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

<u>Ricardo León^{1*}</u>, Christopher Rochelle², André Burnol³, Carmen Julia Giménez- Moreno¹, Tove Nielsen⁴, John Hopper⁴, Isabel Reguera¹, Margaret Stewart⁵, Miguel Llorente¹, Pilar Mata¹, Silvia Cervel¹



León, R. et al. Marine Gas Hydrate Geohazard Assessment on the European Continental Margins. Appl. Sci. 2021, 11, 2865

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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



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731166





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

GARAHydrates – Data Model Structure

GEOLOGICAL & GEOCHEMICAL EVIDENCES-INDICATORS

GasHydrate_Site_Evidences&Indicators -- Points

GasHydrate_Profile_Seism_Indicators -- Lines FIELDNAME FORMAT

GasHydrate Local Seism Indicators -- Points

ocalSite

MpLength Double 15,6 Cartographical length in km of the indicator oSetting Text, 50 Geographical / Geological Setting - Constrains I calSite Text, 50 Local site where the evidence is located

 Location
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 Location
 Location

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4 Depth of the bottom of the evidence below seabed in seconds TV
 D_ind_UMT_tz
 Deuble 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
 References to data Author, Year & Title Link to PDF in data repository

 Comments
 Text, 254
 References to data Author, Year & Title Link to PDF in data repository

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 DOI
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FIELDNAME FORMAT DESCRIPCION

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 Text, 50
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 Text, 300
 Description of the evidence-free text

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 Longitude in derend degrees (WGS4)

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 Seaflood apph

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 Seaflood apph

FILLDRAMIL	FORMAT	DESCRIPCIÓN	
ID_IndiName	Text, 254	Identification code of the evidence - PK	GasElement
Lat_DD	Double 15,6	Latitude in decimal degrees(WGS84)	
Long_DD	Double 15,6	Longitude in decimal degrees (WG584)	ID_IndiNam
WaterDepth	Double 15,6	Seafloor depth	Exp
GeoSetting	Text, SO	Geographical / Geological Setting-Constrains NN, LV	Site
LocalSite	Text, 50	Local site where the evidence is located	Hole
Data_Source	Text, 50	Institution/Company if Owner of Data. Project, database or publication where data have been collected	Core
Cruise	Text, 254	Oceanographic Cruise where data have been recovered or observed	Sect
CName	Text, 50	Contact name	A_W
Email	Text, SO	Contact Email	Top_offset
	Text 50	E - Diseas Fundament I - Indiana Indiana	Bottom_off
5.0	1610, 50	E = Direct Evider Le; i = indirect indicator	Top_depth
FF_Type	Text, 50	Type of evidence o indicator constrains- NN- LV_FF_Type	Bottom_de
Description	Text, 250	Description of the evidence - free text	Top_depth
Sedi_Type	Text, 50	Sediment type-LV_	Bottom_de
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of und full the			Methane_p
D_Indi_m_bt	Double 11,4	Depth of the bottom of the evidence below seabed in meters	Methane_p
Size	Text, 50	Size (volume, km2, tons, etc)	Ethane_ppr
DOI	Text, 254	DOI of main data publication	Ethane_ppr
References	Text, 254	Referencesto data. Author, Year & Title: Link to PDF in data repository	Ethana one
Comments	Text, 254	Comments Freetext	Ethene opr

GasH	varate_Area	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, SO	Institution/Company if Owner of Data. Project, database or publication where data have been collected
CName	Text, 50	Contact name
Email	Text, SO	Contact Email
FF_Type	Text, SO	Type of evidence; FF_Type="Gas Hydrate"
Description	Text, 250	Description of the evidence - free text
Sedi_Type	Text, SO	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

