MINDeSEA

Seabed Mineral Deposits in European Seas: Metallogeny and Geological Potential for Strategic and Critical Raw Materials

MINDeSEA

Deliverable 5.4: WP5 Models of formation for the main provinces of placer occurrence, as defined through this study

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1. INTRODUCTION

GeoERA is a Co-Fund ERA-NET action under Horizon 2020, towards **"Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe"**. Its main objective is to contribute to the optimal use and management of the subsurface.

The project **MINDeSEA**, materialized in the frame of the GeoERA Raw Materials Theme (*Grant Agreement Nº 731166, project GeoE.171.001*), resulted from the collaboration between eight GeoERA Partners and four Non-funded Organizations at various points of common interest for exploration and investigation on seafloor mineral deposits.

2. PURPOSE

This document is a general overview of the main metallogenetic areas and provinces in European seas for placer deposits, elaborated in the frame of MINDeSEA Work Package 5 (WP5) **"Marine Placer Deposits"**, led by the Hellenic Survey of Geology & Mineral Exploration (HSGME). The main aspects of this work are summarized as follows:

1. To provide a general overview of marine placer deposits, in the context of what they are, how they are formed and where they exist.
2. To identify environmental parameters favouring the formation of placer deposits, used as a basis for defining prospective areas for seafloor exploration. The identification and compilation of these factors was gathered through published scientific results. The associated areas do not necessarily contain economically minable placer deposits but simply represent regions where their formation is feasible.
3. To briefly describe the current status of the MINDeSEA database for placer deposits, namely information on the number of occurrences identified so far, as well as relevant information obtained for the previously defined metallogenetic parameters, in order to systematize and define propitious areas for the formation of marine placer deposits.

Towards this scope, an on-shore to off-shore approach was adopted, providing information about possible parent rocks (geological structure), transport mechanism (hydrological regime) and concentration mechanisms (morphology and water movements), which could be used systematically to model confirmed deposits and provide mineral-potential estimates.

The geographical scope of the project, with a pan-European ambition, focuses on delivering comprehensive information for the Marine Placer Deposits within European maritime territory: Mediterranean Sea, Celtic Seas, North Sea, Baltic Sea, Macaronesia, Bay of Biscay and the Iberian coasts, North Atlantic and Arctic, Norwegian Sea, Black Sea (Figure 1).

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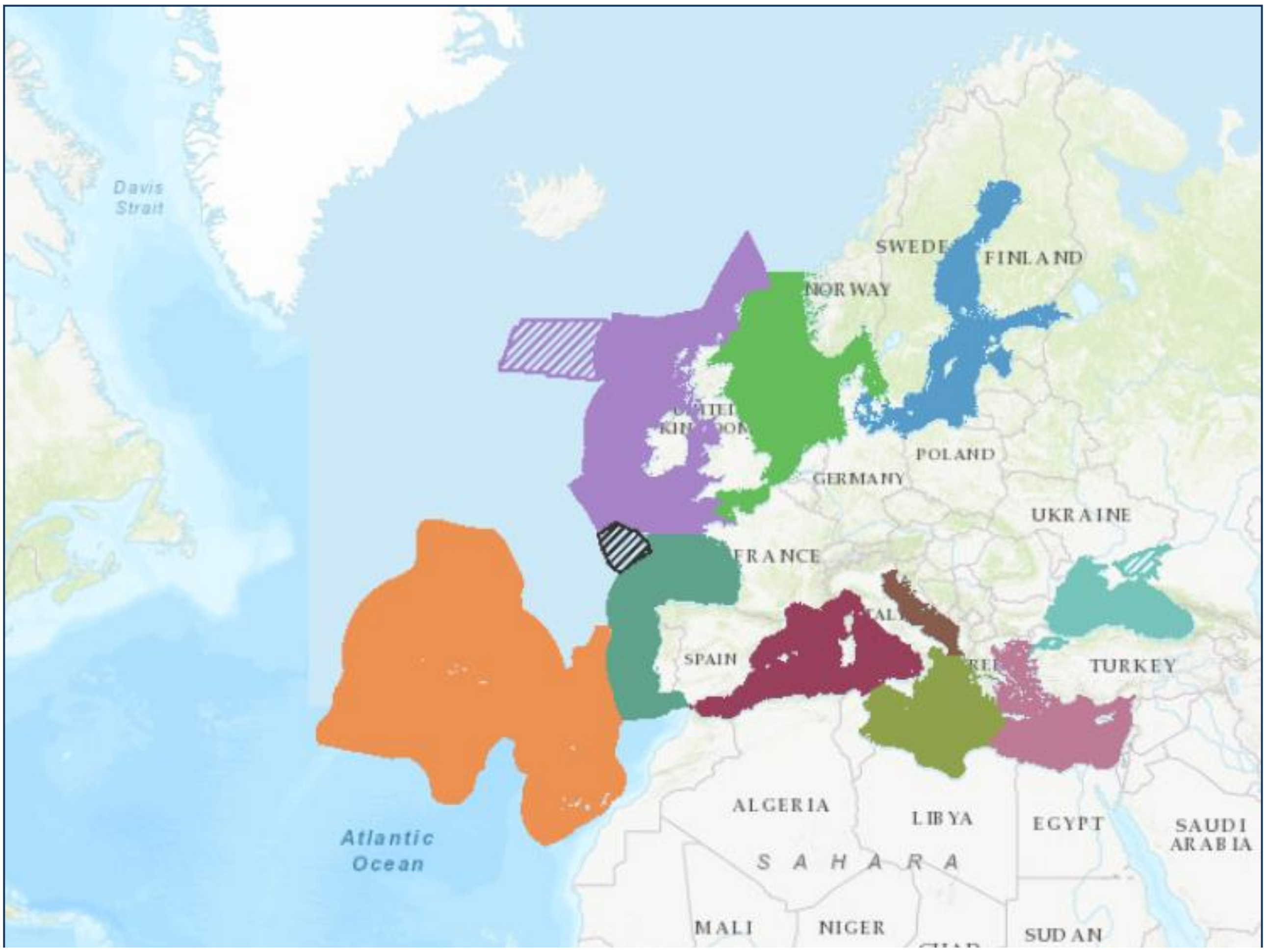

Figure 1: Delimitation of the European marine regions and subregions: http://marine.discomap.eea.europa.eu/arcgis/rest/services/Marine/Marine_regions_subregions_v1/MapServer

3. GENERAL OVERVIEW OF MARINE PLACER DEPOSITS

Covering more than 70% of the planet, marine waters represent a potentially promising new frontier for the exploration of mineral resources.

Table 1: 2020 EU list of Critical Raw Materials (EU COM 2020)

2020 Critical Raw Materials (new as compared to 217 in bold)		
Antimony	Hafnium	Phosphorus
Baryte	Heavy Rare Earth Elements	Scandium
Beryllium	Light Rare Earth Elements	Silicon metal
Bismuth	Indium	Tantalum
Borate	Magnesium	Tungsten
Cobalt	Natural Graphite	Vanadium
Coking Coal	Natural Rubber	**Bauxite**
Fluorspar	Niobium	**Lithium**
Gallium	Platinum Group Metals	**Titanium**
Germanium	Phosphate Rock	**Strontium**

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Security of mineral supply has been identified by the European Commission as a priority challenge facing the raw materials sector; the 2020 list (Table 1) of Critical Raw Materials (CRM) reflects societies growing demand for an ever-increasing number and quantity of elements and minerals that supply the green energy and technology sectors (European Commission, 2020). Marine placer deposits have received much attention during marine exploration and the further development of this raw material source is imminent.

3.1 Marine Placer deposits: what are they?

Placer deposits are an accumulation of economically valuable concentrations of minerals, both dense and resistant to weathering and abrasion, formed by gravity separation during sedimentary processes. Marine placer deposits comprise detrital heavy metallic minerals – having specific gravities of 2.9 or more, heavier than those of common, rock-forming minerals such as quartz and feldspar – and gemstones, eroded from, usually igneous, source rocks on land and transported to sea, mostly by rivers. Thereby, placer deposits are concentrated by water motions (waves, tides, currents).

Table 2: Valuable heavy minerals found in placer deposits (McKelvey, 1986)

Mineral	Composition	Specific Gravity
Andalusite	Al_2SiO_5	3.16 - 3.20
Cassiterite	SnO_2	6.80 - 7.10
Chromite	$Fe^{+2}Cr_2O_4$	4.60
Columbite-tantalite	(Fe, Mn) $(Nb, Ta)_2O_6$	5.30 - 7.30
Corundum	Al_2O_3	3.95 - 4.10
Diamond	C	3.50
Euxenite	(Y, Ca, Ce, U, Th) $(Nb, Ta, Ti)_2O_6$	4.70 - 5.00
Garnet (almandine)	$3FeO·Al_2O_3·3SiO_2$	4.25
Gold	Au	15.60 - 19.30
Ilmenite	$Fe^{+2}TiO_3$	4.70
Kyanite	Al_2SiO_5	3.23
Magnetite	FeO·Fe2O3	5.20
Monazite	$(Ce, La, Nd, Th)PO_4$	4.90 - 5.30
Platinum	Pt	14.00 – 19.00
Rutile	TiO_2	4.18 - 4.25
Scheelite	$CaWO_4$	5.90 - 6.10
Sillimanite	Al_2SiO_5	3.23
Staurolite	$(Fe^{+2}, Mg, Zn)_2Al_9(Si, Al)_4O_{22}(OH)_2$	3.65 - 3.77
Topaz	$Al_2SiO_4(F, OH)_2$	3.40 - 3.60
Tourmaline	H_9Al_3 $(B, OH)_2Si_4O_{19}$	3.00 - 3.20
Wolframite	$(Fe, Mn)WO_4$	5.00 - 5.50
Xenotime	YPO_4	3.23
Zircon	$ZrSiO_4$	4.20 - 4.86

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More than 20 valuable heavy minerals can be found in placer deposits (Table 2) however, the most important of these minerals, from an economical aspect (Harben and Bates, 1990), are:

- cassiterite (tin)
- ilmenite and rutile (titanium)
- zircon (zirconium)
- chromite (chromium)
- monazite (thorium)
- magnetite (iron)
- gold
- and the principle gemstone is diamond.

Marine placer occurrences can be classified taking into account various factors (Emory-Moore and Solomon, 1989; and references therein):

A) <u>Source</u>: marine placers are categorized as *primary*, when derived from post-glacial weathering of bedrock, or *secondary*, when they are the product of reworking of overburden sediment.

B) <u>Environment</u>: *shallow* (beach/near-shore) marine placers are located in the area between the coast and the breaker zone while *offshore* occurrences are found in the area between the breaker zone and the end of the continental shelf.

C) <u>Formation</u>: *allochthonous* placers can occur hundreds of km from source and the corresponding minerals include zircon, monazite ilmenite, rutile, magnetite, chromite, fine-grained gold and platinum; *autochthonous* deposits form close to source, in areas where the rate of marine erosion exceeds the rate of net sediment accumulation, and include cassiterite and coarse-grained gold and platinum (Kartashov, 1971).

D) <u>Physical properties</u>: based on their specific gravity, marine placers are divided in *heavy-heavy* minerals (>6.8), *light-heavy* minerals (4.2 to 6.8) and *gems* (2.9 to 4.1) (Emery and Noaks, 1968).

Moreover, we distinguish the *relict/ fossil/ submerged* placer deposits, formed in the geologic past and changed from a sub-aerial to a marine environment due to various reasons (climate change, tectonic movements etc). These are classified based on depositional environment, i.e. fluvial, eolian, glacigenic, beach-nearshore deposits.

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3.2 Economic importance of Marine Placer deposits

According to Daesslé and Fischer (2013) about 75% of the world's tin, 11% of gold, and 13% of platinum are extracted from placers (Baker *et al.*, 2014). In most cases placer deposits yield more than one mineral, thus feasibility of commercial production can be accomplished; a common assemblage includes titanium minerals, monazite, zircon and perhaps kyanite or staurolite (McKelvey, 1986). Typical uses of main commodities retrieved from marine placer deposits are presented below (United Nations, 2004):

- ✓ Barium: A soft silvery-white heavy metal used for drilling fluids in oil wells, paints, fireworks, glass and rubber making, and as an x-ray tracer in medical applications.
- ✓ Chromium: A lustrous, hard, bluish-grey metal used to make stainless steel; can be polished to a mirror-like finish and used as a decorative and protective plating; hardens steel and may be used in alloys; also used as a yellow colouring agent in the textile industry, and in tanning leather.
- ✓ Diamond: Composed of carbon transformed into the hardest of all minerals used for jewellery and industrial cutting applications
- ✓ Gold: A soft, shiny, malleable, ductile, non-corrosive metal used for currency, jewellery, dental work, electrical/electronic components, photography, heat shields, and pharmaceuticals.
- ✓ Phosphorus: Used in fertilizers, insecticides, fireworks, baking powder, chinaware, glass, water softeners, soft drinks, pharmaceuticals, and metal treatments
- ✓ Rare earth elements (REE) (in mineral monazite and rock-type basanite): A series of 15 metallic elements variously used for heat resistant alloys, and Cd disks and alloys for powerful magnets and lasers; a colouring component in glass and ceramics, in carbon arc lamps, in certain nuclear applications, and colour TV tubes.
- ✓ Thorium: An abundantly radioactive metal used in high-temperature applications, such as incandescent gas mantles, tungsten filament castings, laboratory equipment, as well as in certain camera lenses and other optical instruments; it can be used as a nuclear fuel for breeder reactors.
- ✓ Tin: A soft, silvery-white metal used in food storage containers, coating on other metals and as an alloy in solder, pewter and bronze (with copper); in polymer additives for dyeing and marine anti-fouling paints.
- ✓ Titanium: Corrosive resistant metal used in chemical production and anywhere light strong alloys are needed; also used in some white paints and as a pigment for coating paper and plastic, as a food additive, in sunscreen lotions, and in fireworks.
- ✓ Tungsten: Metal with the highest melting point of any element, used in alloys that resist great amounts of heat, such as light-bulb filaments, in television tubes, paints, lubricants, tanning leather, and fluorescent lighting; also used in high strength applications, such as furnaces, missiles, dental drills, and other cutting tools.

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- ✓ Zirconium: A hard, lustrous, gray-white metal resistant to water, most acids and bases; used as a shield against corrosive compounds in the chemical industry, for steel alloys, bricks, ceramics and abrasives, flashbulbs, explosive primers, lamp filaments, and artificial gemstones.

3.3 Marine Placer deposits: how do they form?

The prerequisites for the formation of marine placers are: (a) a primary mineral source (usually crystalline rocks), (b) a suitable weathering environment, and (c) means of transportation (e.g. running water, wind, currents). Given that all the above conditions are satisfied, the placer-forming minerals are derived from source rocks, transported and deposited to areas of concentration (Figure 2). Thus, the process of marine placers' formation is controlled by three major factors (Davis and Clifton, 1987):

- Sediment supply: can be materialized by means of modern fluvial discharge and coastal (bedrock/unconsolidated bluffs) or submarine erosion.
- Sea-level fluctuations: eustatic and isostatic variations influence the sediment supply (type and volume) and thus control the location and extent of marine placer occurrences.
- Marine energy: the hydraulic conditions (e.g. waves, currents) greatly affect the sediment transport reworking and deposition and regulate the concentration of marine placers.

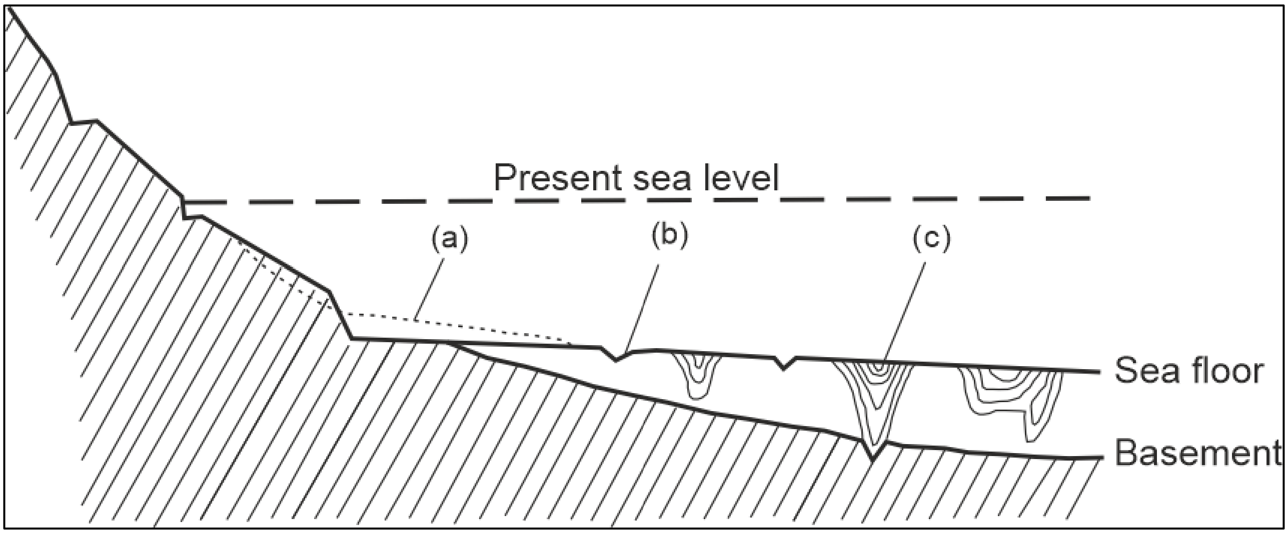

Figure 2: Typical formation of marine placer deposits (after Cronan, 1980)
(a) Placers on submerged beaches
(b) Placers trapped in surface depressions on the seafloor
(c) Placers in buried river valleys

The location and concentration of marine placers is then defined by the physical properties of their minerals (Rona, 2008). Their resistance (hardness, cleavage, density, solubility) to

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mechanical action during transport determines the distance it can reach from its source without material change of state (Kudrass, 2000; Yim, 2000). The median distance of transport from a bedrock source to an offshore placer deposit is 8 km (Emery and Noakes, 1968).

Kudrass (2000) distinguishes between three generic types of placer deposits:

A) Disseminated beach placers, usually containing light heavy minerals (density < 6 g/cm^3, e.g. rutile, ilmenite, magnetite, zircon) concentrated by waves and alongshore currents
B) Drowned fluviatile placers, overlying the bottom of river channels, containing heavy metals (e.g. cassiterite, gold)
C) Eluvial or lag deposits, also containing heavy metals.

From the above, fluviatile placers are most important from an economic perspective (Minter and Craw, 1999).

The size and grade of mineral sand deposits vary considerably (Jones, 2009). Marine placers are typically 100 to 200 m wide, 5 to 15 m thick, and 2 to 20 km long, while heavy mineral grades can vary from several per cent to 90 per cent. Some marine placers comprise strandlines deposited in close proximity to each other and as such can form accumulated deposits up to one kilometre across strike. Dunal deposits close to the shore tend to be larger, more irregular in dimension and exhibit lower grade (generally 0.5 per cent to 15 per cent) heavy minerals.

The potential for the occurrence of placer deposits within the sedimentary accumulations of the continental shelf is significant. However, current knowledge is sparse, mostly limited to seafloor deposits on shallow waters, which are more accessible for exploration. Thus, the need for an integrated research approach on the European seas is imminent, given the present-day RM demands and exploitation technological advances, towards sustainable use and management of the subsurface. In addition to the coastal zone, the whole continental margin must be considered to examine whether Pleistocene sea level fluctuations could have concentrated heavy minerals in deeper waters.

3.4 Marine Placer deposits: where are they?

Marine placer deposits are mined worldwide, over the continental margin (Figure 3), with the main exploitation areas located offshore Australia, Africa and Southeast Asia (Table 3). A thorough review of international and over the years' marine placers mining is presented in the International Seabed Authority publication for Marine Mineral Resources (United Nations, 2004).

