Susceptibility assessment of gas hydrate dissociation occurrence along European continental margins and adjacent areas. GARAH project (GeoERA)

Ricardo León[1*], Christopher Rochelle[2], André Burnol[3], Carmen Julia Giménez- Moreno[1], Tove Nielsen[4], John Hopper[4], Isabel Reguera[1], Margaret Stewart[5], Miguel Llorente[1], Pilar Mata[1], Silvia Cervel[1]

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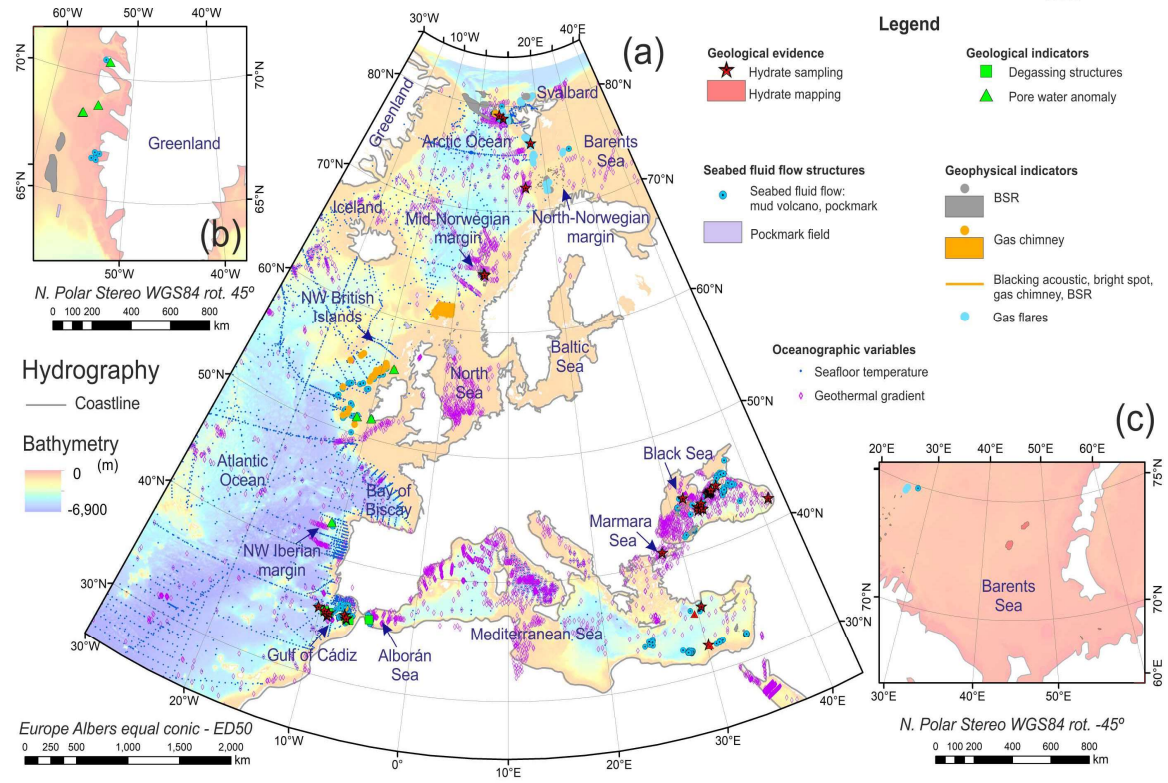

