to develop, maintain and operationalise the two-part classification system to support standardised geomorphic mapping across disciplines.

2.2. Phase two: development and community review

For this phase, the ISGM developed draft database structures to collate peer-reviewed morphological, geomorphic, hydrographic, physiographic and geologic terms into Parts 1 and 2 (morphological and geomorphological, respectively). These drafts, and the Dove et al. (2016) framework, were the topics of targeted workshops at the *Marine Geological and Biological Habitat Mapping Conference* in 2019 (*GeoHab St Petersburgh, 2019*: Dove et al., 2020a; Part 1), and at the inaugural *International Conference on Seafloor Landforms, Processes and Evolution* in 2022 *(ICSLPE Valletta, 2022:* Nanson et al., 2022a: Part 2). Feedback from these forums were incorporated to develop revised versions that underwent internal science agency review before being publicly released on the Zenodo platform (Dove et al., 2020b; Nanson et al., 2023a). Zenodo is a general-purpose repository developed under the European OpenAIRE program and is operated by the European Organisation for Nuclear Research (CERN). Zenodo ensures persistent Digital Object Identifiers, supports versioning, and provides usage metrics, long-term preservation, and open accessibility. In 2025, both reports were formally endorsed by the United Nations Ocean Decade's OBP initiative (Intergovernmental Oceanographic Commission (IOC) of UNESCO, 2023).

2.3. Phase three: revision and maintenance

Though OBP practices are considered complete upon publication and endorsement (Przeslawski et al., 2023), Phase Three mandates capacity for ongoing revision. Updates are anticipated for both ISGM Part 1 and 2 reports (Dove et al., 2020b; Nanson et al., 2023a), as the framework is implemented across sub-disciplines, and as the discipline of marine geomorphology evolves (Micallef et al., 2018). Ongoing edits are supported by the versioning capability of the Zenodo platform on which the reports are hosted, and their accompanying digital vocabularies (Wells et al., 2025a-d). At the time of publishing this manuscript, the classification frameworks presented herein provide the most current version of the system, as follows.

3. Results (I) - ISGM two-part scheme

The full suite of ISGM terminologies presented in the report glossaries (Dove et al., 2020b; Nanson et al., 2023a) were published as digital vocabularies using the Simple Knowledge Organisation System (SKOS: Miles and Bechhofer, 2009; Wells et al., 2025a-d). Of these, the following conceptual groups of terms are important for framing the ISGM two-part scheme (cf. Method Terms vocabulary: Wells et al., 2025a):

- *Morphology* refers to the shape and geometry of seabed features as mapped from bathymetric data (ISGM Part 1: Dove et al., 2020b; Wells et al., 2025b);
- *Geomorphology* refers to the interpreted formative processes responsible for developing these features (ISGM Part 2: Nanson et al., 2023a; Wells et al., 2025c).

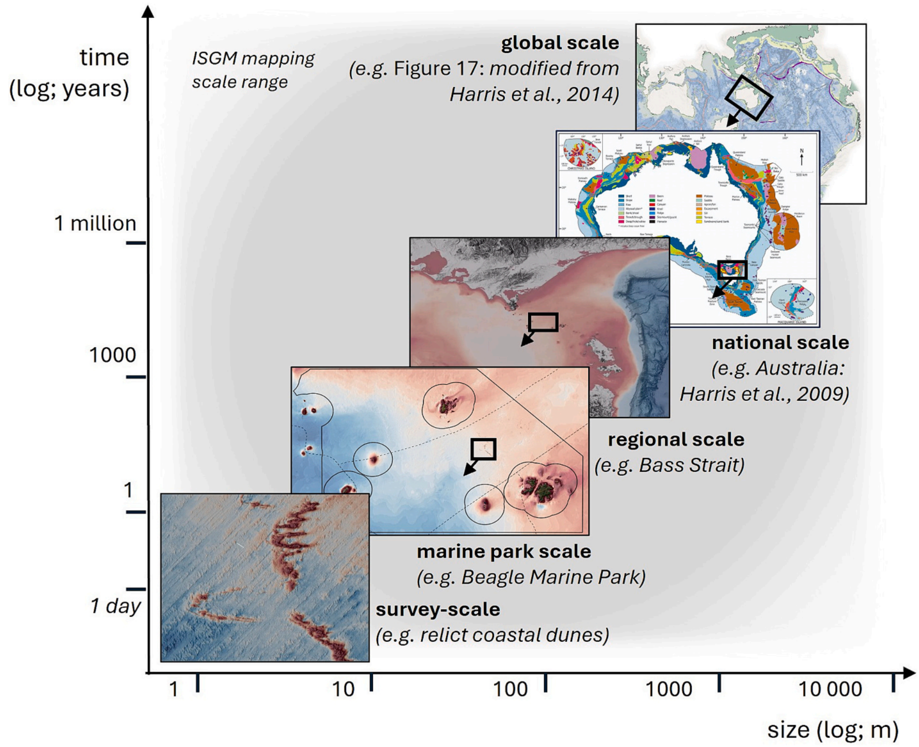

Fig. 1. Global seabed physiographic and morphologic maps (e.g. Fig. 17 derived from Harris et al., 2014a) provide broad scale context for higher resolution bathymetric grids and geomorphic mapping. The units represented across this range of spatial scales tend to broadly correlate with the temporal scales over which they form and are modified. The ISGM scheme can be used to map units across all illustrated scales.

- *Physiography* refers to the macro-scale classification of the seabed at global and oceanic scales, including major geological features (e.g., continental shelves, slopes, mid-ocean ridges etc.; Nanson et al., 2023a; Wells et al., 2025d). These features provide context for mapping Morphology and Geomorphology at finer spatial scales.

It is important to note here that although quantitative geomorphometric mapping and characterisation outputs may be utilised to map ISGM units (cf. Lecours et al., 2016), geomorphometric classifications do not directly correlate with ISGM definitions.

Throughout this manuscript, the ISGM two-part scheme is variously referred to as an approach, framework, or method. These terms are used interchangeably in different grammatical contexts.

The following sections outline the ISGM framework in the context of Physiography, Morphology and Geomorphology.

3.1. ISGM Physiography

The ISGM two-part scheme extends the International Hydrographic Organisation's B-6: Standardisation of Undersea Feature Names (IHO, 2019: the B-6), the most widely adopted lexicon of seabed morphological and physiographic terms. It also builds upon the Global Seafloor Geomorphology Map (GSFM; Harris et al., 2014a), which classifies features from ~1 km resolution bathymetry, primarily using B-6 terminology, and thereby provides broad-scale context for higher-resolution regional mapping. By integrating these prior terminologies into a hierarchical, two-part framework, the ISGM scheme ensures consistent, scalable classification of seabed morphology and geomorphology across multiple spatial scales, from global maps through to local case studies (Fig. 1).

The GSFM represents the most significant advance in global mapping since Agapova et al.'s (1979) pioneering ocean floor geomorphology map. It uses 29 terms to classify shapes delineated from Shuttle Radar Topography Mission (SRTM) bathymetry (~1 km resolution; Becker et al., 2009; cf. Yu et al., 2025). The GSFM defines four physiographic zones (shelf, slope, abyss, hadal) each containing lists of specific features, some repeated between zones (e.g. basins). Two zones (shelf and abyssal) are further subdivided by roughness attributes (low, medium and high relief shelves); and abyssal plains, hills and mountains.

The macroscale morphological features (e.g. ridge, trough) and geomorphic units (e.g. spreading ridge, fan) represented by the GSFM span both the Morphological (Part 1) and Geomorphic (Part 2) terminology of the ISGM two-part scheme. Table 1 presents a translation between these vocabularies and adds additional ISGM physiographic terms (e.g. *accretionary prism*) to complement the GSFM, thereby providing a complete ISGM Physiographic terminology of 12 terms (Nanson et al., 2023a; Wells et al., 2025d; cf. Fig. 3b below). The term "Hadal" has not been retained in the ISGM translation of the GSFM, as depth ranges generally fall outside the classification scope. The features "Basins" and "Reefs", which are not part of the official GSFM map as presented in the paper (Fig. 4 in Harris et al., 2014a) are also not included.

A revised GSFM, incorporating this translation (Table 1), but retaining the Harris et al. (2014b) polygons, is presented in the results (Section 5.1) and is available for download as a Supplementary dataset (Supp Data 1). The following section describes the ISGM method and terms, which typically nest within these macroscale shapes at finer resolution (Fig. 1).

3.2. ISGM two-part scheme

The ISGM two-part scheme distinguishes mapping of shape and form (Part 1: Morphology) from the interpretation of seabed units linked to what are interpreted to be their most likely formative processes (Part 2: Geomorphology). While Morphological class is based on bathymetry data (i.e. seabed topography data alone), additional data and information is generally required for assigning Geomorphological classes, the hierarchical nature of which facilitates classification to the level of detail

Table 1
Translation between Harris et al. (2014a) and ISGM Physiography, Part 1 Morphology and Part 2 Geomorphology. *Part 2 Geomorphology classes are described in Section 4 – Results II. Consistent with Dove et al. (2020a, 2020b): ISGM Part 1) and Nanson et al. (2023a, 2023b): ISGM Part 2), Morphology terms are capitalised as proper nouns whereas Geomorphology terms are not.

Harris et al. (2014a)	ISGM vocabulary	ISGM Feature (Morphology) or unit (Geomorphology) name
Shelf	Morphology	Plain
Shelf	Physiography	continental shelf
Slope		continental slope
Rise		continental rise
Trench		oceanic trench
Mid-ocean ridge		mid-ocean ridge
Rift valley		axial valley
		axial high (new)
Abyssal plains (< 300 m relief)		abyssal plain
Abyssal hills (300–1000 m relief)		abyssal medium relief (cf. Geomorphology - abyssal hills)
Abyssal mountains (>1000 m relief)		abyssal high relief (cf. Morphology - Seamount [chain of])
NA		accretionary prism (new)
		back-arc basin (new)
		fore-arc basin (new)
		island arc (new)
Seamount	Morphology	Seamount
Guyot	Geomorphology (Solid Earth)	guyot
Canyon (shelf-incising and blind)	Morphology	Canyon
	Geomorphology (Marine)	submarine canyon
Fan (and apron)	Morphology	Apron
	Geomorphology (Marine)	submarine fan
Shelf valley	Morphology	Valley
Glacial trough	Geomorphology (Glacial)	cross-shelf trough
Bridge	Morphology	Ridge/various
Sill		Sill
Escarpment		Escarpment
Trough		Trough
Ridge		Ridge/various
Terrace		Terrace
Plateau		Plateau

there is information to support.

Fig. 2 illustrates an example of how the ISGM scheme can be used to manage the ambiguity that is inherent to interpreting seabed geomorphology. In this example of a bathymetric Ridge (Part 1), it is difficult to distinguish between two alternative interpretations; either as a stable relict coastal palaeodune, formed during lower sea levels, or as a modern mobile marine bedform. In this stylised example, sub-bottom profile data help the analyst to decide. The implications for Ocean Economic activities can be significant: semi-lithified palaeodunes provide relatively hard substrates for sessile communities (e.g. Brooke et al., 2017; Wong et al., 2025), whereas mobile bedforms provide very different habitats (e.g. Meijer et al., 2023) and present their own challenges to offshore infrastructure projects (Morelissen et al., 2003). And while the accuracy of seabed morphology mapping is linked to the bathymetry dataset from which shapes are derived, the interpretation of a feature's geomorphic origin introduces varying sources and degrees of uncertainty. Furthermore, the sub-surface and sedimentological data that support geomorphic interpretation are often less spatially ubiquitous, and the availability of regionally appropriate analogue cases on which to base interpretations varies. The ISGM two-part classification scheme separates these mapping steps to compartmentalise these uncertainties.

3.2.1. *Part 1 Morphology*

Using the ISGM two-part scheme, targeted seabed shapes are typically delineated by applying GIS-based bathymetry mapping tools (e.g. ArcGIS Pro Editor Toolbar; Whitebox GAT: Lindsay, 2016; BTM Toolbox: Walbridge et al., 2018; GA-SaMMT - Step 1: Huang et al., 2023; CoMMa: Arosio et al., 2024). These shapes are then classified from a set of 40 Feature types using the ISGM Part 1 illustrated glossary of terms, some of which specify dimensional attributes (e.g. Seamounts >1000 m high; Dove et al., 2020b; Wells et al., 2025b; cf. Steps 2 and 3 in Huang et al., 2023). ISGM Part 1 Morphology shapes are organised into four groups that reflect their relative depths and gradients: (1) planar and inclined surfaces; (2) Lineaments (e.g. Crest, Centreline); (3) Highs (e.g. Plateau, Hill); and (4) Lows (e.g. Valley, Depression). Part 1 Morphology Feature terms are capitalised as proper nouns to help distinguish them from more general descriptors (e.g. upper canyon, canyon wall). Optional geometric attributes can be calculated for individual Features (Dove et al., 2020b; e.g. symmetry, regularity, bounding rectangle orientation) to facilitate subsequent geomorphic interpretation. Features can be mapped at multiple spatial scales as continuous surfaces (e.g. Plane, Slope, Escarpment), may overlap one another (e.g. smaller Depressions can be mapped over larger Plateaus or Hills) and can be mapped individually or as groups (i.e. fields) (e.g. fields of Depressions or fields of Mounds) or chains. Morphology Features (as well as Geomorphic units) may also be mapped using one or more topology types (i.e. points, lines, or polygons). For example, a Ridge may be captured as a polygon (delineating its footprint) as well as a line (delineating the crestline).

A comparative illustration of stylised Feature cross-sections is presented in Fig. 3a. The full suite of Morphology Feature types is defined and illustrated in cross-section and planform views in Dove et al. (2020b), and in the digital vocabulary (Wells et al., 2025b).

3.2.2. *Part 2 Geomorphology*

In Part 2 of the ISGM classification scheme (Nanson et al., 2023a; Wells et al., 2025c, 2025d) the geometries of Features mapped in Part 1 (i.e. their shape, orientation, distribution and depth) are analysed in combination with available seabed data (e.g. sediment texture, lithology, shallow stratigraphy, underwater imagery) and relevant knowledge of the local geology to interpret their geomorphic origins.

For clastic systems (e.g. fluvial, coastal, glacial and marine), sequence stratigraphy (Catuneanu et al., 2009) is frequently used to frame such interpretations and is incorporated into the ISGM scheme. But while sequence stratigraphy is central to the interpretation of clastic depositional systems, it is not sufficient to accommodate the full spectrum of geomorphic processes across both stratigraphic and non-stratigraphic systems. Volcanic units, for example, are often massive and penetrative, though some deposits do erode and accrete (e.g. pyroclastic density currents and ash falls). Karstic systems are strongly shaped by chemical dissolution rather than accretionary processes, and biogenic geomorphologies, though sometimes stratigraphic, are largely governed by chemical and physical controls on carbonate precipitation and the evolution of biotic communities (Schlager, 2005). Part 2 of ISGM provides a standardised classification framework to accommodate this diversity while retaining discipline specific terminology.

The term *Setting* is used to group geomorphic units formed in discrete environments, while *Process* groups units formed by similar formative processes. This framework results in 11 *classes*: five Settings (Fluvial, Coastal, Marine, Glacial, Solid Earth) and six Processes (Current-induced, Biogenic, Mass Movement, Fluid Flow, Karst and Anthropogenic) (Fig. 3b). The Solid Earth class (i.e. bedrock, tectonic and volcanic processes), while not a Setting per se, is treated as one because it encompasses multiple processes and provides the geological background against which other units develop. Units in all classes typically occur at scales finer than the broader Physiographic context (Fig. 3b).

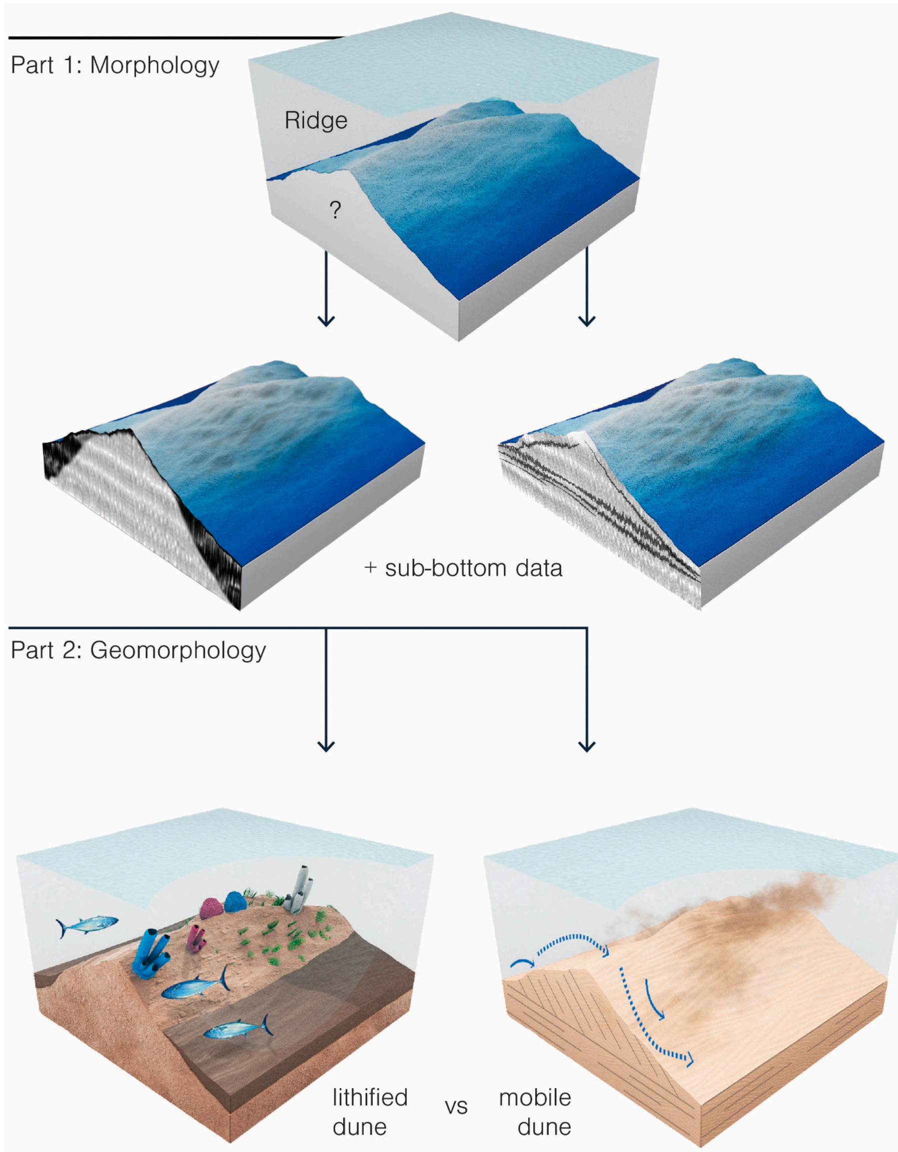

Fig. 2. The ISGM two-part scheme supports seabed mapping and classification in two discrete steps. Morphologies are mapped using bathymetry data; additional subsurface interpretations support geomorphic classification of those shapes.

Fig. 4a illustrates the universal ISGM framework used to structure over 400 Part 2 Geomorphology terms across all 11 classes. Within each class, geomorphic terms are referred to as geomorphic *units*. Interpretations of Part 2 units can then be extrapolated to similar Part 1 Features, producing geomorphic maps that integrate Morphology with process understanding. Unit names are italicised herein (e.g. *delta*, *floodplain*), and generally not capitalised, except to distinguish similar units formed within separate classes (e.g. *Marine barform* vs. *Coastal barform*).

Because Settings and Processes frequently overlap, their units commonly co-occur (Fig. 3b). This is particularly evident in palaeoenvironmental reconstruction on continental shelves, where repeated Cenozoic sea-level fluctuations have produced complex arrangements of geomorphic units (e.g. Swift et al., 1971; Blum and Törnqvist, 2000; Catuneanu et al., 2009). For example, a preserved lowstand Fluvial *subaerial channel* may be mapped on the continental shelf (*Physiography*) adjacent to a Marine *canyon head*, containing or surrounded by *Marine barforms*, and in the vicinity of Coastal *channel belts* of mixed process origin (e.g. fluvial and tide-influenced channel belts: Lane et al., 2023). Bedforms of uncertain origin (e.g. *dunes*, *scour*) may be provisionally classified as Current-induced *bedforms* until a more specific class is identified and the unit reassigned.

Classification trees for each class are consistent in structure (Fig. 4) but are nuanced to accommodate the diversity of rock, clastic and biological units. Within these trees:

- units are clustered and informally labelled to support users in locating terms within sub-themes; such clusters may be cited but are not formal classification elements.
- Each class is structured around the *basic geomorphic unit (BGU)*, which may in turn be subdivided into *BGU Type (BGU-T)* and, in some cases, *BGU sub-Type (BGU-sT)*.
- Citation sources for these more granular units are provided on the connecting arms of the database tree.
- All levels of classification can be simplified to more general (higher) levels, including to their class Setting / Process, to best suit application specific requirements.
- Child units are presented at the same level as their parent unit (e.g. BGU) and either can be subclassed in the same way (e.g. BGU-T).

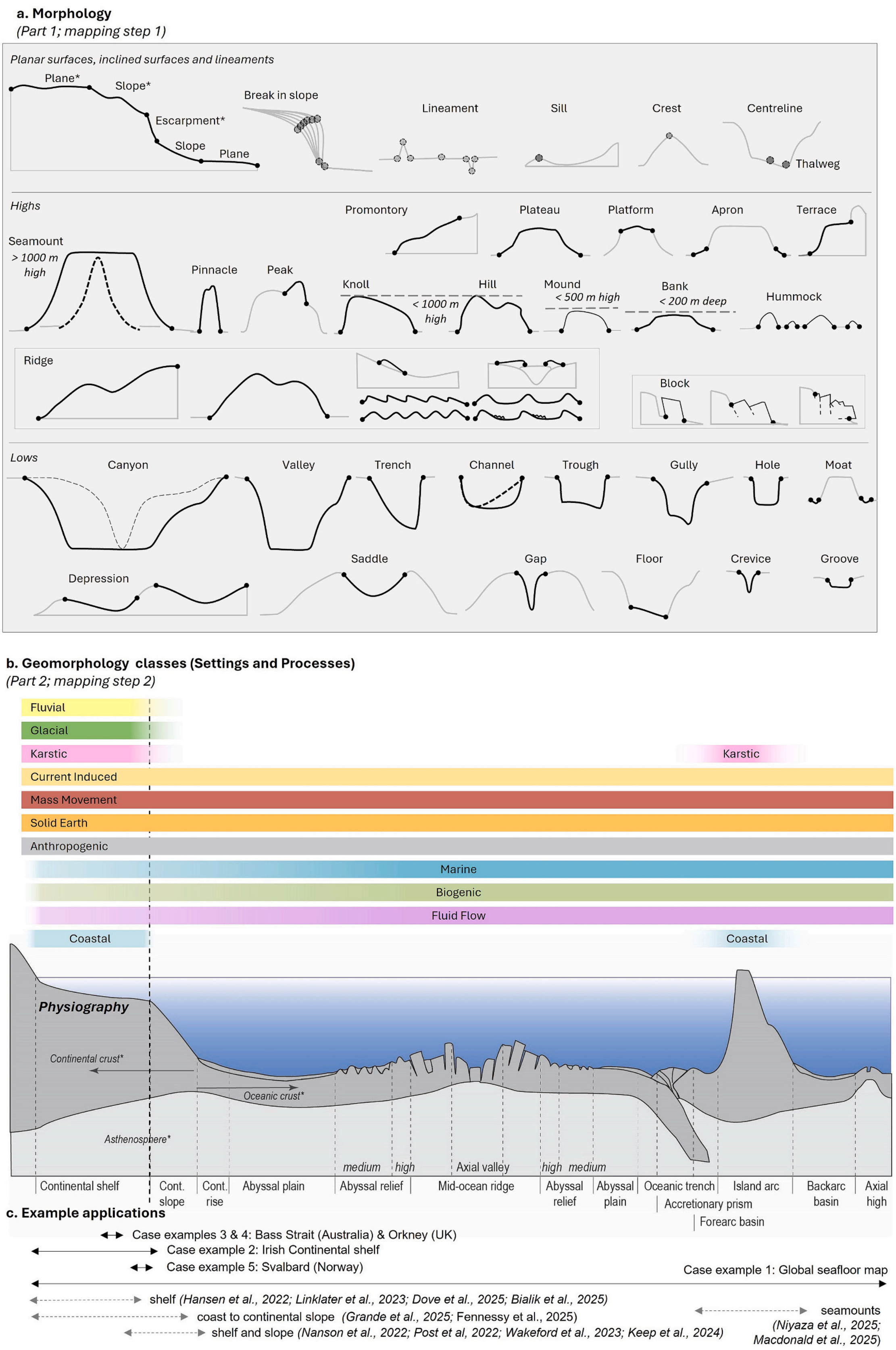

Fig. 3. ISGM mapping method: (a) the Morphology of the seabed (Part 1; modified from Dove et al., 2020b); (b) the extent of 11 geomorphic classes used to classify seabed Features (Part 2; modified from Nanson et al., 2023a). Geomorphic classes demonstrate considerable overlap in their distribution, particularly on the continental shelf and upper slope. Geomorphic units are generally smaller than their Physiographic context. NB *terms are not included in the ISGM vocabulary. (C) The Physiographic extent of case examples described in Section 5; other studies that have utilised the ISGM approach (see Discussion Section 5).