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Table 3: Principle marine placer mining activities (from Murton, 2000)

Placer Minerals	Mined Locations
Rutile and ilmenite	SE and SE Australia, eastern South Africa, South India, Mozambique, Senegal, Brazil, Florida
Ti-rich magnetite	North Island, New Zealand, Java, Indonesia, Luzon, Philippines, Hokkaido, Japan
Tin	Indonesian Sunda shelf, extending from the islands of Bangka, Belitung, and Kundur Malaysia Thailand
Diamonds	West Coast, South Africa Namibia Northern Australia

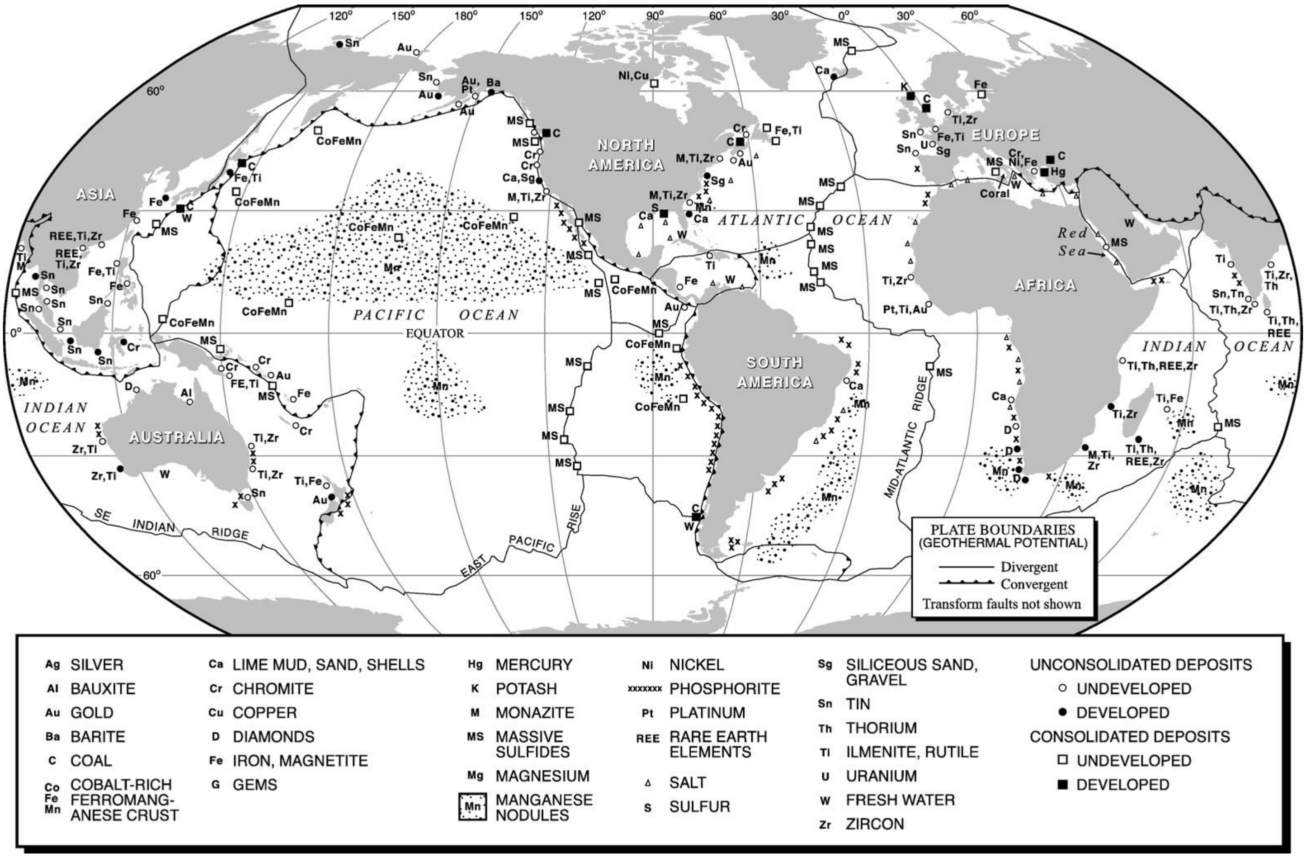

Figure 3: Global distribution of known marine mineral resources (original Cronan, 1980; Rona, 1983, 2003; Lenoble et al., 1995; Cruickshank, 1998; Ghosh and Mukhopadhyay, 2000; Andreev et al., 2000 – modified from Rona, 2008)

A compilation of worldwide operational marine placer deposits was carried out in the framework of MARMIN database project (Lenoble *et al.*, 1995) and is quoted below (Table 4). The update of their status (active or inactive), as well as of the list with additional operational deposits is out of the scope of the present report, focusing on European Seas; however, it is presented to provide a general overview of the economic perspective worldwide.

Table 4: Worldwide operational marine placer deposits (from Lenoble et al., 1995)

Name	Commodity	Water depth (m)	Location (Lat, Long)
Thai Muang	Tin	10	Thailand, 8.5° N, 98.2° E
Tongkah Harbour	Tin	20	Thailand, 7.9° N, 98.5° E
Takua Pa	Tin	0-18	Thailand, 9.0° N, 98.3' W
Copat Kelabat Bay	Tin	0-1	Indonesia, 1.6° S, 105.7° E
Laut Tempilang	Tin	10	Indonesia, 2.2° S, 105.7° E
Belitung (Billiton)	Tin	10-20	Indonesia, 3.0° S, 108.2° E
Heinze Basin	Tin, Tungsten	16-30	Myanmar, 14.7° N, 97.8° E
Nome	Gold	18-20	Alaska, USA, 64.5° N, 165.4° W
Bluff Soloman	Gold	0-10	Alaska, USA, 64.6° N, 164.4° W
Gillespie's Beach	Gold	0-15	New Zealand, 43.4° S, 169.8° W
Richard's Bay	Titanium, Zirconium	0-30	South Africa, 28.8° S, 32.0° E
Fort Dauphin	Titanium, Thorium, REE, Zirconium	-	Madagascar, 25.0°S, 47.0° E
Kanniyaknmari Manavalakurichi	Titanium, Zirconium, Thorium	-	India, 8.2° N, 78.5° E
Chatrapur	Titanium, Zirconium, Thorium	-	India, 19.4° N, 85.0° E
Sulawesi	Chromite	-	Indonesia, 2.0° S, 121.5° E
Chameis Bay	Diamond	0-25	Namibia, 28.0° S, 15.7° E
Broadacres	Diamond	0.5	South Africa, 31.6 S, 18.2 E
Casuarinas Prospect	Diamond	30	Australia, 14.4° S, 127.8 °E

Apart from the abovementioned areas, which have been the target of marine placer exploration, there are many other locations in the continental shelf where placer deposits occur, without considering their economic exploitation feasibility.

3.5 Marine Placer deposits: factors controlling metallogeny

In general, placers deposits, considered both onshore and offshore, are known from five sedimentary environments: washout, river, aeolian, beach, and the continental shelf. The study of placer deposits' characteristics (e.g. Stanaway, 2012; and references therein) is the first step in understanding the factors controlling their formation – and thus assist in identifying promising areas for exploration – and define their exploitation feasibility.

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The primary factors examined, during the study of placers, are the following:

A) Geotectonic environment: unlike most deposit types, marine placers are not necessarily associated with large-scale tectonic features, such as major faults (Van Gosen *et al.*, 2014; and references therein). They are commonly observed in stable tectonic environments; however, recent studies have linked placer metallogenesis with faulting, coastal deformation or progressive tilting of the crustal platform (e.g. Roy *et al.*, 2000; Hou *et al.*, 2008).

B) Distance from source: As mentioned above a crucial factor for the genesis of placer deposits is the availability of a primary mineral source (usually crystalline rocks). However, different commodities can be found in the range distance from this source. For example monazite is prone to be found in sites closer to provenance, since soft and good cleavage minerals cannot sustain extensive sediment recycling; on the contrary zircon occurs in durable sand size grains easily dispersed over hundreds of kilometers, and concentrating only where sorting processes allow (Stanaway, 2012).

C) Sorting factor: Similarly, the sorting factor affects all placer commodities, but not equally; e.g. beach sites comprise appropriate sediments dispersed over a significant extent, concentrating only when the sorting process allows it.

D) Mineral availability: mineral availability, is a key factor in placer exploration; even the most effective processes cannot generate economic deposits where mineral contents are too low, i.e. too far from the source and too dispersed (Stanaway, 2012; and references therein).

E) Environment conditions: The environment condition play a key role in marine placer deposits formation; e.g. oscillatory wave actions, varying velocity turbulent or laminar flows, high density flows etc. can significantly control the sediment supply and concentration of commodities.

F) Physical description of the deposit:

   a. *Planar extent*: Placer deposits can be quite extensive; single deposits are generally developed as part of a district, usually lying discontinuously along the strike of a palaeocoastline, representing different sea-level events through time. Such districts can reach dimensions of 1 km (width) and 14 km (length). An example of multiple heavy-mineral deposits aligned along the strike of a paleostrandline system is the 19 known Pliocene deposits within the upper coastal plain of Virginia and North Carolina (Carpenter and Carpenter, 1991).

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b. *Vertical extent*: Marine placers are usually of limited thickness, where reported thickness of economic deposits range from 3 to 45 m (Van Gosen *et al.*, 2014), with their cost-effectiveness being derived from their significant surface extent.
c. *Form and shape*: In planar view marine placer deposits are elongated, roughly following the (palaeo) coastline strike, when their cross section exhibits convex lens-shaped profiles, similar to channel deposits of fluvial systems. Terraces associated with this deposit type most likely represent major sea level events of paleostrandlines rather than faulting or other structural features. (Van Gosen *et al.*, 2014).
d. *Temporal variation*: Marine placers' operations worldwide exploit sands that range in age from Tertiary to Quaternary and include some modern deposits.

Additionally, an onshore – offshore approach is ideal for the preliminary evaluation of the marine placers' potential in a marine area. Given that inland placer research has been extensive for decades, a big amount of data is available. Those data, indicating at least the presence of an appropriate sediment supply source, can constitute a starting point at the search for offshore promising metallogenic provinces. Similarly, the temporal relations of placer deposits have to be considered; heavy minerals concentrations in ancient strata can be eroded and transported by a fluvial system and brought to the coast (Leonardos, 1974; Ali *et al.*, 2001), thereby recycling, reconcentrating, and redepositing the heavy mineral suite.

4. MINDeSEA database

4.1 About the project

MINDeSEA (https://geoera.eu/projects/mindesea2) project (Seabed Mineral Deposits in European Seas: Metallogeny and Geological Potential for Strategic and Critical Raw Materials) aims to identify the principal types of seabed mineral resources (hydrothermal sulfides, ferromanganese crusts, phosphorites, marine placers and polymetallic nodules) in the seabed under the jurisdiction of European coastal States, addressing their integrative metallogenetic study and assess the potential for marine strategic minerals and Critical Raw Materials (CRM). The geographical scope of the project includes all the regional basins around Europe, as mentioned in the MSFD (https://www.eea.europa.eu/data-and-maps/data/europe-seas-1) (Table 5). Together with these regions in the MINDeSEA project is also the Norwegian Sea, Greenland Sea, Iceland Sea, Barents Sea, and White Sea subregions that are part of the Arctic Ocean (Figure 1).

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Table 5: Marine regions and sub regions according to MSFD

Marine regions	Subregions
Baltic Sea	
North-east Atlantic Ocean	- Greater North Sea
	- Celtic Seas
	- Bay of Biscay and the Iberian Coast
	- Macaronesia
Mediterranean Sea	- Western Mediterranean Sea
	- Adriatic Sea
	- Ionian Sea and Central Mediterranean Sea
	- Aegean-Levantine Sea
Black Sea	

4.2 Marine Placers' database

It is well known that data on marine placers were scattered among national, governmental, academic and private data holders. A primary aim of the MINDeSEA project was to create a Bibliographic Database with the collection of data and information related to marine placer deposits. This database holds centralized data of public and private information on marine placers acquired from EGS, public repositories and various institutions worldwide. Following the compilation MINDeSEA used that database to standardize and evaluate data for mineral assessments, production of maps, databases and reports.

Thus, the MINDeSEA five funded European partners and the four non-funded partners have been collecting the dispersed data, by examining several sources:

(a) The EMODnet-Geology project, WP 7 database (Minerals), which comprised the starting point for data collection,
(b) National databases from the various geological surveys in Europe
(c) Data published in the various scientific journals, searched through various databases,
(d) Online international databases and portals.

The marine placer deposits' data collection and documentation followed specific standards and protocols, previously defined in the frame of MINDeSEA project, through a detailed Task Guide (Deliverable 5.1 – WP 5 Marine Placer Deposits Task Guide; Zananiri, 2018). The data collection schema (Figure 4), designed after thorough discussions of MINDeSEA partners and analysis of existing databases, aimed to provide all available information necessary for the

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	Field Alias	FIELDNAME	Format	Information
General Data	OBJECTID	FID	Number	Feature ID. An internally generated identification number for each feature. Automatically generated within shape file.
	Shape	SHAPE	Geometry	Polygon or point
	Country Code	CODE	Text (2)	Two letter country code, which corresponds to ISO3166- code http://www.iso.org/iso/english_country_names_and_code_elements e.g. FR, IE
	Administration	ADM	Text (40)	Legal status following the division of the Law of the Sea Convention: Territorial Sea (TS), Exclusive Economic Zone (EEZ), Extended Continental shelf (ECS) or the Area (A)
	Geographical Area	GEO_AREA	Text (40)	Atlantic Ocean, Mediterranean Sea, etc
	Sector	SECTOR	Text (40)	Canary Island Seamount Province, Eolian Islands, Gulf of Bothnia, etc
	Ocurrence/Deposit name	OCURRENCE	Text (40)	Name of occurrence/ deposit
	Mineral Ocurrence Type	OCURR_TY	Text (40)	INSPIRE vocabulary (http://inspire.ec.europa.eu/codelist/MineralOccurrenceTypeValue): occurrence, prospect, deposit, district, field
	Year of Database Entry	YEAR	Number	2018, 2019, etc (The original data entry)
	Date of Database Update	UPDATE	Date	dd/mm/yyyy (Date of last update of attributes)
Metallogeny	Deposit Group	DEPOSIT_G	Text (100)	Sediment-related deposits, hydrothermal deposits, volcanogenic deposits, magmatic deposits, metamorphism-related deposits (INSPIRE CODES)
	Deposit Type	DEPOSIT_TY	Text (40)	**Marine Placer** -this exact wording must be entered in bold type (INSPIRE CODE)
	Setting	SETTING	Text (250)	Description of geological setting
	Geomorphic Features	GEOMORPH	Text (250)	Geomorphology of area of Marine Placer crust occurrence
	Event environment	EVENT_ENVI	Text (250)	Environment of formation of the mineral deposit (INSPIRE vocabulary: http://inspire.ec.europa.eu/codelist/EventEnvironmentValue)
	Depositional environeme	DEPOSITION	Text (250)	Environment of deposition of marine placers: fluvial, eolian, glacigenic, beach-nearshore
	Formation	FORMATION	Text (15)	Autochthonous or allochthonous deposit
	Source	SOURCE	Text (40)	Possible source rock (onshore or offshore) derived from literature
	Source type	SOURCE_TY	Text (10)	Source type of deposit: primary or secondary
	Host Rock/Sediment	HOST_ROCK	Text (250)	Substrate rock or sediment surrounding the occurrence
	Metallic Commoditiy	METAL_COMM	Text (40)	Including precious and non-precious metals (USE INSPIRE COMMODITY CODES)
	Other Metals	OTHER-ME	Text (40)	USE INSPIRE COMMODITY CODES
	Commodity Group	COMM_G	Text (40)	Base metals, precious metals, energy metals, technological metals (USE INSPIRE COMMODITY CODES)
	Ore Minerals	ORE_MIN	Text (250)	Principal minerals/commodities (see INSPIRE)
	Gangue Minerals	GANGUE	Text (250)	Non-economic minerals (see INSPIRE)
	Alteration	ALTER	Text (250)	Alteration minerals formed during/after the process of mineralization
	Morphology	MORPH	Text (250)	Shape and internal structure (thickness and texture) of the mineral deposit
	Geochemistry	GEOCHEM	Text (250)	Link to Geochemistry table
Economic Data	Mineral Ocurrence Type	OCURR_TY	Text (40)	INSPIRE vocabulary (http://inspire.ec.europa.eu/codelist/MineralOccurrenceTypeValue): occurrence, prospect, deposit, district, field
	Size	SIZE	Text (250)	Magnitude of the mineral deposit (unknown, occurrence, small, medium, large, very large)
	Importance	IMPORTANCE	Text (250)	Importance of the mineral deposit (INSPIRE vocabulary: http://inspire.ec.europa.eu/codelist/ImportanceValue)
	Resources	RESOURCE	Number	Resources in Mt
	Reserves	RESERVE	Number	Reserves in Mt
	Mined Tonnage	MIN_T	Number	in Mt
	Total Tonnage	TOTAL_T	Number	in Mt
	Remaining Tonnage	REM_T	Number	in Mt
	Resource Reporting Stan	RES_REP	Text (40)	PERC, JORC, NI43-101, etc
	Reference for Tonnage As	REF_T	Text (40)	Company ordering the assesment
	Data Scale	SCALE	Text (100)	Specify the scale in which the deposit has been mapped and delivered
	Status	STATUS	Text (250)	e.g. under exploration, research, identified deposits, hypothetical deposits, etc. (USE INSPIRE CODES)
	Operator	OPERATOR	Text (250)	Research, exploration or operating agency/company
	Exploration Type	EXPLOR_TY	Text (250)	Exploration techniques employed to describe the mineral deposit http://inspire.ec.europa.eu/codelist/ExplorationActivityTypeValue
	Cruises	CRUISES	Text (250)	Cruises identification
	Sampling Methods	SAMPLING_M	Text (250)	Type of method to recover samples (dredge, ROV…)
	Sites Number	SITES_NO	Text (250)	Sampling sites identification
	Deposit Name	DEPOSIT_NAME	Text (250)	Name of the area of the deposit, concession or resource area
	Deposit Number	DEPOSIT_NO	Text (50)	Number of the area of the deposit, concession or resource area
	Data Provider	DATA_PROVI	Text (150)	Name of organisation providing data
	Data Provider Contact	DATA_CONT	Text (150)	The data providing **organisation/institute** contact details – email is required
	Data Holder	DATA_HOLD	Text (150)	Name of the data holder organisation
	Deposit Extent	DEPOSIT_KM2	No. Double (11,4)	Area of deposit **(Sq. Km) -** does not apply to the point shapefile
	Depth to Deposit (m)	DEPTH_TO_D	No. Double (11,4)	Depth to deposit from sea surface
Environment	Fauna	FAUNA	Text (100)	Type of fauna (e.g. corals,…)
Other Data	Description	DESCRIPTION	Text (500)	Deposit summary and metallogenetic model
	Gallery	GALLERY	Image	Images on the mineralization (geophysical, sampling, textural features, paragenesis, etc)
	References	REFERENCES	Text (250)	Link to bibliographic references (DOI and/or Author, Year & Title if you wish)
	Comments	COMMENTS	Text (250)	Any additional comments or observations

Figure 4: Overview of the general schema of data for WP5

This work has been supported by the European Union's Horizon 2020 research and innovation programme, GeoERA (Grant Agreement Nº 731166, project GeoE.171.001).

description of a deposit but also needed for the economic evaluation for present or future exploitation. Thus, it comprised five (5) categories with 58 attributes in total:

- The *General Data* category provides for each occurrence coordinates, country code, administration and marine region, sector, and location.
- *Metallogeny Data* category provides information about the mineralization, the age, the host rock, the main metal commodity and other possible by-products or co-products.
- The *Economic Data* category provides information about resources and reserves as well as geochemistry of the analyzed samples if those data are available.
- The *Environment category* addresses the presence of possible and different marine fauna related to the different mineral deposit types.
- The *Other Data* category provides information about the references for each occurrence.

Additionally, the metallogenetic information was complemented by the available geochemical data of the occurrences, where possible.

To ensure interoperability, data attributes, where possible were chosen from specified codelists; thus, the INSPIRE themes for "Geology" (https://inspire.ec.europa.eu/Themes/128/2892), "Mineral Resources" (https://inspire.ec.europa.eu/id/document/tg/mr), and others as complementary (e.g. Administrative units, Geographical names) formed the basis for the data specifications.

The data for marine placer deposits, collected during the MINDeSEA project, comprise 90 sites (Table 6).

Table 6: Marine placer occurrences in the European Seas (MINDeSEA, July 2021)

ID	LONGITUDE	LATITUDE	CODE	GEO_AREA	STATUS
1	21.723726	57.591732	LVA	Baltic Sea	not operating
2	22.053935	57.637258	LVA	Gulf of Riga	not operating
3	22.277343	57.751483	LVA	Gulf of Riga	not operating
4	21.046862	56.742395	LVA	Baltic Sea	not operating
5	21.246978	56.944928	LVA	Baltic Sea	not operating
6	21.412286	57.256266	LVA	Baltic Sea	not operating
7	20.977501	56.316086	LVA	Baltic Sea	not operating
8	14.602395	54.345561	POL	Baltic Sea	not operating
9	14.674810	54.322292	POL	Baltic Sea	not operating

This work has been supported by the European Union's Horizon 2020 research and innovation programme, GeoERA (Grant Agreement Nº 731166, project GeoE.171.001).