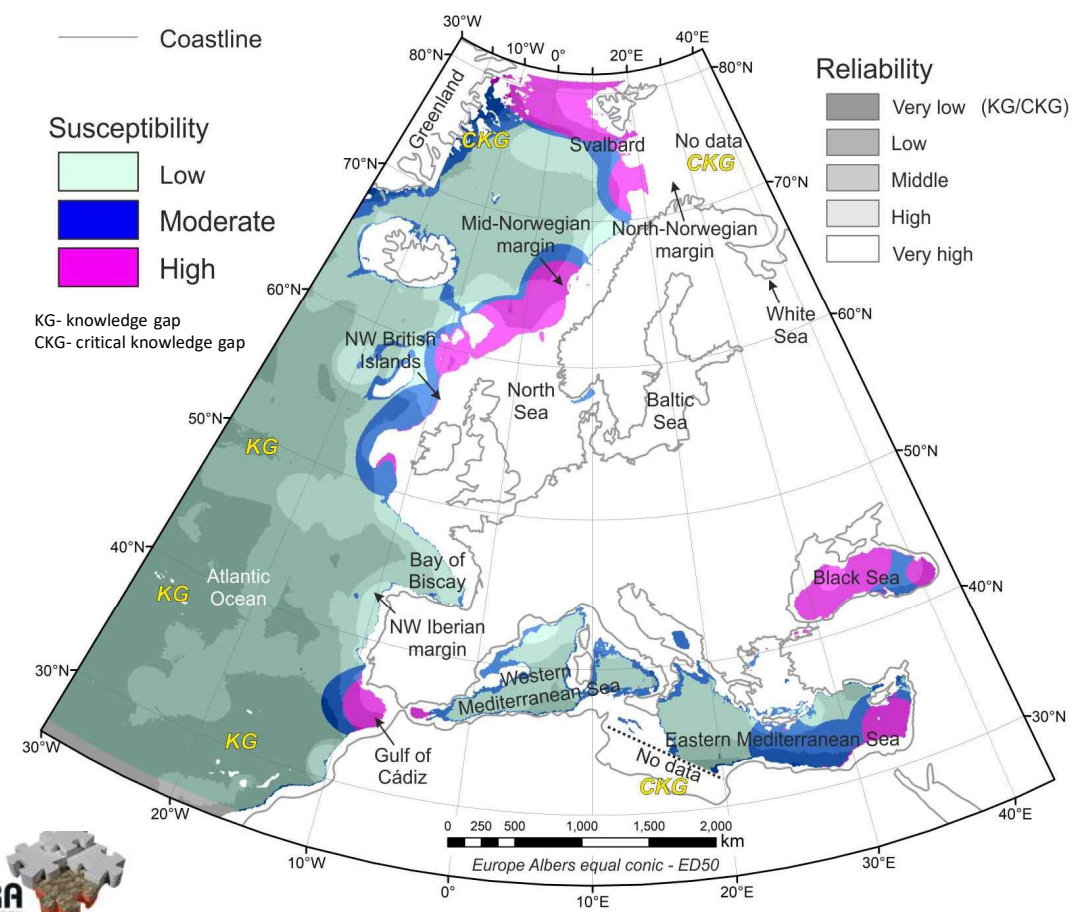

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Abstract

The Pan-European gas-hydrate relate GIS database of GARAH project has allowed assessing the susceptibility of seafloor areas affected by hydrate dissociation. This study has been applied as a first step for the hydrate related risk assessment along the European continental margins. Several factors and variables have been taken into account. They have been defined by their relationship with the presence of hydrates below seafloor and weighted depending on the confidence of finding hydrates in this site. The maximum weight (or confidence) has been given to the recovered samples of gas hydrates or hydrate-dissociation evidences such as degassing or liquation structures observed in gravity cores. Seismic indicators of the presence of gas hydrate or hydrocarbon seabed fluid flow such as BSR, blanking acoustic, amplitude anomalies or the presence of geological structures of seabed fluid flow in the neighbouring of the GHSZ have been weighted with a lower value. The theoretical gas hydrate stability zone (GHSZ) for a standard composition for biogenic gas has been taken into account as another control factor and constrain feature. Seafloor areas out of the theoretical GSHZ have been excluded as potential likelihood to be affected by hydrate dissociation processes. The base of GHSZ has been classified as a critical area for these dissociation processes.

The proposed methodology analyses the geological hazard by means of the susceptibility assessment, defined by the likelihood of occurrence of hydrate dissociation, collapses, crater-like depressions or submarine landslides over seafloor. The baseline scenario is that gas hydrate occurrence is only possible in seafloor areas where pressure (bathymetry) and seafloor temperature conditions are inside the theoretical GHSZ. Inside GHSZ, the occurrence of gas hydrate is directly related to the presence of its evidences (direct samples of hydrates) or indicators (eg. pore water and velocity anomalies, BSR, gas chimneys, among others), as well as the occurrence of hydrocarbon fluid flow structures inside GHSZ. Finally, the likelihood of the seafloor to be affect gas hydrate dissociation processes will be major at the base of the GHSZ and in the neighbouring of the gas hydrate evidences and indicators. In order to proof this initial hypothesis, a susceptibility assessment has been carried out throughout map algebra in a GIS environment from a density map of evidences and indicators and the Pan-European map of the GHSZ over seafloor. Specifically, it has been conceived as a segmentation in three levels by quantiles resulting of the addition of the density map of evidences and indicators and the weighted map of the GHSZ over seafloor.

Acknowledgment

GARAH project. GeoERA - GeoE.171.002

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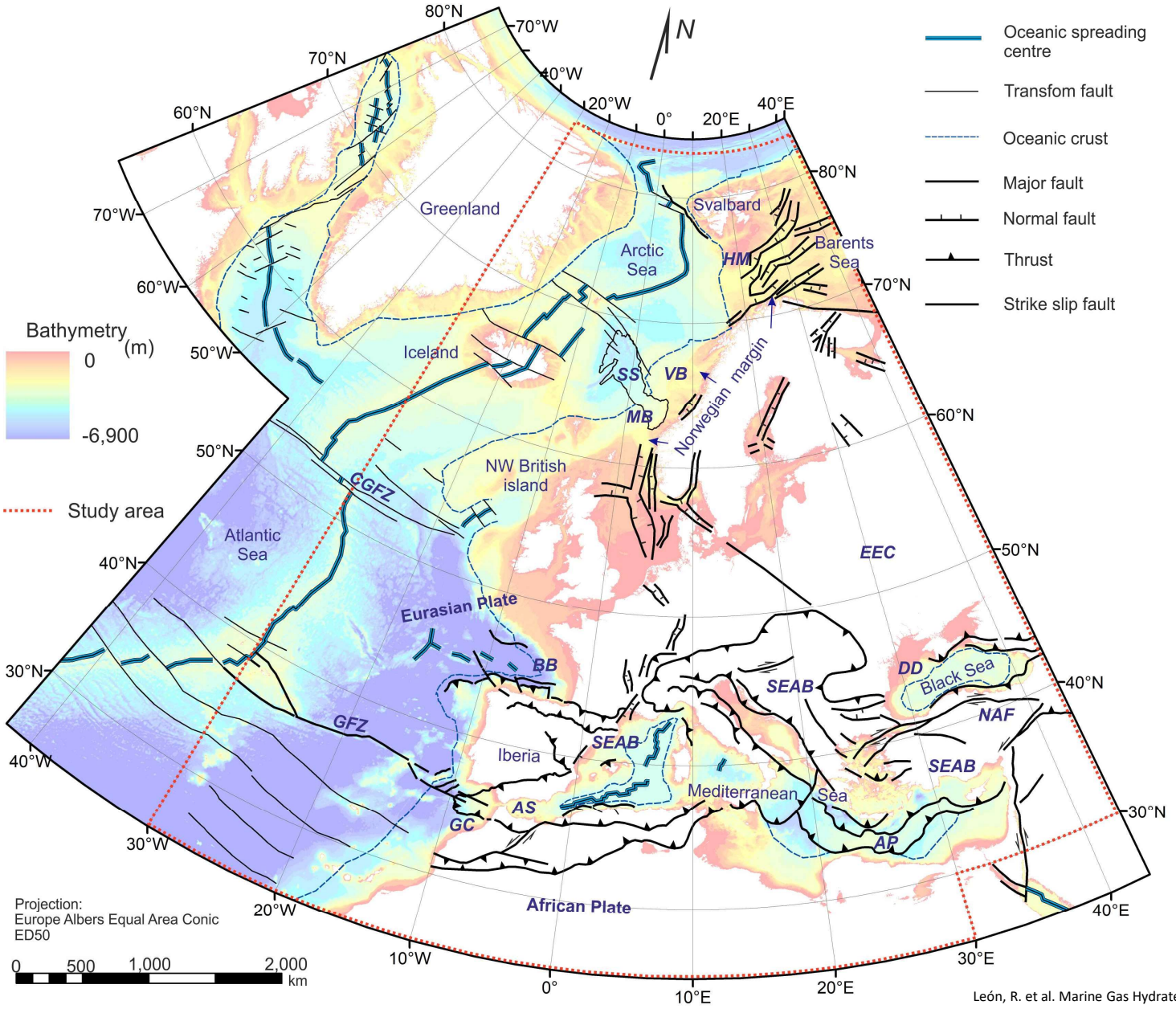

Study Area

Main tectonic structures and geological domains on the European continental margins and adjacent areas. Location of the study area. HM, Håkon–Mosby mud volcano; VB, Vøring Basin; MB, Møre Basin; SS, Storegga Slide; CGFZ, Charlie–
Gibbs fracture zone; EEC, East European craton; Biscay Bay; GFZ, Gloria Fracture Zone; GC, Gulf of Cádiz; AS, Alborán Sea; SAEB, south European Alpine Belt, NAF, North Anatolian Fault; DD, Danube delta fan.