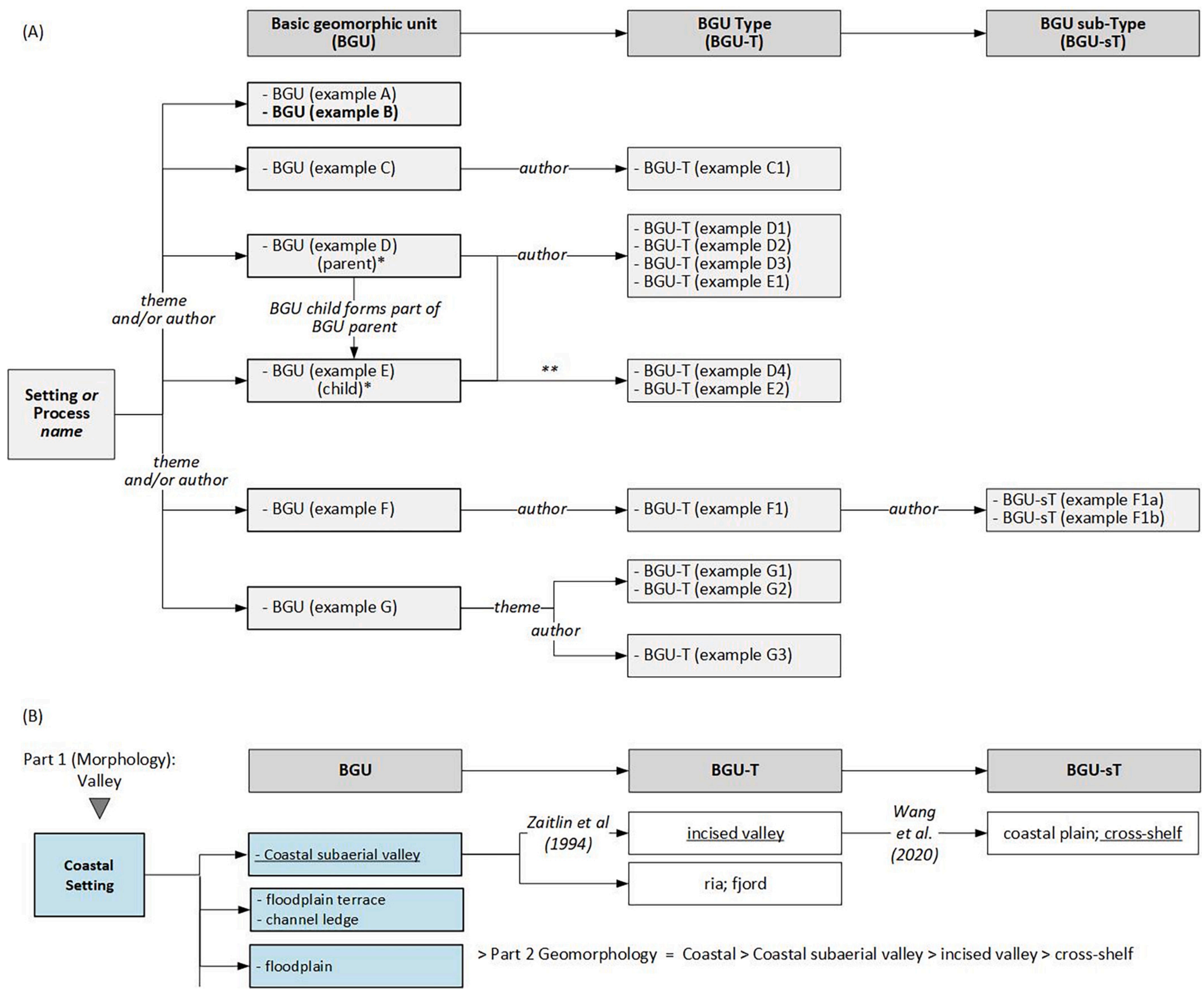

Fig. 4. (A) the database template used to structure Part 2 terminology within each of the 11 Process/Setting classes. Bold units appear in multiple Settings / Process trees; * parent units are used for decision logic; these needn't be mapped prior to their children; ** classifications needn't always have an author to cite. (B) An excerpt from the Coastal Setting decision tree (Fig. 8), illustrating the Part 2 geomorphic level to which a Part 1 (Morphology) Valley can be classified using the ISGM two-part scheme (selected unit terms are underlined).

The example in Fig. 4b illustrates how a Part 1 Morphology Feature is classified through this hierarchy. A Valley (Morphology) may be classified as Coastal in origin. With additional datasets and context, it can be classified as a *Coastal subaerial valley* (BGU), then an *incised valley* (BGU-T; Zaitlin et al., 1994), or most specifically as a *cross-shelf valley* (BGU-sT; cf. *coastal plain valley*: Wang et al., 2020). In this case, the classification of a *Coastal subaerial valley* (BGU) down to the level of BGU-sT (*cross-shelf* vs *coastal plain*) indicates a specific set of palaeoenvironmental processes, and distinct facies, with implications for the geotechnical and hydrogeological properties of the deposit and for regional palaeoenvironmental studies. Importantly, this example also highlights that the ISGM classification requires the user to determine the most appropriate unit term for their needs. In this case, a drowned *incised valley* (i.e. a *ria*) may be a better classification choice for the exact same unit, depending on the application.

Though ISGM classification structures unit terms that encompass a broad range of spatial scales, which form over a similarly broad spectrum of timeframes (Fig. 1), the vocabulary deliberately limits its classification precision to terms that are relevant to a range of applications (e.g. infrastructure planning, fisheries management, habitat mapping – see section 3.3). These selected terms are intended to allow more detailed, sub-discipline-specific classifications to be augmented, where required, enabling users to tailor the framework for specific applications. A total of 396 terms are formally defined across the Physiography, Morphology, and Geomorphology levels (BGU and BGU-T), with definitions provided in digital vocabularies (Wells et al., 2025b–d) that reproduce and standardise terminology from the glossaries presented in the Dove et al. (2020b) and Nanson et al. (2023a) reports.

3.3. ISGM Part 2 potential applications

Full coverage seabed geomorphology maps provide invaluable context for a broad range of marine applications and form the standard for multipurpose marine map products (e.g. Bristol Channel 1:10,000 scale geology and geomorphology map: British Geological Survey, 2022). For many applications, however, only discrete assemblages of geomorphic units are of interest to the user (e.g. Perth Canyon Mass Movement and Current-induced Process units: Nanson et al., 2022b), or are possible to produce from available data. Indeed, the detail provided by full coverage maps may obscure priority units. In many cases, digital

Table 2
Potential applications for mapped BGU and BGU-T. These applications are indicated alongside each term in the Part 2 ISGM glossary (Nanson et al., 2023a). Note: this list emphasises the principal scientific insights gained from mapping geomorphic units at the seabed; nearly all buried palaeo-units contribute to palaeoenvironmental and climate reconstructions (Application 4). These applications are also summarised visually in the graphical abstract (a).

Potential applications	Description
ISGM Application 1 - *Habitat* and biodiversity (biological)	Ocean management, seafood industry, biodiversity, conservation (e.g. Harris and Baker, 2011; Harris, 2012; Micallef et al., 2018; Spalding, 2016).
ISGM Application 2 - *Geohazard* assessment and seabed stability	To assess landslide and tsunami hazard (e.g. Bardet et al., 2003); develop GIS ground models for offshore renewables (e.g. Barwise et al., 2014); for safe navigation and infrastructure developments; seabed stability (Hough et al., 2011).
ISGM Application 3 - *Sediment* dynamics and process studies	To infer near seafloor energy, sediment transport pathways, volumes / budgets (e.g. Stow et al., 2009).
ISGM Application 4 - *Palaeoenvironmental* and climate reconstruction	For studies of modern climate change, paleoenvironmental reconstruction, archaeology (e.g. Brooke et al., 2017; O'Leary et al., 2020).
ISGM Application 5 - Marine *management* and governance	To investigate environmental hazards, erosion, seafood industry, recreational fishing, administrative borders.
ISGM Application 6 - Resource *exploration*	To locate fluvial and coastal placer deposits (Kudrass, 2017) and aggregates.

map platforms can readily facilitate the conversion of full coverage maps to versions that emphasise subsets of units for specific end-user applications (e.g. constraint maps: Mellett et al., 2015). Alternatively, it may be economical to consider priority geomorphic unit targets much earlier in a project program, particularly during seabed survey planning stages. Early identification of target geomorphic units is key to the appropriate prioritisation of typically finite survey resources; geophysical data should be collected at scales sufficient to resolve the target units in bathymetry grids (e.g. Wölfl et al., 2019), and planning should ensure that resourcing for the collection of ancillary data (e.g., sub-bottom profiles, sediment samples, imagery) is adequate to minimise uncertainty in geomorphic interpretations.

BGU and BGU-T were selected for their relevance across the diverse applications summarised in Table 2. These applications extend to all ISGM Part 2 units, highlighting the primary scientific and applied relevance of each. While not exhaustive, these applied foci illustrate how the ISGM framework can guide the prioritisation of geomorphic units to map for research, environmental assessment, and resource evaluation, and underpin the selection of units structured within the ISGM Part 2 classification.

4. Results (II) – geomorphic classes (settings and processes)

This section summarises and describes the relationship between the key geomorphic units of the ISGM scheme across the eleven Setting and Process classes (Fig. 3b). Updated hierarchical decision trees for each class are provided here as a revision to the archived Version 1.0 report (Nanson et al., 2023a). As the Zenodo platform supports iterative versioning, users are encouraged to consult the dynamic Dove et al. (2020b) and Nanson et al. (2023a) reports for the most current release following this manuscript.

Where multiple terms have traditionally been used to describe the same target units, a single term is stated as the preferred term and the alternative (*also known as*: aka) term is provided in brackets, to facilitate users who wish to continue using their preferences but also support translation between practitioners. Definitions for all unit terms are provided in the published vocabularies of Wells et al. (2025c).

ISGM units were selected to balance the need for sufficient terminology to facilitate map development for the six ISGM Applications outlined above (habitat, geohazard, sedimentary, palaeoenvironmental / climate, and resource assessments), against the risk of introducing overly niche units that are generally difficult to interpret or map (e.g. *lava flow* versus pahoehoe). More granular classification is best served by discipline-specific terminology applied where specialist objectives require it.

Units formed within or by all eleven classes (Figs. 3 and 5) can co-occur across multiple Physiographic zones. Fig. 5a illustrates a stylised suite of 23 Morphology Features mapped on the seabed. Fig. 5b illustrates the classification of these example Feature types into 67 geomorphic units (BGU and BGU-T), thematically coloured by class to highlight their similarity in bathymetric form and the potentially complex arrangement of units from different classes. This figure underscores the value of applying Part 2 geomorphic classification: morphologically similar units can differ fundamentally in their stratigraphy, origin and geotechnical properties.

In addition to the geomorphic units reviewed in the following sections, the ISGM scheme also lists a suite of optional attributes used to characterise units more fully. These attributes extend the classification by capturing temporal, compositional, and morphometric information that is frequently used in habitat mapping, geohazard assessment, sediment budget analyses, and palaeoenvironmental reconstructions (Nanson et al., 2023a). These are not required for all mapping exercises but enable users to incorporate relevant context where data permit. *Optional attributes* fall into eight broad categories: (i) unit associations (fields, chains); (ii) relative age (modern, palimpsest, relict: Swift et al., 1971); (iii) stratigraphic position (surface, partially buried, buried); (iv) relative sea-level association (forced regressive; lowstand normal regressive; highstand normal regressive; transgressive: Catuneanu et al., 2009); (v) lithology (hard, soft, consolidated sediment); (vi) particle size (Wentworth, 1922) and texture (Folk, 1954)); (vii) terrain attributes (e.g. slope, rugosity, orientation: e.g. (Dove et al., 2020b); and (viii) dominant marginal-marine processes (aeolian; fluvial, wave, tide: Ainsworth et al., 2011. Note that Fluvial and Coastal prefixes to unit names (Sections 4.2 and 4.3) indicate the Setting to which each term belongs, and does not replace the wave, tide- and fluvial- process classification of these units. Collectively, these descriptors operate as a flexible tagging system within GIS databases, supporting nuanced analyses while remaining interoperable with the ISGM framework.

The potential lexicon for describing marine geomorphic features is extensive, encompassing thousands of terms drawn from diverse subdisciplines. The ISGM classification scheme intentionally constrains this complexity by standardising a curated set of terms that are broadly interpretable, mappable at practical scales, and directly relevant to applied marine science. The following section reviews how those terms are structured within the eleven geomorphic Setting and Process classes, providing an overview of their hierarchical relationships and key sources.

4.1. Current-induced

In many cases, the named units described within each Setting (e.g. 'Glacial') and Process (e.g. 'Biogenic') class are relatively unique to each. Current-induced Process units are an exception as they can occur within multiple Settings and form by multiple Processes including those driven by air (aeolian), gas, fluid, density (e.g. turbidity, pyroclastic), bottom, tidal, ice, fluvial and wave (oscillatory) currents. This multi-class applicability is a strength of the ISGM two-part scheme, which offers a framework for interpreting and categorising units where formative origins may be uncertain, or where the formational process is similar within multiple environments (e.g. *dune* within Marine and Fluvial settings). We present the review of the Current-Induced unit terms first, as it underpins many subsequent classes, and effectively

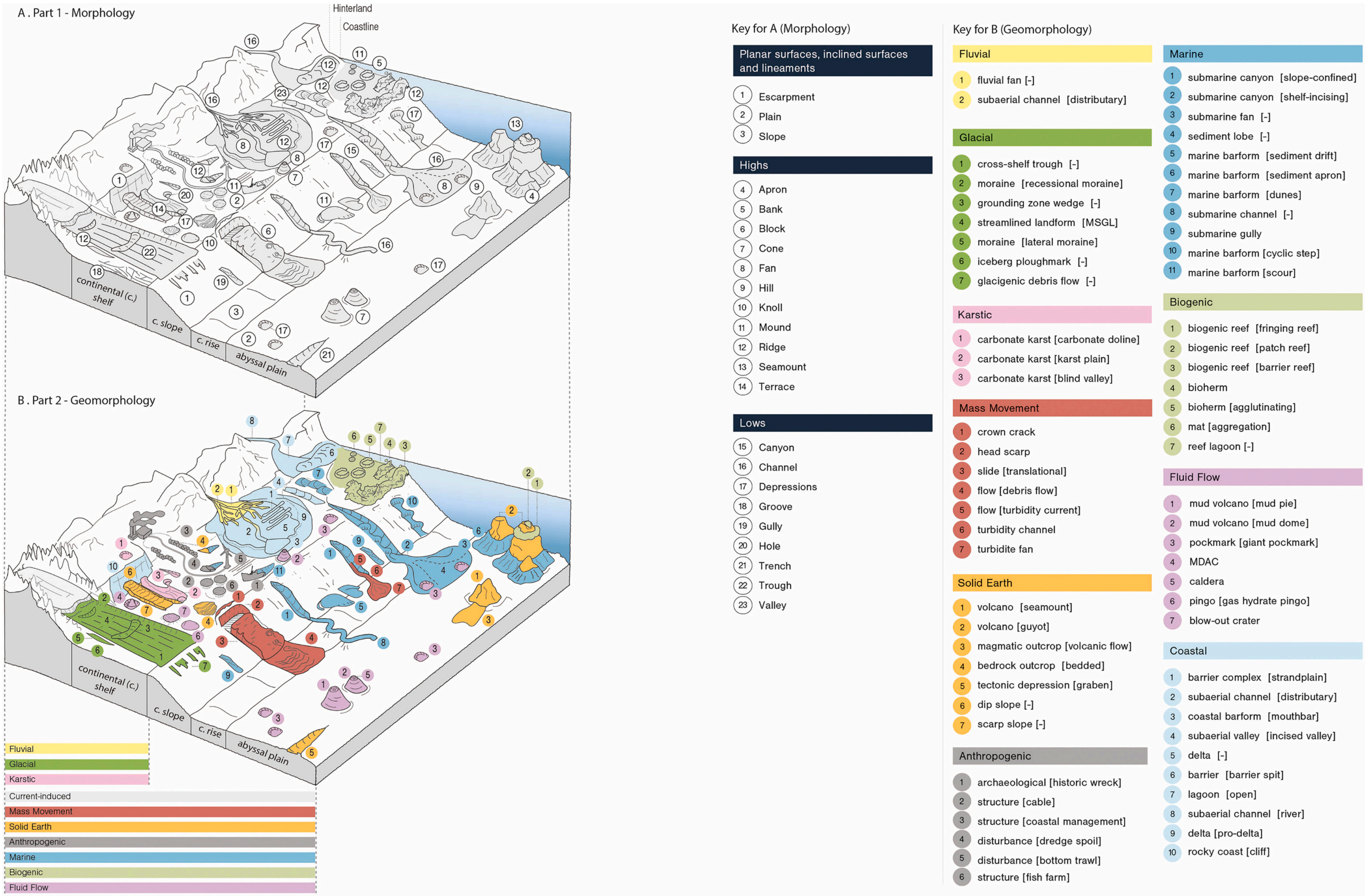

Fig. 5. Stylised marginal to marine geomorphology mapping on the continental shelf, slope, rise and abyssal plain (cf. Fig. 3), using the ISGM two-part scheme. (A) Morphology Features (B) Classification of Part A Features as geomorphic units (terms are listed in the key as BGU [BGU-T]). A simplified summary of (B) is presented in the graphical abstract (b).

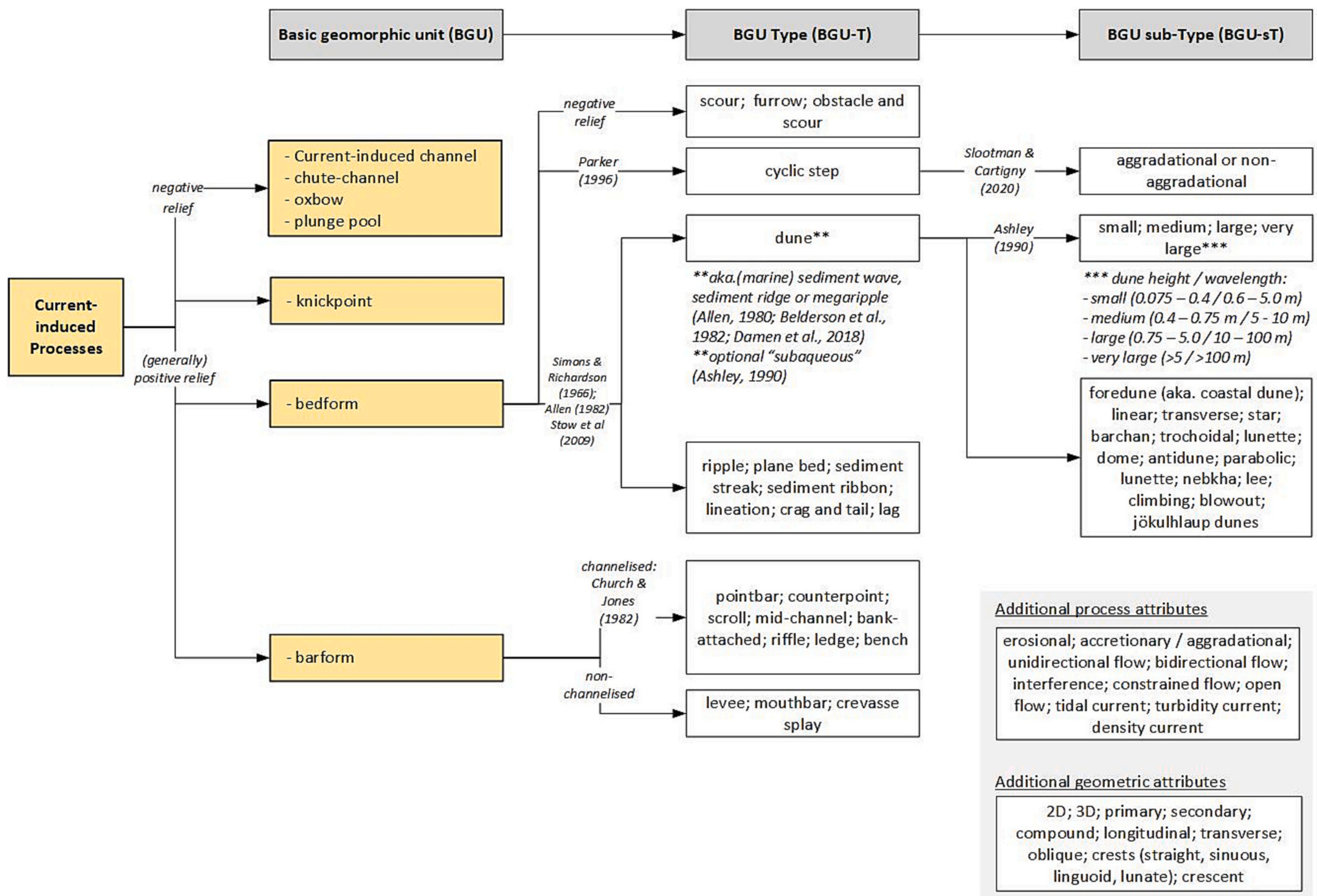

Fig. 6. Units formed by Current-induced processes. These units can form via various flow types across multiple classes, as indicated by Current-induced sign posts boxes on other classification trees (see Fig. 9 for a fully illustrated example of this).

"bolts-on" to other classes where the formative origin of these units may be determined and reclassified (e.g., into Fluvial, Marine, Coastal).

Hydrodynamic classifications of bedforms have relied on extensive flume and field data. Increased flow velocity, shear stress and Froude number relative to sediment grain size have been comprehensively demonstrated to drive the transition of mobile bed reorganisation from no movement through ripples to dunes and upper stage plane beds, and these relationships are captured in bedform phase diagrams (e.g. Simons and Richardson, 1961; Allen, 1982; Ashley, 1990; Perillo et al., 2014; Best, 1996; Venditti et al., 2016). Stow et al. (2009) extended the phase diagrams of Ashley and Best to also include continental slope and deep marine bedforms and some barforms; we incorporate the list of terms from Stow et al. (2009) (NB: without grain size descriptors Section 4 into the Current-induced Processes classification tree. This hydrodynamic framework underpins the distinctions made herein between *barform* and *bedform* units and informs further subdivisions of *dunes* and *cyclic steps*.

