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André Burnol, Isabelle Thinon. Storage of CO₂ at low temperature as liquid or solid gas hydrate Application in the French and Spanish EEZ in North-East Atlantic. GEOCO₂, Colloque Franco-Espagnol “ Stockage géologique du CO₂ et microfluidique ”, Oct 2016, Bordeaux, France. , 2018, 10.13140/RG.2.2.12554.72640 . hal-01970582

HAL Id: hal-01970582

<https://brgm.hal.science/hal-01970582>

Submitted on 5 Jan 2019

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Storage of CO₂ at low temperature as liquid or solid gas hydrate Application in the French and Spanish EEZ in North-East Atlantic

André Burnol⁽¹⁾, Isabelle Thion⁽²⁾

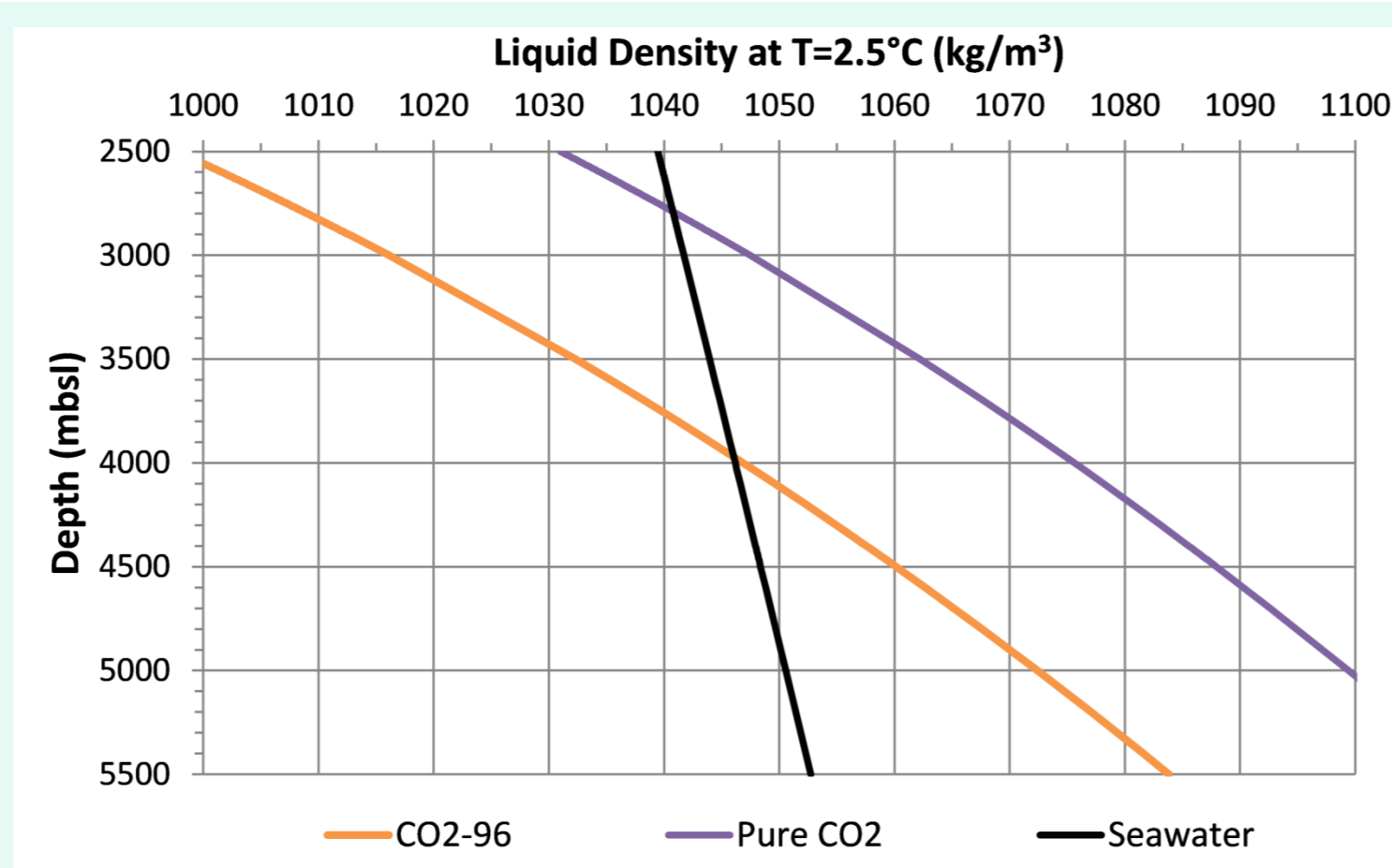
(1) BRGM, Risks and risk Prevention Division (DRP)