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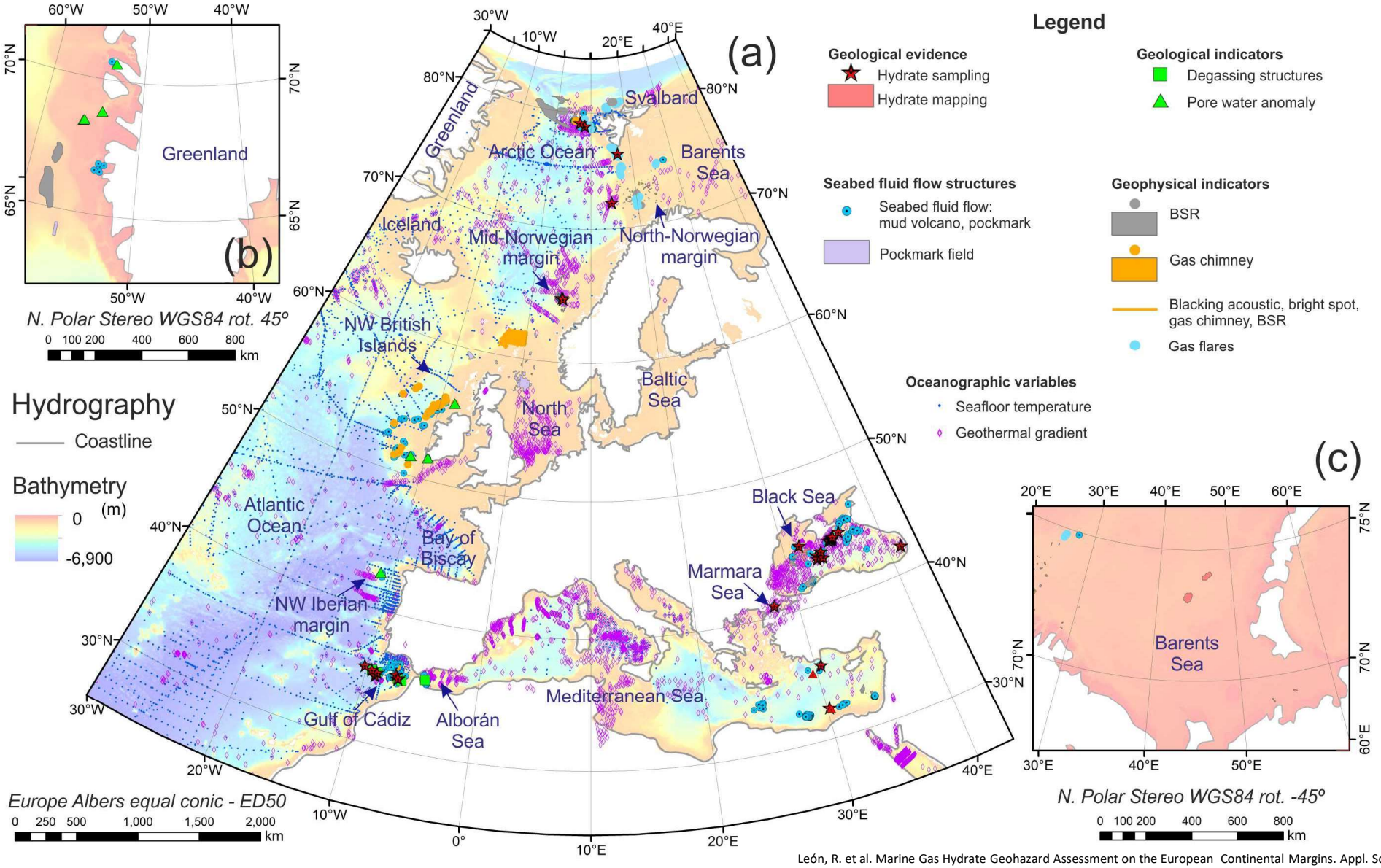
GARAHydrates GIS database



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GARAHydrates – Data Model Structure

GEOLOGICAL & GEOCHEMICAL EVIDENCES-INDICATORS

GasHydrate_Site_Evidences&Indicators -- Points

FIELDNAME	FORMAT	DESCRIPCION
ID_IndiName	Text, 254	Identification code of the evidence - PK
Lat_DD	Double 15,6	Latitude in decimal degrees(WGS84)
Long_DD	Double 15,6	Longitude in decimal degrees (WGS84)
WaterDepth	Double 15,6	Seafloor depth
GeoSetting	Text, 50	Geographical / Geological Setting – Constrains NN, LV
LocalSite	Text, 50	Local site where the evidence is located
Data_Source	Text, 50	Institution/Company if Owner of Data. Project, database or publication where data have been collected
Cruise	Text, 254	Oceanographic Cruise where data have been recovered or observed
CName	Text, 50	Contact name
Email	Text, 50	Contact Email
E_I	Text, 50	E= Direct Evidence ; I = Indirect Indicator
FF_Type	Text, 50	Type of evidence o indicator – constrains- NN- LV_FF_Type
Description	Text, 250	Description of the evidence - free text
Sedi_Type	Text, 50	Sediment type – LV_
D_Indi_m_tp	Double 11,4	Depth of the top of the evidence below seabed in meters
D_Indi_m_bt	Double 11,4	Depth of the bottom of the evidence below seabed in meters
Size	Text, 50	Size (volume, km2, tons, etc)
DOI	Text, 254	DOI of main data publication
References	Text, 254	Referencesto data. Author, Year & Title. Link to PDF in data repository
Comments	Text, 254	Comments -- Free text

GasHydrate_Areal_Evidences -- Polys

FIELDNAME	FORMAT	DESCRIPCION
ID_IndiName	Text, 254	Identification code of the evidence - PK-
MpArea	Double 15,6	Cartographical area of the evidence in km2
GeoSetting	Text, 50	Geographical / Geological Setting – Constrains NN, LV
LocalSite	Text, 50	Local site where the evidence is located
Data_Source	Text, 50	Institution/Company if Owner of Data. Project, database or publication where data have been collected
CName	Text, 50	Contact name
Email	Text, 50	Contact Email
FF_Type	Text, 50	Type of evidence_ FF_Type = "Gas Hydrate"
Description	Text, 250	Description of the evidence - free text
Sedi_Type	Text, 50	Sediment type – LV_
D_Evi_m_tp	Double 11,4	Depth of the top of the evidence below seabed in meters
D_Evi_m_bt	Double 11,4	Depth of the bottom of the evidence below seabed in meters
D_Evi_TWT_tp	Double 11,4	Depth of the top of the evidence below seabed in seconds TWT
D_Evi_TWT_bt	Double 11,4	Depth of the bottom of the evidence below seabed in seconds TWT
Size	Text, 50	Size (volume, km2, tons, etc)
DOI	Text, 254	DOI of main data publication
References	Text, 254	Referencesto data. Author, Year & Title. Link to PDF in data repository
Comments	Text, 254	Comments -- Free text