The BGU of the Current-Induced Process classification tree are clustered into three broad groups (Fig. 6): (i) negative-relief forms: *Current-induced channel, chute-channel, oxbow,* and *plunge pool*; (ii) *knickpoints*; and (iii) typically positive-relief *bedforms* and *barforms*. This clustering serves two purposes: (1) erosion and deposition provide a logical first-order separation, reflecting inverse ratios between sediment transport and flow energy; and (2) bathymetric highs (accretionary) and lows (erosional) are fundamental divisions in Part 1 Morphology mapping and typically correspond to the relief of these geomorphic units.

Bedform BGU are distinguished from *barform* BGU to reflect their different relationships with their formative flows (Dalrymple and Rhodes, 1995). *Bedforms* respond rapidly to variations in flow energy / sediment supply to moderate their flow resistance and sediment transport (Best, 1996; Simons and Richardson, 1966). The type and magnitude of bedforms scale with grain size, flow velocity, shear stress and flow depth (BGU-T: *ripple, plane bed, sediment streak, sediment ribbon, lineation, crag and tail, lag*: Allen, 1982; Best, 1996; Simons and Richardson, 1966). Typically, either Marine or Fluvial *cyclic steps* (BGU-T; Parker et al., 1996; Allen, 1982) can be sub-classified (as BGU-sT) into *aggradational* or *non-aggradational* (Slootman and Cartigny, 2020). Though at least partially negative in profile, *scour*, *furrow*, and *obstacle and scour* (BGU-T) are also grouped within the *bedform* BGU because they develop along the same continuum of shear to sediment supply ratios.

An exception to the bedform / barform sediment to flow ratio rule above is *dune* (BGU-T), which can form under higher velocity and shear conditions than *ripples*. *Dune* may also be used to name Marine *sediment waves* and *megaripples* (both aka of *dune;* for further discussion see Section 4.4 - Marine), which are longer-lived than most *bedforms* and, therefore, more akin to *barforms* (Allen, 1980; Belderson et al., 1982; Damen et al., 2018). *Dunes* can be subdivided into BGU-sT on the basis of either size (height / wavelength – *small*: 0.075–0.4 / 0.6–5.0 m; *medium*: 0.4–0.75 m / 5–10 m; *large*: 0.75–5.0 / 10–100 m; *very large*: >5 / >100 m): Ashley, 1990) or the shape and dominant flow medium and/or processes that they represent (*foredune* – aka *Coastal dune; linear; transverse, star, barchan, trochoidal, lunette, dome, antidune, parabolic, nebkha, lee, climbing, blowout, jokulhlaup*). Combinations of many such *dunes* frequently comprise *Coastal dune* fields (BGU-sT; aka. foredune) and these can be preserved on continental shelves and slopes (e.g., Bøe et al., 2015; Nanson et al., 2025).

Barforms generally develop more slowly over multiple flow events (e.g. *sediment waves*, cf. *contourite drifts* in section 4.4 – Marine, which evolve over millions of years: Stow et al., 2009) and are often forced by local or regional topographic characteristics (e.g. *pointbars* on channel bends; Nanson, 1980; Leuven et al., 2018). Channelised *barform* BGU-T include *pointbar, counterpointbar, scroll, mid-channel, bank-attached, riffle, ledge, bench* (Church and Jones, 1982), and non-channelised barfom BGU-T include *mouthbar, levee* and *crevasse splay*.

Additional attributes (cf. *optional attributes* described above) that can be usefully assigned to Current-induced units include:

1. Geometric characteristics. Primary, secondary, or compound forms (Allen, 1982); crest shape, classified as straight, sinuous, or lunate/linguoid (Dalrymple et al., 1978); and dimensionality, described as 2D, quasi-3D/2.5D, or fully 3D (Perillo et al., 2014).
2. Process associations. Origin (erosional versus accretionary/aggradational); formative flows (unidirectional, bidirectional, or interfering currents); flow settings (constrained or open); and driving mechanisms such as tidal, turbidity, or density currents.

Class-specific unit terms are addressed in the following sections. The Marine Setting classification tree (see section 4.4: Fig. 9) demonstrates how the Current-induced classification tree can be bolted on to these classes.

4.2. Fluvial

Because riverine, coastal and marine systems all respond to hydraulic forcing, these classes exhibit similar process-form relationships that produce analogous landforms across domains. Furthermore, exorheic rivers connect terrestrial and marine realms, and their geomorphic processes and arrangement of units are particularly sensitive to climate change and sea level fluctuations (Blum and Törnqvist, 2000). During lowstands, subaerial fluvial systems extended across continental shelves, incising valleys (Van Wagoner et al., 1990; Dalrymple et al., 1992) and depositing floodplains, deltas, and channel belts (e.g. Posamentier, 2001). During transgressions marine processes migrated up-dip, drowning continental shelves, and encroaching into these fluvial systems. Modern fluvial systems are similarly sensitive to variations in sea level and climate (e.g. estuarine squeeze: Little et al., 2022), and these drivers are expected to severely impact coastal and fluvial geomorphology and the communities that rely on them (Nicholls et al., 2007). Because fluvial and coastal systems are so inextricably linked, and because these are so often preserved as mixed-process assemblages on continental shelves (Ainsworth et al., 2011), the ISGM scheme incorporates Fluvial Setting terminology to support seamless integration of marginal- through deep-marine. Key sources for ISGM Fluvial unit terms include Knighton (1998), Goudie (2006), Brierley and Fryirs (2013), and Rhoads (2020), and more specific sources are cited for individual units.

In contrast to Current-Induced units, which are arranged in the decision tree by bathymetric relief and formative process, Fluvial BGU are organised in an approximately downstream order such that large portions of the Fluvial tree (Fig. 7) and the Coastal tree (Fig. 8) overlap with one another. To indicate this, these BGU are two-tone in both figures. Exclusively fluvial *drainage basins* (BGU; aka *catchments*) and their

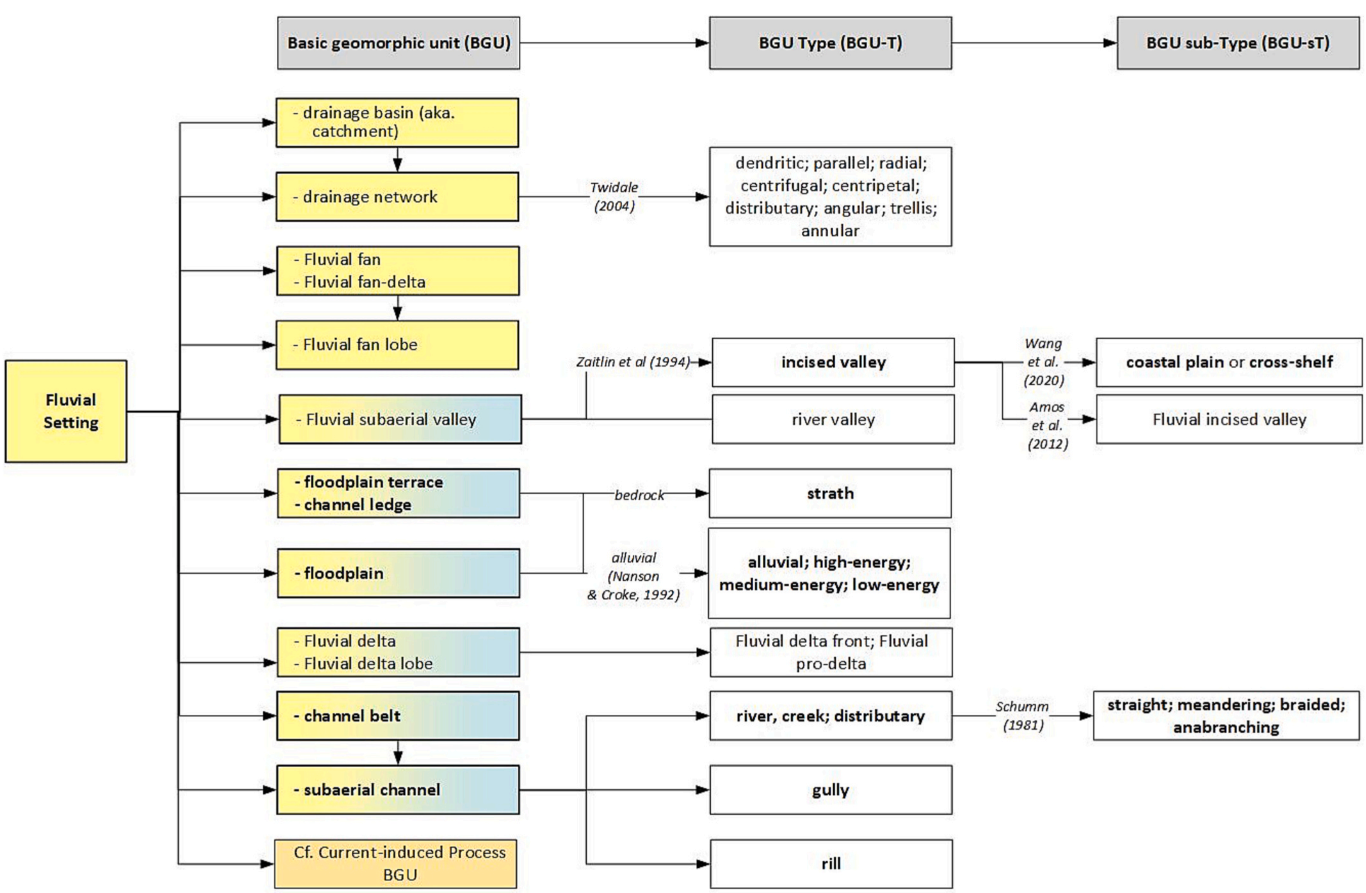

Fig. 7. Units formed in the Fluvial Setting. Bold units appear in multiple Setting/Process classification trees, and two-tone BGU are used to indicate units that can develop in both Fluvial (yellow) and Coastal (blue) settings (these are duplicated in the Coastal Setting tree – Fig. 8). See the Current-Induced Process tree (Fig. 6; orange) for additional units that can be reclassed as Fluvial. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

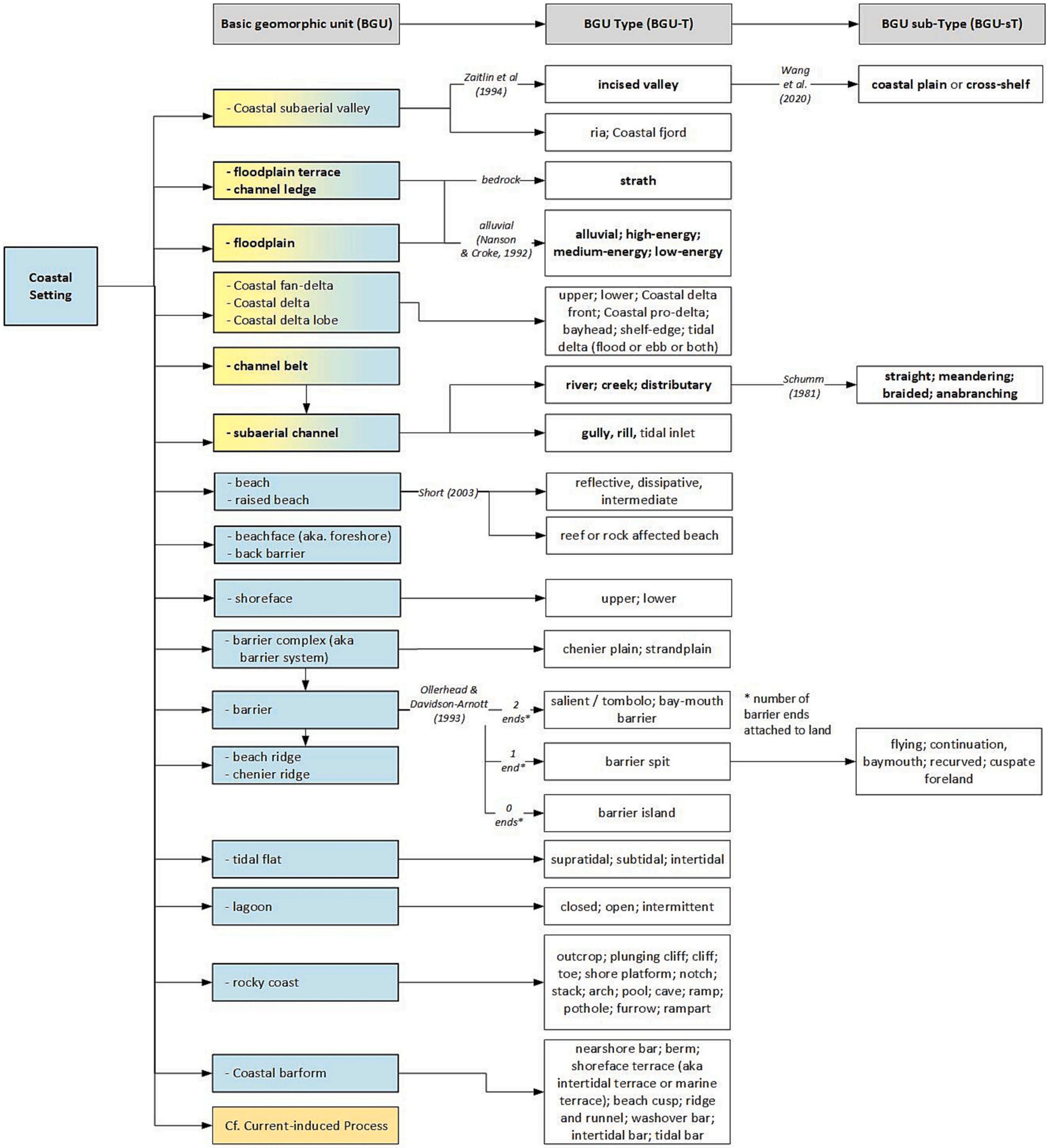

Fig. 8. Units formed in the Coastal Setting. Bold units appear in multiple Setting/Process classification trees, and two-tone BGU are used to indicate units that can develop in both Fluvial and Coastal settings (these are duplicated in the Fluvial Setting tree - Fig. 7). See the Current-Induced Process tree for additional units that can be reclassed as Coastal.

drainage networks (BGU; BGU-T: *dendritic, parallel, radial, centrifugal, centripetal, distributary, angular, trellis* and *annular*; Twidale (2004), are followed by the BGU *Fluvial fans* and their *Fluvial fan lobes* and *Fluvial fan-delta* (Nemec and Steel, 1988). Potentially coastally influenced BGU such as *Fluvial subaerial valleys* (cf. Blum et al., 2013), *floodplains*, *floodplain terraces* and *channel ledges* (and BGU-T *straths* that form in response to tectonic, climate or volcanic processes: Montgomery, 2004) are presented beneath these, as these BGU are duplicated in the Fluvial and Coastal decision trees. Fluvial *floodplain terraces* are created in response to various changes in the relationship between sediment load and stream energy, but all form in response to incision into bedrock or unconsolidated sediment whereby terraces are left as stranded landforms. Changes in base level, especially sea level, are major causes for their formation (Bull, 1990). *Fluvial fan-deltas* (i.e. with lacustrine termini: e.g. Nanson and Nanson, 2025*),* their *delta lobes (Fluvial)*, *channel belts* and *subaerial channels* are likewise repeated in the Coastal Setting (e.g. *delta* (*Coastal*)).

More specific terms are used to sub-classify Fluvial BGU where doing so provides useful insights into their discrete properties. With the exception of *drainage network* BGU-T patterns (above) and *river valleys* (BGU-T; as a type of *Fluvial subaerial valley* BGU), all BGU-T in the Fluvial tree have coastal equivalent units and are repeated in the Coastal classification tree. Where channel networks are preserved on drowned continental shelves, classifying their BGU-T provides insights into their origins, geotechnical properties, and potential habitat (Linklater et al., 2019). *Fluvial subaerial valleys* can preserve *floodplains*, *floodplain terraces* and incisional *channel ledges*; the hydraulic conductivity of these deposits, and their vulnerability to salt-water incursion, vary with their sedimentology (e.g. Klassen and Allen, 2017). Nanson and Croke (1992) described three broad categories of *floodplain* with relatively distinct stratigraphy*,* and these are adopted herein: *high-energy; medium-energy; low-energy* (BGU-T), and *alluvial* (BGU-T) can be used to indicate any of these.

Within the ISGM scheme, *Fluvial subaerial valleys* (BGU) are subclassified as either *river valleys* or *incised valleys*. *River valleys* form by fluvial incision upstream of tidal limits, and grade over geological timescales (e.g. Schumm and Ethridge, 1994; Blum et al., 2013) whereas *incised valleys* form further downstream on the coastal plain and continental shelf during relatively short sea-level lowstands (e.g. Blum, 1993; Zaitlin et al., 1994) and grade to mid- to outer shelf positions (Blum et al., 2013). *Fluvial incised valleys* (BGU-sT; Amos et al., 2012) result from fluvial incision and can be partly to fully infilled with lacustrine and fluvial sediment, whereas other types of *incised valley* may have purely Fluvial fills in their upper reaches that transition into marginal-marine and open-marine fills downdip (BGU-sT: *Coastal plain* and *cross-shelf*; Wang et al., 2020; cf. Coastal section 4.3).

Subaerial channels scale from smaller erosional *gullies* and *rills* to larger, lower gradient *rivers*, *creeks* and *distributary* channels. The latter are characterised by fill facies (Miall, 2013) that can be broadly classified into being the result of *straight*, *meandering*, *braided* and *anabranching* channel patterns (BGU-sT; Schumm, 1977, 1981). *Floodplains* and *subaerial channels* and their *channel belts* can be preserved within *Fluvial subaerial valleys*, or in *Fluvial fans* where channels become unconfined. *Fluvial deltas* and *Fluvial fan-deltas* can form where fluvial systems discharge into standing bodies of water (Nemec and Steel, 1988; Tye and Coleman, 1989; Nichols and Fisher, 2007). The boundary between a *Fluvial fan* and its *Fluvial delta* is defined by the backwater length, the upstream limit of the hydraulic effect of base level (Lane, 1957). The backwater limit, which determines the zone of maximum channel avulsion and migrates with fan-delta evolution (cf. Lane et al., 2017), provides a first order control on the distribution of discrete *Fluvial delta lobes* (BGU). The effects of coastal processes on the architecture of *Coastal deltas* are captured within the Coastal Setting section (Section 4.3), and subaqueous *Fluvial delta* components are subclassed as *Fluvial delta front* (coarser-grained and above wave base: Postma, 1984; Suter, 1994) or *Fluvial pro-delta* (finer-grained and below wave base; both BGU-T) (cf. *Coastal delta* BGU-T). Finer-scale bedforms and barforms formed by Fluvial processes are classified within the Current-induced Setting (Fig. 6) and can be reclassified to Fluvial where this origin is known.

4.3. Coastal

Coastal depositional systems develop in response to often complex interactions between tide, wave, fluvial (Boyd et al., 1992) and aeolian processes, and their architecture and composite units vary between transgressed and prograded states (Boyd et al., 1994). In contrast, hard, or rocky coasts respond primarily to tide and wave processes, but at longer time scales and these are essentially erosional in origin (Trenhaile, 1987). Seminal coastal texts (e.g. Boyd et al., 1992; Woodroffe, 2002; Short, 1999; Trenhaile, 1987; Griffin et al., 2012; Wright et al., 1974) were used to develop the list of units structured into the Coastal Setting.

Similar to Fluvial Settings, many coastal units can be formed by purely coastal, or by combinations of both fluvial and coastal, processes (cf. optional attributes above; Ainsworth et al., 2011) and are duplicated in the classification trees for each. Coastal processes can extend furthest inland via tidal and sea-level influences on *Coastal subaerial channels* and *Coastal subaerial valleys* (BGU-T: *incised valleys*; *–fjords, rias*) (Boyd et al., 1994; Wang et al., 2020), and these processes are preserved in their *channel belt* and *floodplain* facies (Nanson et al., 2012; Bourget et al., 2014; Lane et al., 2023). *Coastal incised valley* fills have traditionally been categorised into lower, middle and upper (up-dip) segments (Van Wagoner et al., 1990; Dalrymple et al., 1992; Boyd et al., 1994; Dalrymple and Zaitlin, 1994), and are simplified in the ISGM scheme as *coastal plain* and *cross-shelf* BGU-sT (Wang et al., 2020).

Coastal fan-deltas (Nemec and Steel, 1988) are similarly impacted by base level fluctuations and can be divided into three zones that preserve characteristic facies assemblages: (1) the *Fluvial fan* (upstream of the backwater limit: see Fluvial Setting); (2) the *upper delta* (BGU-T; between the backwater limit and the tidal limit) delta; and (3) the *lower delta* (BGU-T), within the tidal zone. The division between the *upper* and *lower* delta is a key classifier as this zoning captures contrasting river avulsion frequency (Chatanantavet et al., 2012) and the type and distribution of *river, creek and distributary* facies (*channel belts:* e.g. Woodroffe et al., 1989; Lane et al., 2017, 2023; Nanson et al., 2014; Nanson and Nanson, 2025) and *gullies* and *rills* (BGU-T). Their characteristically coastal geometries can also be used for palaeoenvironmental reconstruction (e.g. modern *creeks*: Nanson et al., 2013; ancient *subaerial channels* and *tidal inlets* in 3D seismic imagery: Bourget et al., 2013, 2014).

In addition to the full spectrum of delta types that are captured as optional attributes (Section 4) using the wave, tide and fluvial ratios described in Ainsworth et al. (2011), *bayhead* (Syvitski and Farrow, 1983), *shelf edge* (Steel et al., 2013), and *tidal deltas* (*flood-* or *ebb-* BGU-T; Boothroyd, 1985) are provided as more granular delta units and classifications. The subaqueous portion of Coastal *lower* deltas can also be further subdivided into their stratigraphically distinct *Coastal delta front* and *Coastal pro-delta* portions (cf. *Fluvial deltas*: Fig. 7).

Exclusively Coastal units are presented in the lower half of the Coastal Setting tree (Fig. 8), though these can be indirectly affected by fluvial processes (e.g. sediment supplied to prograde *barrier complexes*). *Beach* and *raised beach* BGU develop along wave-dominated clastic coasts (BGU-T: *reflective*, *dissipative* or *intermediate* beach types*; reef* or *rock-affected*: Short, 2003, 2006). Beach profiles can be broadly classified into the *beachface* (aka foreshore), between low-tide and the *berm* (BGU-T) crest at the maximum height of wave effect, and the *shoreface*, that extends from low tide to the inner continental shelf (Physiography). The shoreface is divided into an *upper*-shoreface, above which fair-weather waves interact with the seabed to construct nearshore *barforms*, and the *lower-shoreface* (BGU-T) that extends to storm wave base.

Where sediment supply is sufficient, *barriers* and *barrier complexes* (*chenier plain* and *strandplain* BGU-T) can net-prograde. These *barriers* (BGU) are comprised of individual *beach* or *chenier ridges* (Smart, 1977) and can be land attached at both ends (*tombolos / salient* (BGU-T) and *bay-mouth* barriers (BGU-T)), or at one end (*barrier spits* BGU-T; *flying*, *continuation*, *baymouth*, *recurved*, or *cuspate foreland*) or may have no land attachment *(barrier islands* BGU-T) (Ollerhead and Davidson-Arnott, 1993).