GEOPHYSICAL INDICATORS

DESCRIPCION

FURMAI	DESCRIPCION
Text, 254	Identification code of the evidence - PK-
Text, 254	Expedition number
Text, 254	Site number
Text, 254	Hole number
Text, 254	Core name
Text, 254	H-advanced piston core, X-extended core barrel, R-rotary core barrel
Text, 254	Section
Text, 254	Number of Section: A-Archive half, W-Working half
Double	Top offset
Double	Bottom offset
Double	Top depth, core depth below seafloor, overlap if long. Method-A
Double	Bottom depth, core depth below seafloor, overlap if long. Method-A
Double	Top depth, core depth below seafloor, overlap if long. Method-8
Double	Bottom depth, core depth below seafloor, overlap if long. Method-B
Text	HS - headspace analysis, VAC - vacutainer analysis
Double	Methane. Parts per million by volume – Gas Chromatography
Double	Methane. Parts per million by volume - NGA
Double	Ethane. Parts per million by volume Gas Chromatography
Double	Ethane. Parts per million by volume - NGA-FID. Natural Gas Analysis by
	Flame Ionization Detector
Double	Ethene. Parts per million by volume Gas Chromatography
Double	Ethene. Parts per million by volume - NGA-FID. Natural Gas Analysis by
	Flame Ionization Detector
Double	Ethene. Parts per million by volume Gas Chromatography
Double	Propene. Parts per million by volume Gas Chromatography
Double	Propane - Propene. Parts per million by volume - NGA-FID. Natural Gas
-	Analysisby Flame Ionization Detector
Double	Iso Butane. Parts per million by volume - NGA-FID. Natural Gas Analysis by
_	Flame Ionization Detector
Double	n Butane. Parts per million by volume - NGA-FID. Natural Gas Analysis by
Daubla	riame ionization betector
Course	So Pericalle, Paris per initiation by volume - NGAPTO, Natural Gas Analysis by
Double	n Bantana Parte ner million by volume - NGA-EID, Natural Gar Analysis by
Dodore	Singe Ionization Detector
Double	Iso Havana, Parte ner million by volume - NGA-FID, Natural Gas Analysis by
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Double	n Heyane, Parts ner million by volume - NGA-FID, Natural Gas Analysis by
(Corners)	Flame Ionization Detector
Double	Iso Heptane, Parts per million by volume - NGA-FID, Natural Gas Analysis by
1000000000	Flame Ionization Detector
Double	n Heptane, Parts per million by volume - NGA-FID, Natural Gas Analysis by
second second	Flame Ionization Detector
Double	Nitrogen, Parts per million by volume - NGA-TCD, Natural Gas Analysis by
100002000	Thermal Conductivity Detector
Double	Oxygen, Parts per million by volume - NGA-TCD, Natural Gas Analysis by
1000000000	Thermal Conductivity Detector
Double	Carbon dioxide. Parts per million by volume - NGA-TCD. Natural Gas
100000000	Analysisby Thermal Conductivity Detector
Double	Xenon, Parts per million by volume
Double	Ethylene, Parts per million by volume
Double	Propylene, Parts per million by volume
Text, 254	Label in the proceedings
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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, SO	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 colle
CName	Text, 50	Contact name
Email	Text, 50	ContactEmail
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 Freetext

FIELDNAME	FORMAT	DESCRIPCION
longitude	Num (Double) (15,6)	
latitude	Num (Double) (15,6)	
Z VALUE	Num (Double) (15.6)	

FILID FILID W_SE	ajioor_Point	_reacures 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 Freetext