GEOPHYSICAL INDICATORS

GasHydrate_Profile_Seism_Indicators -- Lines

FIELDNAME	FORMAT	DESCRIPCION
ID_IndiName	Text, 254	Identification code of the evidence - PK-
MpLength	Double 15,6	Cartographical length in km of the indicator
GeoSetting	Text, 50	Geographical / Geological Setting – Constrains NN, LV
LocalSite	Text, 50	Local site where the evidence is located
Data_Source	Text, 254	Institution/Company if Owner of Data. Project, database or publication where data have been collected
Cruise	Text, 254	Oceanographic Cruise where the evidence has been recovered or observed
CName	Text, 50	Contact name
Email	Text, 50	Contact Email
FF_Type	Text, 50	Type of evidence – constrain- NN- LV_FF_Type
Description	Text, 250	Description of the evidence - free text
D_Indi_m_tp	Double 11,4	Depth of the top of the evidence below seabed in meters
D_Indi_m_bt	Double 11,4	Depth of the bottom of the evidence below seabed in meters
D_Indi_TWT_tp	Double 11,4	Depth of the top of the evidence below seabed in seconds TWTT
D_Indi_TWT_bt	Double 11,4	Depth of the bottom of the evidence below seabed in seconds TWTT
DOI	Text, 254	DOI of main data publication
References	Text, 254	Referencesto data. Author, Year & Title. Link to PDF in data repository
Comments	Text, 254	Comments -- Free text

GasHydrate_Local_Seism_Indicators -- Points

FIELDNAME	FORMAT	DESCRIPCION
ID_IndiName	Text, 254	Identification code of the evidence - PK-
Lat_DD	Double 15,6	Latitude in decimal degrees(WGS84)
Long_DD	Double 15,6	Longitude in decimal degrees (WGS84)
WaterDepth	Double 15,6	Seafloor depth
GeoSetting	Text, 50	Geographical / Geological Setting – Constrains NN, LV
LocalSite	Text, 50	Local site where the evidence is located
Data_Source	Text, 254	Institution/Company if Owner of Data. Project, database or publication where data have been collected
Cruise	Text, 254	Oceanographic Cruise where the evidence has been recovered or observed
CName	Text, 50	Contact name
Email	Text, 50	Contact Email
FF_Type	Text, 50	Type of evidence– constrain- NN- LV_FF_Type
Description	Text, 250	Description of the evidence - free text
D_Indi_m_tp	Double 11,4	Depth of the top of the evidence below seabed in meters
D_Indi_m_bt	Double 11,4	Depth of the bottom of the evidence below seabed in meters
D_Indi_TWT_tp	Double 11,4	Depth of the top of the evidence below seabed in seconds TWTT
D_Indi_TWT_bt	Double 11,4	Depth of the bottom of the evidence below seabed in seconds TWTT
DOI	Text, 254	DOI of main data publication
References	Text, 254	Referencesto data. Author, Year & Title. Link to PDF in data repository
Comments	Text, 254	Comments -- Free text

GasElement

FIELDNAME	FORMAT	DESCRIPCION
ID_IndiName	Text, 254	Identification code of the evidence - PK-
Exp	Text, 254	Expedition number
Site	Text, 254	Site number
Hole	Text, 254	Hole number
Core	Text, 254	Core name
Type_	Text, 254	H-advanced piston core, X-extended core barrel , R-rotary core barrel
Sect	Text, 254	Section
A_W	Text, 254	Number of Section: A-Archive half , W-Working half
Top_offset_cm	Double	Top offset
Bottom_offset_cm	Double	Bottom offset
Top_depth_CSF_A_m	Double	Top depth, core depth below seafloor, overlap if long. Method-A
Bottom_depth_CSF_A_m	Double	Bottom depth, core depth below seafloor, overlap if long. Method-A
Top_depth_CSF_B_m	Double	Top depth, core depth below seafloor, overlap if long. Method-B
Bottom_depth_CSF_B_m	Double	Bottom depth, core depth below seafloor, overlap if long. Method-B
Sample_type	Text	HS - headspace analysis, VAC - vacutainer analysis
Methane_ppmv_GC3	Double	Methane. Parts per million by volume – Gas Chromatography
Methane_ppmv_NGA_FID	Double	Methane. Parts per million by volume – NGA
Ethane_ppmv_GC3	Double	Ethane. Parts per million by volume -- Gas Chromatography
Ethane_ppmv_NGA_FID	Double	Ethane. Parts per million by volume – NGA-FID. Natural Gas Analysis by Flame Ionization Detector
Ethene_ppmv_GC3	Double	Ethene. Parts per million by volume -- Gas Chromatography
Ethene_ppmv_NGA_FID	Double	Ethene. Parts per million by volume – NGA-FID. Natural Gas Analysis by Flame Ionization Detector
Propane_ppmv_GC3	Double	Ethene. Parts per million by volume -- Gas Chromatography
Propene_ppmv_GC3	Double	Propene. Parts per million by volume -- Gas Chromatography
Propane_Propene_ppmv_NGA_FID	Double	Propane - Propene. Parts per million by volume – NGA-FID. Natural Gas Analysis by Flame Ionization Detector
Iso_Butane_ppmv_NGA_FID	Double	Iso Butane. Parts per million by volume – NGA-FID. Natural Gas Analysis by Flame Ionization Detector
n_Butane_ppmv_NGA_FID	Double	n Butane. Parts per million by volume – NGA-FID. Natural Gas Analysis by Flame Ionization Detector
Iso_Pentane_ppmv_NGA_FID	Double	Iso Pentane. Parts per million by volume – NGA-FID. Natural Gas Analysis by Flame Ionization Detector
n_Pentane_ppmv_NGA_FID	Double	n Pentane. Parts per million by volume – NGA-FID. Natural Gas Analysis by Flame Ionization Detector
Iso_Hexane_ppmv_NGA_FID	Double	Iso Hexane. Parts per million by volume – NGA-FID. Natural Gas Analysis by Flame Ionization Detector
n_Hexane_ppmv_NGA_FID	Double	n Hexane. Parts per million by volume – NGA-FID. Natural Gas Analysis by Flame Ionization Detector
Iso_Heptane_ppmv_NGA_FID	Double	Iso Heptane. Parts per million by volume – NGA-FID. Natural Gas Analysis by Flame Ionization Detector
n_Heptane_ppmv_NGA_FID	Double	n Heptane. Parts per million by volume – NGA-FID. Natural Gas Analysis by Flame Ionization Detector
N2_ppmv_NGA_TCD	Double	Nitrogen. Parts per million by volume – NGA-TCD. Natural Gas Analysis by Thermal Conductivity Detector
O2_ppmv_NGA_TCD	Double	Oxygen. Parts per million by volume - NGA-TCD. Natural Gas Analysis by Thermal Conductivity Detector
CO2_ppmv_NGA_TCD	Double	Carbon dioxide. Parts per million by volume - NGA-TCD. Natural Gas Analysis by Thermal Conductivity Detector
Xenon_ppmv	Double	Xenon. Parts per million by volume
Ethylene_ppmv	Double	Ethylene. Parts per million by volume
Propylene_ppmv	Double	Propylene. Parts per million by volume
Proceeding_label	Text, 254	Label in the proceedings
Comments	Text, 254	Comments