Along open coasts, or in *back barrier* zones (e.g. *lagoon* BGU), where tides dominate over waves, *tidal flats* (Woodroffe, 2002) can form and, depending on their elevation and setting controls, these can be *supratidal*, *intertidal* or *subtidal* (BGU-T). Further up-dip, coastal *floodplains* (BGU), *floodplain terraces* and in-channel ledges can also be usefully subclassified as *alluvial* or more specifically as *high-energy; medium-energy; low-energy* (BGU-T; Nanson and Croke, 1992). *Reef* and *rock-*

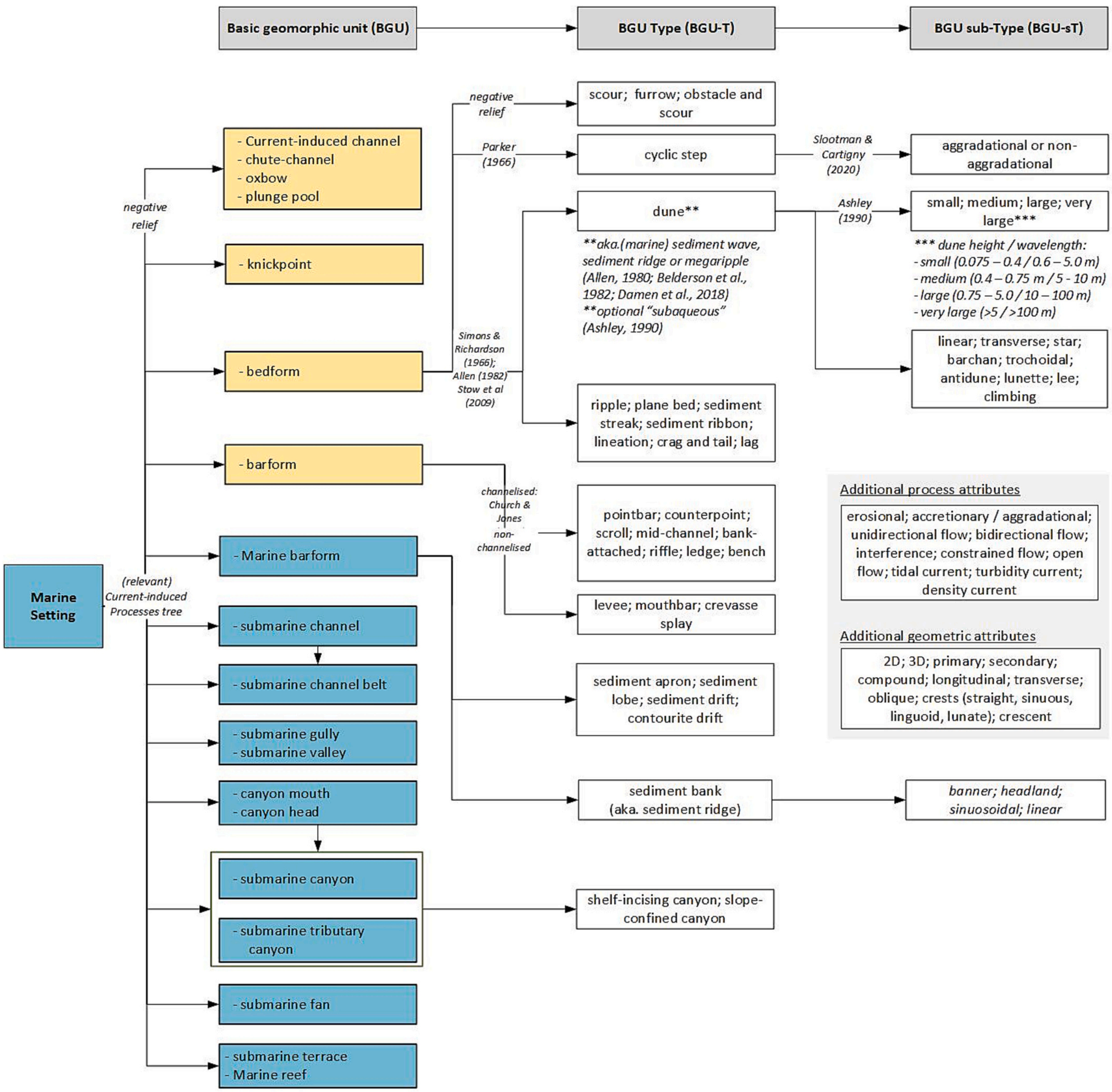

Fig. 9. Units formed in the Marine Setting. The Current-induced Process tree (Fig. 6) is "bolted-on" here as an example of how these units can be reclassed within multiple other Settings (e.g. Fluvial, Coastal). The remaining (blue) Marine Setting geomorphological units develop exclusively within the submarine environment. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

affected (BGU-T) *beaches* have immobile intertidal zones, with limited clastic material, and the anatomy of fully *rocky coasts* (BGU) can be mapped using a suite of BGU-T terms that are listed in Fig. 8 (e.g. *stack*, *arch*, *shore platform*: Trenhaile, 1987; Sunamura, 1992; Masselink et al., 2014).

A comprehensive list of *Coastal barforms* (BGU) types (BGU-T) are provided in Fig. 8, however, additional *bedforms* and *barforms* can be adopted from the Current-induced Process tree (Fig. 6) and process-classified as Coastal where their formative setting is known to be so.

4.4. Marine

Due to the expansive nature of the marine environment, all Processes (e.g. Mass Movement), and all Settings (e.g. Solid Earth) described within this classification framework include units that developed either entirely, or at least partially, within a submarine environment. Many of these units are more effectively understood and characterised within those other classes (e.g. *trough-mouth fan* – Glacial; *debris flow* – Mass Movement). The Marine Setting therefore incorporates geomorphological units that develop within the submarine environment (i.e. below Lowest Astronomical Tide (LAT)) and that are not more appropriately assigned to other classes.

One partial exception relates to Current-induced Processes, which, due to their prevalence in the marine environment, are duplicated within the Marine Setting classification tree (Fig. 9). The Marine Setting also incorporates a number of exclusively marine sedimentary (e.g.

contourite drift BGU-T) and erosional units (e.g. sub*marine canyon* BGU*)*, and together these are reviewed below to characterise the full suite of units within the Marine Setting.

Geomorphic classification of marine sedimentary bedforms has been a subject of extensive theoretical and applied research (Allen, 1968, 1980, 1982; Ashley, 1990; Belderson et al., 1982; Couldrey et al., 2020; Damen et al., 2018; Dix et al., 2023; Hulscher and Dohmen-Janssen, 2005; Lefebvre and Winter, 2021; Perillo et al., 2014) and this review incorporates their terminology and reasoning. Seabed geomorphic units are formed within the marine environment through interactions between complex hydrodynamic processes and variable geological substrates, over variable spatial and temporal scales (Camerlenghi, 2018). Relatively shallow continental shelves are variably impacted by both wave and tidal-current forcings, where *bedforms* and *barforms* of

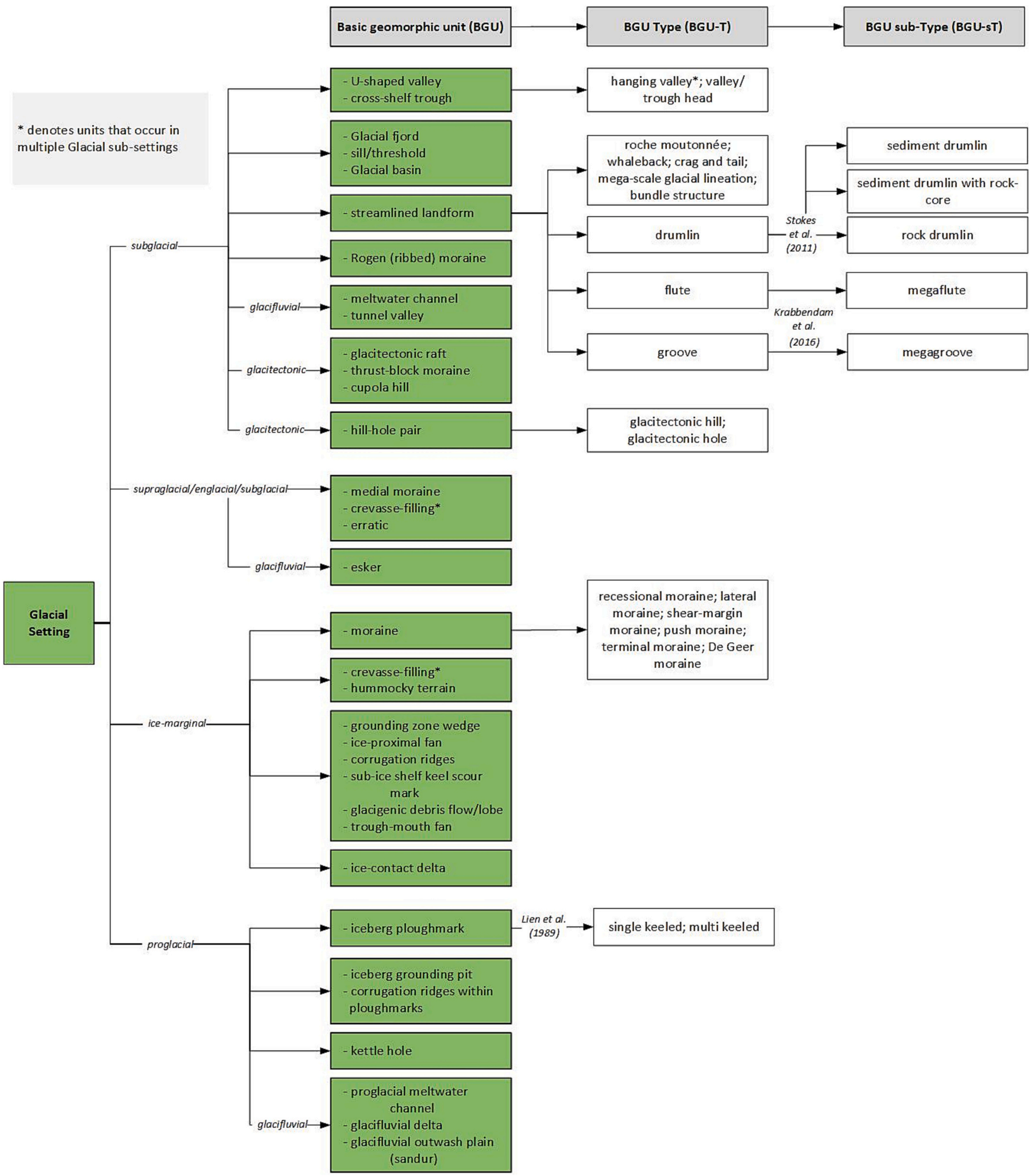

Fig. 10. Units formed in the Glacial Setting. * Denotes units that occur across multiple Glacial sub-settings (Lien et al., 1989).

unconsolidated sediments are common (e.g. Hashemi et al., 2015; King et al., 2021). Their character and distribution are functions of the balance between wave and tidal forcing (and their amplitudes/ variability) (e.g. Green et al., 2009), as well as the underlying geological substrate (e.g. sediment composition, consolidation, and thickness) and relative sediment supply (e.g. Durán and Guillén, 2018). These processes lead to a spectrum of both positive and negative-relief units that are commonly ephemeral and potentially mobile. As such, Marine Setting units are of significant interest for both anthropogenic developments (e.g. Dix et al., 2023; Couldrey et al., 2020) and ecosystem characterisation (e.g., Ryan et al., 2007; Meijer et al., 2023).

Descending from the shelf onto continental slopes, tidal and wave processes give way to oceanic (e.g. thermohaline) and density/gravity currents as the dominant forcing on unit genesis and character (e.g. Marine barform (BGU)- *contourite drifts* (BGU-T)) (e.g. Stow et al., 2009; Rebesco et al., 2014). Relatively large erosional units develop over longer time periods. *Submarine channels* can form on continental shelves and slopes, as well as at abyssal depths (e.g. Peakall et al., 2000). *Submarine gullies* and *submarine canyons* are the subject of significant research, due to their ecosystem significance and role in sediment delivery to the deep ocean basins (Baker et al., 2024). *Submarine canyons* form via a combination of turbidity currents and mass wasting, but may also have links to *submarine channels, submarine valleys* and terrestrial fluvial systems (Amaro et al., 2016; Amblas et al., 2018; Harris and Whiteway, 2011; Puig et al., 2014).

Some marine unit terminology varies slightly from Fluvial and Coastal Setting literature, partly resulting from distinct hydrodynamic processes and environments, but largely also due to variable usage between disciplines and researchers. In particular, the term *sediment wave (*e.g. *'sand wave')* has persistently been the preferred term for many practitioners describing Marine *dunes* (BGU; Hulscher and Dohmen-Janssen, 2005); their height / length and scales are described in Section 4.1 (Current-induced). The term *megaripple* has also been used to describe smaller *dunes* in Fluvial and Marine Settings (e.g. McCave and Geiser, 1979; Miall, 1988). Though Ashley (1990) reported the findings of a SEPM symposium focused on standardising the use of these three terms (*megaripple*, *sediment wave* and *dune),* and recommended the universal use of the term *dune*, many marine practitioners continue to use their preferred terminology. The Current-induced and Marine Processes tree's are intended to support these preferences and include megaripple and sediment waves as alternative ("aka") terms to describe *dunes*. For further discussion on *bedform* terminology see Section 4.1 (Current-induced), Hulscher and Dohmen-Janssen (2005), Madricardo and Rizzetto (2018) and Lefebvre and Winter (2021).

In the Marine Setting *Marine reef* includes any spatially heterogeneous, three-dimensional structures with morphological form that is different from the underlying substrata (Goudie, 2006). This broad definition encompasses any rocky outcrop substrate without inferring any particular process interpretation (See also *Biogenic reef* (BGU) in Biogenic Processes Section 4.7 for bioconstructed reefs).

4.5. Glacial

The Glacial Setting describes submarine landforms formed on currently or previously glaciated continental shelves. The majority of the described landforms are products of direct glacial action such as erosion, transport, deposition and deformation, but selected features of glacifluvial and periglacial origin are also included. The transient nature of glacial environments and processes means that many of the units are transitional and may be hard to differentiate, e.g. different types of streamlined landforms (e.g. Benn and Evans, 2010; Stokes and Clark, 2002; Stokes et al., 2011; Krabbendam et al., 2016).

Glacial landforms can be subdivided in different ways, such as based on their placement within a glacial sedimentary environment or land system, by their main formational processes and/or whether they are erosional or depositional (Benn and Evans, 2010). Here we cluster the landforms by their glacial sedimentary environment (e.g. "subglacial", "ice-marginal", "proglacial"). The Glacial Setting tree (Fig. 10) includes branches for these three environments, as well as a fourth for describing geomorphic units that are formed on the surface of, within and beneath the glacier ("supraglacial/englacial/subglacial").

The "subglacial" branch includes fourteen BGU formed at the glacier bed. It is further subdivided into glacifluvial and glacitectonic units formed subglacially. This part of the Glacial Setting tree includes eleven BGU-T and five BGU-sT. Eight of the BGU-T and all the BGU-sT belong to the BGU *streamlined landform*. Such units are frequently used as indicators for both ice flow speed and directions and are often mapped at this generalised level.

The "supraglacial/englacial/subglacial" branch of the Glacial Setting tree includes four depositional units that can be found in all three parts of a glacial system, where *erratic* is one example. The remaining three landforms are typically identified in the ice-marginal environment, where they have the highest preservation potential (although that varies somewhat between them). For instance, *medial moraines* are generally easy to spot on glacier surfaces but can be hard to distinguish post-deposition, while glacifluvial *eskers* usually stand out clearly in a glacier forefield. *Crevasse-filling* units are primarily observed post-deposition close to the ice-margin. Therefore, this BGU is included in both the "supraglacial/englacial/subglacial" and the "ice-marginal" sub-settings.

The "ice-marginal" branch includes units formed in the zone immediately beneath and beyond the glacier margin. This branch contains nine BGU and seven BGU-T. The latter all belong to the BGU *moraine*. As moraines mark the extent and pattern of retreat of a glacier/ice sheet they are often mapped at the BGU level. However, identification at the BGU-T level may further inform on both their palaeo-glacial environments and dynamics.

The "proglacial" branch of the Glacial Setting tree includes eight BGU and two BGU-T. Four of the BGU are related to calved icebergs and four are of glacifluvial origin. There is a degree of overlap or transition between the "ice-marginal" and "proglacial" branches. One of the BGU described in the Glacial tree (*glacifluvial outwash plain (sandur)* on the "proglacial" branch) is formed in sub-aerial landscapes. Submarine examples have later been drowned during a marine transgression.

In the Glacial Setting tree, some BGU are collective terms for a generalised landform population where they represent the coarsest level of meaningful mappable landforms. Examples in the Glacial Setting tree include *streamlined landform* and *moraine*. Streamlined landforms are indicators of ice flow direction and in some cases ice flow velocity. Similarly, moraines mark the lateral extent of glaciers, and their relative positions show the pattern of glacier/ice sheet retreat. These collective terms thus have value for geomorphic mapping and understanding of landscape evolution even without classifying the landforms to BGU type or subtype. Landforms that are typically found in close proximity to, or nested on top of, the glacial landforms described here are not included in the Glacial tree. Examples of these include *submarine gullies* and *submarine channels* (both in Marine Setting) on *trough mouth fans*. Landforms described from the terrestrial environment (but for which good examples have yet to be identified in marine records), have also been omitted here (e.g. 'ice shelf moraine': Smith et al., 2019).

For the majority of the BGU, BGU-T and BGU-sT included in the Glacial Setting tree we have adopted the terminology and glossary definitions (Bell et al., 2016, adapted from Bell et al., 1997) provided in the *Atlas of Submarine Glacial Landforms* (Dowdeswell et al., 2016*)* – one of the most comprehensive collections of papers on submarine glacial landforms that is currently available.

4.6. Solid Earth

The Solid Earth Setting classifies geomorphic units that belong to the broad remit of "solid geology". Although it cannot be considered as a "Setting" sensu stricto, it includes bedrock units that act as background

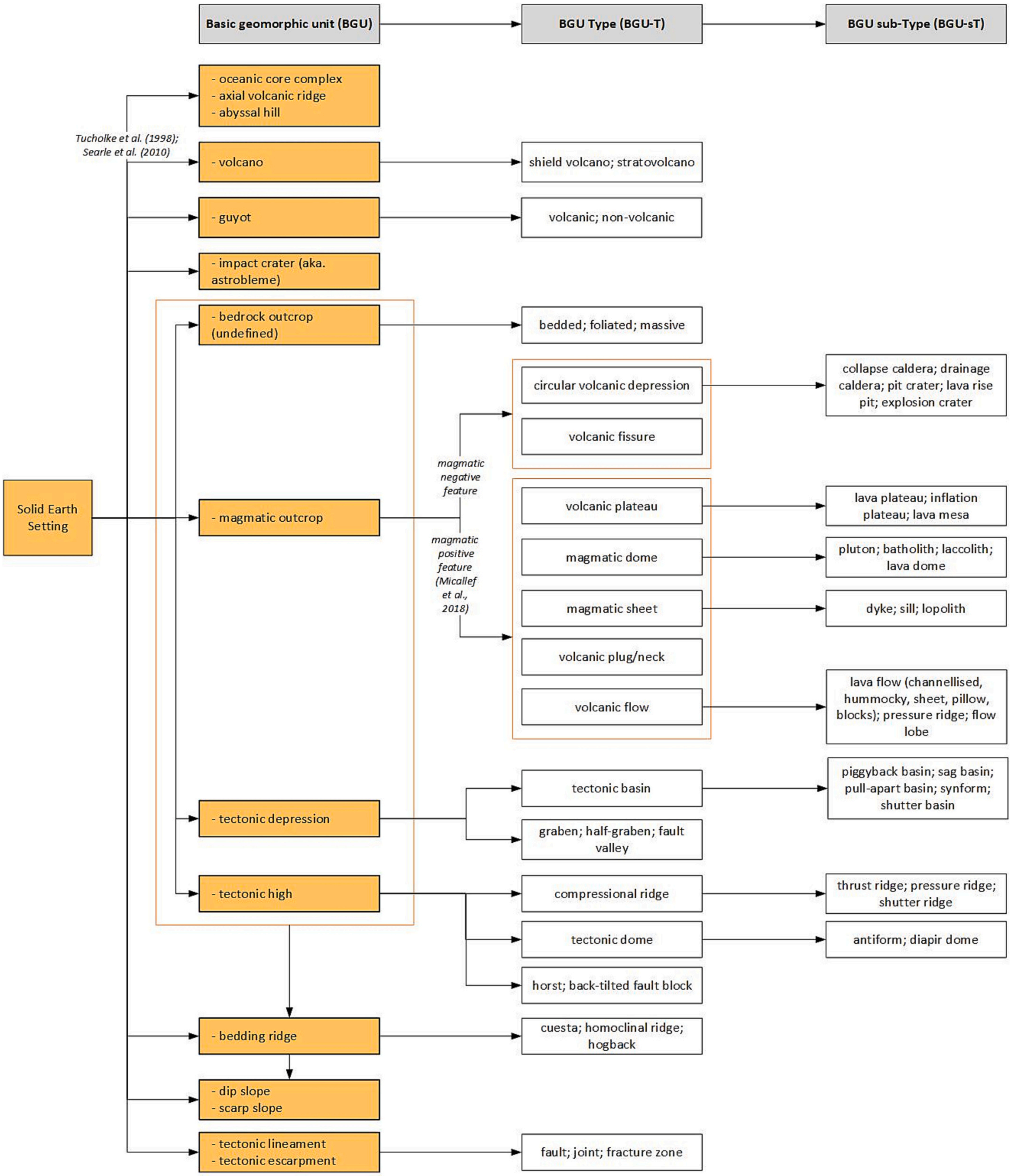

Fig. 11. Units formed in the Solid-Earth Setting. This tree contains units related to the structure of substrate geology itself. Only processes that formed (e.g. volcanism) or tectonically deformed the rock are included. The only exception is the astrobleme.

and underlie all other Settings and Process units. The units in this Setting include any bedrock outcrop independent of scale and lithology. This includes completely exposed or partially buried crystalline basement, overlying sedimentary strata, and intrusive/extrusive volcanic complexes. Units related to the configuration of the bedrock geology itself are structured and classified herein. We only consider the processes that formed (e.g. volcanism) or tectonically deformed the rock when using this setting to ascribe an interpretation to a feature. For example, *shore platforms* (Coastal) or bedrock *channels* (Current-induced; cf. additional attributes Section 4) are not included in Solid Earth as they are formed by wave and current erosion, respectively. The only exception is represented by the BGU *astrobleme*, which is technically an extra-terrestrial impact process, but has been included in this Setting for simplicity. While identification of impact structures in the submarine environment is relatively rare, there are at least a dozen identified astroblemes on the seabed (e.g. Legg et al., 2004; Lajeunesse et al., 2013), and it is useful to distinguish these from other crater-like forms for a range of applications.

Though there is a rich established terminology for describing bedrock geology, there is minimal precedent for systematic grouping and structuring purely for the purpose of geomorphic seabed classification, at least equivalent to that of other more established settings (e.g. Glacial or Fluvial). Because of the inaccessibility of the sites of interest, Solid Earth classification must be more generalised than onshore mapping. Therefore, in the selection and structuring of terminology for this Setting, we have relied on standard handbook terminology of subaerial geology (e.g. basic fold types) that can be readily transposed to the marine environment (Davis et al., 2012; Huggett, 2017; e.g. Thouret, 1999). Specialised marine geomorphology terms were also sourced from anthologies (Harff et al., 2016; Micallef et al., 2018) and internationally recognised classification systems, such as the EMODnet glossary (Asch et al., 2021), usually with minimal modification.

The underlying rationale for the list of BGU adopted herein (Fig. 11) is the ease of use and efficacy in the marine landscape where very high-resolution data or ground-truthing is often absent. BGU-T and BGU-sT are also grouped into a practical framework for geomorphic application, where generalisation and applicability for different end users are important. For example, the BGU *bedrock outcrop (undefined)* and *tectonic lineament* meet the specific need for managing uncertainty when mapping unknown seabed outcrops, and can be replaced by any of the other more accurate units if a better knowledge of the nature of the outcrop is acquired (e.g. *magmatic outcrop* [BGU]; *tectonic depression* [BGU] - *fault valley* [BGU-T]). The classification tree also operates a split between clusters of *magmatic*, *tectonic depression* or *tectonic high*, and general *bedrock outcrop* BGU. It essentially distinguishes between forms produced by magmatic activity, crustal deforming forces (e.g. folding, faulting and diapirism) and forms created by the geometrical disposition of bedding planes. Broad *magmatic outcrop* process categories (BGU-T and BGU-sT) are then clustered into negative and positive features, followed by more specific morphotypes. Emphasis is given to morphologies of magmatic intrusions or extrusions and tectonic forms, rather than outlining their geological or petrological implications, as the latter would add excessive complication to the classification system. Specific descriptions can be added and personalised by the mapper if required. Sources for the magmatic classification system and unit terms were mainly based on Casalbore (2017), Harff et al. (2016) and Thouret (1999), while structural terms were derived from general geology textbooks (e.g. Huggett, 2017).