(2) BRGM, Georesources Division (DGR)

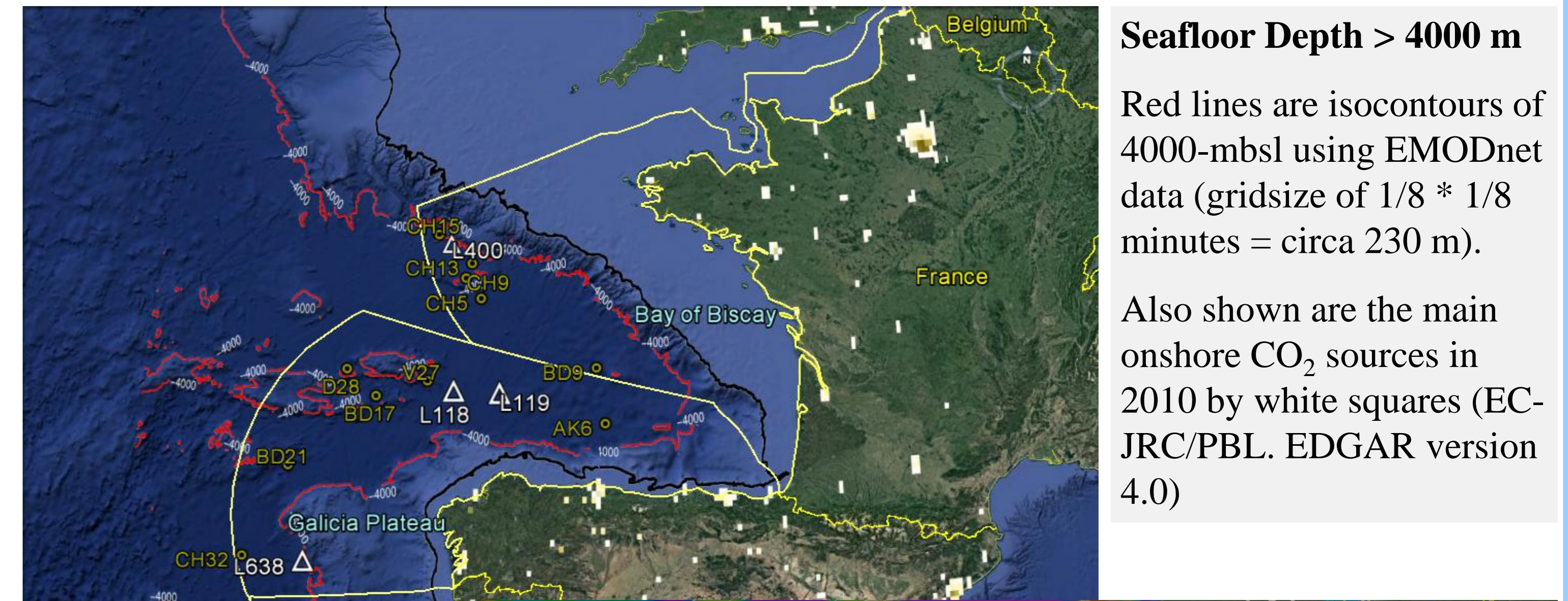
Main objectives:

- (1) Estimation of the CO₂ theoretical storage volume in the French and Spanish Exclusive Economic Zone (EEZ) in North-East Atlantic
- (2) Comparison between the CO₂ storage capacity as liquid or as solid gas hydrate in the French and Spanish EEZ

Mole fraction (%)	CO ₂ -96	CO ₂ -100 (Pure CO ₂)	Dynamics recommendations
CO ₂	96.4	100	>95.5
N ₂	3.6	0	< 4
H ₂ S	0	0	< 0.02