GasHydrate_Areal_Seism_Indicators -- Polys

FIELDNAME	FORMAT	DESCRIPCION
ID_IndiName	Text, 254	Identification code of the evidence - PK-
MpArea	Double 15,6	Cartographical area of the evidence in km2
GeoSetting	Text, 50	Geographical / Geological Setting – Constrains NN, LV
LocalSite	Text, 50	Local site where the evidence is located
Data_Source	Text, 254	Institution/Company if Owner of Data. Project, database or publication where data have been collected
Cruise	Text, 254	Oceanographic Cruise/es in which the evidence is supported
CName	Text, 50	Contact name
Email	Text, 50	Contact Email
FF_Type	Text, 50	Type of evidence– constrain- NN- LV_FF_Type
Description	Text, 250	Description of the evidence - free text
D_Indi_TWT_tp	Double 11,4	Depth of the top of the evidence below seabed in seconds TWTT
D_Indi_TWT_bt	Double 11,4	Depth of the bottom of the evidence below seabed in seconds TWTT
Size	Text, 50	Size (volume, km2, tons, etc)
DOI	Text, 254	DOI of main data publication
References	Text, 254	Referencesto data. Author, Year & Title. Link to PDF in data repository
Comments	Text, 254	Comments -- Free text

FLUID FLOW SEABED INDICATORS

FluidFlow_Seafloor_Poly_Features -- Polys

FIELDNAME	FORMAT	DESCRIPCION
ID_IndiName	Text, 254	Identification code of the evidence - PK-
MpArea	Double 15,6	Cartographical area of the evidence in km2
GeoSetting	Text, 50	Geographical / Geological Setting – Constrains NN, LV
LocalSite	Text, 50	Local site where the evidence is located
FF_Type	Text, 50	Type of evidence– constrain- NN- LV_FF_Type
Description	Text, 250	Description of the evidence - free text
Data_Source	Text, 254	Institution/Company if Owner of Data. Project, database or publication where data have been collected
CName	Text, 50	Contact name
Email	Text, 50	Contact Email
DOI	Text, 254	DOI of main data publication
References	Text, 254	Referencesto data. Author, Year & Title. Link to PDF in data repository
Comments	Text, 254	Comments -- Free text

FluidFlow_Seafloor_Point_Features -- Points

FIELDNAME	FORMAT	DESCRIPCION
ID_IndiName	Text, 254	Identification code of the evidence - PK-
Lat_DD	Double 15,6	Latitude in decimal degrees(WGS84)
Long_DD	Double 15,6	Longitude in decimal degrees (WGS84)
WaterDepth	Double 15,6	Seafloor depth
GeoSetting	Text, 50	Geographical / Geological Setting – Constrains NN, LV
LocalSite	Text, 50	Local site where the evidence is located
FF_Type	Text, 50	Type of evidence– constrain- NN- LV_FF_Type
Description	Text, 250	Description of the evidence - free text
Data_Source	Text, 254	Institution/Company if Owner of Data. Project, database or publication where data have been collected
CName	Text, 50	Contact name
Email	Text, 50	Contact Email
DOI	Text, 254	DOI of main data publication
References	Text, 254	Referencesto data. Author, Year & Title. Link to PDF in data repository
Comments	Text, 254	Comments -- Free text

GHSZ 3D MODELS:

FIELDNAME	FORMAT	DESCRIPCION
longitude	Num (Double) (15,6)	
latitude	Num (Double) (15,6)	
Z_VALUE	Num (Double) (15,6)	

OCEANOGRAPHIC VARIABLES / GEOLOGICAL CONSTRAINS

HeatFlow_Global POINTS

FIELDNAME	FORMAT	DESCRIPCION
OBJECTID	Number	Feature ID. An internally generated identification number for each feature. Automatically generated within shapefile.
shape	Geometry	points
Data_Numbe	Text, 254	Number arbitrary
Codes	Text, 254	Codes based on Lee and Uyeda 1965
Site_Name	Text, 254	Code from "AAPG Datapages" (Jessop et al 1975)
Latitude	Num (Double) (0,0)	Latitude
Longitude	Num (Double) (0,0)	Longitude
Elevation	Text, 254	Elevation
minD	Text, 254	Minimum depth for the heat flow calculation
maxD	Text, 254	Maximum depth for the heat flow calculation
No__Temps	Number	Number of temperature point used in the calculation
Gradient	Gradient	Temperature gradient
No__Cond_	Number	0, Estimated by roc type or existing data. Blank , lack of info
Conductiv	Num (Double) (0,0)	Average conductivity
No_Heat_Pr	Text, 254	Number of samples used in the calculation
Heat_Flow	Num (Double) (0,0)	Heat flow in mE/m2
No__sites	Number	Differnt of 1 if grouping has occurred. Blank in subitems. More information in Jessop et al (1975)
Year_of_Pu	Text, 254	Year of publication
Year_of__1	Num (Double) (0,0)	Delete
Year_of__2	Num (Double) (0,0)	Delete
Reference	Text, 254	Source of data
Comments	Text, 254	Additional references
Comments2	Text, 254	Methods, Geographical setting, or additional references