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

	🗄 🔛 Backscatter	Folder containing backscafter data
	I CATA	Folder containing data Hyperfinked to backscatter features
	= 🛄 ØS	Folder containing GIS data of backscatter features
GIS	6) 🔛 GROS	Folder containing raster data of induvidual grid bathymetry data sets
- 010	a arru, 2012, boks	Backscatter mesaic of AMALEY_ZEEE_2012 outsets
	in the stage_scol	Backcaller House, or OAAAA, 2011 Class
	8 adv bols	Backscatter mosaic of MAEC_SUBVENT-1_2013 cruise cruise
	iii 🎆 zee2011_bcks	Backscatter mosaic of ZEEE_2011 truise
GIS	E E 200900_bcks	Backscatter mosaic of ZEEE_1999 and ZEEE_2000 cruites
010	🗄 🛄 Bathymetry	Folder containing bathymetry data
CONTENT	# 🛄 DATA	Folder containing data. Hyperfinited to Bathymethy Isatures
INTRODUCTION		Foder containing GIS data of Bathymetry Isatures Evider containing code data of bathymetry
The aim of the database structure		Foder containing caser bats or benymeny Evider containing caser bats of behavior of half-umativ data sets
included in this appendix is to remove fast of all	iii iii amurael2 dm	Dathal terrain model of AMULEY ZEEE 2012 cruiters
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two countries over a long	ii 🗱 gaire_dan	Digital tensin model of GARE_2011 cruise
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specifications, e.g. survey, time-	ii 🛄 garse_dhri	Digital tensin model of GAPIOE_2315 cruite
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proreferenced and tubulated	# I resell dtm	Digital terrain model of ZEEE, 2011 cruite
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Ocographic internation system.	🗟 🞆 zeed99_dtm	Digital tensin model of ZEEE_1999 cruise
Spatial	ii 🐻 zeed99_shd	Hilshade of the sigilal terrain model of ZEEE_1999 cruise
The projection used for each file	Buthymetry MBES.lyr	Symbology file for merged MBES swath bathymetry
feature being represented. Thus	Eathymetry Regional Jyr	Symbology file for the regional bathymetry
different projections are utilised	a magence data	Digital terrain model of OF GESICO data tasse
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dataset in the selected map	2 mbesmerg shd	Hilshade of the digital terrain model of merged MBES data
projection (UTM 27N, WGS84).	III 🛄 SHAPES	Folder containing vector data of bathymetry
Tabalar	ASIP_Location.lyr	Syntology file for the locations of bathy-thermographic profiles made for multibeam echosounder surv
Tabular information, linked to	ASIP_Location.shp	Locations of hathy-thermographic profiles made for multibeam echosounder survey
features, conforms to a relational	Cebco_Contours_220m.shp	toobathic lines made from GEBCO data base each 100m depth
database. Although relationships	CEBCO_Contours_100m(Colour).lyr	smoogy to accare; was made thin usacco care base each thim depen
much as possible to simplify user	MES Man Contours (Colored by	Syntoxigy for sociarric lines made from UEBCU data take each 100m depth
queries, many identifiers and	MIES 200m Cantaura (Concerption	Symbology the for lastarties thesi made from MEE2 digital lenses model each 100m degle
Relate' operations between	🗃 mbes, contours, 200m.shp	toobathic lives made from MBES digital tentain model each 100m depth
tables. Where appropriate,	MBES_Extent.lyr	Symbology file for the extent of assas surveyed using multibeam accoounder cruises
hyperlinks between features and	MBES_Extent.shp	Extent of areas surveyed using Multibeam Ecosounder
raw data are utilised. Kaw data is stored in a Data folder inside the	MBES_Tracklines.lyr	Sinbology for vessel tracks during Multibeam Echosounder acquisition
Theme folder and the field in the	MIES_Tracks.shp	Vessel tacks during Multibeam Echosounder acquisition
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- 47-	🔀 Base_pointLabp	Base prints of tentorial boundaries
2.4	Ocest.lyr	Symbology for WVS coastine from GEIRCO 2003
THEME	Coast.shp	WVS coastine from GEBCO 2003
- Data	Countries.shp	Countries of world
	Taponymy_InesJyr	Symbology for toponymy linear features
	Toponymy_snes.anp	Toponymy for Insur Isultures
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6475	Straight_lines_connecting_Fixed_points.shp	Lines connecting outer limits fixed points
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OD/GS_Deception.doc	🗉 🛄 mbes_2000_dtm.img	Digital tensin model generalized from the merged MBES grid (1000 m)
	iii mbes_2derv	Second derivative or curvature (profile curvature) values derived from the merged MBES grid