Volcanoes, *guyots* and *abyssal hills*, *axial volcanic ridges* (Searle et al., 2010) and *oceanic core complexes* (OCCs) (Cann et al., 1997; Tucholke et al., 1998) are kept separate from *magmatic outcrop* for their composite, specific nature, and for their significance and abundance in our oceans. In their traditional interpretation *guyots* are a type of marine volcanoes whose distinctive shape is caused by subsidence and marine action (Menard, 1984); however, in modern literature the term has been also applied to flat-topped seamounts or microcontinents where faulting or plate tectonics are the dominant formational processes, or where biogenic growths build topography from microcontinental cores (Serrano et al., 2017). *Abyssal hills* are elongated topographic highs trending parallel to *mid-Ocean ridge* (Physiography: Wells et al., 2025d; Fig. 3b) axis. These are the most abundant landform on Earth and are also formed by competing crustal extension (block faulting) and volcanism (Buck and Poliakov, 1998). OCCs are domal massifs found at slow- and ultraslow-spreading *mid-ocean ridges*. They form where long-lived detachment faults unroof sections of lower crust (gabbros) and upper mantle (peridotites), bringing these rocks to the seabed (Maffione et al., 2013). The surface expression is often a corrugated dome or "megaboudin-like" structure, with a domal core and overlying volcanic carapace. Their surfaces often show corrugations (BGU *tectonic lineament*) caused by slip along detachment faults, and they are flanked by termination faults and axial valleys (Physiography), with adjacent *volcanic flows*. *Axial volcanic ridges* are instead elongate volcanic ridges that occupy the rift valley floor at slow- and ultraslow-spreading *mid-ocean ridges*. They form through repeated episodes of localized volcanic construction above the ridge axis, often within the axial *graben* (Searle et al., 2010). They show sub-parallel ridges with *lava flows (hummocky or pillow),* and they are often aligned with spreading direction, giving a segmented, ridge-in-ridge pattern.

While the *mid-ocean ridge* is strongly linked to volcanic processes, we have opted to move it to the Physiographic nomenclature for consistency with other macrozones (e.g. *oceanic trenches*; *continental shelves*).

4.7. Biogenic

Biogenic landforms (including positive relief bioconstructions and build-ups, and negative relief bioerosion) are three dimensional structures that can be attributed to the activity of organisms. Bioconstructions are formed in the submerged environment by a wide variety of organisms belonging to diverse taxa. Construction is typically modulated by biologically controlled or induced carbonate mineralization. The term 'bioconstruction' (Höfling, 1997) is a useful catch-all term in the context of biogenic geomorphology as it infers a process, as well as a landform component (Lo Iacono et al., 2018). The more general term 'build-up' can also be universally applied to morphological features of biogenic origin which develop from processes such as sediment trapping and baffling, or when no further information is available. In contrast, bioerosion, mainly by burrowing activity (bioturbation) shifts and removes material from the seabed (Kristensen et al., 2012).

This Biogenic Processes classification defines BGU terms that describe bioconstructions and build-ups that can be universally applied across any biogeographic region. The selection of terms and their definitions are intended to translate equally well across cold, temperate, and tropical settings to enable consistency between practitioners irrespective of oceanographic/climatic regime. The separation of BGU terms reflects discrete processes of formation resulting in geomorphic forms that can logically group together. Further, these BGU terms and their definitions are intended specifically for application to geomorphic mapping, while acknowledging that other disciplines (e.g., ecology, geology) and applications (e.g., habitat mapping) may apply different interpretations of these terms. For example, 'reef' used as a common catch-all term for all biogenic build-ups, as well as other features, can also be applied as a habitat type or community description.

Unlike most Settings described in Part 2 (Fluvial, Coastal, Glacial etc.) which have a mature, widely accepted and applied nomenclature, biogenic processes and bioconstructions are comparatively poorly defined in the context of geomorphology. Over time and across disciplines, a wide range of disparate features have been classified as 'reef' (Goudie, 2006; Riding, 2002) producing much debate in the literature over what constitutes a reef, and what non-reef or 'reef-like' features should be called. Despite almost a century of scientific discussion, most attribute-based definitions have proven contentious and difficult to apply (Riding, 2002). The challenge is further exacerbated in the context of geomorphology, where there is currently no unified, widely accepted and applied classification scheme inclusive of both cold, temperate and tropical terminology.

In defining the term "bioconstruction", Höfling (1997) recognised four main categories: bioherm, biostrome, reef mound, and mud mound. In Höfling's scheme, skeletal 'true reefs' were a subdivision of bioherms (Riding, 2002). The *Encyclopedia of Geomorphology* (Goudie, 2006) defines 'Reef' as "spatially heterogeneous, three-dimensional structures which have morphological form that is different from the underlying substrata". This broad definition includes rocky outcrops not just bioconstructions, and does not infer any particular process interpretation (see entry in Marine Setting: *reef* BGU). Definitions for 'Coral reef' are often tropical-centric and not inclusive of cold-water coral reefs (e.g., Goudie, 2006). *Submarine Geomorphology* (Micallef et al., 2018) provides a comprehensive chapter on cold-water-coral reefs and mounds (Lo Iacono et al., 2018), but tropical reefs are only mentioned quite generally in a section on continental shelf landforms, with no descriptions of geomorphic units. Similarly, the geomorphology of tropical coral reefs is well-described (Hopley, 1982, 2011; Maxwell, 1968), but does not translate well to cold-water-coral or temperate algal reefs. Bioconstructions that are aggregations of individual small elements such as rhodoliths (maerl), and non-calcareous bioconstructions are also poorly captured.

Temperate coastal bioconstructions by serpulids, vermetids, oysters and agglutinating polychaetes such as *Sabellaria* must also be satisfactorily captured in a unified biogenic geomorphic classification scheme. In temperate regions 'reefs' are often more like bioherms or biostromes in structure and include constructors such as *Sabellaria*, oyster, calcareous red algae, vermetids and serpulids (Goudie, 2006). Bioherms are "reef-like, mound-like, or lens-like" features with positive relief and of purely organic origin, while biostromes are thinner, sometimes bedded, and less developed structures than bioherms (Cumings, 1932). These categories have some merit in the context of geomorphology (Goudie, 2006) since discrete geomorphic units should differentiate between process, as well as form. However, many authors persist with the universal term 'reef', and this remains problematic since it provides no distinction between formative processes (e.g., autochthonous skeletal framework precipitated by tropical coral/algal comunities vs agglutinated sediment constructions by *Sabellaria* polychaetes).

The term 'mound' is similarly problematic. Several definitions for 'mound' and 'carbonate mound' are in common usage (see Riding, 2002

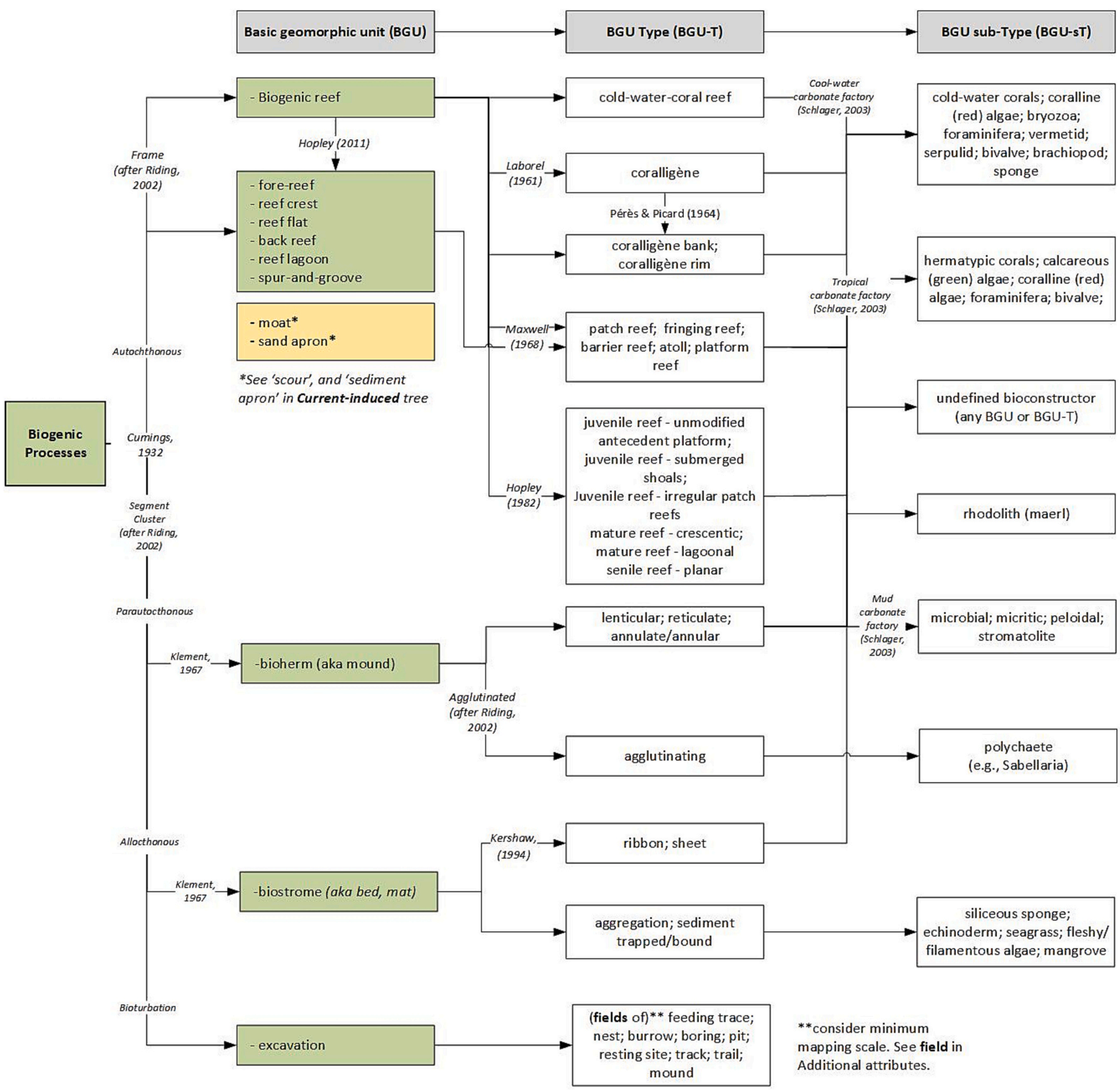

Fig. 12. Units formed in the Biogenic Setting (Kershaw, 1994; Klement, 1967; Laborel, 1961).

as well as Henriet et al., 2011, for discussion), that are equally as broad as 'reef'. In carbonate sedimentology 'mound' commonly refers to 'carbonate mud' mounds, although the term may also be used for poorly lithified structures such as '*Halimeda* mounds' (Braga et al., 1996), making it conflate with 'bioherm'. Similarly, mound is also commonly applied to deep/cold-water coral bioconstructions (Lo Iacono et al., 2018). In this context a cold-water-coral mound comprises a high skeletal component plus matrix, whereas a mud mound, by definition, contains few or no skeletons (Riding, 2002). These descriptions provide no unambiguous distinction to separate 'mound' from either reef or bioherm. Additional confusion is introduced since 'Mound' is an IHO Feature name and one of the adopted terms in Part 1 Morphology (Dove

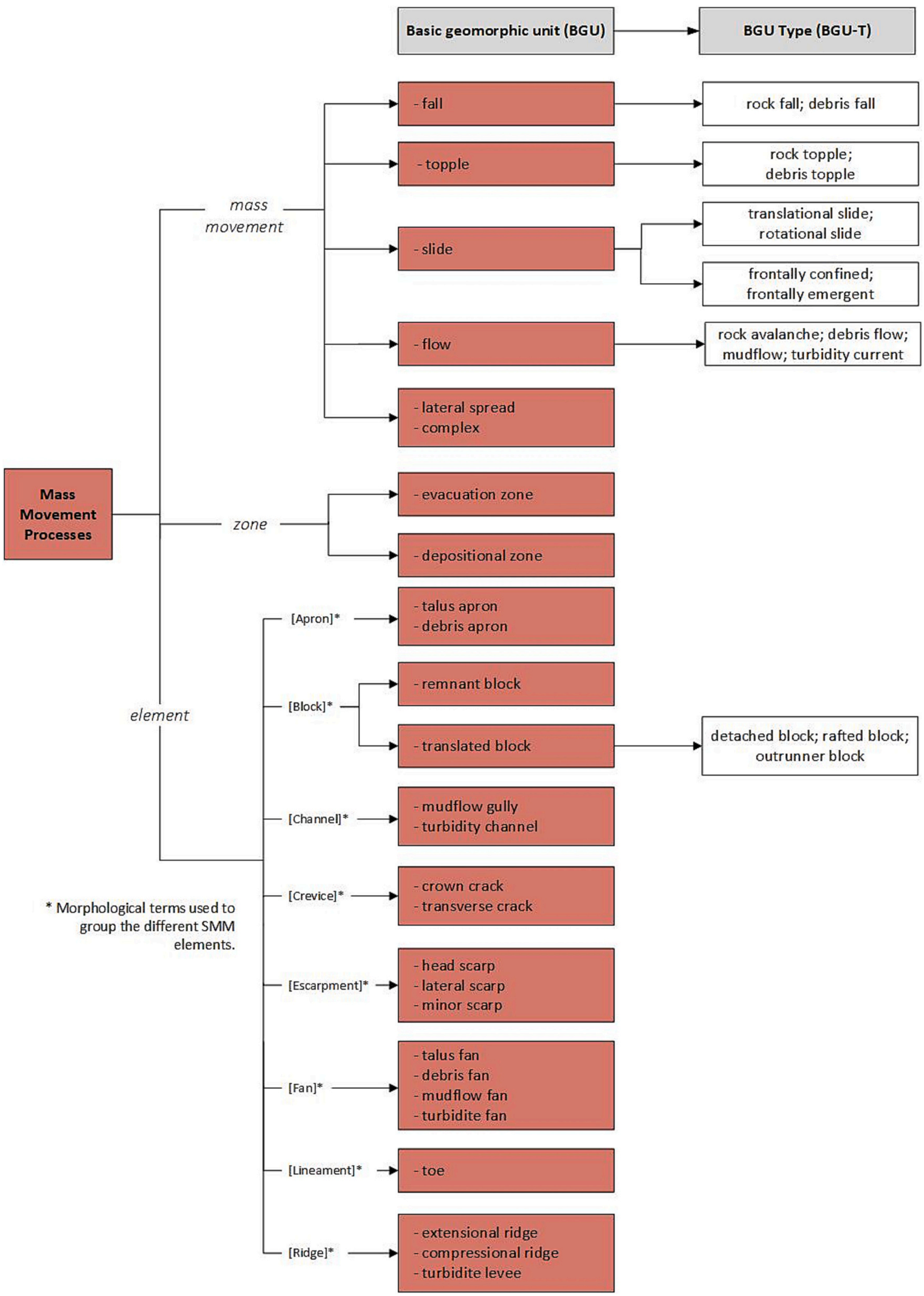

Fig. 13. Units formed by Mass Movement Processes.

et al., 2020b) describing any 'mounded' seabed feature whether biogenic or not. Where 'mound' is used in literature in relation to biogenic build-ups, it is often not apparent whether the author is describing morphology or geomorphology, or using the term interchangeably.

We have attempted to address these challenges and resolve a unified Biogenic geomorphology classification scheme that incorporates form as well as process, that is largely modified from the organic 'reef' classification scheme of Riding (2002). With only some modification, some aspects of Riding's scheme readily translate to geomorphology because their structure-based definitions (i.e., the physical, sedimentary support of the feature) can infer the biophysical processes that reflect fundamental controls on formation (Riding, 2002).

The list of BGU provided herein can be clustered firstly as autochthonous (formed in its present position), allochthonous (accumulating in a place different than the site of formation) or parautochthonous (any state where part of the material is in place and part is transported) skeletal components, and secondly (sensu Riding, 2002) as frame, segment/cluster, or agglutinated to provide discrete BGU based on form, structure, and process. The catch-all suffix 'reef' is removed except as applied to autochthonous framework *reefs*, and we include the terms *bioherm* (synonym *mound*) (adapted definition to exclude framework reefs) and *biostrome* (synonym *bed/mat*). The bioherm/mound and biostrome/bed/mat synonyms provide flexibility for workers to apply established terms in common use according to their discipline.

Biogenic reef may be further classified based on the main component (e.g., *cold-water-coral reef*, *coralligène*) or size/morphology (e.g., *patch*, *fringing*, *barrier*, *atoll* and *platform*) which relates to specific Types (BGU-T). The tropical coral reefs may also be classified using the development stages *juvenile*, *mature*, *senile* described by Hopley (1982) which relate to geomorphic forms resulting from biophysical processes and response to sea-level change. Biogenic build-ups are often described by naming the bioconstructor: e.g., *coral* reef, *Halimeda* bioherm, *algal* mat etc. These names are independent of geomorphology but for convention we have provided groupings of important bioconstructors as BGU sub-Type (BGU-sT) following the Carbonate Factory concept of Schlager (2003) where appropriate. The supporting classifiers *Frame*, *Segment* and *Cluster* adapted from Riding (2002)) are used as directional signposts to navigate the Biogenic classification tree (Fig. 12). The classifier *Frame* refers to state in which the structure is provided primarily by in-situ skeletons that are in mutual contact. *Segment* refers to a state where primarily matrix supported skeletons are adjacent and some may be in contact, but are mostly disarticulated. While *Cluster* refers to a state where the structure is primarily matrix supported including sediment trapping; skeletons are adjacent but not in contact.

The BGU *excavation* includes all features of positive or negative relief formed by the activity of living organisms (i.e. bioturbation). Some common excavations are listed as examples (BGU-T), but a full classification of ichnofacies/lebenspuren is beyond the scope of this scheme. Consideration should be given to the mapping scale whereby excavations may be mapped as a single *Field* rather than individual elements, although intensity and size of bioturbation may form separate geomorphological units on the sea floor when mapped in high resolution such as by photography or synthetic aperture sonar (Rubin-Blum et al., 2025).

4.8. Mass movement

Mass movement deposits comprise a wide spectrum of materials transported downslope *en masse* by gravity. These processes are also referred to in the literature as gravitational collapse, mass wasting, slope failure, or mass transport. Research on submarine mass movements has increased significantly in the past 20 years, supported by advancements in marine geophysical techniques. The classification of these movements has been continuously debated due to their occurrence in diverse geological settings and the range of transport mechanisms involved (e.g., rigid block motion to turbulent flow). Additionally, researchers from different disciplines often use varied terminology (e.g. Mulder and Alexander, 2001; Nardin et al., 1979; Shanmugam, 2000).

Mass movement classification schemes typically consider factors such as mechanical behaviour, particle-support mechanisms, sediment concentration, and deposit geometry to distinguish between mass movement types (e.g., Moscardelli and Wood, 2008; Nardin et al., 1979; Normark and Piper, 1991). However, static classification terminologies often do not adequately account for the continuous changes in shape and dynamics that may occur in a mass movement between its initiation and the final deposition (Mulder and Cochonat, 1996).

The BGU of the Mass Movement Processes classification tree are clustered into three broad groups, which indicate if the BGU represents: a) the totality of the seabed disrupted by a mass movement, b) a zone within the mass movement, or c) a specific element (Fig. 13). The terminology used in the first cluster includes units encompassing the total area affected by mass movement processes, and is primarily based on that of subaerial mass movements, following Varnes' classification (Varnes, 1978). The kinematic behaviour of the process (whether elastic, plastic or fluid) provides the rationale for the separation between BGU, with the BGU-T distinguished by criteria such as the type of displaced material or the geometry of the sliding surface. This cluster includes the following terms: *fall* (BGU-T: *rock fall*; *debris fall – depending of the material displaced*), *topple* (BGU-T: *rock topple; debris topple* – depending of the material displaced), *slide* (BGU-T: *rotational slide*; *translational slide* – depending of the geometry of the sliding surface*;* or BGU-T: *frontally confined; frontally emergent* – depending to their form of frontal emplacement according to Frey-Martínez et al., 2006), *flow* (BGU-T: *rock avalanche; debris flow; mudflow; turbidity current* distinguished by flow regime and material displaced), *lateral spread* and *complex*. The second cluster of terms is comprised of two BGU: the *evacuation zone* and *depositional zone*, corresponding to areas dominated by either the depletion or accumulation of the displaced material.

The third cluster of BGU terms is grouped by their prevalent morphology (Part 1 Morphology Glossary) and was sourced from commonly accepted and utilised terminology (e.g. Varnes, 1978; Bull et al., 2009; Scarselli, 2020). *Talus apron* and *debris apron* typically have a concave form and result from the accumulation of angular rock fragments and debris, respectively. Within the mass movement deposits and surrounded by deformed material, it is possible to find blocks of undeformed, coherent material, which can be in situ, in the case of the *remnant block* (BGU), or may have been transported over considerable distances, in the case of the *translated block* (BGU-T: *detached block*, *rafted block*, *outrunner block* - depending on the distance and type of transport). During the mass movements, channels can be carved, such as *mudflow gully* (BGU) or *turbidity channel* (BGU). Both *crown crack* and *transverse crack* are crevices associated with mass movements like landslides, with the primary difference being their location and orientation in relation to the landslide. The *head scarp* (BGU) is the escarpment that defines the upslope boundary of a mass movement, set between undisturbed and remobilised material. This contrasts with *lateral scarp* (BGU)*,* normally parallel to the main direction of transport, which represents the lateral confining boundaries. Secondary escarpments that can appear morphologically similar to the *head scarp* but are fully located within the *evacuation zone* are called *minor scarp* (BGU). A fan formed as a result of multiple mass movement events will be described as *talus fan, debris fan, mudflow fan or turbidite fan* according to the flow regime and material displaced. The lower boundary of a mass movement, set between the remobilised and undisturbed material, will define the *toe* (BGU). Finally, the ridges within a mass movement can be classified as *extensional ridge* (BGU)*, compressional ridge* (BGU) or *turbidite levee* (BGU). E*xtensional ridges* are typically observed close to the head scarp, *compressional ridges* are typically found in the distal parts of slides and *turbidite levee* flank the margins of a turbidity channel, formed by the embankment of sediments overflowed from a *turbidity channel.*

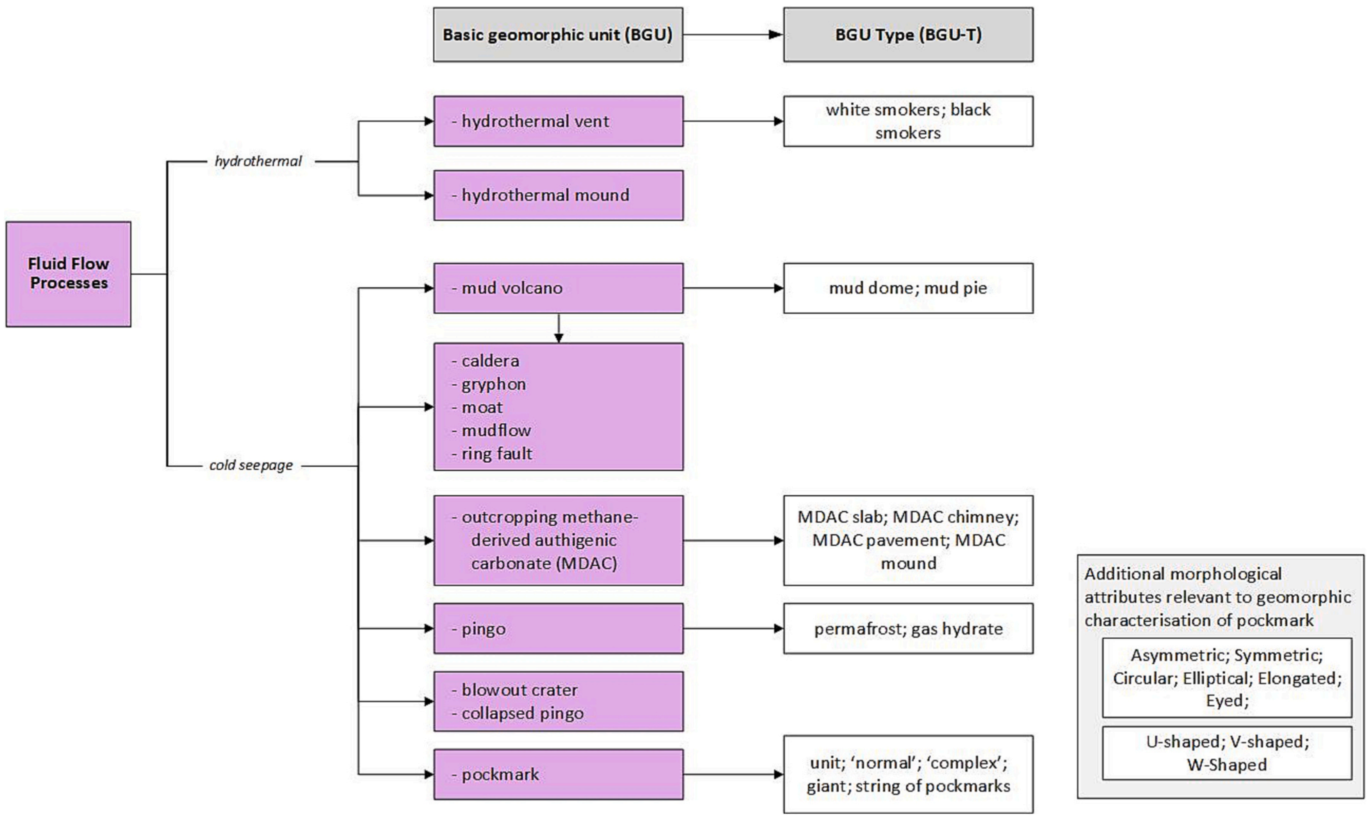

Fig. 14. Units formed by Fluid Flow Processes.