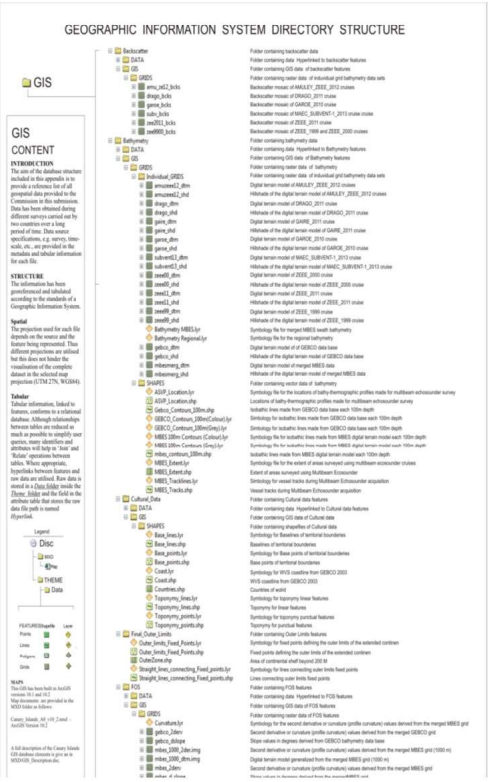
Seafloor_Temperature: POINTS

FIELDNAME	FORMAT	DESCRIPCION
ID_OceName	Text, 254	Identification name of data - PK
Lat_DD	Double 15,6	Latitude in decimal degrees(WGS84)
Long_DD	Double 15,6	Longitude in decimal degrees (WGS84)
WaterDepth	Double 15,6	Seafloor depth
Measure_Depth	Double 15,6	Water depth of the temperature measured (m)
Temp	Double 15,6	Temperature (ºC)
Data_Source	Text, 254	Institution/Company if Owner of Data. Project, database or publication where data have been collected

Sediments_Thickness

FIELDNAME	FORMAT	DESCRIPCION
longitude	Num (Double) (15,6)	)
latitude	Num (Double) (15,6)	
Z_VALUE	Num (Double) (15,6)	

GEOGRAPHIC INFORMATION SYSTEM DIRECTORY STRUCTURE



Geological and geophysical evidence and indicators of marine gas hydrates stored in GARAHydrates

geological settings	geological evidences				geophysical indicators								
	hydrates		degassing structures	pore water anomalies	BSR		high res.	gas chimney		blanking acoustic	gas flares	seabed structures		
	samples	km²/ levels			loc. sites	km²/ levels		loc. sites	km²/ levels			pock-seeps loc. Sites	pock-seeps km²/levels	mud volcano
Western Greenland				6		9,410 / 2					5		3,565 / 1	2 mud diapir
E. Greenland-Svalbald-Barents Sea	4	2,163 / 4 E. Barents S.			14	26,316 / 58		16	3,110 / 95		65	1007		1
Mid-Norwegian margin	6					4,278 / 9						76		
NE Atlantic				8	139			24		139		36	58,273 / 42	
S Iberian - NW African margins	22 Gulf of Cádiz		10		1			7		4		44	233 / 1 Alborán	63
Eastern Mediterranean Sea	2					2,360 /4						24		59
Marmara Sea	1											512		2
Black Sea	23	3,655 / 7			15	15,058 / 14	4					31		102

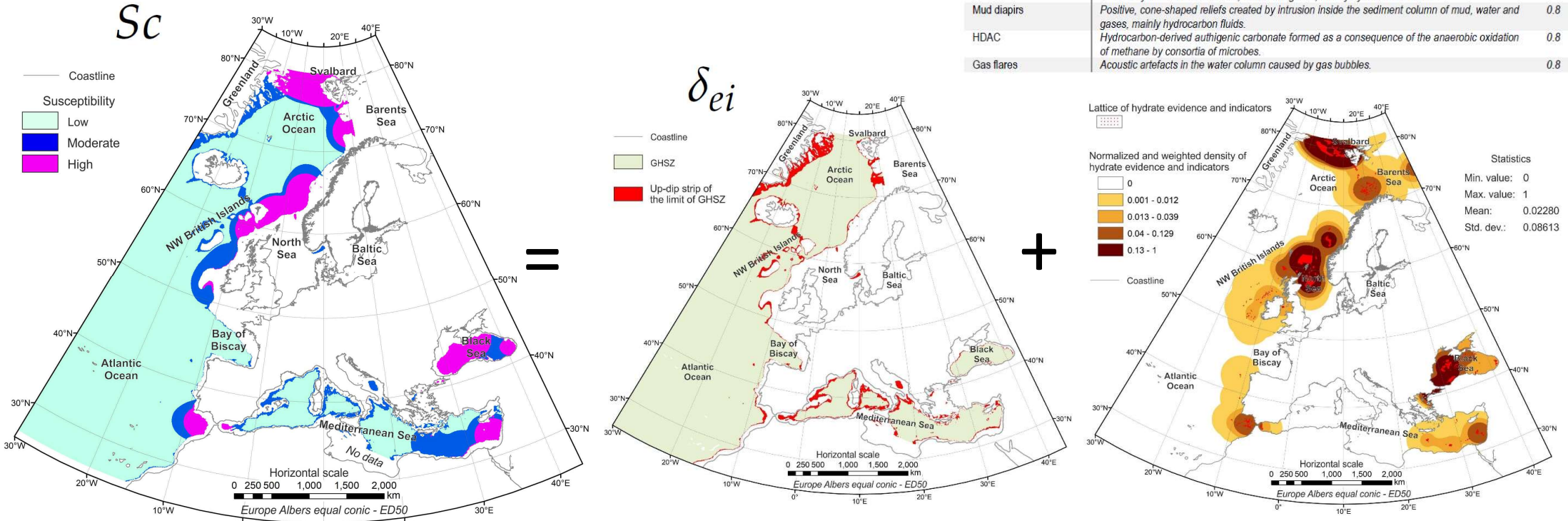
Susceptibility Assessment

$$Sc = \delta_{ei} + GHSZ_w$$

where Sc is the susceptibility map; δ_{ei} is the normalized weighted density map of hydrate evidence and indicators; and $GHSZ_w$ is the weighted map of the GHSZ on the seafloor. The final Sc value was masked with the positive values of the GHSZ map. Seafloor areas outside the GHSZ have a susceptibility value of zero.