	OCEANOGRAPHIC VARIABLES / GEOLOGICAL CONSTRAINS
HeatFlow Global POINTS	

FIELDNAME	FORMAT	DESCRIPCION
DBJECTID	Number	Feature ID. An internally generated identification number for each feature. Automatically generated within shape file.
hape	Geometry	points
Data_Numbe	Text, 254	Number arbitrary
odes	Text, 254	Codes based on Lee and Uyeda 1965
ite_Name	Text, 254	Code from "AAPG Datapages" (Jessop et al 1975)
atitude	Num (Double) (0,0)	Latitude
ongitude	Num (Double) (0,0)	Longitude
levation	Text, 254	Elevation
ninD	Text, 254	Minimum depth for the heat flow calculation
naxD	Text, 254	Maximum depth for the heat flow calculation
lo_Temps	Number	Number of temperatura point used in the calculation
Gradient	Gradient	Temperatuegradient
loCond_	Number	0, Estimated by roc type or existing data. Blank , lack of info
onductivi	Num (Double) (0,0)	Average conductivity
Io_Heat_Pr	Text, 254	Number of samples used in the calculation
leat_Flow	Num (Double) (0,0)	Heat flow in mE/m2
lo_sites	Number	Differnt of 1 if grouping has occurred. Blank in subitems. More information in Jessop et al (1975)
'ear_of_Pu	Text, 254	Year of publication
'ear_of1	Num (Double) (0,0)	Delete
'ear_of2	Num (Double) (0,0)	Delete
teference	Text, 254	Source of data
omments	Text, 254	Additionalreferences
omments2	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(WG584)	
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(fC)	
Data_Source	Text, 254	Institution/Company If Owner of Data. Project, database or publication where data have been collected	

	collected	
ediments_Thickn	ess	
FIELDNAME	FORMAT	DESCRIPCION
longitude		

Z_VALUE	Num (Double) (15,6)	
latitude	Num (Double) (15,6)	
longitude	Num (Double) (15,6)	1

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 col						
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 evidenceconstrain-NNLV_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 Freetext						

-	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 database
	Cruise	Text, 254	Oceanographic Cruise/es in which the evidence is supported
	CName	Text, 50	Contact name
4	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

FLUID FLOW SEABED INDICATORS

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

geological settings	geological evidences					geophysical indicators								
	hydrates			pore	BSR			gas chimney			1 - 1803	seabed structures		
	samples	km²/ levels	degassing structures	water anomalies	loc. sites	km²/ levels	high res.	loc. sites	km²/ levels	- blanking acoustic	gas flares	pock-seeps loc. Sites	pock-seeps km²/levels	mud volcano
Western Greenland				6		9,410 / 2					5	22	3,565 / 1	2 mud diapir
E. Greenland- Svalbald- Barents Sea	4	2,163 / 4 E. Barents S.			14	26,316 / 58	<u>.</u>	16	3,110 / 95		65	1007		1
Mid- Norwegian margin	6					4,278 /9	5 - F		5		10-	76	15	
NE Atlantic		й		8	139	**	,	24		139		36	58,273 / 42	
S Iberian - NW African margins	22 Gulf of Cádiz	ŧ.	10	, ,	1		,	7	<u>.</u>	4	x.	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			4.7	M-0	31		102

Susceptibility Assessment

$GHSZ_w$

Weight

Description

Bubbles and/or vacuoles (porosity) in sediment liquefactions observed in gravity core samples.

Crystals or aggregates of gas hydrates observed in gravity cores.



Evidence & indicator

Gas hydrate samples

Degassing structures

León, R. et al. Marine Gas Hydrate Geohazard Assessment on the European Continental Margins. Appl. Sci. 2021, 11, 2865

Reliability, impact of knowledge gaps



León, R. et al. Marine Gas Hydrate Geohazard Assessment on the European Continental Margins. Appl. Sci. 2021, 11, 2865



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