4.9. Fluid flow

The Fluid Flow Processes classification tree organises geomorphic units formed by the migration of fluids (liquids and gases) driven by pressure gradients. This migration can create structures of varied sizes, ranging from small methane-derived authigenic carbonate (MDAC) chimneys, typically 10 to 30 cm wide, to much larger mud volcanoes, several kilometres wide. These features can be found at different depths, from pockmarks in shallow coastal areas, e.g. Ria de Vigo in Spain (Martínez-Carreño and García-Gil, 2013), to black smokers typically located at depths of 2500 to 3000 m. The fluids can have diverse sources, including biogenic shallow-gas produced by microbial methanogenesis in anaerobic conditions (Judd and Hovland, 2007), or thermogenic deep-gases generated from thermocatalytic breakdown of complex organic molecules.

Petroleum geology literature often uses the term “seepage” to describe the expulsion of hydrocarbon-rich fluids, primarily methane (CH_4), from sedimentary basins prone to oil and gas formation. Etiope (2015) classified gas seepage into “macro-seeps” and “microseepage.” “Macro-seeps” are further divided into “focused flow” and “diffuse flow”, with focused flow subdivided into “gas seeps,” “oil seeps,” “gas bearing springs,” and “mud volcanoes”. This classification relies on the characteristics of the fluids, which are not always identifiable from seabed survey data due to the sporadic nature of seepage events. Therefore, terms that do not require the knowledge of fluid type have been adopted as well. The term “pockmark” was first introduced by King and MacLean (1970) to describe depressions formed in soft sediments off the coast of Nova Scotia as the result of fluid escape. Hovland and Judd (1988) classified pockmarks based on their morphology and other attributes, such as the presence of exposed MDAC at their base, thereby reinforcing their association with fluid flow processes. However, “pockmark” has also occasionally been used to describe depressions of similar shape with different origins (e.g., depressions excavated by fish: Mueller, 2015). In this paper, the term “pockmark” is used exclusively to refer to seabed depressions directly resulting from fluid flow.

The Fluid Flow Processes classification tree presented consists of two main branches (Fig. 14), broadly distinguished by the temperature of the fluids migrating through sediments: *a)* hydrothermal and *b)* cold seepage. Hydrothermal systems differ from cold seepage, as the temperatures of expelled fluids can reach 200–400 °C, while fluids from cold seepage are typically warmer than surrounding seawater but usually below 100 °C. *Hydrothermal vents* (BGU) are formed when seawater percolates through fissures in the ocean crust near spreading centres or subduction zones. The cold seawater is heated by hot magma and reemerges to form the vents. The particles are predominantly very fine-grained sulphide minerals formed when the hot hydrothermal fluids mix with near-freezing seawater. These minerals solidify as they cool, creating chimney-like structures. *Black smokers* (BGU-T) are characterised as black chimneys formed from iron sulphide deposits, while *white smokers* (BGU-T) are white chimneys formed from barium, calcium, and silicon deposits. *Hydrothermal mounds* (BGU) are structures composed of precipitated minerals that accumulate at hydrothermal vent sites. Although *hydrothermal mounds* (BGU) are not further classified here, they could be subdivided based on their dominant mineralogy (e.g., seabed massive sulphide primarily composed of iron sulphides, along with sphalerite, chalcopyrite, and/or galena as principal economic minerals).

The cold seepage branch includes the following BGU: *mud volcano* and their associated child-BGU, *outcropping MDAC*, *pingo*, *blowout crater*, *collapsed pingo*, and *pockmark*. The BGU *mud volcano* can be further classified into BGU-T based on the mud volcano morphology (*mud dome* and *mud pie*), with the main distinction made according to the angle of their flanks, which is determined by conduit morphology and the lithology of the mobilised sediments. The mud volcanoes child-BGU are: *mud volcano caldera* (the depression at the summit of a *mud volcano*), *mud volcano gryphon* (steep-side cone formed at gas-mud vents), *mud volcano*

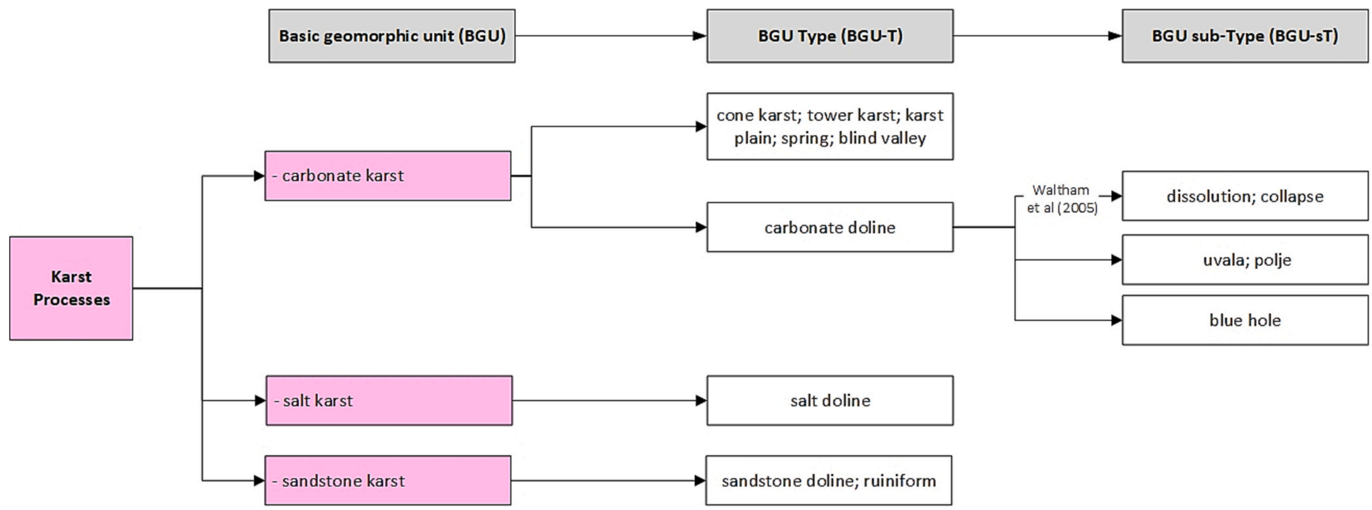

Fig. 15. Units formed by Karstic Processes.

moat (annular depression around a *mud volcano dome*), *mud volcano mudflow (*muddy slurry which moves downslope from the flanks of a *mud volcano) and ring fault (*semi-circular scarp around the *mud volcano caldera)*. *Outcropping MDAC* can be subdivided into BGU-T based on their geometry (*MDAC slab, MDAC chimney, MDAC pavement and MDAC mound*). This subdivision is significant as the MDAC geometry reflects its development based on the migration style and pathways of methane-rich fluids. The accumulation of hydrates within the subsurface can lead to the formation of *gas hydrate pingos* (BGU) and *blow-out craters* (BGU) due to abrupt gas expulsion. *Permafrost pingos* (BGU) and *collapsed pingo* (BGU) are found in submarine permafrost and are strongly associated with glaciations and related sea level changes (e.g., Paull et al., 2022). *Pockmark*, the most common cold seepage BGU, are prevalent in various marine environments. They can be further categorised into BGU-T types (*unit*, *'normal'*, *complex*, *giant* and *string of pockmarks*) based on Hovland and Judd (1988) pockmark types. Additional morphological attributes, such as asymmetric, elliptic and W-shaped, are often used to describe the shape of a pockmark and may indicate specific aspects of its development or seabed conditions.

4.10. Karst

The overriding geomorphic process forming karst landscapes is dissolution. Karst has been defined as a separate category (Process) in seabed geomorphology for those areas that have been dominantly shaped by chemical dissolution of soluble rocks, most commonly carbonates (carbonate karst BGU) but also found in gypsum/halite (evaporite karst BGU), and occasionally found in quartzite and sandstones (Wray and Sauro, 2017). The ISGM Karst Processes geomorphic terminology is sourced from general published texts (e.g. Ford and Williams, 2007). This nomenclature (Fig. 15) has been applied to submarine karst.

The key indicator of seabed karst geomorphology in carbonate rocks is generally the presence of closed depressions (*carbonate dolines*: BGU-T), but other features like *cone karst* (BGU-T), *tower karst* (BGU-T) and caves (with stalactites) have been identified. *Carbonate karst* (BGU) landforms in the Marine Setting are primarily relict (i.e. palaeokarst) and did not form under current conditions, as seawater is generally supersaturated with respect to calcium carbonate and so cannot dissolve carbonate rocks on the sea floor. The frequent glacio-eustatic sea-level changes throughout the Quaternary have led to the submergence of karst landscapes and coastal *karst plain* (BGU-T) that developed subaerially, and submerged Karst units, including *cone karst*, *carbonate dolines*, *blind valleys*, *springs* (all BGU-T), and caves (with stalactites: not included because beneath the seabed) have been identified in many coastal areas globally (e.g. Kan et al., 2015; Smart et al., 2006; Taviani et al., 2012). The *blue holes* (BGU-sT) found in reefs around the world, including the Bahamas and the Great Barrier Reef, are submerged karst features (Backshall et al., 1979; Mylroie et al., 1995). Some seabed karst landforms are still active; submarine Karst *springs*, which generally occur at shallow depths (<30 m below sea level), may discharge a mixture of freshwater and seawater that favours continuing limestone dissolution, resulting in ongoing enlargement of the caves feeding the springs (Surić, 2002).

Around the Mediterranean, submarine palaeokarst features can occur much deeper than elsewhere in the world, because sea level at the end of the Miocene dropped over 1500 m (Fleury et al., 2007), much greater than the ~120 m decrease during the LGM.

There are a few karst seabed features that did not originally form subaerially. *Carbonate dolines* (BGU-T) along the South Florida Margin, too deep to have ever been exposed subaerially, probably formed by enhanced dissolution due to freshwater/seawater mixing at the down-gradient end of the groundwater flow system (Land and Paull, 2000). The seabed dolines along the Bahama Escarpment, that lie at water depths of over 4 km, are interpreted to have formed by karstic processes at abyssal depths (Cavailhes et al., 2022).

Seawater is undersaturated with respect to salt (halite), and submarine *salt karst* topography appears to be actively developing on exposed areas of salt on the seabed in the Gulf of Mexico and the Red Sea, forming rough terrain with networks of ridges and valleys (Talbot and Augustin, 2016). On the floor of the Red Sea there are also collapse *salt dolines* (BGU-T) due to dissolution by upwelling fluids.

Sandstone karst (BGU) landforms formed by solutional weathering have similar morphology to their counterparts in carbonate rocks (Wray and Sauro, 2017), ranging from *sandstone dolines* to towers and cones (Migoń et al., 2017) and *ruiniform* (BGU-T) seascapes. Although the increasing role of mechanical erosion with increasing size of solutional features set *sandstone karst* landforms apart from dissolution-dominated *carbonate karst*, they are included in the Karst Processes tree for their similarities. No submarine examples of solutional sandstone landforms are currently known.

4.11. Anthropogenic

From the nineteenth century onwards Earth surface processes and landscapes have been increasingly and profoundly influenced by human activity. In the marine realm these activities include (but are not limited to) fishing, aggregate mining, oil and gas exploration, infrastructure and development (including aquaculture), coastal development, tourism, seabed cables, shipping, and the construction of wind farms. In addition to the threat that these activities can pose to the marine environment

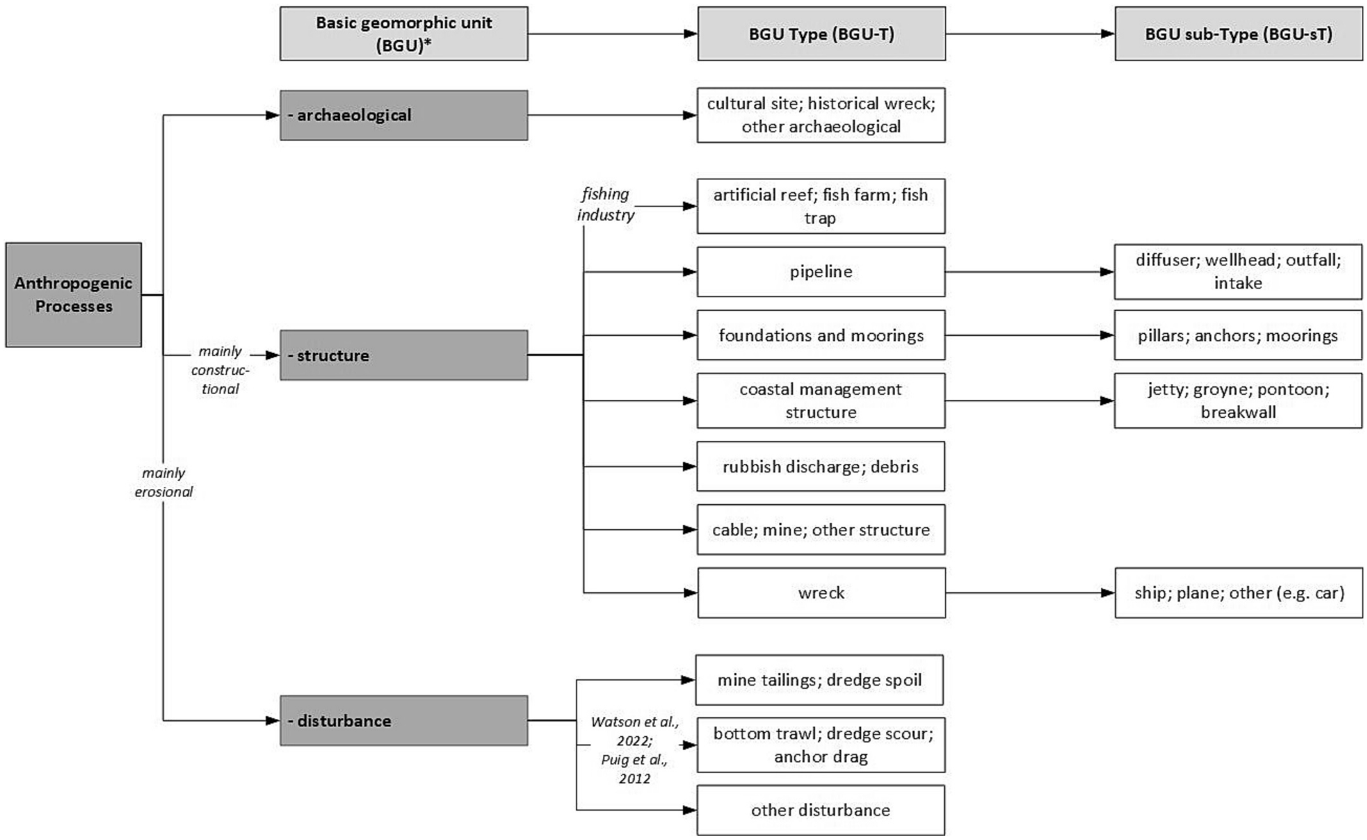

Fig. 16. Units formed by Anthropogenic Processes. Listed units are intentionally limited to those that are most frequently encountered and have no pretention of completeness. "Other archaeological", "other structure" and "other disturbance" allow for customised entries (Puig et al., 2012).

(Harris, 2020) they can also result in the placement of a broad range of ephemeral to long lasting structures and anthropogenic landforms that are mappable units on the seabed. The ISGM scheme addresses this new set of landforms in the Anthropogenic Processes classification tree and structures its fundamental terminology.

The three BGU in the Anthropogenic Processes tree represent the main groupings of anthropogenic units found at the seabed (Fig. 16). Following Watson et al. (2020), we separate *structure* and *disturbance* units, which represent mainly constructional (positive relief) and erosional human activities (negative relief), respectively. A third BGU, *archaeological*, adds further distinction to highlight units that might have particular heritage or cultural importance. As a complete list of Anthropogenic Process BGU-T would exceed the needs of this primarily geomorphic classification system, listed units are intentionally limited to those that are most frequently encountered. Additional BGU-T are captured as the generic other to support the user in inserting their own bespoke unit terms as required.

Unlike most "natural" geomorphic units, anthropogenic landforms may be considered non-uniformitarian, arising abruptly at human timescales, lacking natural analogues and changing configuration depending on the development of human technology (Hooke, 1994; Szabó et al., 2010). Their longevity ranges from ephemeral disturbance marks to persistent archaeological structures, and many interact dynamically with natural processes to form hybrid morphologies. Where a BGU from any other Setting or Process is the result of anthropogenic modification, that BGU can be classified using the original Setting or Process tree but with an added tag, "anthropogenic". For example, a scour caused by the presence of a wreck will be classified as Current-induced (Process) – *bedform* (BGU) - *scour* (BGU-T), anthropogenic (additional attribute).

5. Case examples

The author geoscience agencies and their collaborators have begun systematically applying the ISGM method to develop geomorphology map products across a range of spatial scales and resolutions. The following case examples highlight the diversity of Physiographic zones, geomorphic units and depth ranges to which the method has been applied by these agencies (Table 3; Fig. 3c). The first example presents a reclassified global Physiographic map that provides context for finer-resolution studies, followed by a selection of regional applications that are intended to showcase diverse agency priorities across a broad selection of Settings and Process classes (cf. Applications 1–6: Section 3.3).

Semi-automated and/or manual GIS workflows were used to map the Features (Part 1 Morphology) in these case examples, and these tools are indicated in each case example presented below. These Features were subsequently interpreted and then classified into geomorphic units using an Esri open-access tool (ISGM Seabed Geomorphology Classifier - ISGM SGC: Huang et al., 2026). The resulting maps are intended to showcase the distributions of geomorphic units, however, some examples retain Morphology features where their geomorphic origins are uncertain. A draft Esri style, including unique unit codes, has been used to illustrate these case examples and is intended to be published for community use.

5.1. Example 1: a reclassified global seafloor map

Harris et al. (2014a) described the first digital Global Seafloor geomorphic Feature Map (GSFM: Harris et al., 2014b), which was developed using a modified version of the SRTM30_PLUS bathymetric grid at 30-arc-second (~1 km) resolution, supplemented in key regions with higher resolution data (Becker et al., 2009). Their method combined fully manual, algorithm-assisted manual digitisation, and semi-automated delineation using ArcGIS tools, including contours, slope

Table 3
Summary attributes of case examples presented in Figs. 17–21. Basic Geomorphic Units (BGU) and BGU- Types (BGU-T) are listed. For ISGM Applications (App 1–6) see Table 1.