NBZ using GERG-2008 (Kunz, 2012)

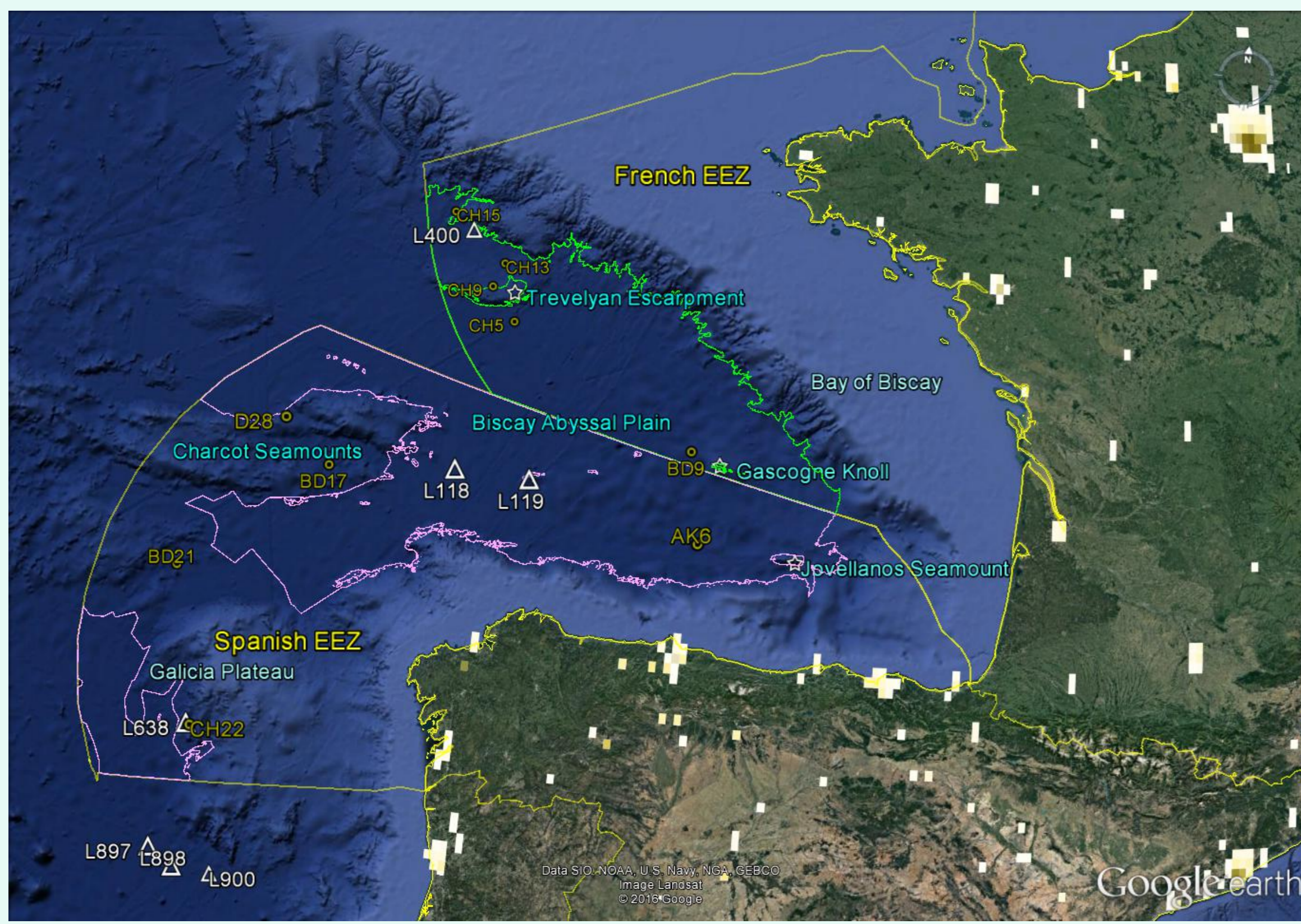


Red lines are isocontours of 4000-mbsl using EMODnet data (gridsize of 1/8 * 1/8 minutes = circa 230 m).