$GHSZ_w$

Evidence & indicator	Description	Weight
Gas hydrate samples	Crystals or aggregates of gas hydrates observed in gravity cores.	1
Degassing structures	Bubbles and/or vacuoles (porosity) in sediment liquefactions observed in gravity core samples.	1
Pore water anomalies	Chemical and isotopic pore water anomalies that are caused by hydrate dissociation (e.g. downward chlorinity decrease combined with δ18O increase).	0.9
BSRs	Only bottom-simulating reflectors generated by the impedance contrast between the gas-hydrated sediment above and a free gas layer below. Opal BSRs are excluded.	0.9
High resistivity	Anomalous high electrical resistivity in logs due to the presence of massive hydrates.	0.9
Velocity anomalies	Anomalous seismic propagation velocity in the sediment due to the presence of both gas hydrates and free gas.	0.8
Acoustic blanking facies	Zones devoid of reflections in seismic profiles because of the presence of free gas in the sediment.	0.8
Dim spots	Local low-amplitude seismic attribute anomalies that may indicate the presence of hydrocarbons.	0.8
Bright spots	Seismic amplitude or high-amplitude anomalies that may indicate the presence of hydrocarbons.	0.8
Gas chimneys	Areas of poor data quality or push-downs caused by subsurface leakage of gas from a poorly sealed hydrocarbon accumulation.	0.8
Seabed features	Geomorphological features related to seabed fluid flow.	0.8
Gas seepage: pockmarks, mud volcanoes, gryphons	Steady or episodic, slow or rapid, visible or invisible flow of gaseous hydrocarbons from subsurface sources to the Earth's surface. Pockmarks are craters in the seabed caused by fluids erupting and streaming through the sediments. Mud volcanoes are positive cone-shaped reliefs created by the extrusion of mud, water and gases, mainly hydrocarbon fluids.	0.8
Mud diapirs	Positive, cone-shaped reliefs created by intrusion inside the sediment column of mud, water and gases, mainly hydrocarbon fluids.	0.8
HDAC	Hydrocarbon-derived authigenic carbonate formed as a consequence of the anaerobic oxidation of methane by consortia of microbes.	0.8
Gas flares	Acoustic artefacts in the water column caused by gas bubbles.	0.8



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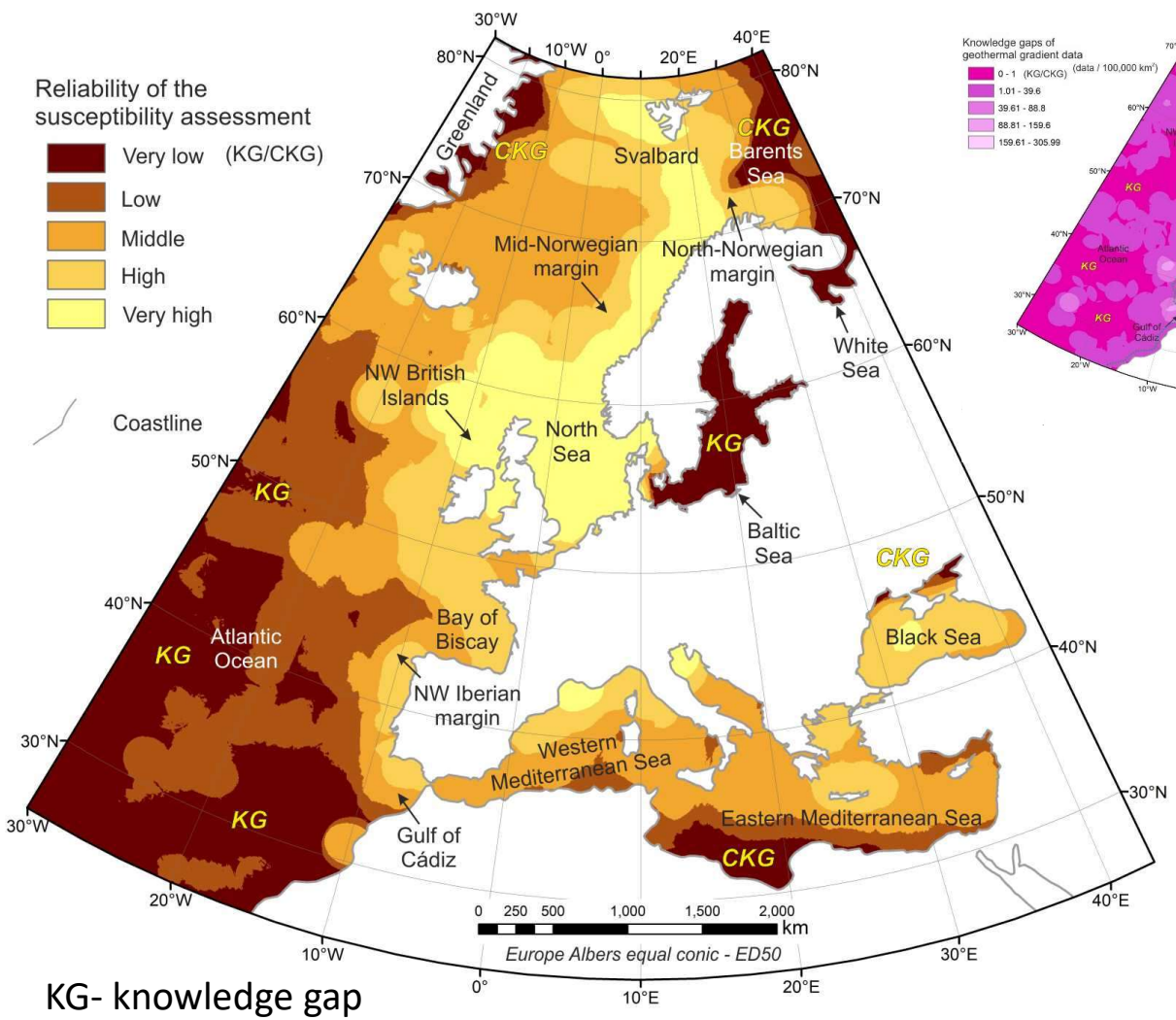
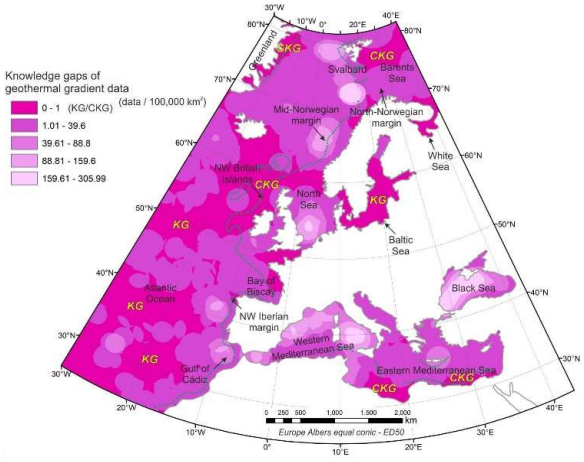
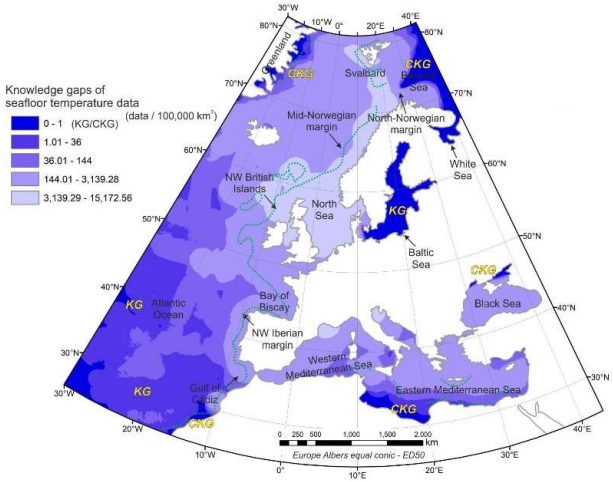
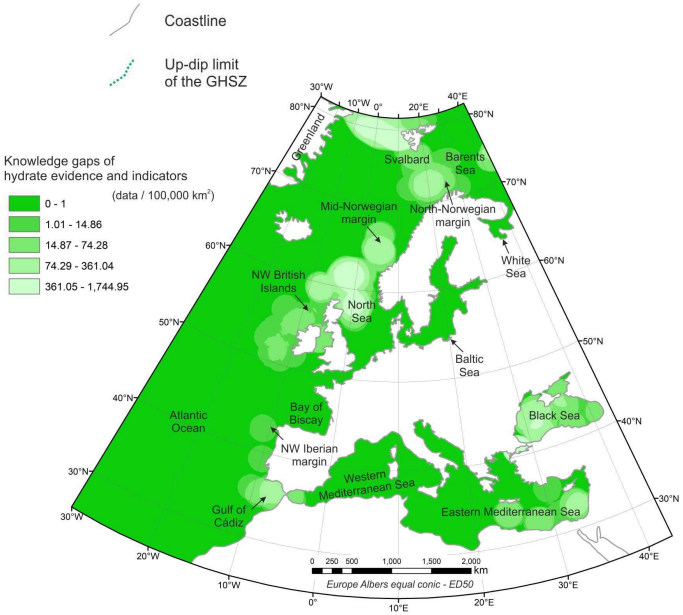
Reliability, impact of knowledge gaps