Example #; scale; bathymetry grid resolution	Physiography	Setting / Process classes											Depth (m)			
		Fluvial	Coastal	Marine	Glacial	Solid E	Curr.-i.	Bio.	Mass M.	Fluid F.	Karst	Anthro.	min.	max.	mean	app
1. ISGM global map – Fig. 17 (Supp 1; modified from Harris et al., 2014b) 1: 1,000,000; 1 km grid	All	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	10,500	3900	All
2. Irish continental shelf – Fig. 18 (Arosio et al., 2023a) 1: 40,000; 10 m grid	Continental shelf	*Subaerial channel*	NA	*scour; dune; sediment ribbon; sediment bank*	NA	*bedrock outcrop*	NA	NA	NA	NA	NA	NA	0	57	28	All
3. Beagle Marine Park (Australia) – Fig. 19 (Nanson et al., 2023b) 1: 25,000; 30 m grid	Continental shelf	NA	*Coastal dune; barchan; lagoon*	*submarine channel; sediment ribbon; sediment drift.*	NA	NA	NA	NA	NA	NA	*Carbonate karst plain*	NA	42	79	65	1, 4, 5
4. Orkney (UK) – Fig. 20 (Dove et al., 2025) SCALE 1: 10,000; 5 m grid	Continental shelf	*subaerial channel*	*shore platform*	*dune, sediment ribbon, sediment bank*	*iceberg ploughmark; moraine; meltwater channel; streamlined landform*	*bedrock outcrop; bedding ridge*	NA	NA	NA	NA	NA	*wreck; cable or pipeline*	*0*	*220*	*81*	*1,2,4,5*
5. Area north of Rijpfjorden (Svalbard, Norway) – Fig. 21 (Jakobsen et al., 2023) 1: 100,000; 5 m grid	Continental shelf	NA	NA	NA	*grounding zone wedge; glacigenic debris flow/ lobe; crevasse-filling; moraine; streamlined landform; drumlin; mega-scale glacial lineation*	NA	NA	NA	NA	NA	NA	NA	71	254	141	1, 3, 4, 5

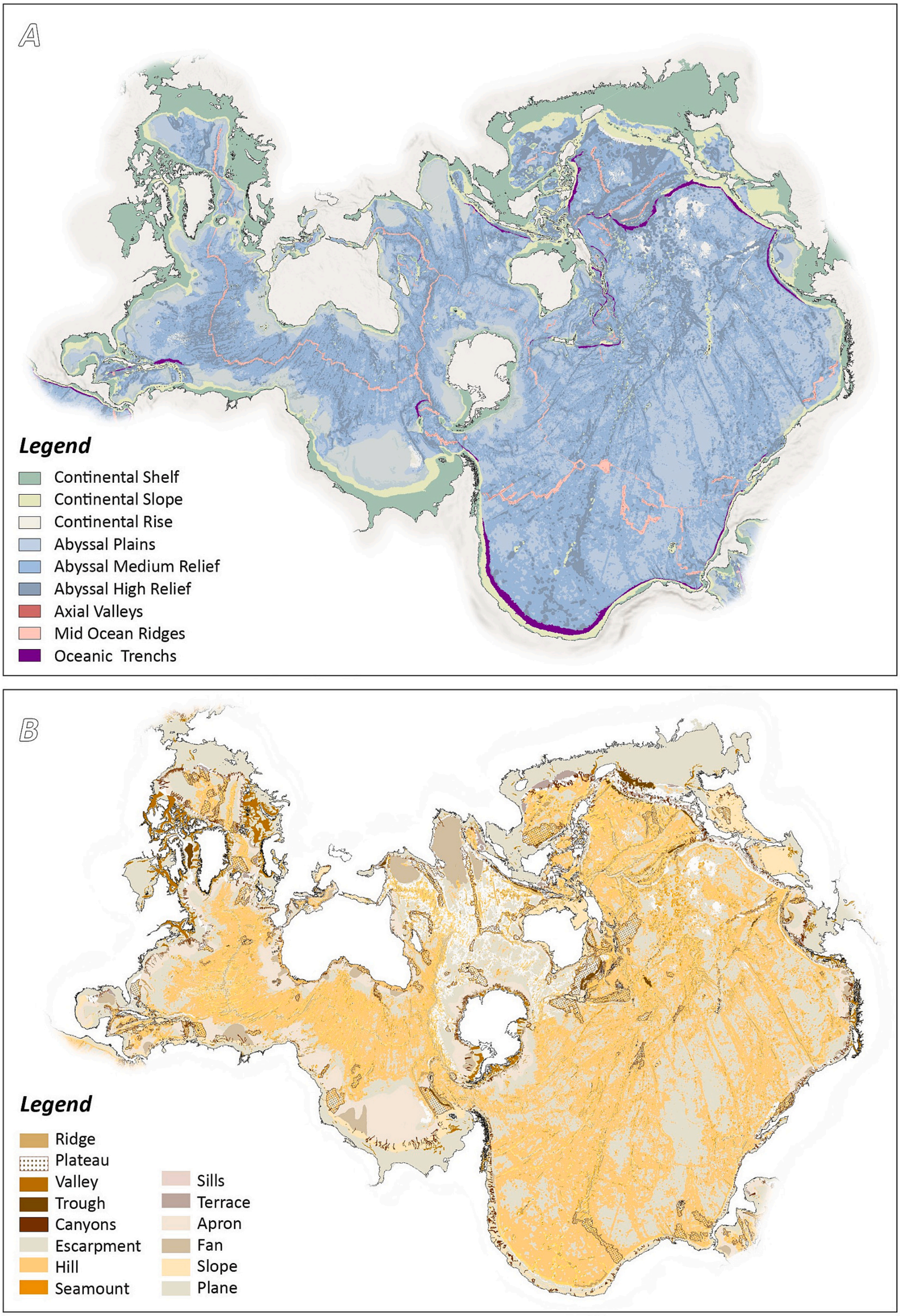

Fig. 17. A translation of the Global Seafloor geomorphic Feature Map (GSFM) (Harris et al., 2014b) into: (a) ISGM Physiography, and (b) ISGM Morphology. In (b) Aprons correspond to Continental Rise in (a). Adapted from the GSFM shapefiles developed by GRID-Arendal, Geoscience Australia and Conservation International (Harris et al., 2014b), licensed under CC BY 4.0. (https://bluehabitats.org/?page_id=58).

and shaded-relief analyses, followed by visual validation. The resulting dataset includes 131,192 polygons classified into 29 feature types.

In this case example the ISGM Physiography vocabulary (Nanson et al., 2023a; Wells et al., 2025d) has been applied to polygon shapefiles from Harris et al. (2014b), preserving the original boundaries and following the translation presented in Table 1. Physiographic units have been separated from Morphology Features to produce separate global map products that are fully aligned with ISGM terminology (Fig. 17a: ISGM Global Physiography; Fig. 17b: ISGM Global Morphology; Supplementary dataset 1: modified from Harris et al., 2014b). This new

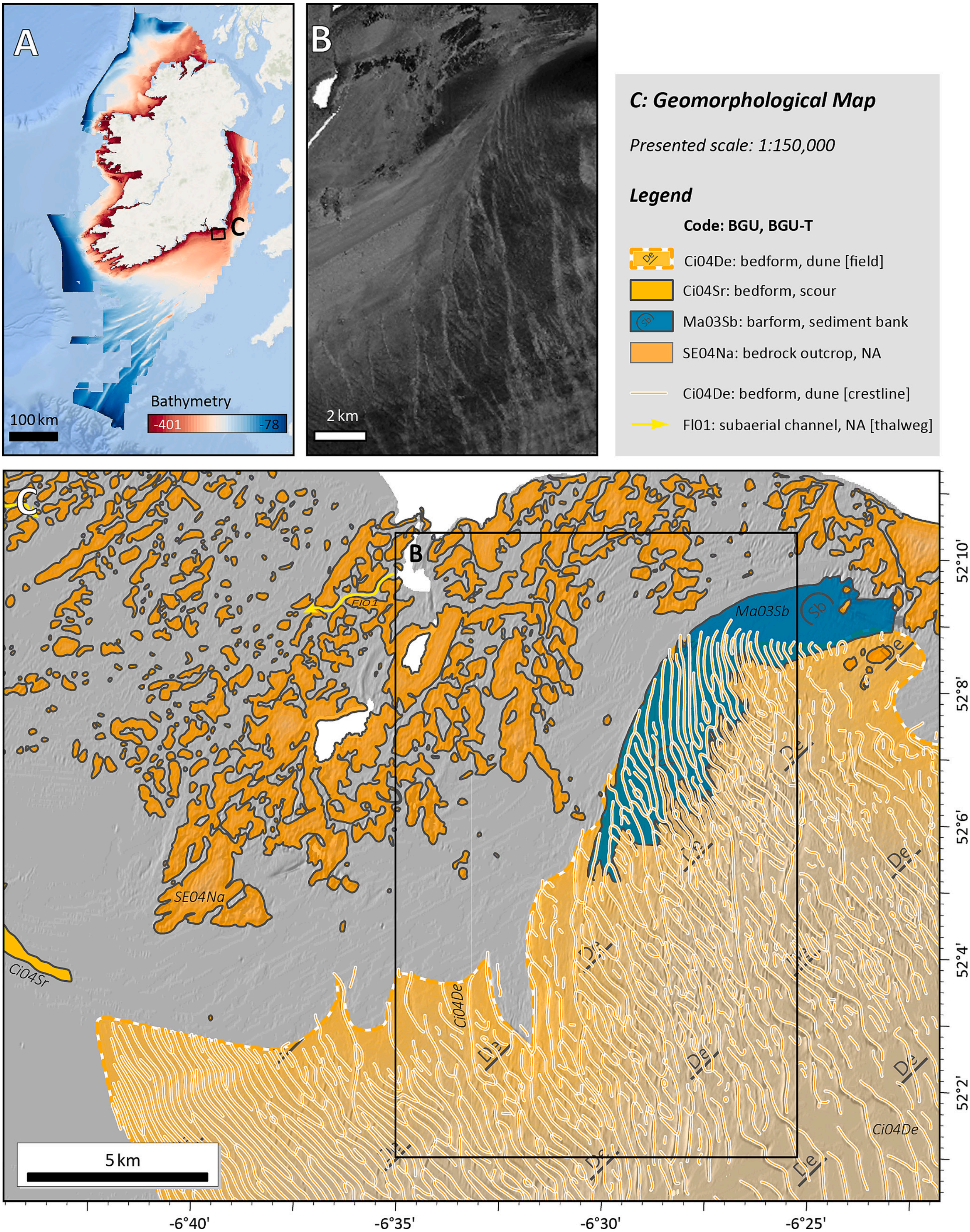

Fig. 18. (A) Bathymetry (10 m) of the Irish continental shelf that underpins the Irish Shelf Seabed Geomorphological Map v2023; (B) a sample backscatter grid indicating harder (light) and softer (dark) seabed (position indicated in part (C); (C) an example of the geomorphology mapping (Arosio et al., 2023a).

dataset avoids the original conflation of terms in the GSFM, clearly separating them into ISGM Physiographic, Morphological and Geomorphic terms (Table 1). The resulting Physiographic map (Fig. 17a) provides a distinctly geological representation of the world's seabed, with macroscale Morphology Features (Fig. 17b) presented separately without unintentional inferences made for their specific origins (e.g. Ridges and Troughs). This updated GSFM dataset provides a temporary ISGM-consistent macroscale context for finer scale studies that adopt the scheme. Future work should revisit the morphological analysis of global bathymetric datasets (e.g. GEBCO Compilation Group, 2025) for a targeted application of the ISGM classification.

The GSFM (Harris et al., 2014b) revealed several global-scale geomorphological patterns and the revised dataset continues to provide broad-scale context for various applications. For example, passive continental margins have a much wider average continental shelves (~88 km) than those associated with active margins (~31 km) and have broader continental slopes (~46 km vs ~36 km). Conversely, active-margin slopes contain much larger areas with gradients exceeding 5° (3.4 million km^2) than do passive margins (1.3 million km^2). These trends are relevant to process studies on sediment connectivity (ISGM Application 3 – *sediment*) and can be used to help frame geohazard assessments (ISGM Application 2 - *geohazards*). Harris et al. (2014a) also found that polar submarine canyons average twice the size of non-polar canyons, reflecting the influence of glacial sediment export to the deep sea, and that abyssal regions adjacent to glaciated margins exhibit lower seabed roughness, indicative of substantial Cenozoic glacial sediment deposition (ISGM Application 4 - *palaeoenvironments*).

Another key application of the GSFM has been for habitat and biodiversity assessment (ISGM Application 1 - *habitat*). Morphologic Features such as seamounts, ridges, canyon systems and continental slopes act as proxies for benthic habitats and biodiversity hotspots. The GSFM provides a spatial framework for understanding where different

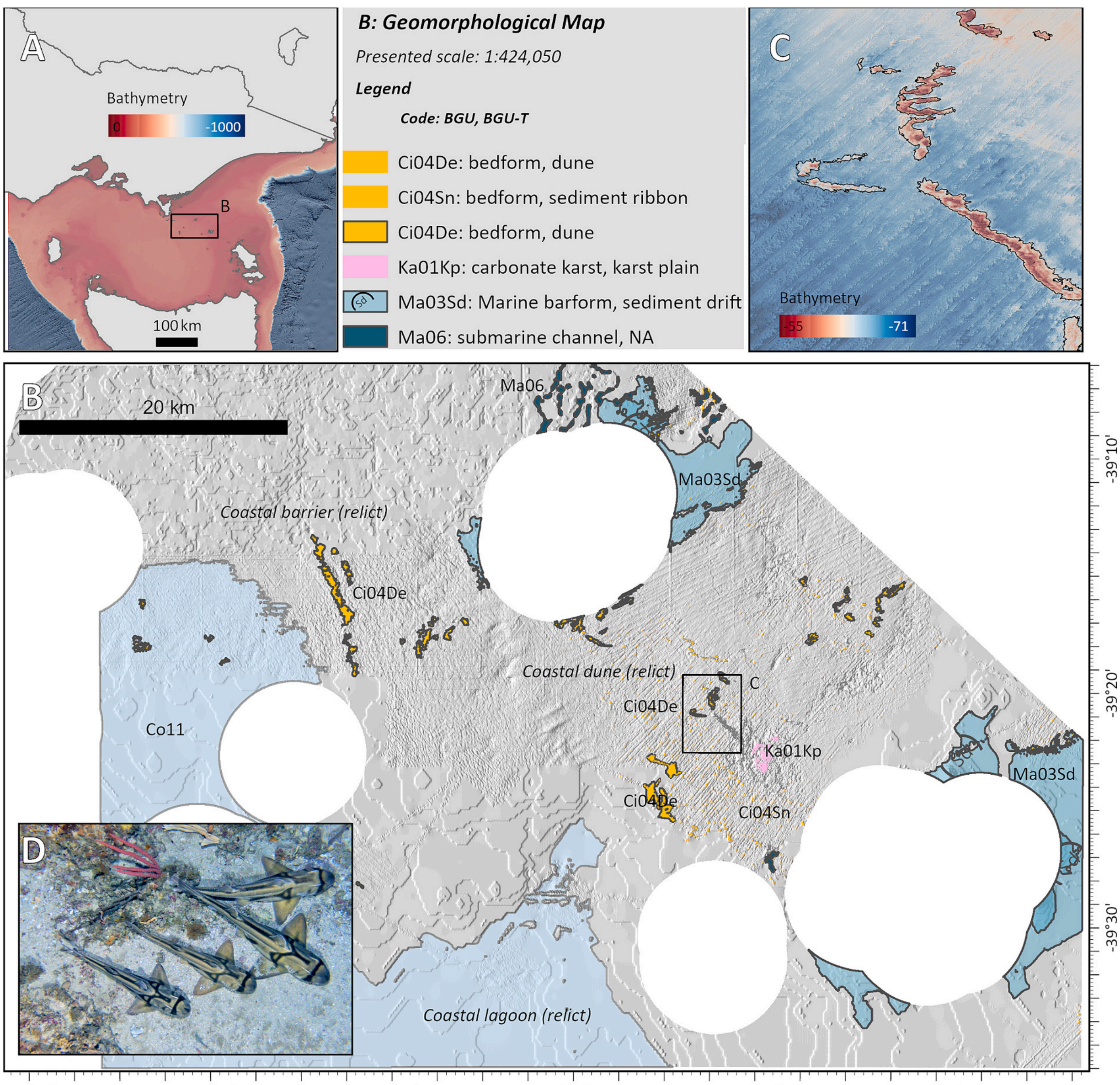

Fig. 19. (A) Bathymetry (30 m: Beaman, 2022) of the Bass Strait that underpins the Beagle Marine Park geomorphology map; (B) Multi-scale geomorphic mapping of the Beagle Marine Park using 30 m interpolated grid (modified from Nanson et al., 2022a, 2022b), with interpretations (e.g. relict Coastal barriers (Ci04De – outlined) and aeolian dunes, and active Marine sediment ribbons) supported by (C) patches of 1 m resolution bathymetry data (Nanson and Nichol, 2018). White areas are outside the marine park and are not included in the bathymetry grid. (D) Port Jacken sharks (Heterodontus portjacksoni) sheltering in the lee of relict coastal dunes in (C) (Barrett et al., 2021).

species assemblages may occur, aiding marine conservation planning and ecosystem mapping (e.g. Fischer et al., 2019).

5.2. Example 2: Irish Shelf Seabed Geomorphological Map

The Irish Shelf Seabed Geomorphological Map v2023 extends across the entire continental shelf of Ireland and draws on extensive multibeam echosounder bathymetry and backscatter datasets collected under the INFOMAR / Irish National Seabed Survey programmes. These bathymetric data were re-gridded to 10 m and 20 m resolution (https://www.infomar.ie/data) and processed via a semi-automated mapping workflow within GIS (ArcGIS Pro v2.8.8, Python 3.6; QGIS) to extract seabed landforms, supplemented by expert interpretation, backscatter grids (e.g. Fig. 18b) and harmonisation of earlier published mapping efforts. The ISGM classification scheme was adopted at the time of mapping.

The Irish Shelf Seabed Geomorphological Map (Arosio et al., 2023a); Irish Marine Atlas – https://atlas.marine.ie/) is intended to support the full suite of ISGM applications (1–6) but in particular for marine management and governance (ISGM Application 5 - management) by providing the digital baseline for spatial planning for maritime industries such as renewable energy, fisheries and seabed infrastructure, and can be used to inform environmental assessments. The map also has direct relevance to sediment dynamics and process studies on a shelf-wide level (ISGM Application 3 - *sediment*) as it records all the observable active seabed shaping processes (scouring, submarine bedforms etc.). Key science-interest points include the identification of previously unmapped landforms (e.g. *scours* and *subaerial channels,* Fig. 18), the harmonisation of earlier mapping interpretations (e.g. identifying contentious zones: north-west shelf and its glacial imprint), and demonstration of a semi-automated workflow bridging high-resolution bathymetry to thematic geomorphology for shelf-wide mapping, which were subsequently developed into the CoMMA toolbox (Arosio et al., 2024).

5.3. Example 3: Bass Strait, Australia

The ISGM scheme is being progressively applied to Australia's extensive marine park network, which spans tropical to cold temperate continental shelf and deep-water environments. These maps provide critical habitat proxy data for improved park management and conservation planning (Perth Canyon Marine Park: Nanson et al., 2022b; Beagle Marine Park: Nanson et al., 2023b; Flinders Reefs, Cairns Seamount: McNeil et al., 2023c; Zeehan Marine Park: McNeil et al., 2023b). The application to Beagle Marine Park in the Bass Strait (Fig. 19A) represents a key example whereby geomorphic mapping (Nanson et al., 2022b) and habitat data (Barrett et al., 2021) have been used to inform key management decisions.

Mapping in Beagle Marine Park was undertaken using Geoscience Australia's Semi-automated Morphological Mapping Tools (GA-SaMMT: Huang et al., 2023), applied to a 30 m resolution interpolated bathymetric grid (Beaman, 2022) to produce a (Part 1) Morphology Feature map at 1: 25,000 (Fig. 19B). Backscatter, seabed imagery, sediment samples and sub-bottom profile images, with additional interpretation of discontinuous 1 m resolution bathymetry data (Nichol et al., 2019; Fig. 19C), were used to interpret the geomorphology of these shapes. The resulting map illustrates a diffuse arrangement of thin, modern and relict geomorphic units over shallow basement. This example underscores the need for high resolution bathymetry datasets to effectively interpret units observed in coarser-resolution grids. Here, Marine *sediment ribbons* aligned approximately parallel with survey track lines (Fig. 19B, C) intersect with relict units (described below); the geometry and geomorphic interpretation of both units were inconclusive when using only the coarser grid.

The Beagle Marine Park is positioned on the Continental Shelf over the ancient Bass Strait land bridge that connected mainland Australia to Tasmania intermittently during the Quaternary (Lambeck and Chappell, 2001). Within the park, modern Marine *bedforms* and *barforms* intersect with semi-lithified relict coastal dunes (*barriers)*, which developed along the shoreline of the former *Coastal lagoon* (interior seaway), and 2–5 m high aeolian *dunes, which* formed at higher elevations across the subaerial corridor (ISGM Application 4 – *paleoenvironment*; Nanson et al., 2025). These *dunes* are preserved discontinuously across 20 km of seabed between the Kent and Hogan Island Groups. They now represent rare mesophotic reef ecosystems that support a sessile invertebrate assemblage comprised of bryozoans, hydroids and a high diversity of temperate sponges (Barrett et al., 2021). Abundant and diverse demersal fish communities are associated with these reefs, as well as large aggregations of Port Jackson sharks (*Heterodontus portjacksoni*; Fig. 19D), suggesting that these features are important for the species during winter foraging migrations to Bass Strait (Barrett et al., 2021; ISGM Application 1 - *habitat*). This information has guided marine park rezoning decisions, culminating in the declaration of a new National Park Zone in February 2025 to recognise the high natural value of these habitats (Director of National Parks, 2025; ISGM Application 5 - *management*). These findings also underscore the cultural and ecological significance of the region (ISGM Application 4 - *paleoenvironment*; Kennedy et al., 2025) and demonstrate the utility of geomorphology mapping for underpinning the management of Australia's marine park network.

5.4. Example 4: Orkney, UK

The British Geological Survey (BGS) has recently initiated a seabed geology mapping programme to develop fit-for-purpose geospatial products to support a range of offshore activities, including offshore energy and infrastructure development, environmental dynamics research, and marine spatial planning (including conservation) (https://www.bgs.ac.uk/datasets/bgs-seabed-geology/). These consistent maps are designed to provide detailed and accurate baseline map products using high-resolution multibeam echosounder bathymetry, supported by further data (e.g. available cores and seismic) and information (relevant academic and commercial publications). This new Seabed Geology map suite incorporates three separate thematic layers: Seabed Geomorphology, Substrate Geology, and Structural Geology.

The developing ISGM scheme has been fundamental to this initiative, providing a robust classification standard on which to base geomorphological analysis and mapping. One geographic region that has been mapped is a large area of seabed surrounding the Orkney Islands, off mainland Scotland (Fig. 20) (BGS, n.d.). The waters around Orkney host a number of Marine Protected Areas (MPAs) and key fisheries (ISGM Applications: 1 – *habitat*; 5 – *management*), numerous active and planned renewable energy developments (wave, tidal, and wind; ISGM Application 2 – *geohazard* assessment), and important maritime archaeological sites (from pre-history to WWII, notably Scapa Flow; ISGM Application 4 – *paleoenvironment*).

Multibeam echosounder bathymetry and backscatter data from Orkney, like much of the UK, were acquired by the UK's Civil Hydrography Programme. In total, the Orkney Seabed Geology mapping area covers approximately 10,000 km^2. The geomorphological linework was captured both via manual digitisation, and by semi-automated processes to produce consistent linework for specific seabed features. Semi-automated linework was employed, where appropriate, to enhance mapping accuracy and efficiency, reducing geologist bias. Within this BGS mapping, Morphological Features and geomorphological units may be captured as points (e.g. wrecks), lines (e.g., break in slope), polygons (e.g. moraine), and polygons as unit assemblies (e.g., field of *dunes*).

The seabed around Orkney records a number of environmental processes that have operated over variable timescales. The bedrock comprises primarily Devonian sedimentary rocks, which due to the modern high-energy hydrodynamic environment, are frequently exposed at the seabed (Fig. 20). Glacial landforms from the Last Glaciation (MIS 2), including ice-marginal *moraines*, *streamlined landforms*,

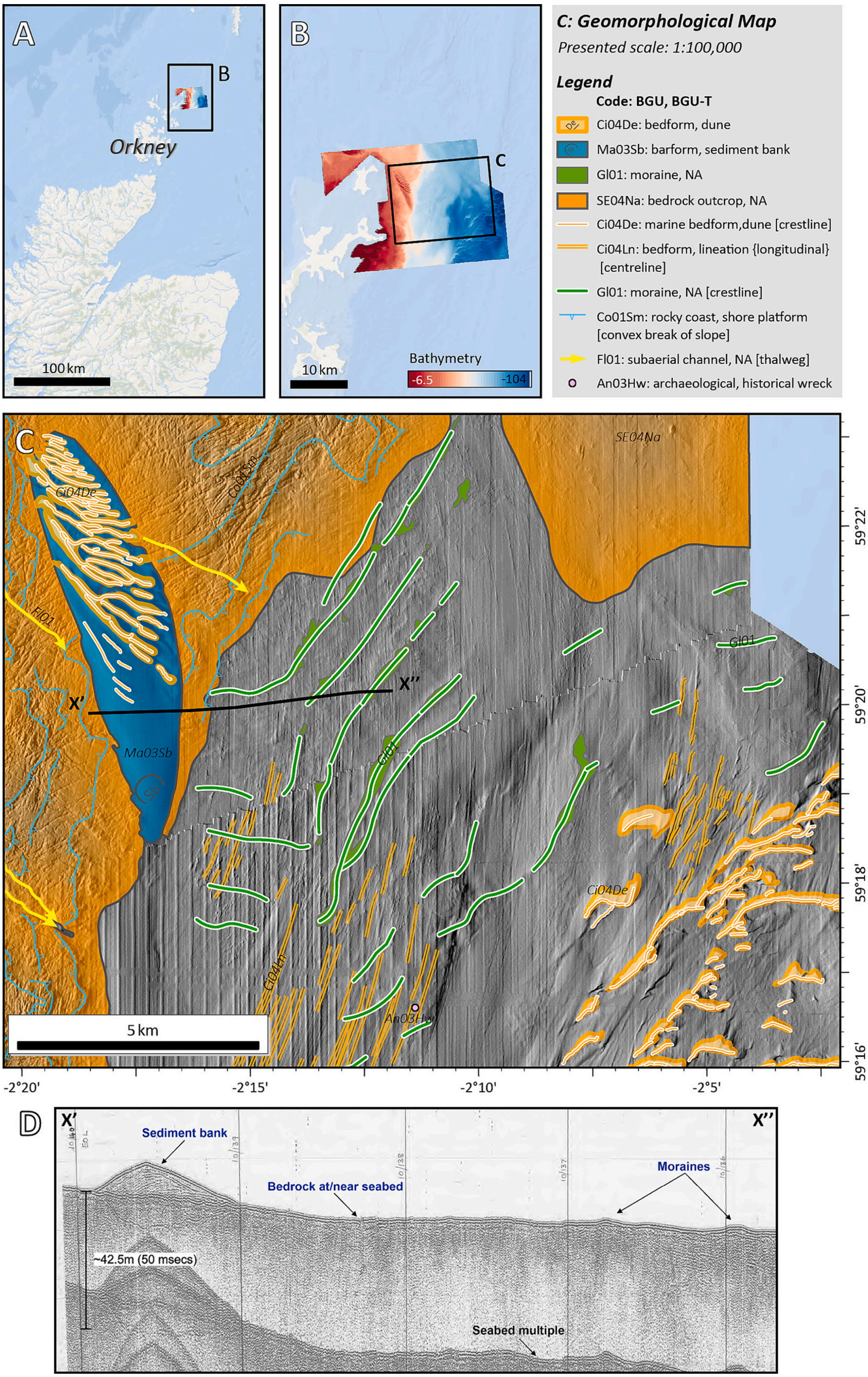

Fig. 20. (A and B) Bathymetry of the Orkney that underpins map C (Dove et al., 2025); (D) Extract of legacy BGS seismic line (sparker source) demonstrates how shallow sub-surface data can support bathymetry-based geomorphology interpretation (position indicated in part (C).