10	-6.506717	36.736918	ESP	Bay of Biscay	not operating
11	-1.948389	36.858114	ESP	Mediterranean Sea – W. Basin	not operating
12	-8.771724	42.242889	ESP	Bay of Biscay	not operating
13	0.839937	40.654122	ESP	Mediterranean Sea – W. Basin	not operating
14	3.209094	42.013990	ESP	Mediterranean Sea – W. Basin	not operating
15	3.141903	42.196895	ESP	Mediterranean Sea – W. Basin	not operating
16	-1.720988	37.295914	ESP	Mediterranean Sea – W. Basin	not operating
17	-1.759067	37.263123	ESP	Mediterranean Sea – W. Basin	not operating
18	-8.289988	43.561865	ESP	Bay of Biscay	not operating
19	-8.676500	42.416300	ESP	Bay of Biscay	not operating
20	-8.685700	42.276000	ESP	Bay of Biscay	not operating
21	-0.848200	37.581800	ESP	Mediterranean Sea – W. Basin	not operating
22	-2.490000	47.480000	FRA	Bay of Biscay	not operating
23	-3.530000	47.750000	FRA	Bay of Biscay	not operating
24	-4.810000	48.450000	FRA	Bay of Biscay	not operating
25	-2.820000	48.650000	FRA	English Channel	not operating
26	-2.530000	47.360000	FRA	Bay of Biscay	not operating
27	-4.053100	52.716100	GBR	Irish Sea & St. George's Channel	not operating
28	-6.330400	56.941000	GBR	Inner Seas off the West Coast of Scotland	not operating
29	-1.841500	57.622300	GBR	North Sea	not operating
30	-3.651300	58.113700	GBR	North Sea	not operating
31	-6.071200	56.448500	GBR	Inner Seas off the West Coast of Scotland	not operating
32	-6.021000	57.177000	GBR	Inner Seas off the West Coast of Scotland	not operating
33	-6.145355	56.353913	GBR	Inner Seas off the West Coast of Scotland	not operating
34	-7.041535	56.904234	GBR	Inner Seas off the West Coast of Scotland	not operating
35	-6.370241	56.907174	GBR	Inner Seas off the West Coast of Scotland	not operating
36	-6.292483	56.921725	GBR	Inner Seas off the West Coast of Scotland	not operating
37	1.026119	51.510454	GBR	North Sea	not operating
38	-1.568228	55.389798	GBR	North Sea	not operating
39	1.778482	54.300520	GBR	North Sea	not operating
40	-4.721392	50.320170	GBR	English Channel	not operating
41	-4.767415	50.283976	GBR	English Channel	not operating
42	-5.486243	50.097905	GBR	English Channel	not operating

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43	-5.433279	50.219215	GBR	Celtic Sea	not operating
44	-5.249708	50.292698	GBR	Celtic Sea	not operating
45	-5.184731	50.352844	GBR	Celtic Sea	not operating
46	4.750000	53.000000	DNK	North Sea	not operating
47	-22.500000	64.500000	ISL	Arctic Ocean	not operating
48	33.274000	34.714000	CYP	Mediterranean Sea – E. Basin	not operating
49	33.369000	34.731000	CYP	Mediterranean Sea – E. Basin	not operating
50	33.559000	34.820000	CYP	Mediterranean Sea – E. Basin	not operating
51	19.350842	40.626115	ALB	Adriatic Sea	feasibility
52	19.325326	40.656877	ALB	Adriatic Sea	feasibility
53	19.480002	40.982951	ALB	Adriatic Sea	feasibility
54	19.436136	40.906386	ALB	Adriatic Sea	feasibility
55	19.382405	40.775407	ALB	Adriatic Sea	feasibility
56	19.412096	40.814349	ALB	Adriatic Sea	feasibility
57	19.388111	40.737767	ALB	Adriatic Sea	feasibility
58	19.462076	41.092635	ALB	Adriatic Sea	feasibility
59	19.515084	41.226237	ALB	Adriatic Sea	feasibility
60	19.513307	41.473058	ALB	Adriatic Sea	feasibility
61	19.493746	41.443551	ALB	Adriatic Sea	feasibility
62	19.579851	41.660944	ALB	Adriatic Sea	feasibility
63	19.583728	41.584779	ALB	Adriatic Sea	feasibility
64	19.599896	41.608485	ALB	Adriatic Sea	feasibility
65	19.603312	41.691960	ALB	Adriatic Sea	feasibility
66	19.600633	41.711941	ALB	Adriatic Sea	feasibility
67	12.631546	41.440297	ITA	Mediterranean Sea – W. Basin	feasibility
68	10.250000	42.820000	ITA	Mediterranean Sea – W. Basin	feasibility
69	11.800000	42.000000	ITA	Mediterranean Sea – W. Basin	feasibility
70	30.453454	46.020108	UKR	Black Sea	not operating
71	30.730743	46.258567	UKR	Black Sea	not operating
72	29.732783	45.555725	UKR	Black Sea	not operating
73	31.165706	45.802137	UKR	Black Sea	not operating
74	32.017645	46.019846	UKR	Black Sea	not operating
75	30.879021	46.477995	UKR	Black Sea	not operating
76	31.375787	44.562761	UKR	Black Sea	not operating
77	31.190058	44.250467	ROU	Black Sea	not operating
78	31.232663	44.481894	ROU	Black Sea	not operating
79	30.891237	44.041482	ROU	Black Sea	not operating
80	30.510878	43.807730	ROU	Black Sea	not operating

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81	30.134359	43.630485	BGR	Black Sea	not operating
82	43.666046	66.169447	RUS	Arctic Ocean	not operating
83	42.299388	66.574300	RUS	Arctic Ocean	not operating
84	45.947772	67.718700	RUS	Arctic Ocean	not operating
85	51.913533	72.171223	RUS	Arctic Ocean	not operating
86	53.434683	73.217309	RUS	Arctic Ocean	not operating
87	55.955702	74.639675	RUS	Arctic Ocean	not operating
88	37.902552	63.964503	RUS	Arctic Ocean	not operating
89	33.185160	66.762019	RUS	Arctic Ocean	not operating
90	24.282529	40.594449	GRE	Aegean Sea	not operating

Currently, the MINDeSEA database includes 90 sites of marine placer occurrences the majority of which located in the Adriatic Sea (16 occurrences, corresponding to 18% of the total), the Celtic Seas (15 occurrences, corresponding to 17% of the total), the Black Sea (12 occurrences, corresponding to 13% of the total) and the Western Mediterranean (10 occurrences, corresponding to 11% of the total). The remaining occurrences (41%) are distributes through the other regions/ sub regions (Figure 5; Figure 6).

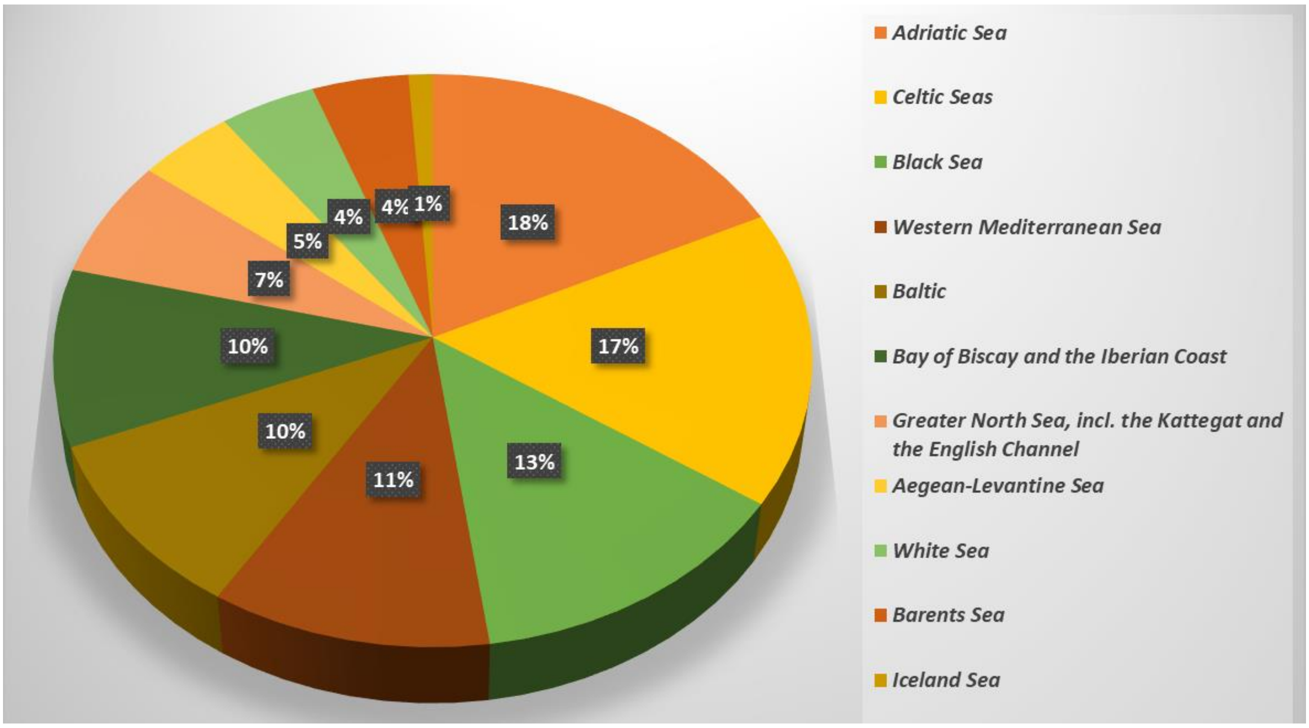

Figure 5: Distribution of marine placers' occurrences, documented in the MINDeSEA database, in relation to MSFD regions and sub regions

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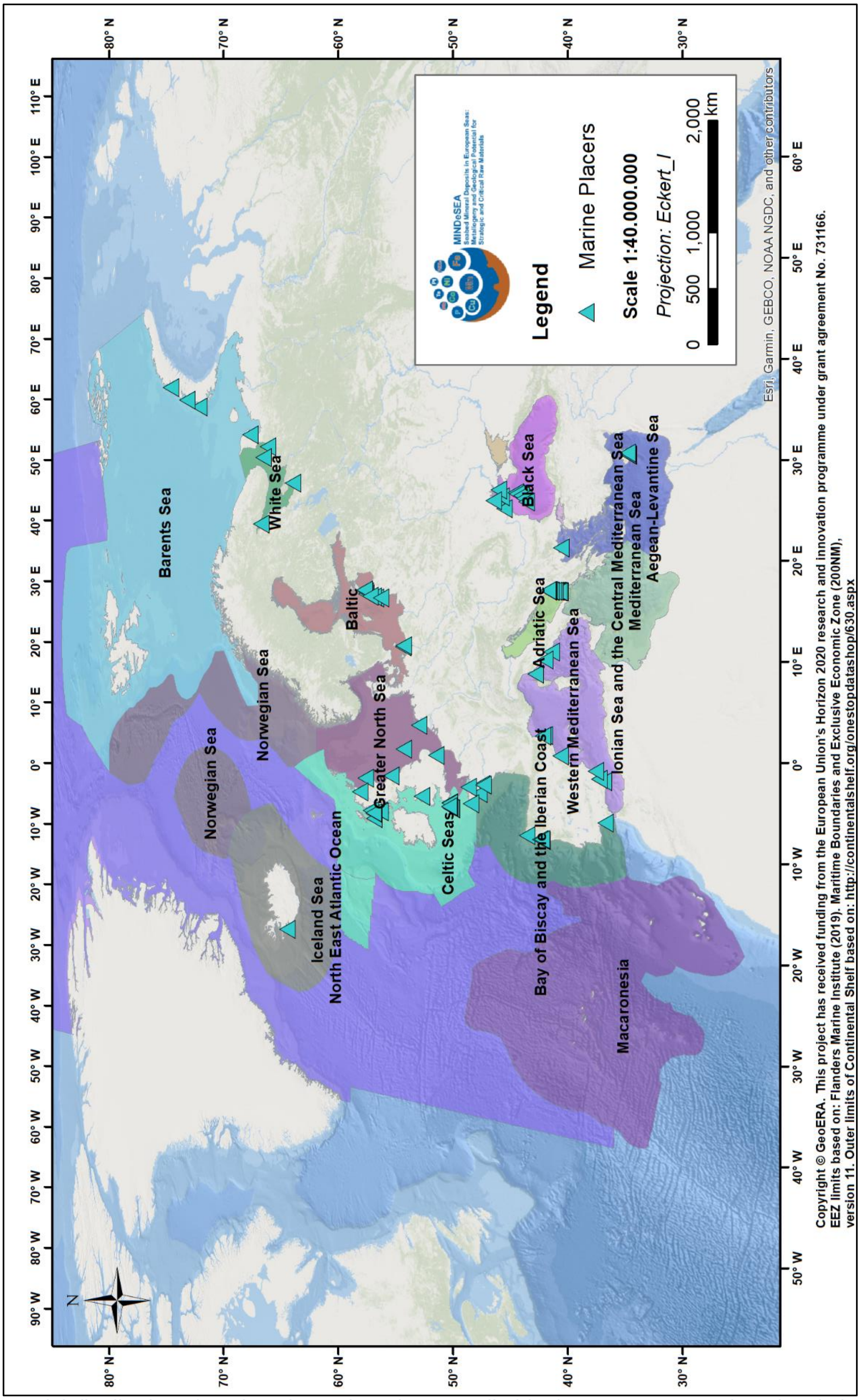

Figure 6: Spatial distribution of marine placer deposits, compiled in the MINDeSEA project, in relation to MSFD marine regions and sub regions

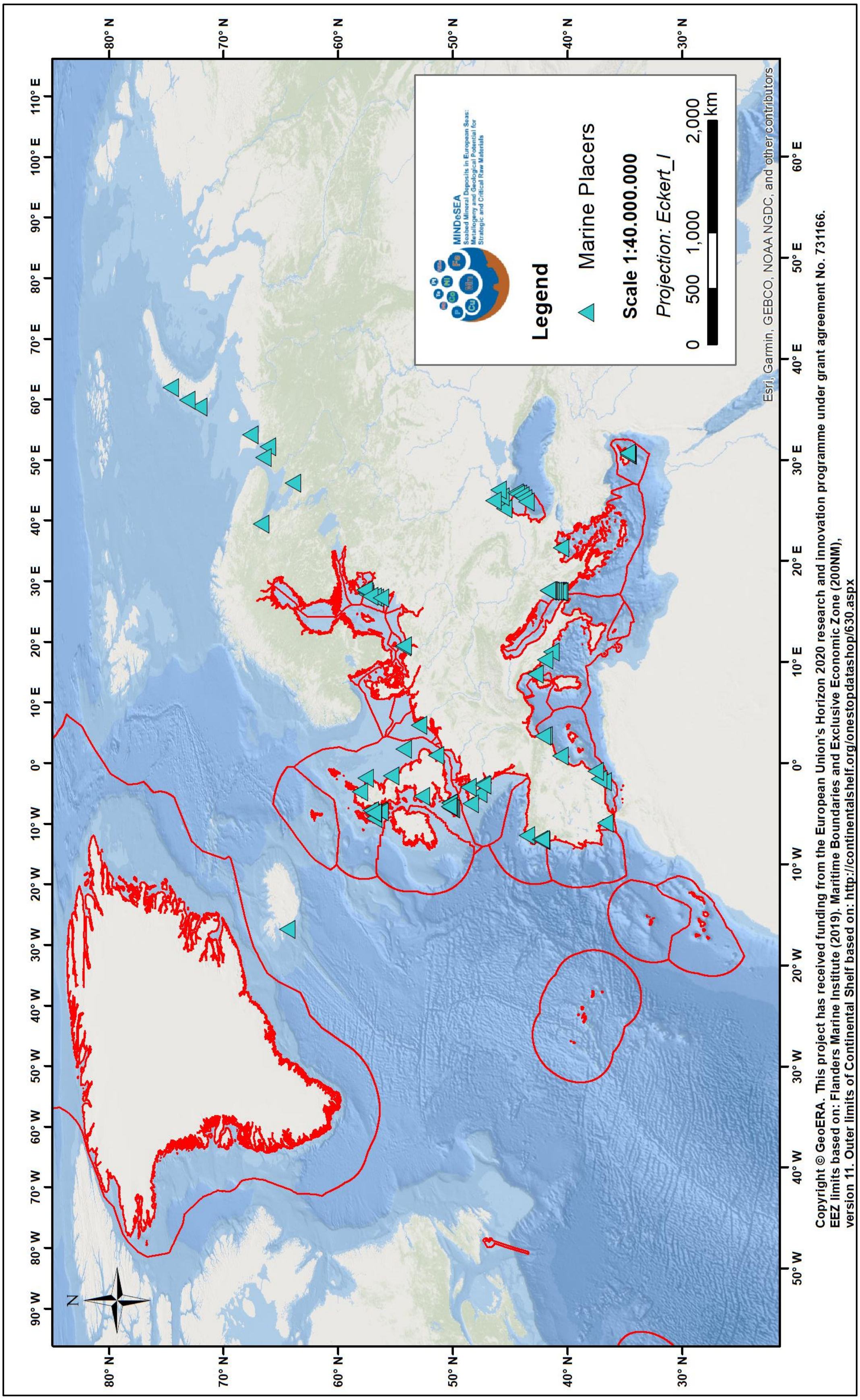

Figure 7: Spatial distribution of marine placer deposits, compiled in the MINDeSEA project, in relation to EEZ's

Similarly, the spatial distribution of marine placer deposits, included in the MINDeSEA dataset, is examined in relation to Exclusive Economic Zones (Figure 7).

It has to be noted, however, that the aforementioned analysis is only indicative, due to the fact that thoroughly exploited areas are represented by several neighbouring points in the database, whereas areas of preliminary research activities are considered as a single point.

4.3 Metallogenic provinces

Following, a detailed analysis is presented of the marine regions / sub regions where placer occurrences have been documented. The main characteristics of the area are discussed along with corresponding off-shore, as well as on-shore data controlling the formation of placers. Those data were derived mainly from the European Geological Data Infrastructure – EGDI portal (https://edgi.org/ - where metadata and legends for the used data files can be retrieved), complemented by information, maps and datasets from individual publications and possibly other international portals.

4.3.1 Black Sea

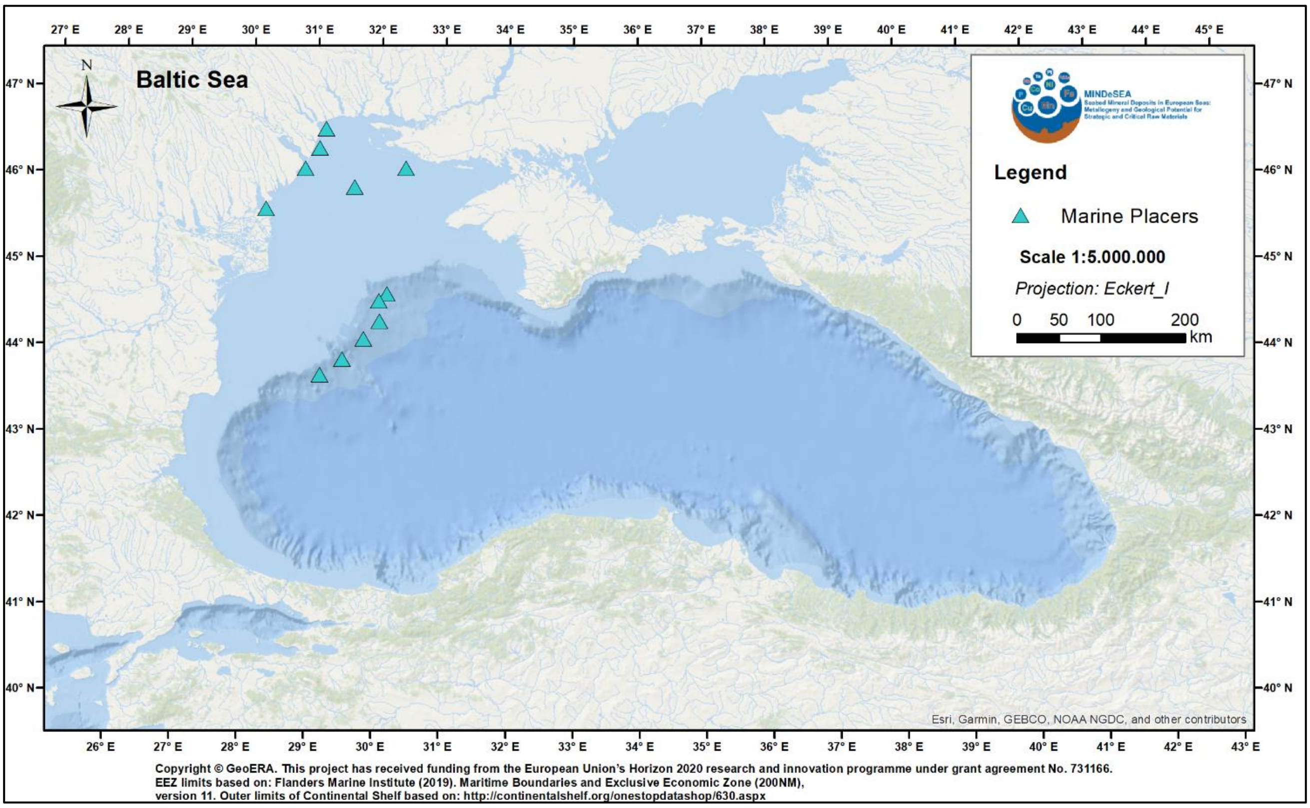

Figure 8: Marine placer deposits in Black Sea

This work has been supported by the European Union's Horizon 2020 research and innovation programme, GeoERA (Grant Agreement Nº 731166, project GeoE.171.001).