KG- knowledge gap

CKG- critical knowledge gap

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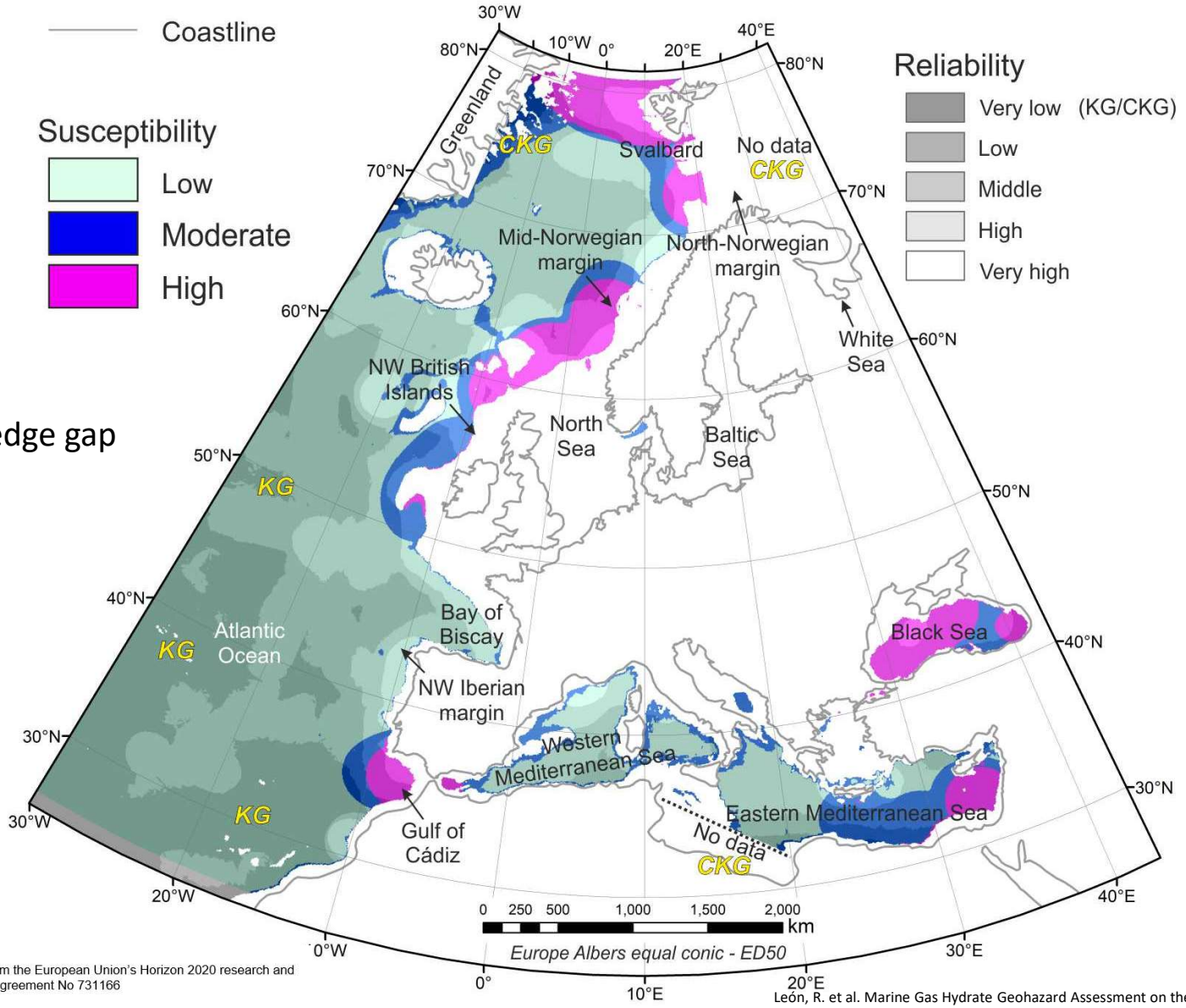
Susceptibility assessment of gas hydrate dissociation occurrence along European continental margins and adjacent areas. GARAH project (GeoERA)



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