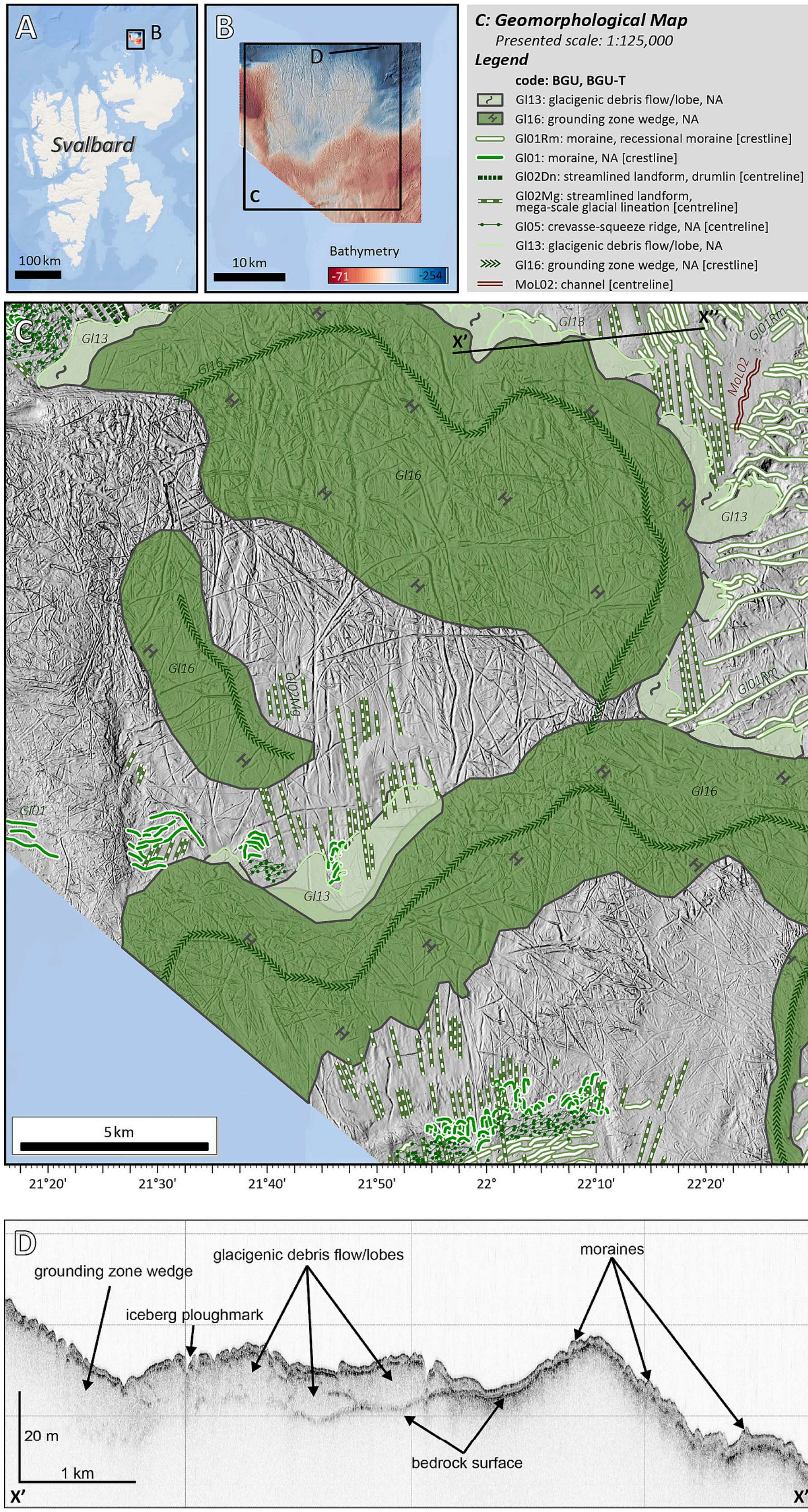

Fig. 21. (A) Location of the study area on the shelf north of Svalbard (B) bathymetry data (C) ISGM morphology/geomorphology map (NGU after Jakobsen et al., 2023) with hillshaded bathymetry data ©Kartverket (D) Sub-bottom profile line illustrating how these data give further insight supporting the interpretation of geomorphic features.

and *meltwater channels* illustrating past ice sheet dynamics, and influencing sub-surface sediment heterogeneity (Bradwell et al., 2021). Post-glacial to early Holocene sediments are preserved within large basins, and numerous modern Current-induced *bedforms* are widely distributed (including *sediment ribbons, dunes*, and large *sediment banks*). One geomorphic assemblage of particular interest is a sequence of bedrock terraces interpreted as submerged *shore platforms*. These units have been the focus of targeted research (Dove et al., 2025), which shows that each landform pair (i.e. terrace = *shore platform* and landward Escarpment) likely represents a single sea-level stillstand event. The well-preserved *shore platforms* attest to formation during multiple, separate periods of RSL stillstand (probably 5–7), though chronology remains unconstrained.

5.5. Example 5: Svalbard, Norway

The Norwegian seabed mapping programme MAREANO maps selected landforms as part of their extensive product portfolio in Norwegian waters (Bøe et al., 2020). The example presented in Fig. 21 is from Norway's Arctic area, specifically the previously glaciated continental shelf north of the Svalbard archipelago in the Barents Sea. This geomorphic map is one of several seabed geology maps produced by The Geological Survey of Norway (NGU) in this area (Jakobsen et al., 2023). Mapping was based on expert interpretation of bathymetry (5 m resolution, acquired and compiled by The Norwegian Hydrographic Service for MAREANO), sub-bottom profiles, videos and sediment samples. All landforms presented in this example are of glacial origin, mapped using polygon and/or line geometries at a scale of 1: 100000. The original interpretations (Jakobsen et al., 2023) follow the official Norwegian SOSI-standard for landforms (Kartverket, 2016; Norges geologiske undersøkelse, 2017). Here they have been translated to the ISGM-convention (see Section 4.4: Glacial Setting) with one line Feature remaining as a Channel (Part 1 Morphology) in keeping with its original SOSI classification. The resulting map includes six different BGU (*grounding zone wedge, glacigenic debris flow/lobe, crevasse-filling, moraine, streamlined landform, meltwater channel*) and two BGU-T (*drumlin, mega-scale glacial lineation*). Abundant *iceberg ploughmarks* are also visible in the hillshaded bathymetry but since these are so prolific on the Norwegian continental shelf they are not mapped.

This geomorphic map not only provides information on the landforms in the area, but also on how they were formed. This is important for studies of glacial processes and sediment dynamics (ISGM application 3 – *sediment*), and paleoenvironmental and climate reconstruction (ISGM application 4 – *paleoenvironment*). Landforms differ in their dimensions and geometry, but also in other physical properties e.g. grain size and friability. Consequently, they provide suitable environments for different benthic communities and can serve as important indicators of habitat and biodiversity (ISGM application 1 – *habitat*). In this area, for example, seapen fields are frequently observed on *grounding zone wedges*. These are just one of several vulnerable habitats of particular management interest (ISGM application 5 – *management*), especially when considered with other activities in the area, e.g. fisheries.

High-resolution bathymetry data and landform interpretations are currently only available for limited areas north of Svalbard. However, when viewed together with regional data this provides important insights on the glacial history of the area, such as the extent and retreat dynamics of the Barents-Svalbard ice sheet during the last deglaciation. This example demonstrates how landforms originally mapped according to the national SOSI-standard can be readily reclassified into ISGM Morphology and geomorphology classes. It also illustrates how ISGM-classes can be incorporated in parallel with national standards as needed, which can facilitate trans-border mapping.

6. Discussion and future work

Since its release (Dove et al., 2020b; Nanson et al., 2023a), the ISGM approach has seen promising international uptake and is increasingly being used to support terminological consistency across diverse Physiographic zones (Fig. 3c). Studies to date have focused on a range of applications, including habitat mapping (Australia: Wakeford et al., 2023; Mediterranean Sea: Grande et al., 2025; Bialik et al., 2025; Western Indian Ocean: Fennessy et al., 2025), continental shelf studies (Denmark: Hansen et al., 2022; eastern Australia: Linklater et al., 2023), shore platform analyses (Orkney Islands: Dove et al., 2025), seabed stability research (Christmas Island: Niyazi et al., 2025a, 2025b), seamount mapping (Ascension Islands: Macdonald et al., 2025), offshore windfarm siting (Dakin, 2025) and canyon studies (Western Australia: Post et al., 2022; Nanson et al., 2022b; Keep et al., 2024). The case examples presented herein (Section 5) also demonstrate the utility for developing geomorphology maps across multiple Physiographic zones and for a variety of ISGM applications (ISGM 1–6; Section 3.3; Graphical abstract (a)).

A likely factor underpinning early adoption of the ISGM approach is its universal framework (Fig. 4), which collates and organises existing terminology across sedimentological, stratigraphic, and geo-ecological sub-disciplines, rather than redefining it. It lists preferred terms alongside recognised alternatives to accommodate user preferences (e.g. *dune*: aka sediment wave) and by doing so, the approach provides a standardised starting-point that can be tailored to specific datasets and to more granular discipline-specific classification schemes.

6.1. Managing uncertainty and standardisation

A key intention of the ISGM approach is to compartmentalise uncertainty between Part 1 Morphological mapping and classification (Dove et al., 2020b), and Part 2 geomorphic interpretation and classification, as well as to limit the misrepresentation of morphology as geomorphology and vice-versa.

6.1.1. Morphology delineation and classification

Part 1 terms are primarily based on the SCUFN B-6 (IHO, 2019) list of terms, and the ISGM-modified versions of these are intentionally non-prescriptive to allow flexibility in application to diverse datasets. As a result, however, these terms retain a degree of ambiguity. For example, whether a shallow water Feature (<200 m) is classified as a Mound, Bank, or Ridge may vary with regional conventions, analyst and end-user preferences.

Consistent delineation of Morphological Features in a GIS environment is also challenging and is compounded by differences in bathymetric data resolution and quality. Feature boundaries vary due to the inherent uncertainty about the nature and continuity of many landforms (Evans, 2012), the subjectivity of manual mapping (e.g. Huang et al., 2023), and the composite, inherited topographies resulting from overlapping geomorphic units (e.g. modern Marine *bedforms* amongst relict Coastal *dunes* (Fig. 19) and relict Glacial *moraines* (Fig. 21). Inconsistencies may also result from the necessarily vast number of unique combinations of tool parameter settings (e.g. size of neighbourhood and openness settings) when implementing even ISGM-aligned toolboxes, even those that are implicitly designed to standardise delineation (e.g. CoMMa: Arosio et al., 2024; Step 1 Map - GA-SaMMT: Huang et al., 2023). Incorporating explicit mathematical and geomorphometric workflows into the delineation and classification of Part 1 Features may reduce some of these uncertainties, and emerging technologies such as artificial intelligence (e.g. Arosio et al., 2023b; Garone et al., 2023; Zhang et al., 2024), may offer promising future opportunities. The semantics of ISGM Feature boundaries will, however, continue to elude strict mathematical definition and absolute objectivity. An alternative may be found in traditional geomorphometry, where academics define "elementary forms" which represent the most basic landscape units that cannot be divided further at a stated level of resolution (Minár and Evans, 2008). Relatively homogeneous mathematical descriptions, such as curvature, gradient or steepness, make these elementary forms fundamental components of the seabed (e.g. upper slopes, ridges, peaks etc.). While these forms are not Features sensu ISGM Morphology, they are the building blocks that make up the Features and may be used to better formalise Feature definitions.

Despite these challenges, Huang et al. (2023) integrated an Attribute toolbox (Step 2 Characterise) within GA-SaMMT to quantify 80 geometric characteristics of a subset of 18 (of the total of 40) Part 1 Feature types. The toolbox can be applied to outputs from various semi-automated workflows or manually digitised polygons, and is followed by a final step where these geometric attributes are used to automatically classify outputs into ISGM Part 1 Morphology Feature types (Step 3 Classify). ISGM reports, tools, and database structures are intended to be updated iteratively, supporting evolving vocabularies and methods. Planned enhancements to GA-SaMMT include the mapping and classification of additional Feature types, expansion of Feature mapping tools, enhancement of Feature characterisation tools and diversification of the tools into fully open-source GIS environments.

6.1.2. Geomorphic interpretation

Although Part 1 Morphological classification remains stable when data and methods are unchanged, Part 2 interpretation of these shapes typically involves higher degrees of uncertainty. This uncertainty arises from:

- variable availability and quality of ancillary data;
- the inherently remote nature of seabed observations;
- heterogenous sediment and sub-surface datasets;
- limited availability of suitable analogue datasets;
- variable geomorphic expertise and unconscious bias (e.g. Bond et al., 2007).

Discipline understanding and standards also evolve. For example, widespread recognition of *cyclic steps* has led to the increasing categorisation of these units, and the reclassification of some *dunes* as such (e.g. Slootman and Cartigny, 2020). These changes are expected as marine geomorphology continues to evolve.

Part 2 of the ISGM approach seeks to minimise, document and accommodate this uncertainty. The scheme supports multiple levels of geomorphic specificity, from Setting / Process classes to BGU, BGU-T and BGU-sT, allowing generalised through more detailed interpretations. This tiered structure supports the development of simplified maps for non-specialist users, such as mapping Marine versus Solid Earth shapes rather than more detailed BGU classifications, and allows users to classify to the level of specificity supported by the data. For example, a Solid Earth *tectonic high* (BGU) *tectonic dome* (BGU-T) may be interpreted by concentric outcrop patterns in bathymetry data, but it may not be possible to ascertain whether the unit is more specifically an *antiform* or a *diapir dome* (BGU-sT). Generalised BGU units are included to accommodate unspecific classification in such cases (e.g. Solid Earth – *bedrock outcrop (undefined)* (BGU)*;* Anthropogenic - *structure* (BGU) – *other structure* (BGU-T)). In many cases, however, the interpretation of a specific geomorphic unit is necessarily precise and context-specific, and although these detailed interpretations can be simplified upward within ISGM classification classes, the detailed assessment necessarily precedes simplification.

The ISGM Seabed Geomorphology Classifier tool (ISGM-SGC: Huang et al., 2026) supports the consistent application of ISGM Part 2 terms and will be maintained on GitHub (Huang et al., 2026) to match updates to the glossaries (Wells et al., 2025a-d). Ongoing work aims to develop a confidence framework to explicitly represent the certainty of morphological and geomorphic interpretations alongside the quality of supporting data.

6.2. Multidisciplinary applications

Nanson et al. (2023a) identified the utility of all listed BGU and BGU-T for each of the six ISGM applications (Section 3.3) and the case examples in Section 5 (Figs. 17–21) illustrate how ISGM can be applied to produce maps that support these applications. Future updates to the digital vocabularies (Wells et al., 2025a-d) will similarly highlight applied uses for individual units.

The ISGM approach can provide a foundation for geohazard assessment (ISGM Application 2 – geohazards), including recent applications such as the Geological Service for Europe (GSEU) hex-maps - that provide a Pan-European geological complexity assessment for Offshore Windfarms (Dakin et al., 2024; Dakin, 2025). Standardised geomorphic maps can also inform geotechnical characterisation of the shallow seabed to guide engineering assessments (ISGM Applications 2 and 6) and to support studies of sediment dynamics (ISGM Application 3), to model sediment composition and distribution patterns that strongly influence marine ecosystems (e.g., Snelgrove, 1997). Beyond their ecological applications and role as proxies for habitat distribution (ISGM Application 1), the ISGM approach is also designed to support a range of ecological and geomorphological classification systems.

Examples of habitat mapping frameworks include: EMODnet (Asch et al., 2021), which harmonises the use of a suite of geomorphic terminology across Europe using INSPIRE vocabulary; the Coastal and Marine Ecological Classification Standard (CMECS: e.g. Kingon, 2018), which integrates geoform, substrate, water column, and biotic components for United States coastal and marine environments; Seamap Australia (Butler et al., 2017), which additionally collates benthic habitat datasets for national management; and Greene et al. (2007) benthic habitat classification, which pioneered coded schemes for seabed habitat mapping. More recently, Grande et al. (2025) reviewed 14 such habitat-focused schemes and built on these (and Dove et al., 2020b) to propose CoDeMap, a framework that integrates morphology, substrate, and biology classes for coastal to deep marine habitat mapping in the Mediterranean and Black Sea, with potential for global expansion. While these systems incorporate geomorphic terms, they are not designed to provide a comprehensive geomorphic framework. The ISGM approach offers these discipline-specific schemes such a structured framework that can be translated into the shorter lists of ecologically relevant units used in their habitat classifications.

The ISGM approach also complements and extends two globally recognised geomorphology classification schemes by explicitly building on the International Hydrographic Organisation's B-6 lexicon of undersea feature names (IHO, 2019), and the Global Seafloor Feature map (Harris et al., 2014a). While the reclassified GSFM presented herein (Fig. 17; Supplementary 1) provides global physiographic context, ISGM nests finer-scale geomorphic units within these macroscale features, enabling scalable mapping from global physiographic zones to regional and local scales (e.g. Figs. 17–21).

6.3. Scale

The ISGM approach supports standardised geomorphic classification across a broad range of spatial and temporal scales, from very large Physiographic regions that evolve over geological timescales, to much smaller *bedforms* that develop within single flow events (Fig. 1). Swath and LiDAR bathymetry can be used to create spatially continuous, high-quality bathymetry grids, and their resolution can be scaled to match the density of the input datasets, or downgraded to suit project needs. Composite bathymetry grids combine various data sources, including some that are widely spaced (e.g. satellite-derived altimetry), and integrate these with swath data to produce interpolated grids of variable quality (e.g. cf. Picard et al., 2018 re the Global SRTM grid; Bass Strait 30 m grid: Beaman, 2022).

Understanding the quality of the underlying data and the spatial scale of geomorphic units that can be identified is critical for appropriate geomorphic interpretation and mapping. For example, areas of high-quality data in regional composite bathymetry grids may support the identification and delineation of key *Marine bedforms*, but their absence from lower quality areas of the same grid cannot be interpreted as evidence of true absence. Similarly, understanding the range of bathymetric data resolutions required to map the full suite of ISGM unit types is essential for understanding the practical applications for such maps (Section 2.3: ISGM Applications 1–6), and for supporting appropriate survey design. These considerations also form an essential component of uncertainty management within ISGM; work is ongoing to develop a confidence framework that can link data quality and resolution to the certainty of morphological and geomorphic classifications, to document and communicate the reliability of mapped units.

Planning for marine surveys must balance the time allocated to competing survey tasks and target applications (e.g. ISGM Applications 1–6). Intentionally widening swath widths to cover broader areas at lower resolution (e.g. Picard et al., 2020) to match larger scale target units for mapping can free up resources for other survey activities, such as sub bottom profiling and sediment core / sample collection, which in turn can support more confident interpretations of geomorphic units. But doing so creates a trade-off between these larger units and smaller ones that may not be fully visible in the resulting coarser-resolution bathymetry grids. ISGM work is currently underway to quantify the spatial scale range of geomorphic units to support targeted swath survey design, and to quantify the temporal scales over which units form and evolve to design monitoring programs that can adequately capture geomorphic change.

7. Conclusion

The ISGM classification system provides a standardised, hierarchical framework for interdisciplinary adoption across a wide range of users, from environmental managers, to undergraduates and senior Earth scientists. The framework and supporting vocabularies allow direct comparison of interpretations and terminologies between discrete studies and user groups, and can feed into discipline-specific applications (e.g. marine park management; geohazard assessment), while remaining adaptable to user needs. The system can be applied at multiple spatial scales, from broad physiographic regions to local case studies, and provides a basis for more specialised classification schemes in related disciplines (e.g. habitat mapping). By standardising morphologic and geomorphic terminology, the ISGM framework supports more coordinated progress in the global effort to map the seabed during the UN Ocean Decade and beyond. In doing so, the approach enables improved consistency and interoperability, resulting in improved rigour and reproducibility for seabed mapping products.

Marine geomorphology remains an evolving discipline, and our collective understanding of seabed systems continues to advance as new data and analytical approaches emerge. The ISGM framework is intended as an evolving contribution to this developing field, building on the foundations established by the IHO B-6 standard and previous regional and global classification efforts (e.g. Heap and Harris, 2008; Harris et al., 2014a; Asch et al., 2021).

The ISGM approach has been developed through the Ocean Best Practice (OBP) process, which requires community input and ongoing revision to ensure its continued relevance. While the majority of the most significant geomorphic units are reviewed herein, and 400 of these are structured into the scheme, future priorities for inclusion will be identified by iterative, real-world application of the approach, particularly as new environments are mapped and additional data become available. Continued refinement will benefit from ongoing engagement across the marine geomorphology community as the framework is implemented across diverse settings. Planned updates to ISGM reports (Dove et al., 2020b; Nanson et al., 2023a), implementation tools (e.g. GA-SaMMT: Huang et al., 2023; CoMMA: Arosio et al., 2024; ISGM-SGC: Huang et al., 2026), the universal ISGM framework structure (Fig. 4: Nanson et al., 2023a) and digital vocabularies (Wells et al., 2025a-d) will be supported by the platforms on which they are hosted. At the time of publication, this paper represents the most up to date version of the ISGM framework.

Work is currently underway to develop a confidence framework that will capture the uncertainty around geomorphic interpretations and the quality of the underlying data. Updates are also planned for the digital vocabularies (Wells et al., 2025a-d) to specify the applied uses (ISGM Applications 1–6) for identifying and mapping individual geomorphic units, and to guide appropriate monitoring intervals for marine survey planning. While these vocabularies are currently designed for standalone “look up” use and for implementation in a GIS environment (e.g. via the ISGM-SGC tool: Huang et al., 2026), their standardised framework and digital glossaries position them for future machine-readable integration, including potential use in emerging AI-assisted workflows. Draft unit codes, as presented in the case examples, will also be integrated into future versions of the vocabularies and ISGM tools to support multilingual application. These ongoing revisions to the ISGM approach are essential for maintaining alignment with the Ocean Best Practice process and ensuring that the method remains suited to the needs of applied geomorphologists and related specialists. In doing so, the ISGM approach provides the first cohesive, cross-class (Setting / Process) geomorphic framework capable of supporting consistent terminology from global physiography to local scales.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Supplementary data

Supplementary Dataset 1 contains shapefiles sourced from Harris et al. (2014b), which has been translated into two new datasets that align with the ISGM scheme: (1) global Physiography; (2) global macroscale Morphology. GSFM_ISGM_translation (Original data)

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