The Black Sea is a 2200 m deep marine basin surrounded by alpine mountains including the Balkanides, the Pontides, the Greater Caucasus and the Crimean Mountains. A significant characteristic, directly related with the formation of marine placer deposits, is the frequent shifting of shorelines of the Black Sea during the Quaternary.

During the period of continental glaciations, the level of the Black Sea would fall below the Bosphorus sill, whereupon the waters would freshen and the Sea would turn into a large inland lake; during the interglacial periods, rising water in the Mediterranean Sea and Sea of Marmara would restore the connection (Dimitrov *et al.*, 2005). Ancient coastlines have left permanent traces along the continental shelf and slope, and they exist today as relict seafloor features and offshore deposits that together create a well-defined sea complex in the littoral relief. The oldest basin coastline is located along the upper continental slope at depths between 155-170 m.

The influence of the these sea level fluctuations on the generation of placer deposits is obvious, when examining the distribution of documented occurrences (Figure 8; Figure 9; Figure 10), verifying the fact that necessary conditions are met. As a result similar localities at the present and palaeo- margins of the Black Sea are possible targets for future exploration.

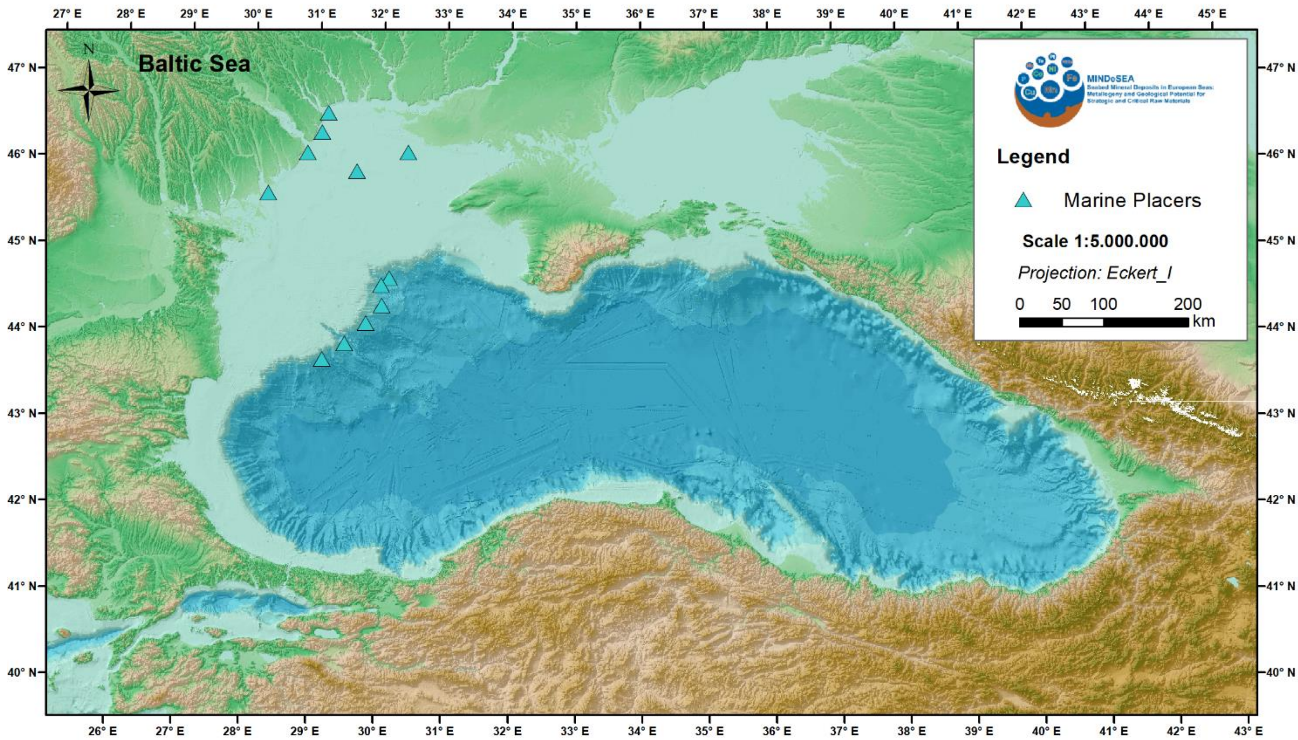

Figure 9: Black Sea and surrounding area shaded relief (GEBCO 2021 Grid)

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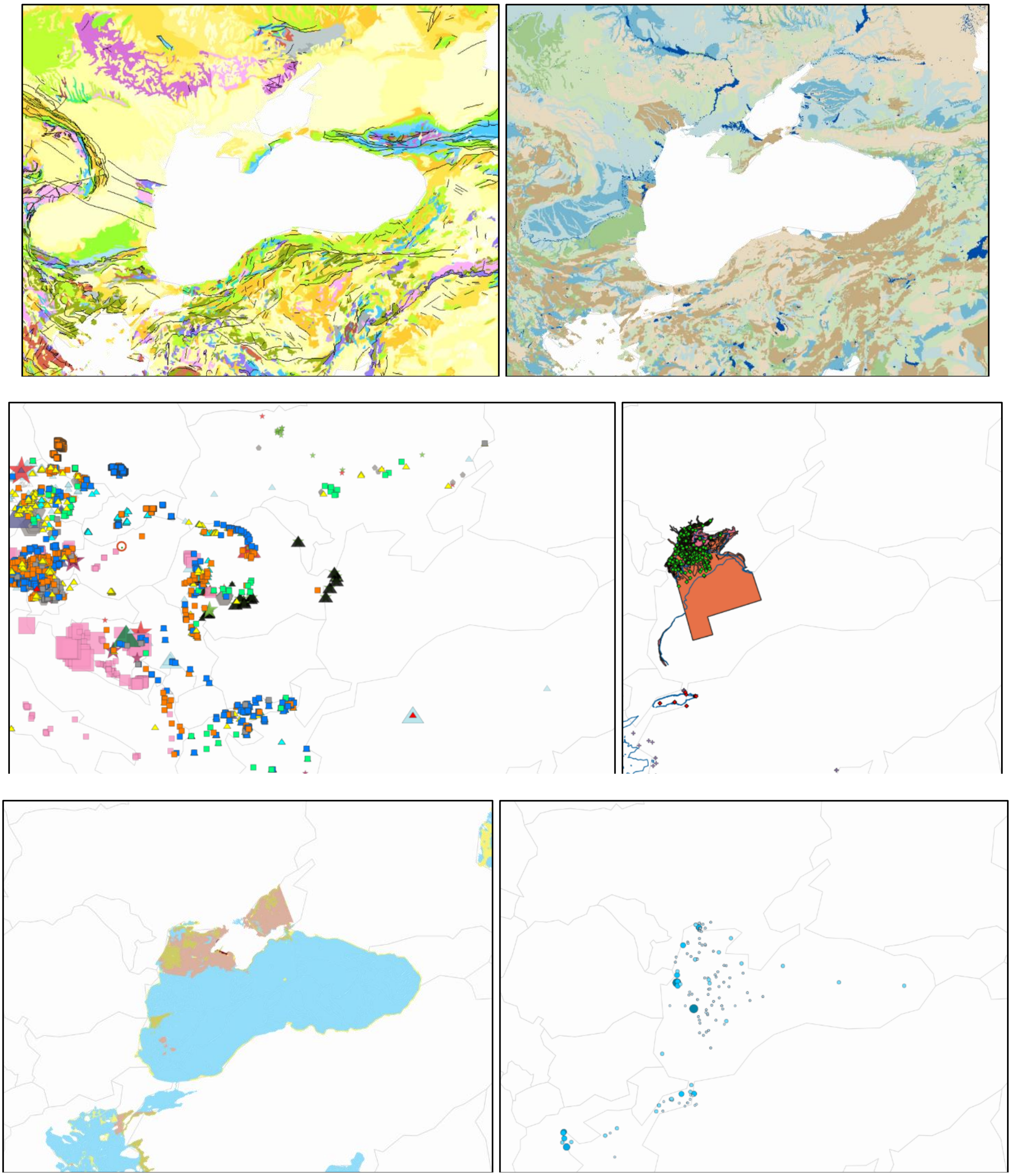

Figure 10: On-shore and off-shore data of the Black Sea and surrounding area available from EGDI portal (a) Geological setting (Asch, 2005), (b) Hydrogeology map (BGS, EGS, UNESCO, 2008), (c) On-shore mineral deposits (Minerals4EU, Mintell4EU, Reseerve), (d) Submerged landscapes (EMODnet-Geology WP8), (e) Seabed substrate (EMODnet-Geology WP3), (f) Marine minerals (EMODnet-Geology WP7)

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4.3.2 Aegean – Levantine Sea

The Aegean – Levantine Sea extends over the eastern part of the Mediterranean Basin, one of the most seismically active and rapidly deforming regions within the continents. The Aegean Sea is an elongated embayment located between the Balkans and Anatolia; a shallow sea dominated by the subduction of the Aegean microplate along the Hellenic arc and the continental collision in Anatolia and the Caucasus. Levantine Sea is the easternmost part of Mediterranean, characterized by the presence of seamounts, basins, troughs and trenches.

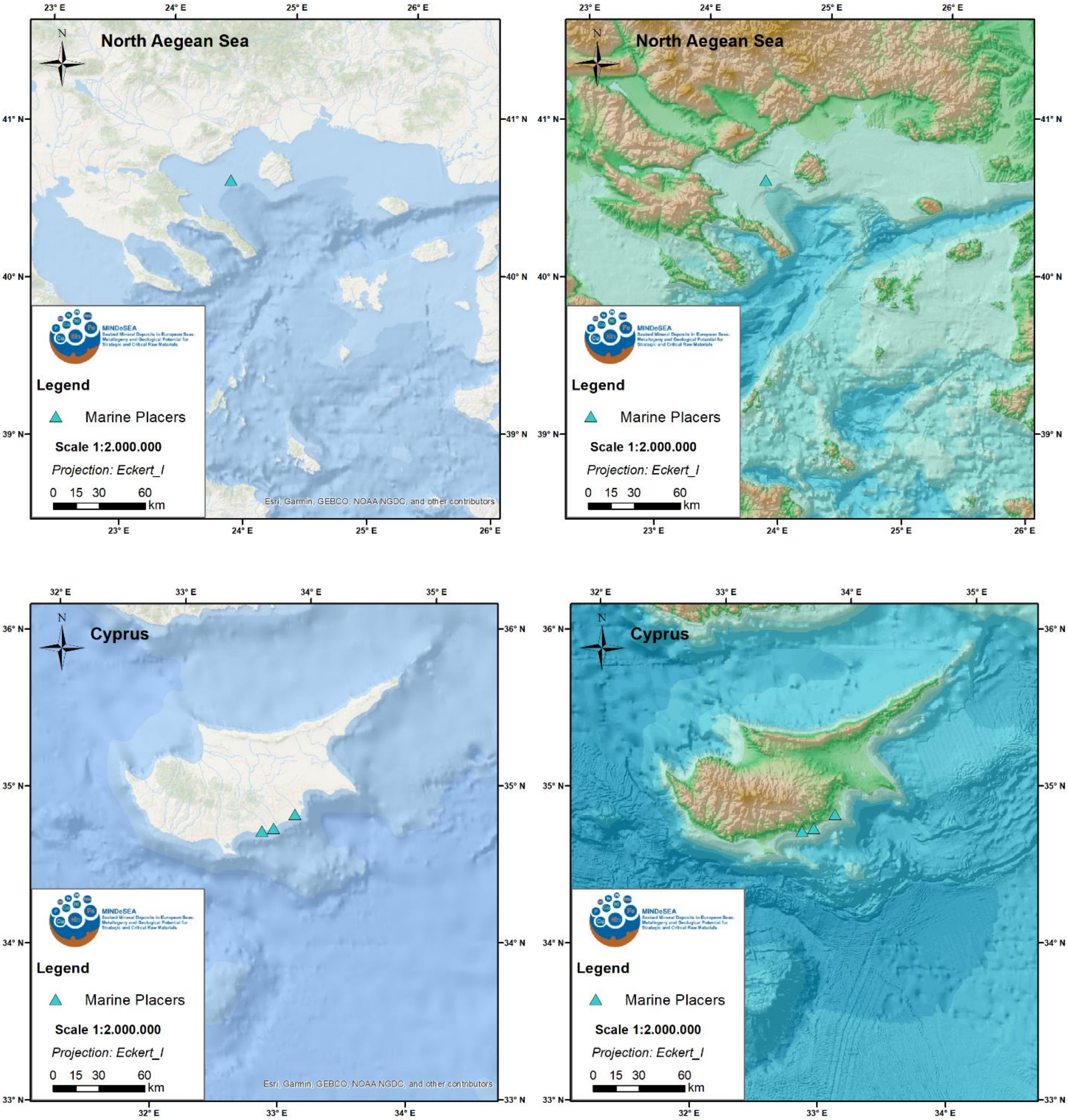

Figure 11: Marine placers' sites in Northern Aegean (top) and Cyprus (bottom)

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The offshore area of eastern Macedonia from the shoreline to the shelf break, namely the Ierissos – Alexandroupolis shelf area, encompasses the Strymonikos Plateau and that of Samothraki (Figure 11 – top; Figure 12).

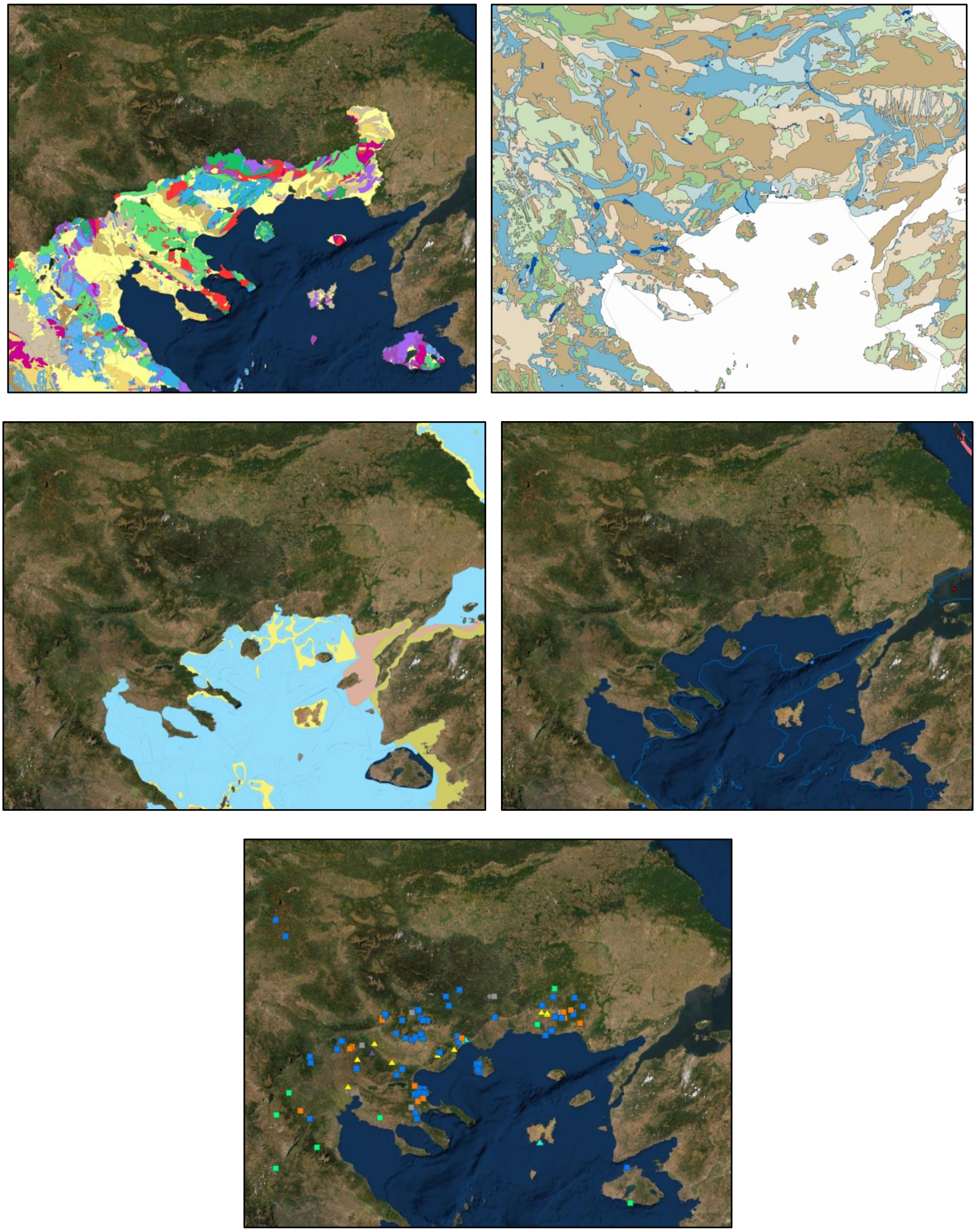

Figure 12: On-shore and off-shore data of the Northern Aegean and surrounding area available from EGDI portal (a) Geological setting (Asch, 2005), (b) Hydrogeology map (BGS, EGS, UNESCO, 2008), (c) Seabed substrate (EMODnet-Geology WP3), (d) Submerged landscapes (EMODnet-Geology WP8), (e) On-shore mineral deposits (Minerals4EU, Mintell4EU, Reseerve)

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The area has a complex evolution during the Late Quaternary, having undergone a series of sea level regressions and transgressions, evident by palaeo-lakes and palaeo-riverbeds at the present-day seafloor (Perissoratis and Mitropoulos, 1989). The surrounding land is covered by metamorphic and igneous rocks, while the area is drained by the Strymon river. Given that the main conditions for placer formations are met – while similar deposits have been found onshore – several studies have been carried out (Perissoratis *et al.*, 1987; Perissoratis *et al.*, 1988; Perissoratis and Mitropoulos, 1989) to study the presence of occurrences.

It has to be noted that the entry in the MINDeSEA database is an area – presented as a point for data compatibility reasons, rather than as a polygon. The detailed mineral potential of the area can be examined through the publications of Perissoratis *et al.* (1987, 1888) (Figure 13).

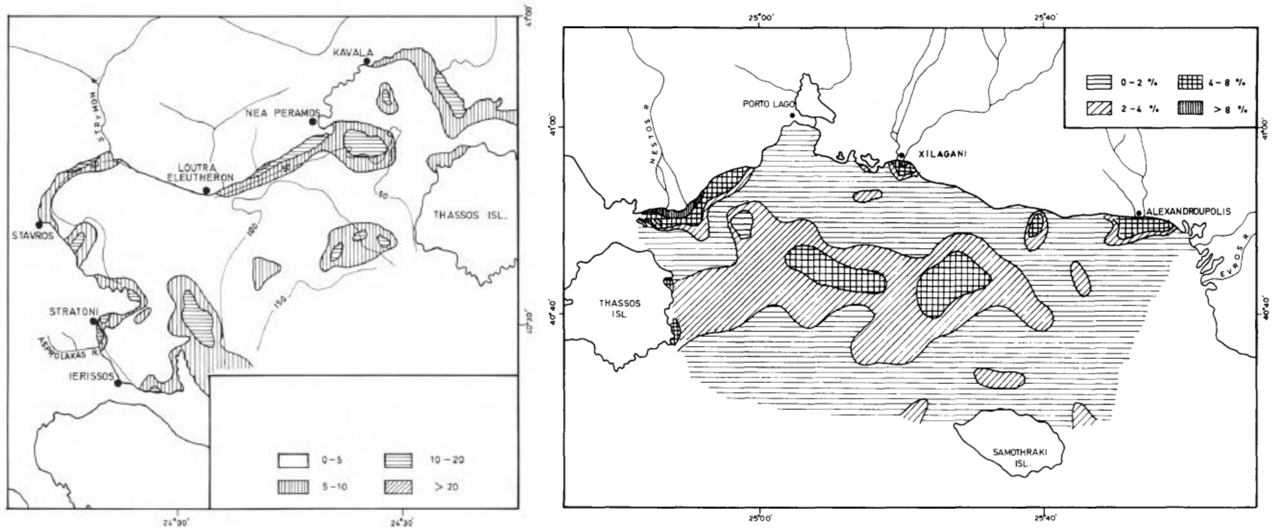

Figure 13: Heavy mineral content in the coarse fraction of surface sediments over the Strymonikos (left) and Samothraki (right) Plateau (Perissoratis et al., 1988; 1989)

Geochemical, sedimentological, and mineralogical data suggest that local geological and oceanographic conditions favor the formation of Fe, Ti, and Cr placer deposits near the mouths of some of the rivers on the Cyprus continental shelf (Varnavas, 1990) (Figure 11 – bottom; Figure 14). Generally, the deposits are associated with finer and better sorted sands to the west of the river mouths. This is a reflection of the prevailing water movements. Metallic ore minerals of the deposits have their source in the mafic and ultramific rocks of the Troodos ophiolite complex.

This work has been supported by the European Union's Horizon 2020 research and innovation programme, GeoERA (Grant Agreement Nº 731166, project GeoE.171.001).

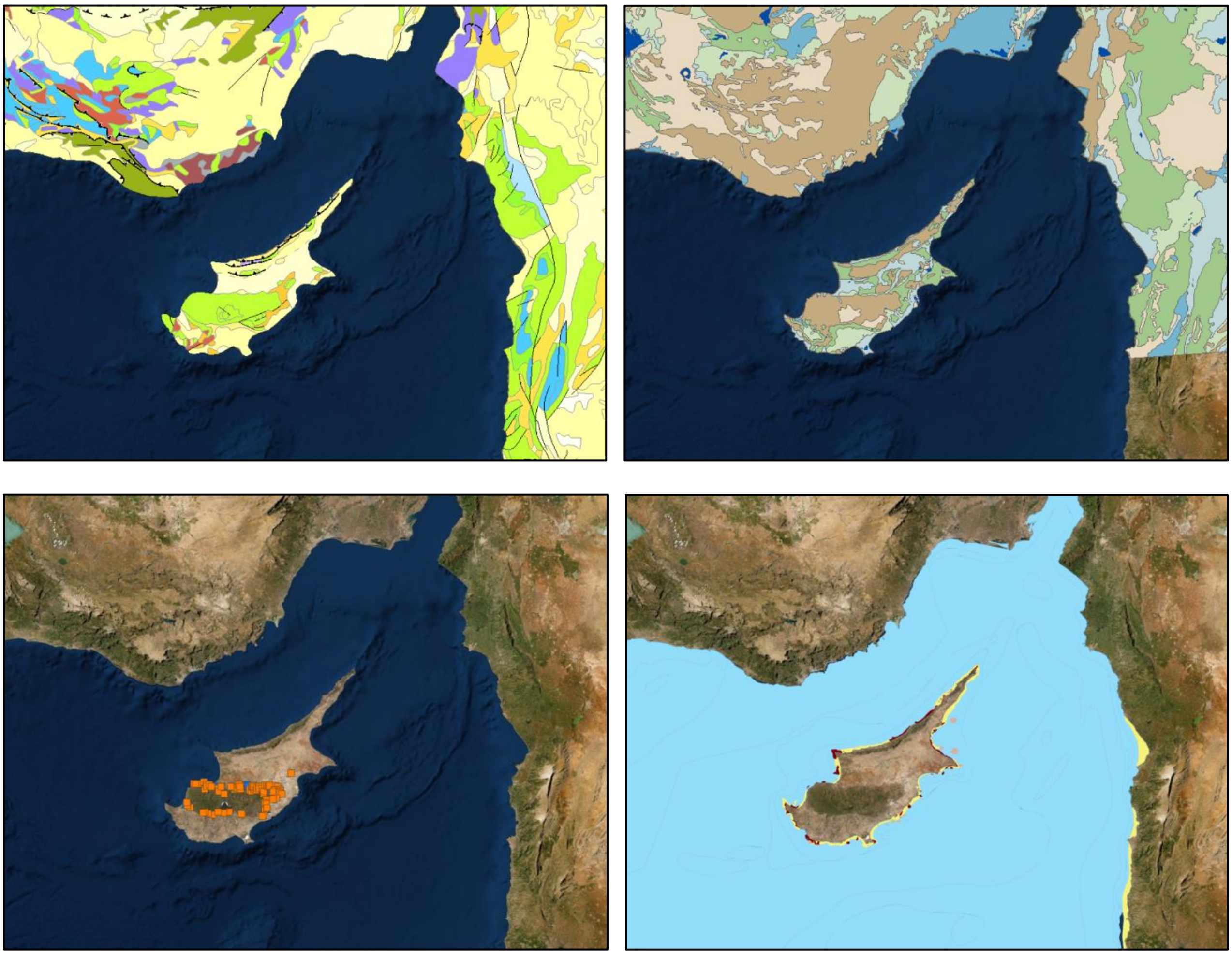

Figure 14: On-shore and off-shore data of Cyprus and surrounding area available from EGDI portal (a) Geological setting (Asch, 2005), (b) Hydrogeology map (BGS, EGS, UNESCO, 2008), (c) On-shore mineral deposits (Minerals4EU, Mintell4EU, Reseerve), (d) Seabed substrate (EMODnet-Geology WP3)

4.3.3 Adriatic Sea

The Adriatic Sea is a mostly shallow, semi-enclosed, elongated basin, NW-SE trending, between Italy and the Balkans. It is subdivided in three main basins, from north to south, exhibiting heterogeneity of the seabed substrate. Along the Montenegro / Northern Albanian Continental Margin – where placers have occurred (Figure 15; Figure 16) at the Vjosa and Mati river delta deposits (Xhafferi *et al.*, 2020) – peculiar morphologies of the bottom are reported, likely due to tectonic compressive deformations. They may be the result of sedimentary processes, such as progradation at river outflows, erosion, and reworking of sediments by longshore currents and seismic shaking. The Late Quaternary sea-level changes affected the presence of seabed forms, diagnostic of erosion or depositional processes, such us large dunes, sediment ridge sand sediment waves (Del Bianco *et al.*, 2014; UNEP/MAP, 2015; and references therein).

This work has been supported by the European Union's Horizon 2020 research and innovation programme, GeoERA (Grant Agreement Nº 731166, project GeoE.171.001).

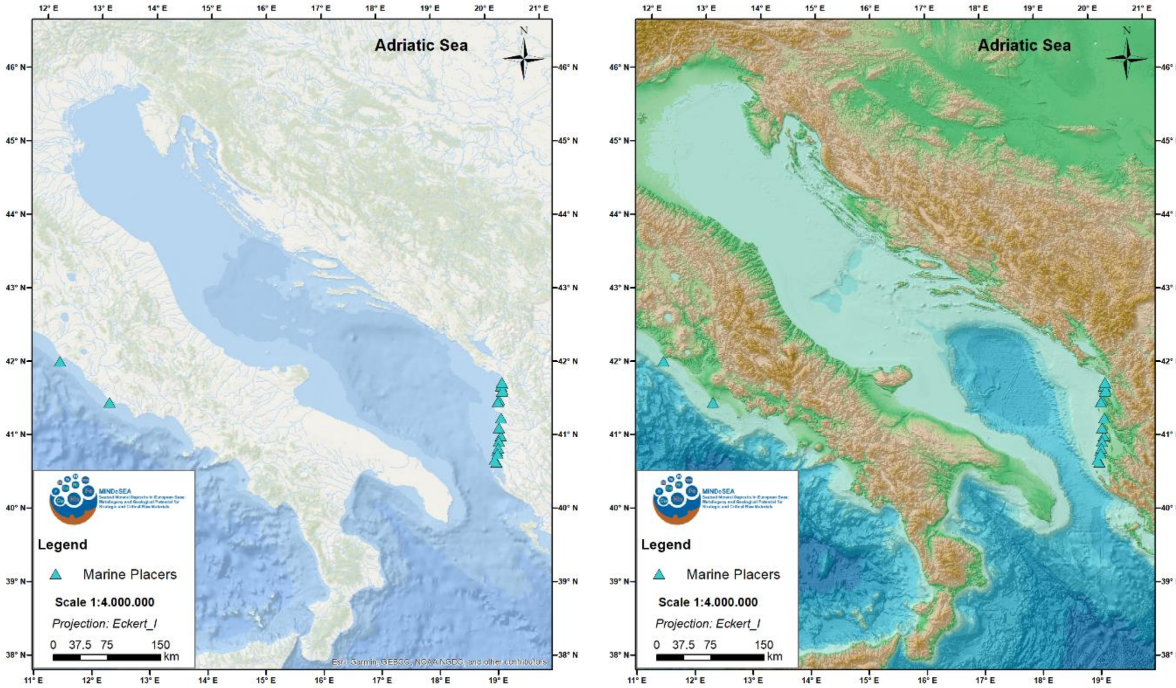

Figure 15: Marine placers' sites in Adriatic Sea

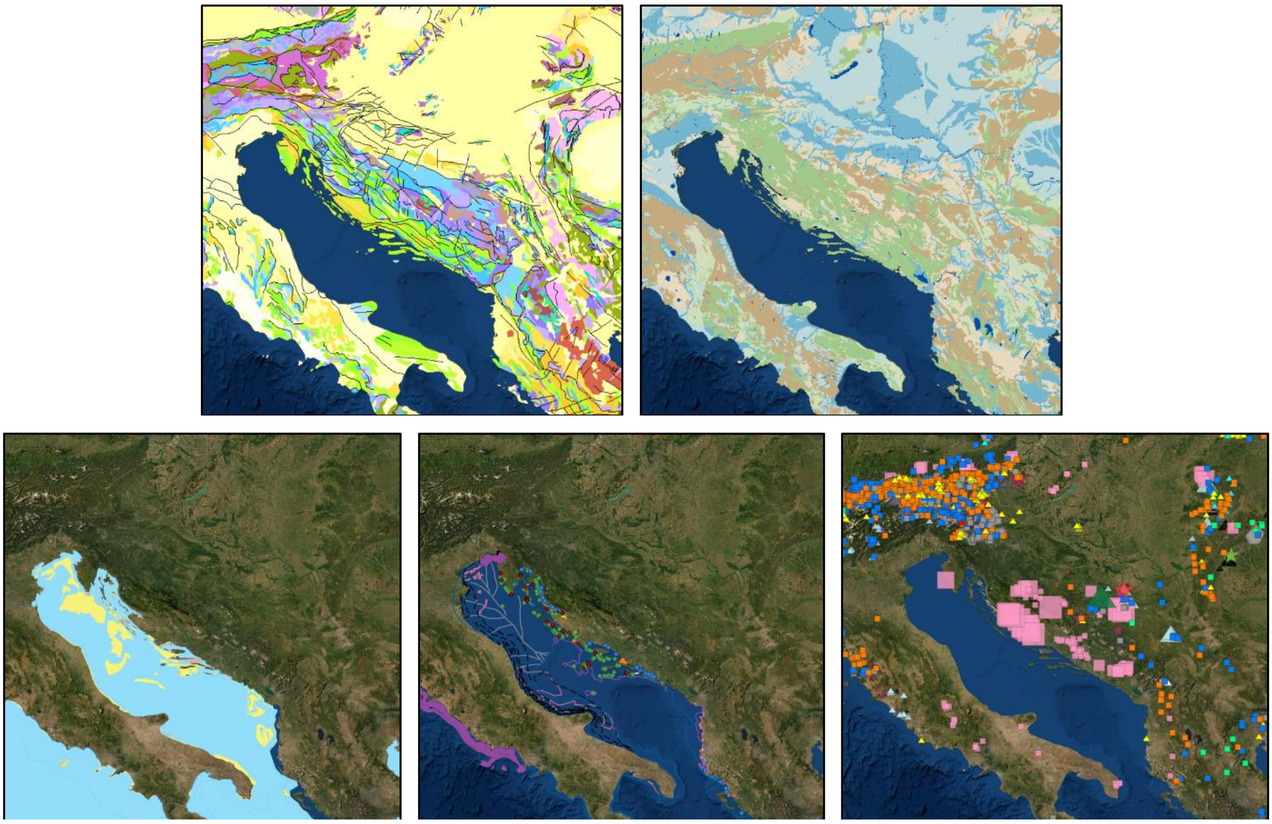

Figure 16: On-shore and off-shore data of the Adriatic Sea and surrounding area available from EGDI portal (a) Geological setting (Asch, 2005), (b) Hydrogeology map (BGS, EGS, UNESCO, 2008), (c) Seabed substrate (EMODnet-Geology WP3), (d) Submerged landscapes (EMODnet-Geology WP8), (e) On-shore mineral deposits (Minerals4EU, Mintell4EU, Reseerve)

This work has been supported by the European Union's Horizon 2020 research and innovation programme, GeoERA (Grant Agreement Nº 731166, project GeoE.171.001).

4.3.4 Western Mediterranean Sea

The Western Mediterranean Sea is the younger part of the Mediterranean, and constitutes a marginal basin, generated by the N-NW subduction of the African – Apulian plates beneath the European plate. It comprises a series of sub-basins, reflected the geotectonic evolution of the area (Figure 17; Figure 19; Figure 20). Marine placer occurrences are found at the eastern margins of the Iberian peninsula, as well as offshore western Italy, along Lazio shoreline and near Elba island (Clerici and Morandini, 1987; and references therein).

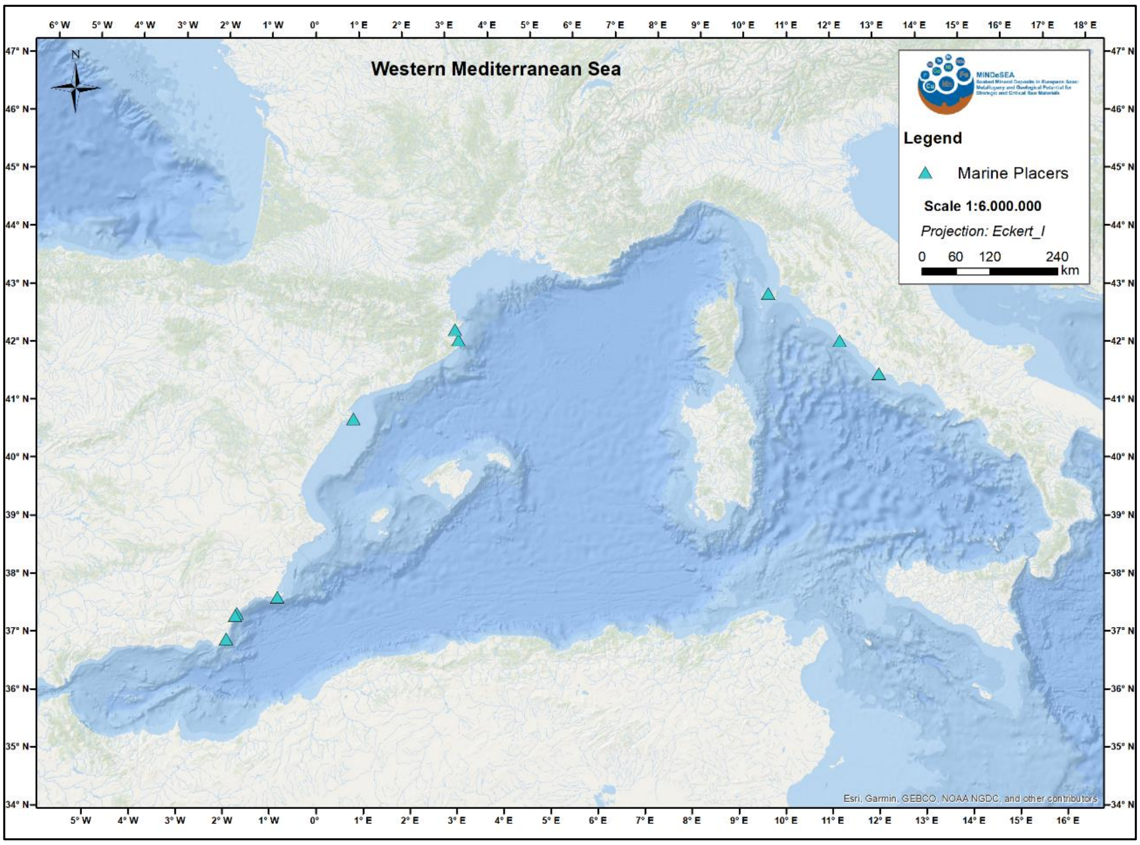

Figure 17: Marine placer deposits in the Western Mediterranean Sea

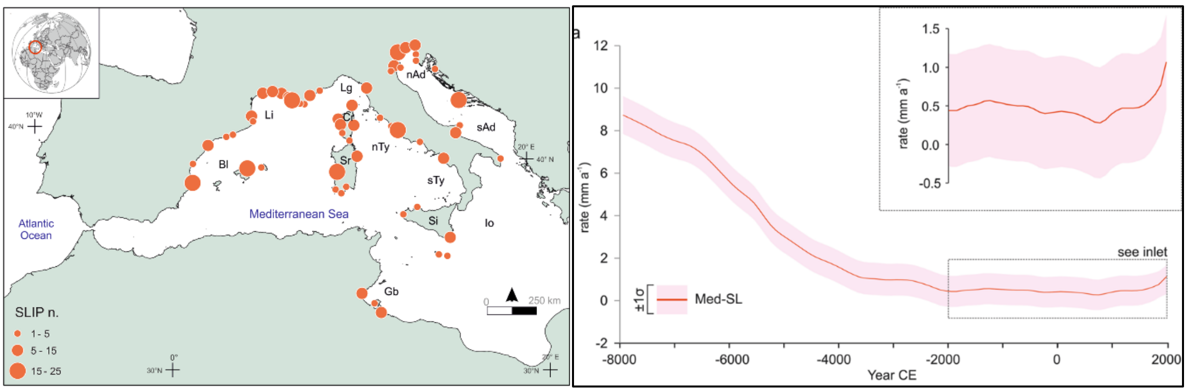

Figure 18: Sea-level index points (left) and rates of relative sea-level change for central and western Mediterranean for the last 10,000 years (from Vacchi et al., 2021)

This work has been supported by the European Union's Horizon 2020 research and innovation programme, GeoERA (Grant Agreement Nº 731166, project GeoE.171.001).

A systematic review of the Holocene sea-level history (Figure 18), a key factor for placers formation, has been recently presented by Vacchi *et al.* (2021).

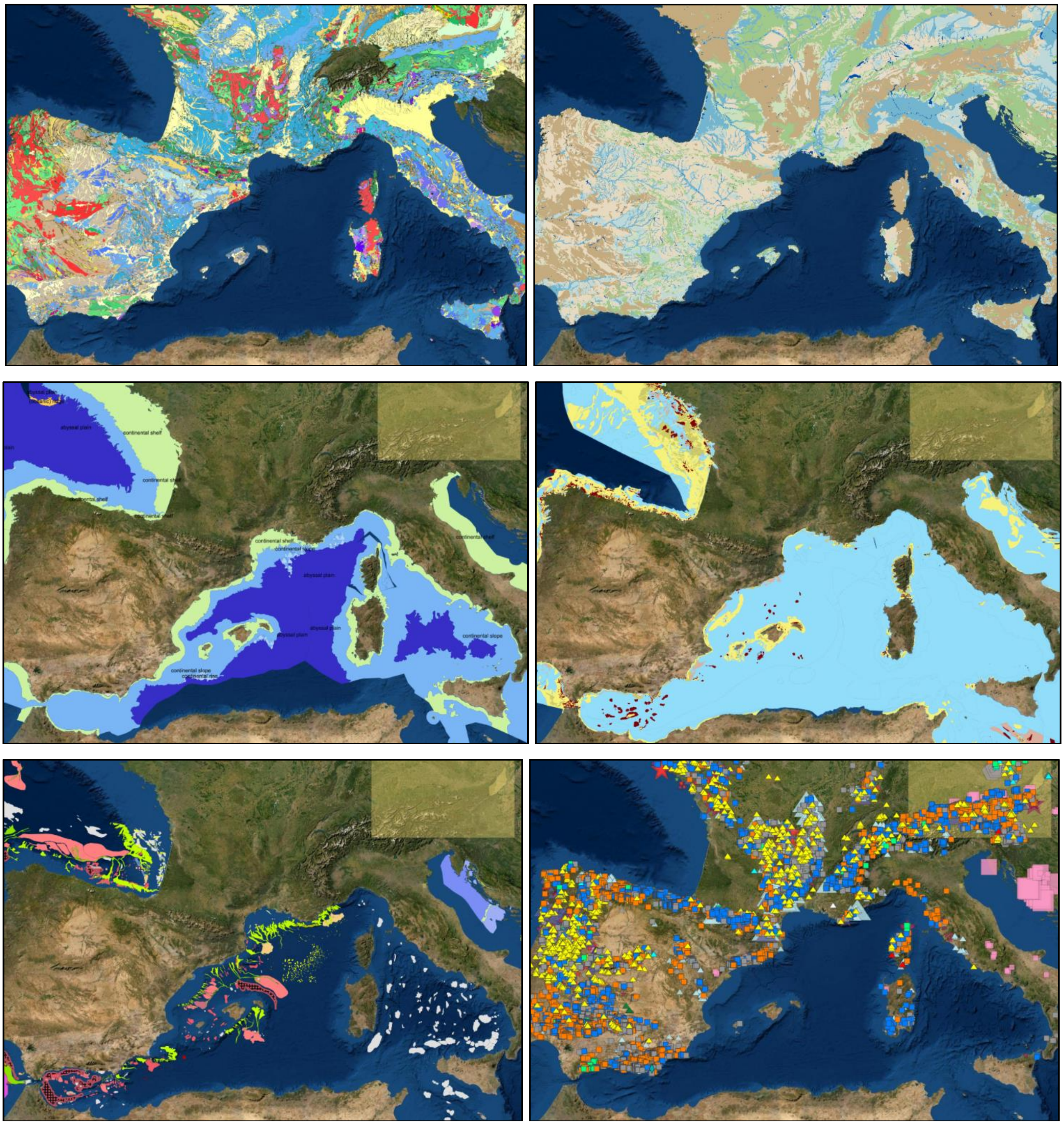

Figure 19: On-shore and off-shore data of the Western Mediterranean Sea and surrounding area available from EGDI portal (a) Geological setting (Asch, 2005), (b) Hydrogeology map (BGS, EGS, UNESCO, 2008), (c) General physiographic features (EMODnet-Geology WP4), (d) Seabed substrate (EMODnet-Geology WP3), (e) Geomorphology (EMODnet-Geology WP4), (e) On-shore mineral deposits (Minerals4EU, Mintell4EU, Reseerve)

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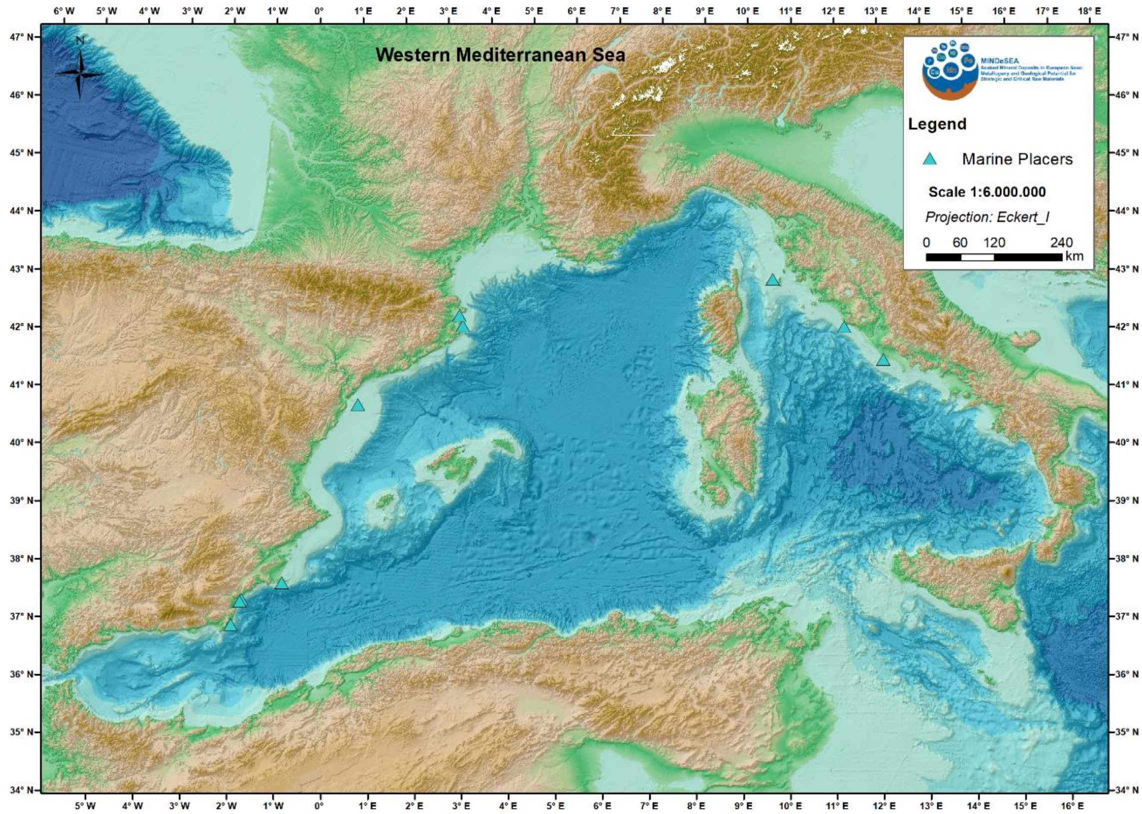

Figure 20: Western Mediterranean and surrounding area shaded relief (GEBCO 2021 Grid)

4.3.5 Bay of Biscay and the Iberian Coast

The Bay of Biscay formed as the North Atlantic opened during the late Cretaceous. Along with the western Iberian coast, it is a complex system including the continental shelf and slope, and the deep abyssal plane (Figure 21).

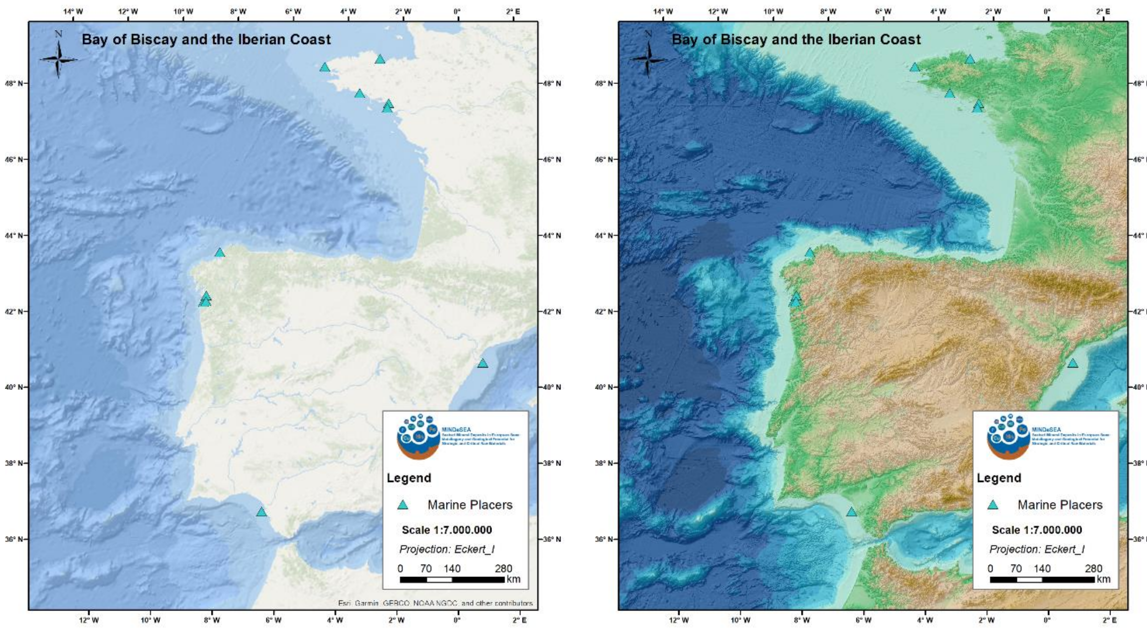

Figure 21: Marine placers' sites in the Bay of Biscay and the Iberian Coast

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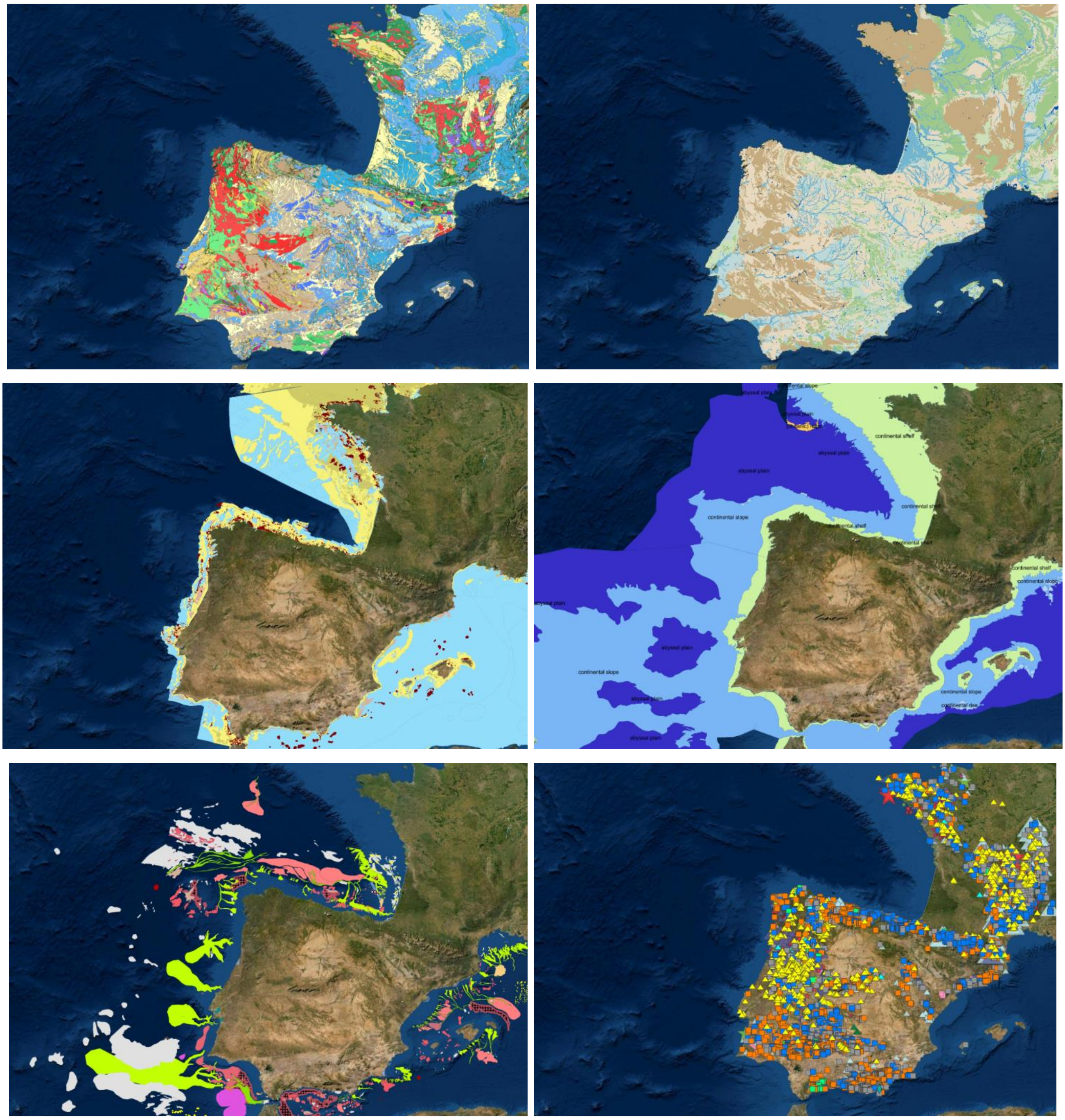

Figure 22: On-shore and off-shore data of the Bay of Biscay – Iberian Coast and surrounding area available from EGDI portal (a) Geological setting (Asch, 2005), (b) Hydrogeology map (BGS, EGS, UNESCO, 2008), (c) General physiographic features (EMODnet-Geology WP4), (d) Seabed substrate (EMODnet-Geology WP3), (e) Geomorphology (EMODnet-Geology WP4), (e) On-shore mineral deposits (Minerals4EU, Mintell4EU, Reseerve)

Tectonic activity and sea-level changes, together with present processes of sediment supply and climatic conditions, have a critical influence on the present configuration of the continental shelf and the distribution of seafloor types (Galparoso Isa *et al.*, 2010; and references therein) (Figure 22; Figure 23). Bay of Biscay exhibits a variety of morphological aspects (Figure 21) –

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thoroughly analysed by De Chambure *et al.* (2013) – resulting in more than 130 canyons, organized in 8 large drainage basins (Bourillet *et al.*, 2006). The complex hydrology (geostrophic and tidal currents, swells, internal waves) and the vast canyons systems play an important role in control of present sedimentary processes determining benthic habitat distribution and development (De Chambure *et al.*, 2013).

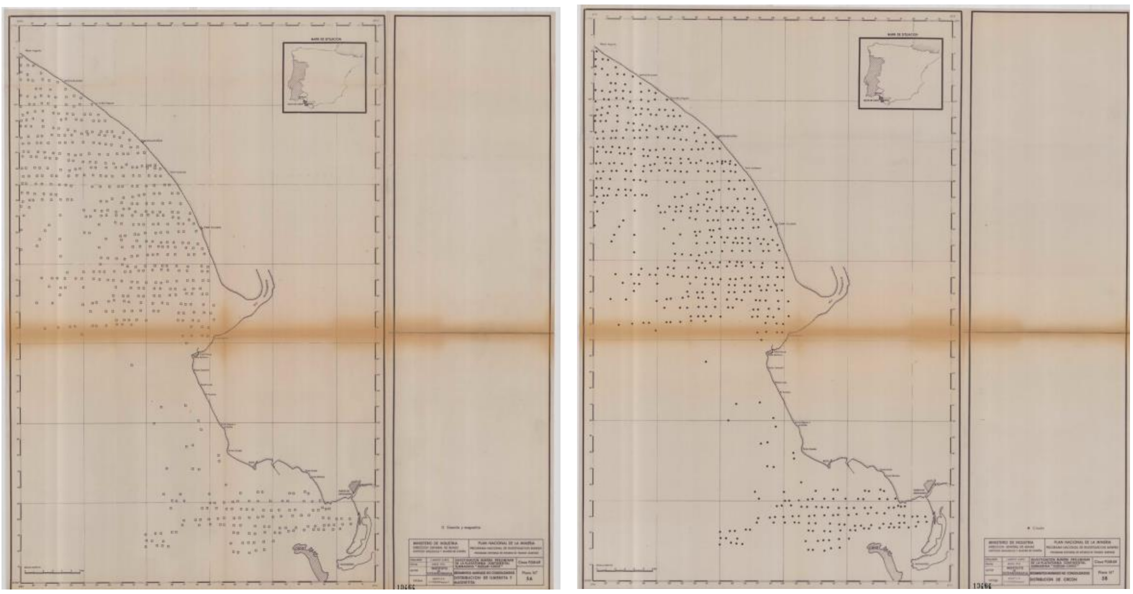

Figure 23: Historical data from the southern Iberian Coast (FOMAR, 1973)

4.3.6 Celtic Seas

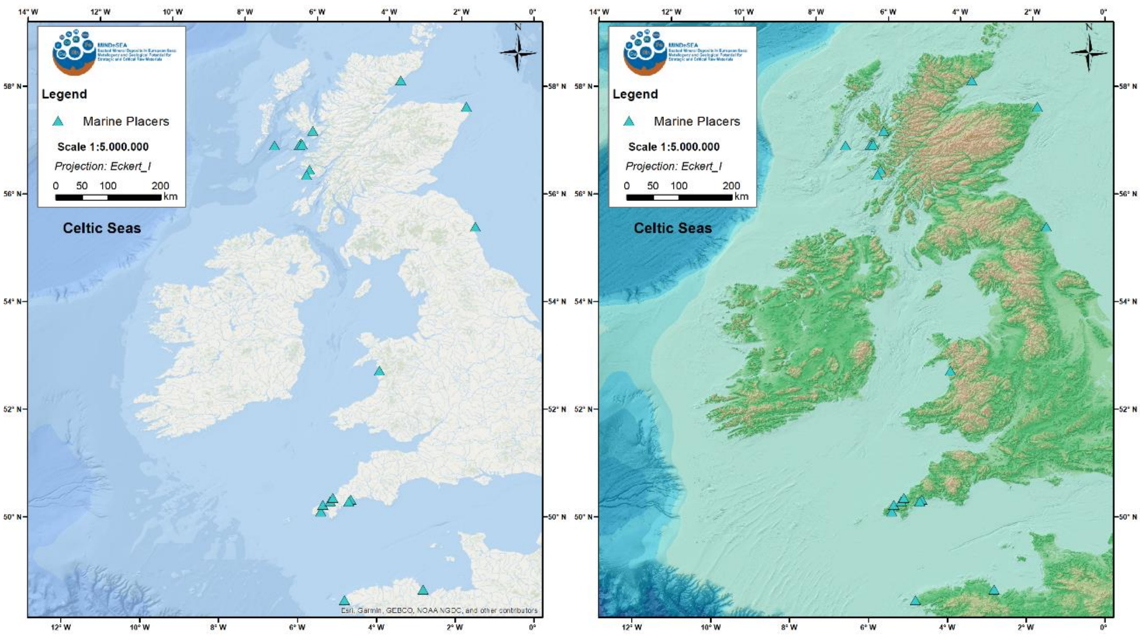

Figure 24: Marine placer occurrences in Celtic Seas

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The Celtic Seas, including Irish, French and UK waters, constitute the southern limit of glaciation of the European continental margin. They are dominated by a system of shelf-crossing sediment ridges, up to 60 m high, 10 km wide and 300 km long, traditionally interpreted as moribund palaeo-tidal sand banks (Praeg *et al.*, 2015) (Figure 24; Figure 25).

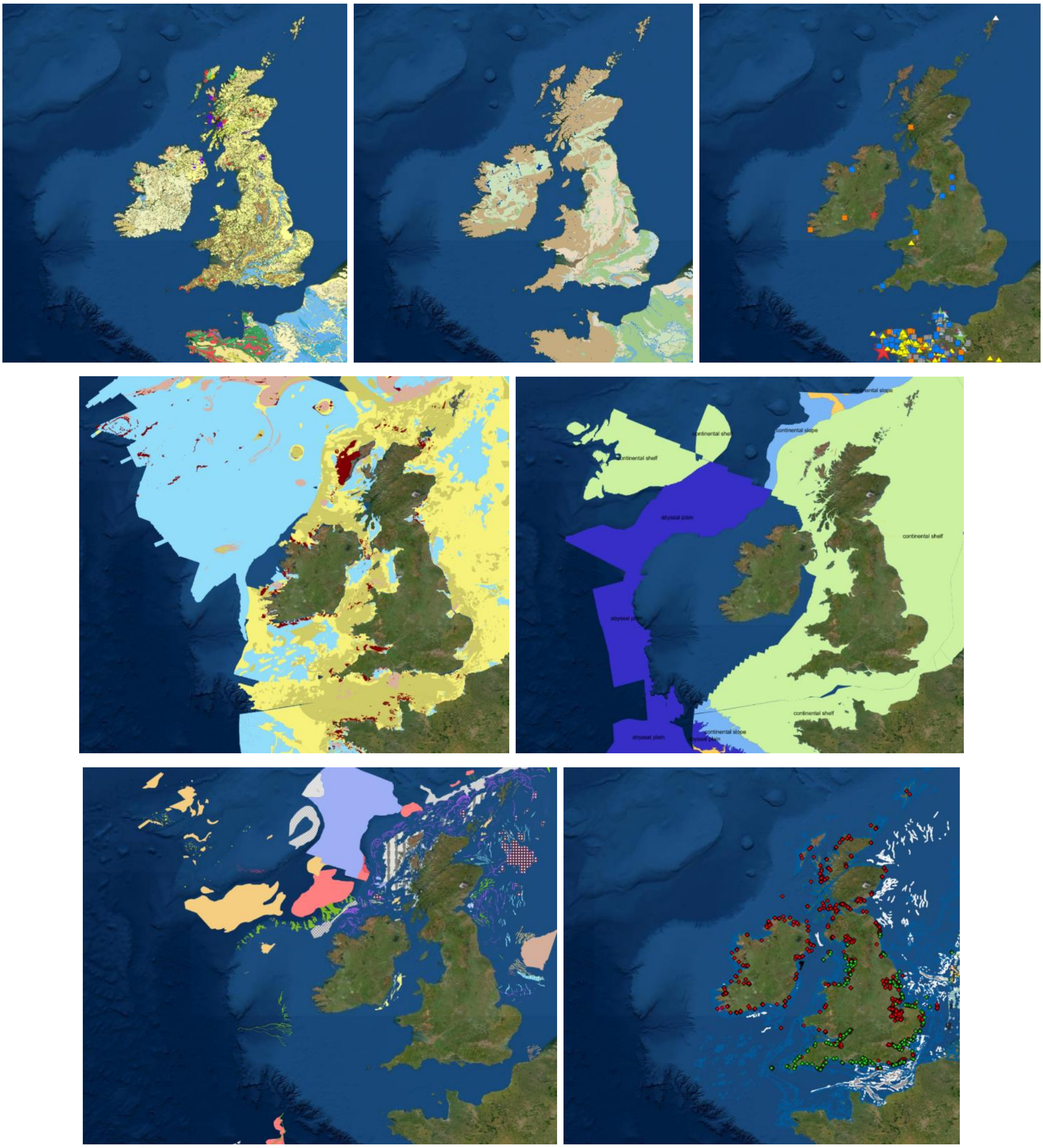

Figure 25: On-shore and off-shore data of the Celtic Seas and surrounding area available from EGDI portal (a) Geological setting (Asch, 2005), (b) Hydrogeology map (BGS, EGS, UNESCO, 2008), (c) On-shore mineral deposits (Minerals4EU, Mintell4EU, Reseerve), (d) Seabed substrate (EMODnet-Geology WP3), (e) General physiographic features (EMODnet-Geology WP4), (f) Geomorphology (EMODnet-Geology WP4), (g) Submerged landscape features (EMODnet-Geology WP8)

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It has to be noted, though, that Ireland has not yet fully explored the potential for economically viable offshore mineral deposits (Burke *et al.*, 2018). Heavy mineral rich sands have been identified in Ireland bearing lucrative Ti-rich minerals e.g. ilmenite, rutile and titanite but could also possess other economically important minerals i.e. rare earth elements (REEs) and platinum group elements (PGEs), amongst others (Geoghegan *et al.*, 1989). Their distribution and accumulation are controlled by source, hydrodynamics and a tendency to sort by individual mineral densities therefore understanding sediment transport pathways is imperative in identifying priority targets and assessing economic viability.

4.3.7 Iceland Sea

Iceland Sea surrounds the islands' rugged coastline, with depths usually ranging from 500 to 2,000 meters but can be shallower on the Continental shelf of East Greenland. In the MINDeSEA database there is only one documented occurrence of offshore placer deposits.

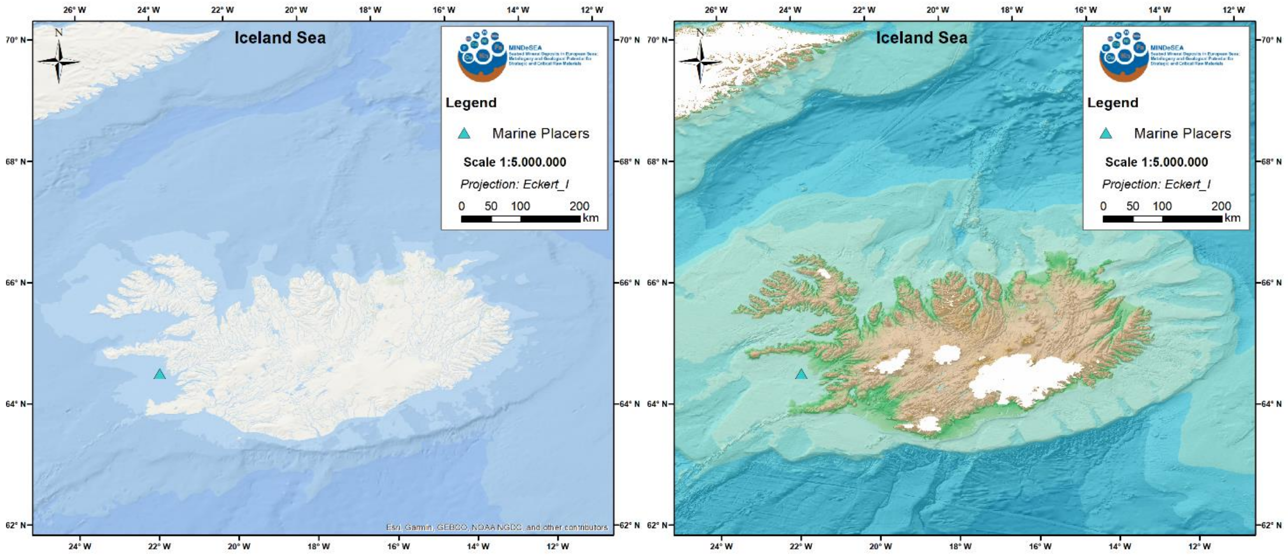

Figure 26: Marine placer occurrence in Iceland Sea

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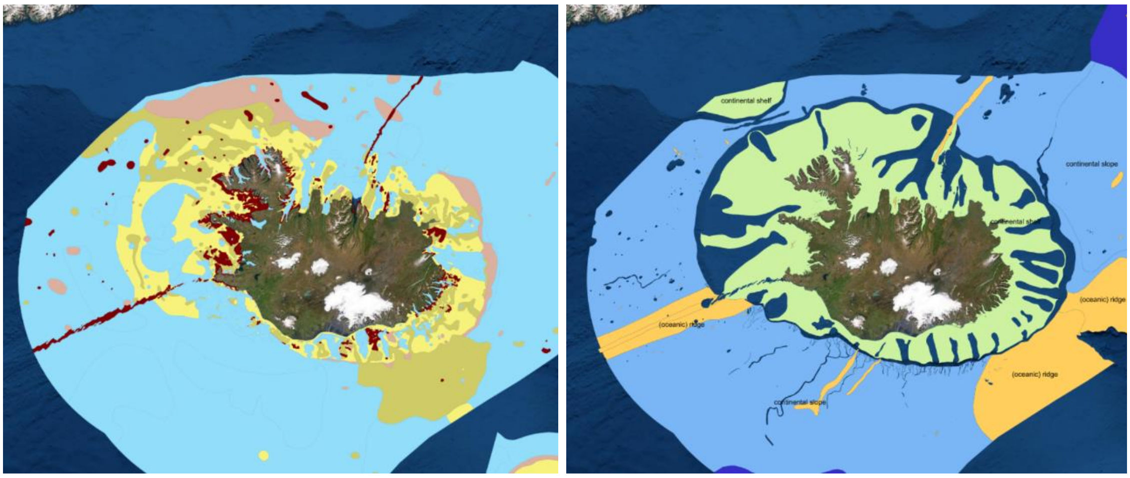

Figure 27: On-shore and off-shore data of the Iceland Sea and surrounding area available from EGDI portal (a) Geological setting (Asch, 2005), (b) Hydrogeology map (BGS, EGS, UNESCO, 2008), (c) Geomorphology (EMODnet-Geology WP4), (d) Seabed substrate (EMODnet-Geology WP3), (e) General physiographic features (EMODnet-Geology WP4)

4.3.8 Greater North Sea

The North Sea is a semi-enclosed marginal sea of the North Atlantic Ocean situated on the north-west European shelf (Quante *et al.*, 2016). Its mean depth is around 94 m with shallow areas of less than 10 m depth in the southern part and much deeper parts (up to 700 m) in the Norwegian Trench area and parts of the Skagerrak (Figure 28). Sea level dynamics in the North Sea are driven by various forces, namely tides (mainly semi-diurnal with a tidal range of up to 8 m), wind and atmospheric pressure, heat and water exchanges as well as river runoff and forcing from open boundaries (Zhang *et al.*, 2020). The general circulation pattern in the North Sea is mainly cyclonic.

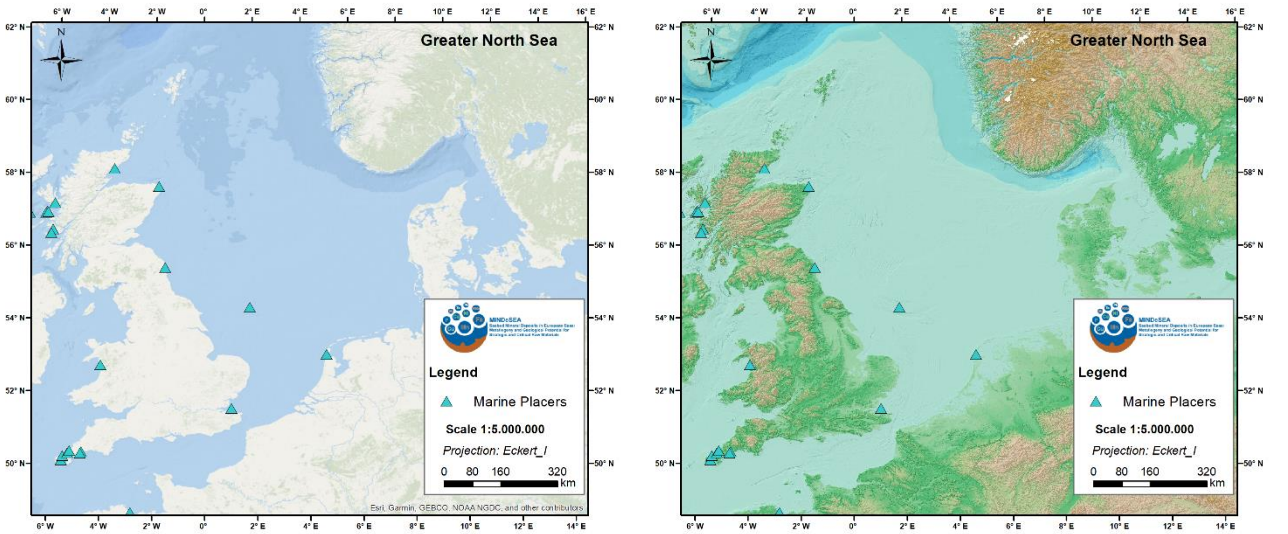

Figure 28: Marine placer occurrences of the Greater North Sea

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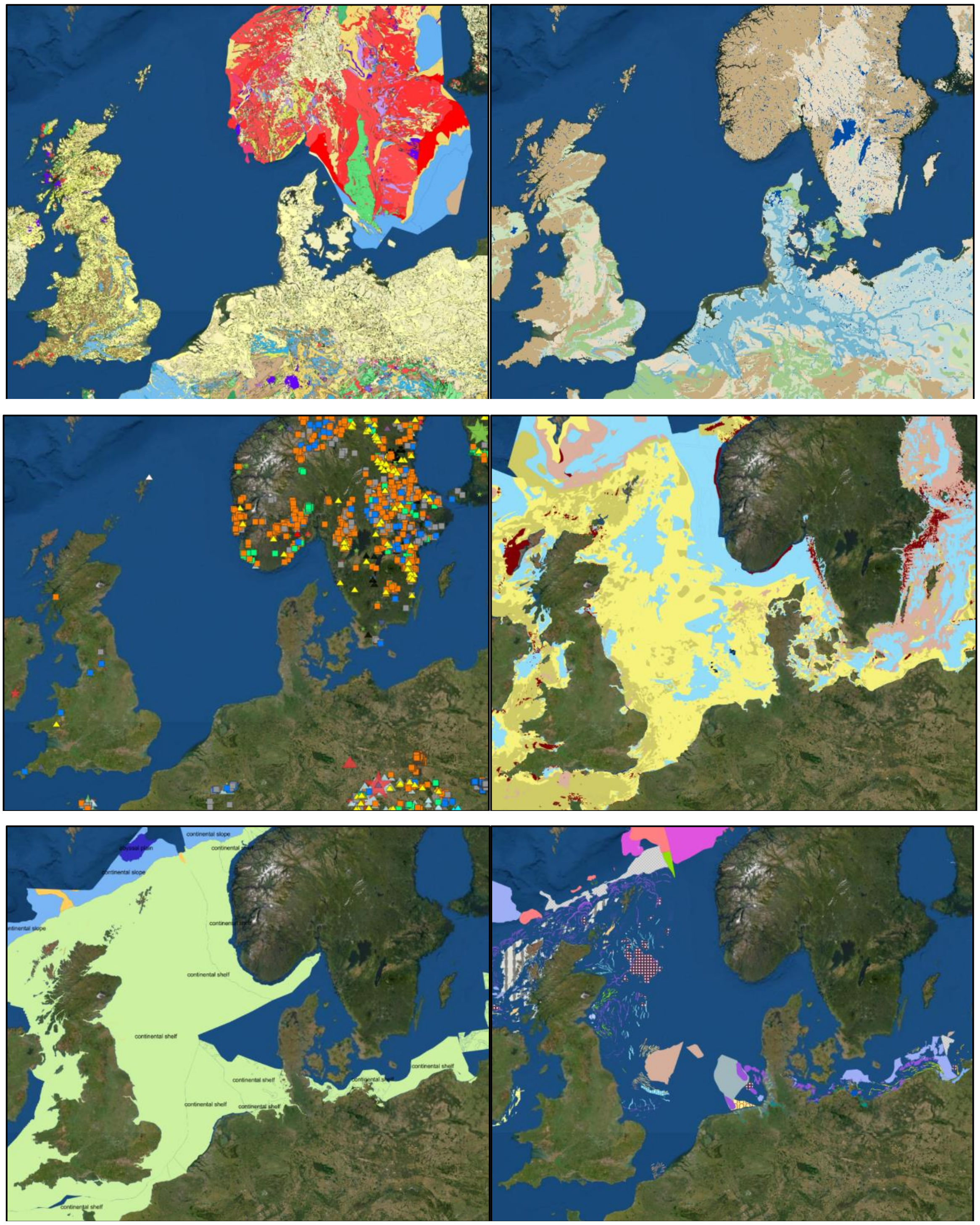
It has to be noted that when examining the Greater North Sea, Kattegat and the English Channel are included. The Kattegat region, located in the transition zone between the Fennoscandian Shield and the Danish Basin, is characterized by the presence of Holocene lagoonal sediments (Figure 29), sea-level fluctuations and sea-level fluctuations where the equilibrium between the saltwater and freshwater has been established in less than 6000 years (Schrøder, 2020).



This work has been supported by the European Union's Horizon 2020 research and innovation programme, GeoERA (Grant Agreement Nº 731166, project GeoE.171.001).

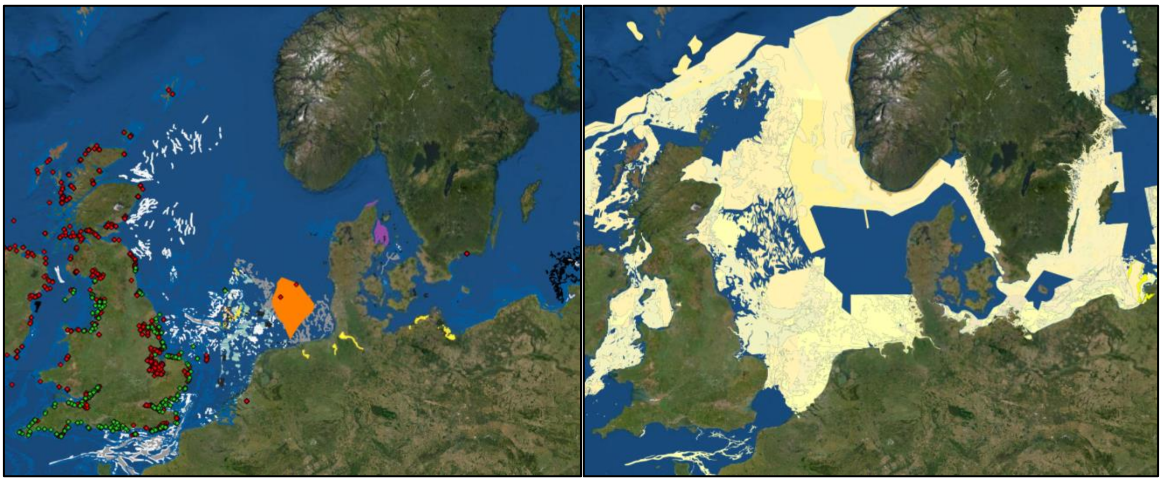


Figure 29: On-shore and off-shore data of the Greater North Sea and surrounding area available from EGDI portal (a) Geological setting (Asch, 2005), (b) Hydrogeology map (BGS, EGS, UNESCO, 2008), (c) On-shore mineral deposits (Minerals4EU, Mintell4EU, Reseerve), (d) Seabed substrate (EMODnet-Geology WP3), (e) General physiographic features (EMODnet-Geology WP4), (f) Geomorphology (EMODnet-Geology WP4), (g) Submerged landscape features (EMODnet-Geology WP8), (h) Quaternary lithology (EMODnet-Geology, WP4)

The English Channel is of geologically recent origin, having been dry land for most of the Pleistocene. The erosional morphology preserved at the sea bed in the eastern English Channel dominantly records denudation of the continental shelf by fluvial processes over multiple glacial–interglacial sea-level cycles rather than by catastrophic flooding through the Straits of Dover during the mid-Quaternary (Mellet *et al.*, 2013; and references therein).

4.3.9 Baltic Sea

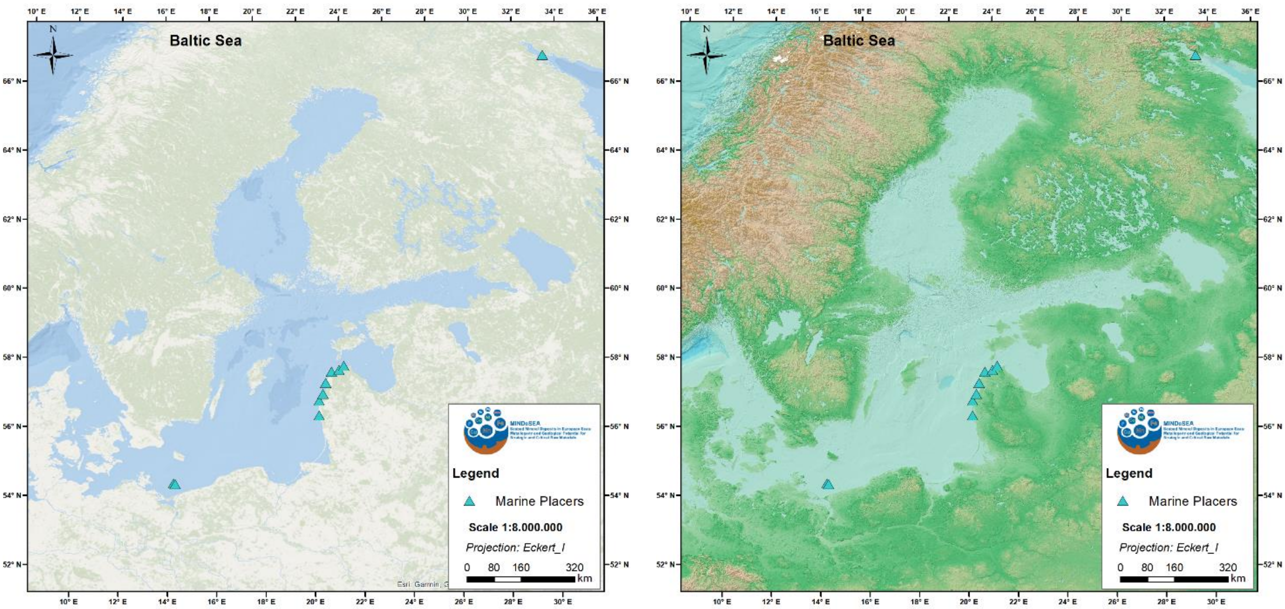


Figure 30: Marine placer occurrences of the Baltic Sea

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The Baltic Sea is the youngest sea on the planet, almost enclosed, experiencing near-arctic conditions and is one of the world's largest brackish waters; the average depth is 50 m (Figure 30). Most of the seafloor is made up of low- or unmetamorphosed sedimentary rocks beneath a cover of Quaternary deposits (Beckholmen and Tirén, 2009; and references therein) (Figure 31). It exhibits a complex morphology, where old pre-glacial river channels, tens of metres deep, have been found on the seafloor of the Bothnian Bay and the Bothnian Sea as extensions of present-day rivers (Tulkki, 1977). Placer occurrences in the Baltic have been discovered off the western coast of Latvia (Ulsts *et al.*, 1970), with titanium and zirconium as the main commodities, and in the marine sands from the Odra and Słupsk Banks (Mikulski *et al.*, 2016).

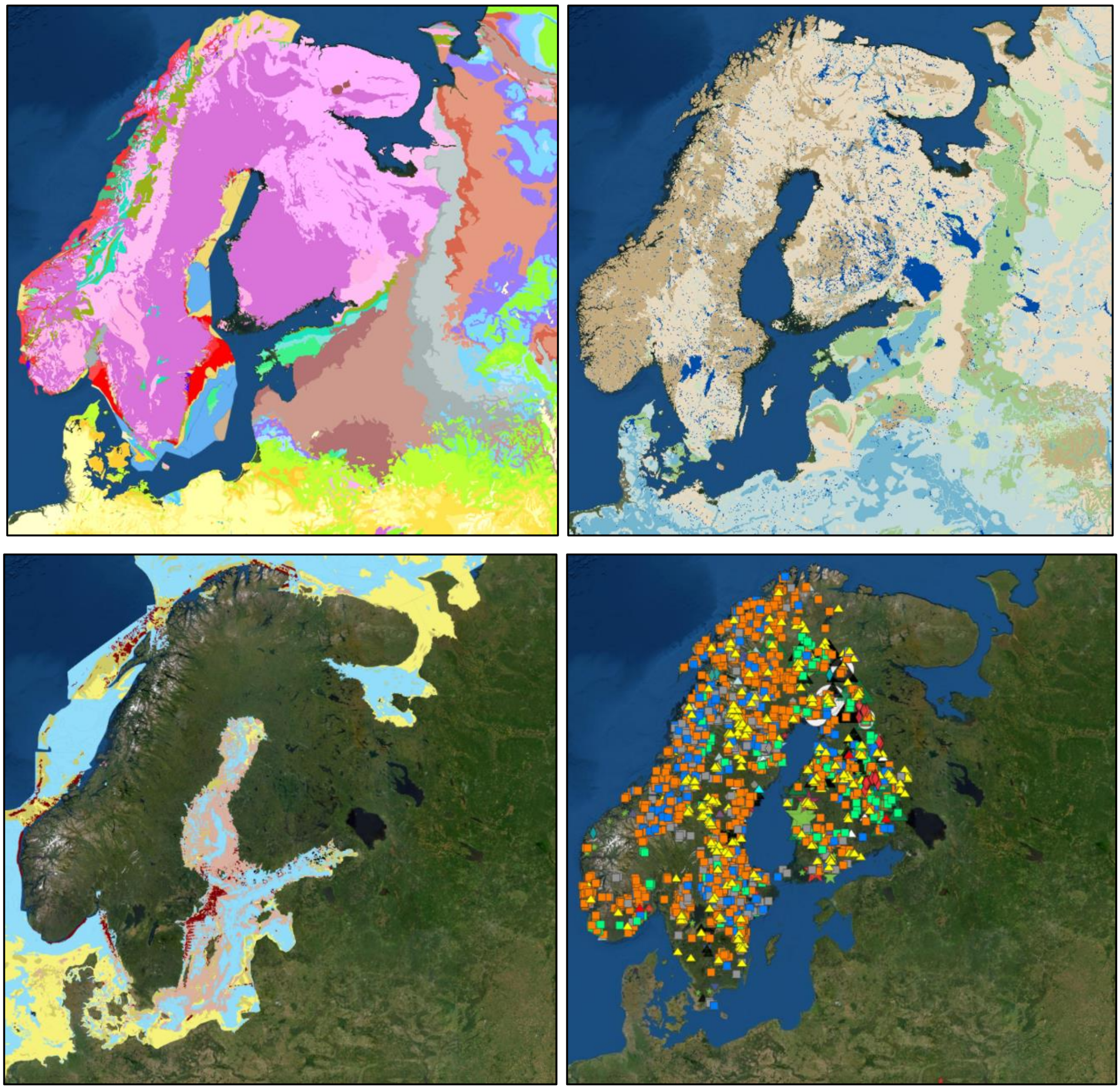

Figure 31: On-shore and off-shore data of the Baltic Sea and surrounding area available from EGDI portal (a) Geological setting (Asch, 2005), (b) Hydrogeology map (BGS, EGS, UNESCO, 2008), (c) Seabed substrate (EMODnet-Geology WP3), (d) On-shore mineral deposits (Minerals4EU, Mintell4EU, Reseerve)

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4.3.10 Barents Sea & White Sea

The Barents Sea is a marginal sea of the Arctic Ocean, located at the northern off coasts of Norway and Russia. In the Late Pleistocene the Barents Sea was surrounded by icecaps, lobes from which extending down to the water from northern Norway, Kola Peninsula, Novaya Zemlya, Svalbard and Franz Josef Land (Pavlidis *et al.*, 1998). Over the time, the sea level has undergone several small oscillations (Ogorodov, 2011).

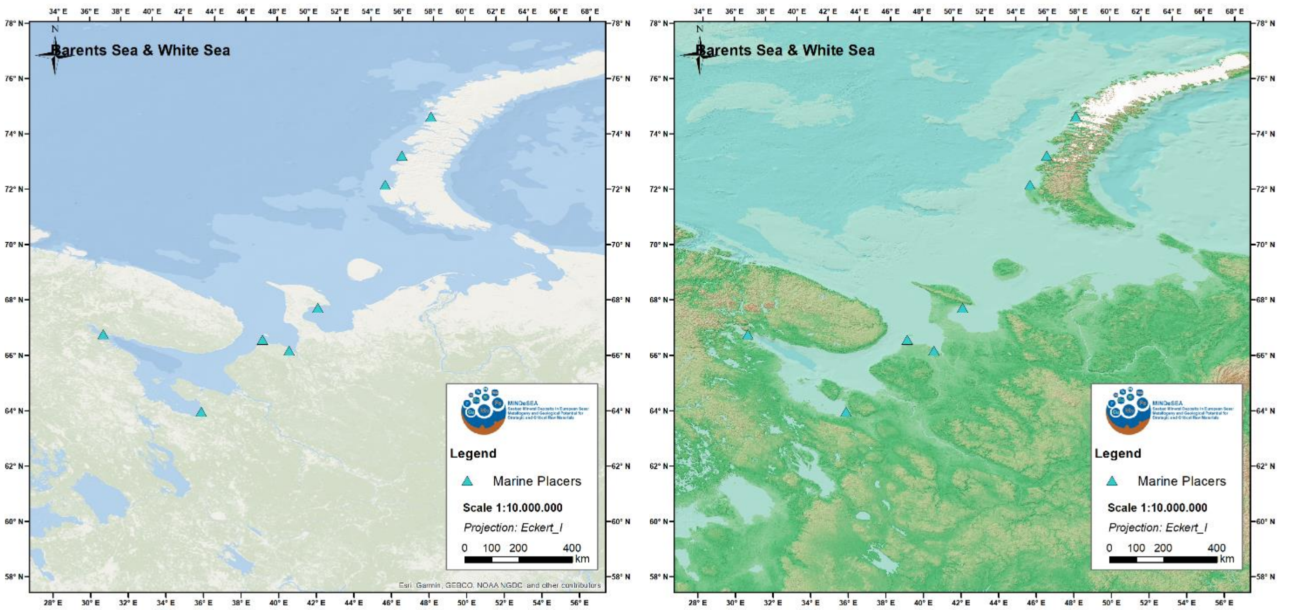
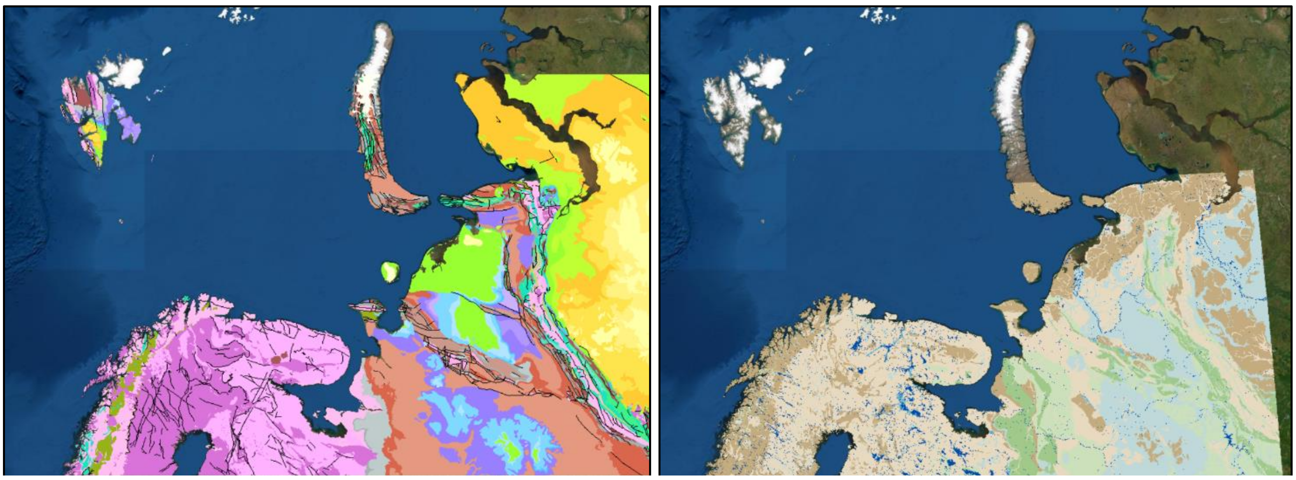


Figure 32: Marine placer occurrences of Barents and White seas

The White Sea is a southern inlet of the Barents, being a water field depression of the Baltic Shield continental shelf. The seafloor is very uneven, with multiple small underwater elevations; within the White Sea many islets are popping out from the present-day sea level (Figure 32).



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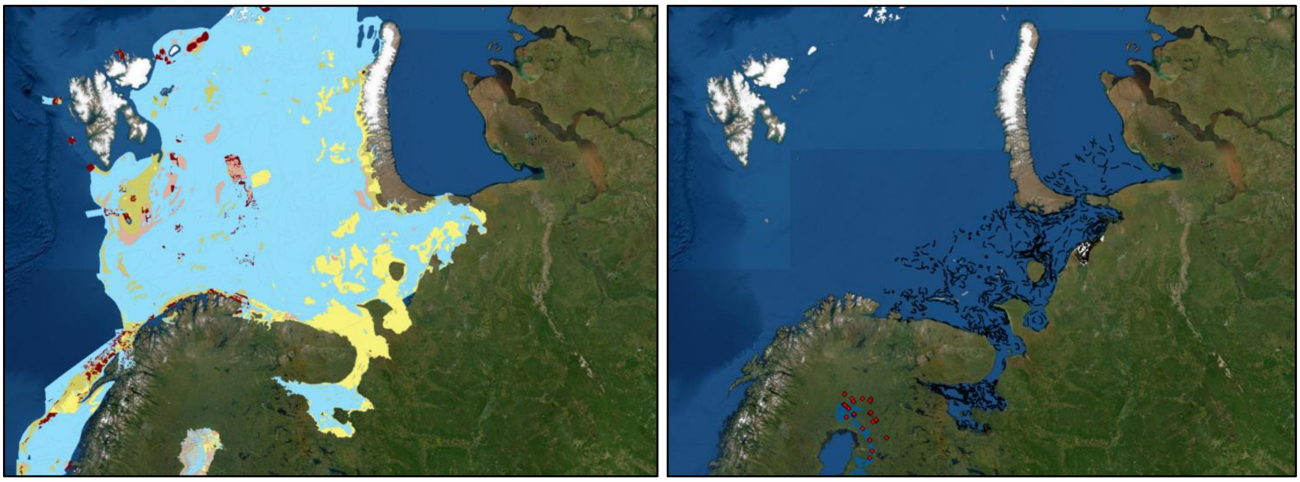

Figure 33: On-shore and off-shore data of the Barents and White seas and surrounding area available from EGDI portal (a) Geological setting (Asch, 2005), (b) Hydrogeology map (BGS, EGS, UNESCO, 2008), (c) Seabed substrate (EMODnet-Geology WP3), (d) Submerged landscapes (EMODnet-Geology WP8)

Marine placer occurrences – mainly titanium, iron and REEs – have been documented offshore the western shorelines of Severny and Yuzhny islands, within the gulfs of the White Sea and offshore Kanin peninsula (Ivanova *et al.*, 1999). The crucial role for placer formation in the broader area of the Arctic shelf, was most likely played by the duration of deposit emplacement of the occurrences under relatively stable subplatform environments and permanent downwarping (Figure 33). These long-lived occurrences may have productive horizons of great thickness and wide age range.

5. RELEVANT INTERNATIONAL PORTALS & E-INFRASTRUCTURES

During the past year several portals and e-infrastructures have been created providing information on data concerning the seafloor geology, raw materials exploration and exploitation, as well as onshore complementary geological data. The main ones are presented below, in alphabetical order:

- **Data Europa EU** (https://data.europa.eu/en): the portal, originally set up in 2012 (former EU Open Data Portal) following European Commission Decision 2011/833/EU on the reuse of Commission documents, provides access to an expanding range of data from the EU institutions and other bodies.
- **EGDI** (http://www.europe-geology.eu): is EuroGeoSurveys' European Geological Data Infrastructure, providing access to Pan-European and national geological datasets and services from the Geological Survey Organisations of Europe.
- **EMODnet Geology project** (www.emodnet-geology.eu): initiated as a pilot project in 2009 (ur-EMODnet), is now running it's forth phase (2019-2021). WP7 (Minerals) of the project has established a framework for collecting harmonized data of marine mineral occurrences across all European Seas, including Marine Placer Deposits.

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- **European Environment Agency** (https://www.eea.europa.eu): is tasked with providing sound, independent information on the environment. It operates as major information source for those involved in developing, adopting, implementing and evaluating environmental policy, and also the general public.
- **European Innovation Partnership (EIP) on Raw Materials** (https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/european-innovation-partnership-eip-raw-materials): is a stake-holder platform bringing together representatives from industry, public services, academia and NGOs. Its mission is to provide high-level guidance to the European Commission, Members States and private actors on innovative approaches to the challenges related to raw materials.
- **GeoERA Project** (https://geoera.eu/): has as a main objective to contribute to the optimal use and management of the subsurface. One of its main themes comprises the Raw Materials, which with four running projects – for onshore and offshore resources – assists in identifying high potential areas that may add to responsible sourcing and supply within Europe. MINDeSEA Project aims at assessing the metallogeny and geological potential for strategic and Critical Raw Materials (CRM) in the European seas, while FRAME project focuses on forecasting and assessing Europe's strategic raw materials' needs. The data and products of GeoERA will be freely available through the GeoERA Information Platform (GIP).
- **Geo-Seas** (https://www.geo-seas.eu/): the project was designed to provide an e-infrastructure of harmonised and federated marine geological and geophysical datasets (sediment samples, cores, profiles etc), using common data standards and exchange formats.
- **International Seabed Authority** (https://www.isa.org.jm/): the portal of the ISA provides, amongst other information, an online deep data database, details about exploration contracts, national legislation database and other legal documents.
- **Marine Strategy Framework Directive** (http://www.msfd.eu/): a knowledge base for the sustainable management of European Seas.The European Union Marine Strategy Framework Directive provides a legislative framework to sustainably manage human activities at all scales - from local to national to regional seas.
- **Minerals4EU** (http://www.minerals4eu.eu): the project was designed to meet the recommendations of the Raw Materials Initiative and develop an EU Mineral intelligence network structure. The study area covered onshore deposits, for which detailed attributes were compiled.
- **Mintell4EU** (https://geoera.eu/projects/mintell4eu7): The overall aim of this proposal is to improve the European Knowledge Base on raw materials by updating the electronic Minerals Yearbook produced in the Minerals4EU project and to extend the spatial coverage and quality of data currently in the Minerals Inventory. The project will, furthermore, aim to increase the degree of harmonization, communication and interaction between existing data platforms,
- **Minventory** (https://ec.europa.eu/jrc/en/scientific-tool/minventory): is one of the scientific tools provided by EU Science Hub. The Minventory metadata portal is a directory of statistical data holders, the characteristics of the data they hold and – where possible – links to where the data may more easily be located. It covers the EU Member States and a number of neighbouring countries.
- **OSPAR** (https://www.ospar.org/): OSPAR is the mechanism by which 15 Governments and the EU cooperate to protect the marine environment of the North-East Atlantic.
- **Other EMODnet Lots** (www.emodnet.eu): EMODnet project, apart from Geology, involves several thematic areas: Bathymetry, Seabed Habitat, Chemistry, Biology, Physics and Human Activities. Their datasets provide relevant information (e.g. Human Activities) and can be used

as background data (e.g. bathymetry) for the compilation of mineral-potential, prospectivity maps and models of formation for the main provinces.

- **Raw Materials Information System** (http://rmis.jrc.ec.europa.eu): the portal, available through the EU Science Hub, provides information and data on Raw Materials in terms of Policy & Legislation, Terminology, Environmental & Social Sustainability, Economics & Trade, Industry & Innovation, Raw Materials' Profiles, Country Profiles.
- **RESEERVE** (https://reseerve.eu): the project represents the first step in establishing fruitful cooperation between countries where there are not yet EIT RawMaterials partners. The geographical coverage of European Minerals Inventory is being extended with data from the West Balkan countries belonging to the RIS region.
- **SeaDataNet** (https://www.seadatanet.org): SeaDataNet is a major pan-European infrastructure for managing, indexing and providing access to marine data sets and data products, acquired by countries neighbouring the European seas.

6. SUMMARY

This report was elaborated in the frame of MINDeSEA project "Seabed Mineral Deposits in European Seas: Metallogeny and Geological Potential for Strategic and Critical Raw Materials", WP5: Marine Placer Deposits; it constitutes Deliverable 5.4 – WP5 Models of formation for the main provinces of placer occurrence, as defined through this study.

The compilation of the present report is a synthesis of available information concerning the location of placer deposits in the European seas. To assess the models of their formation, in relation to the main provinces of occurrence, complementary geological data, controlling the formation of placers (source, sea level changes, transportation etc.) – onshore and offshore – have been retrieved from online databases and scientific publications.

A next step, building upon the outputs of MINDeSEA project, towards the integrated research for marine placer deposits in the European waters would be the systematic and combined analysis of all collected information, using geostatistical analysis tools.

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APPENDIX I

LIST OF ACRONYMS

CRM: Critical Raw Materials

ECS: Extended Continental Shelf

EEA: European Economic Area

EEA: European Environmental Agency

EEZ: Exclusive Economic Zone

EGDI: European Geological Data Infrastructure

EGS: EuroGeoSurveys

EMODnet: European Marine Observation and Data Network

EU: European Union

FOREGS: Forum of European Geological Surveys

FRAME: GeoERA project on Forecasting and Assessing Europe's Strategic Raw Materials needs

GeoERA: ERA-NET action under Horizon 2020; Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe

HELCOM: Convention on the Protection of the Marine Environment of the Baltic Sea Area

INSPIRE: Infrastructure for spatial information in Europe

ISA: International Seabed Authority

IUGS: International Union of Geological Sciences

Minerals4EU: EU-FP7 project uniting European national resource databases into a common data infrastructure and generating a European minerals yearbook

MSFD: Marine Strategy Framework Directive

REEs: Rare Earth Elements

RM: Raw Materials

RMIS: Raw Materials Information System

UNCLOS: United Nations Convention on the Law of the Sea

USGS: United States Geological Survey

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