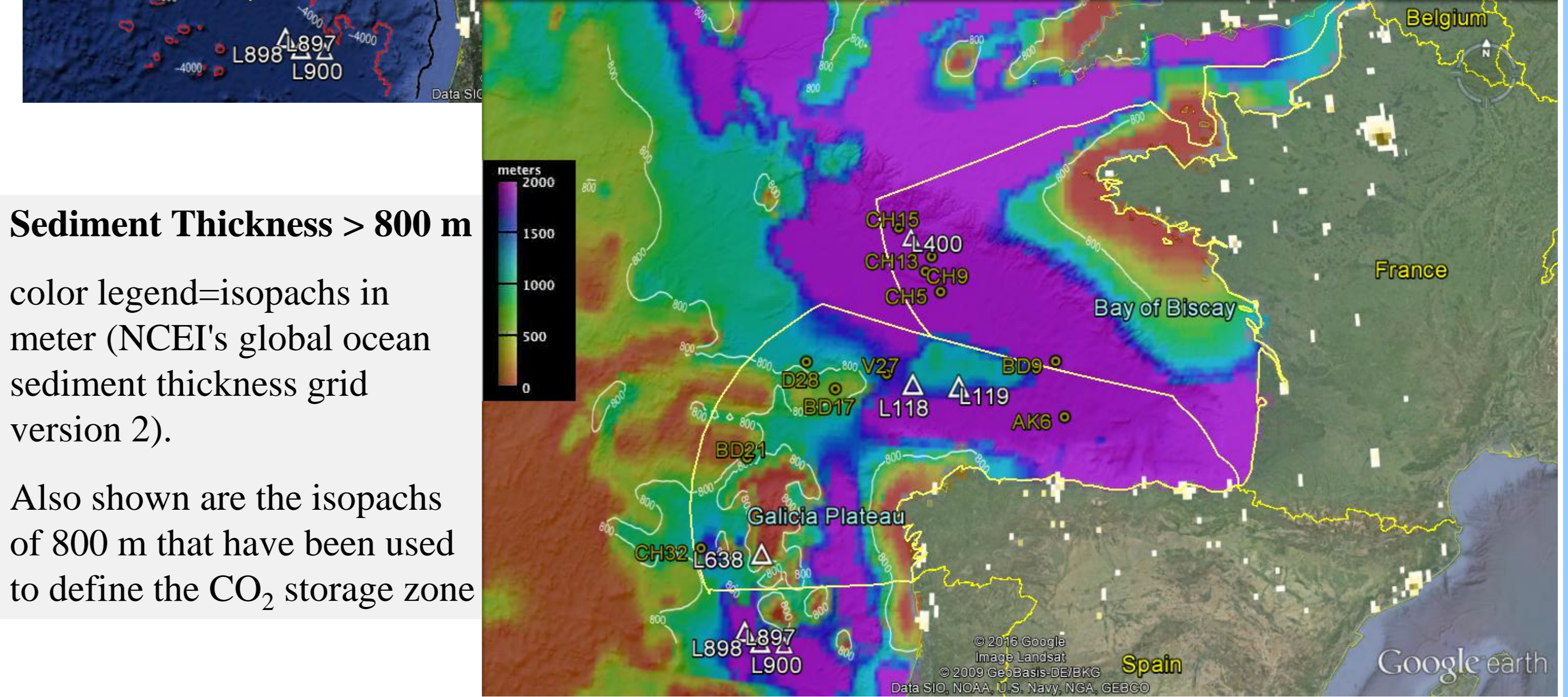
Also shown are the main onshore CO₂ sources in 2010 by white squares (EC-JRC/PBL, EDGAR version 4.0)

The CO₂ Storage Zone in French and Spanish EEZ is defined by three safety criteria using GMT (Wessel, 1998):

- 1) Seafloor Depth > 4000 m => Density (CO₂+impurities) > (Sea Water)
- 2) Slope < 4° => Safety criterium to avoid slumps on the continental slope
- 3) Sediment Thickness > 800 m => to avoid hydrate formation at injection



Green: French EEZ
Pink: Spanish EEZ



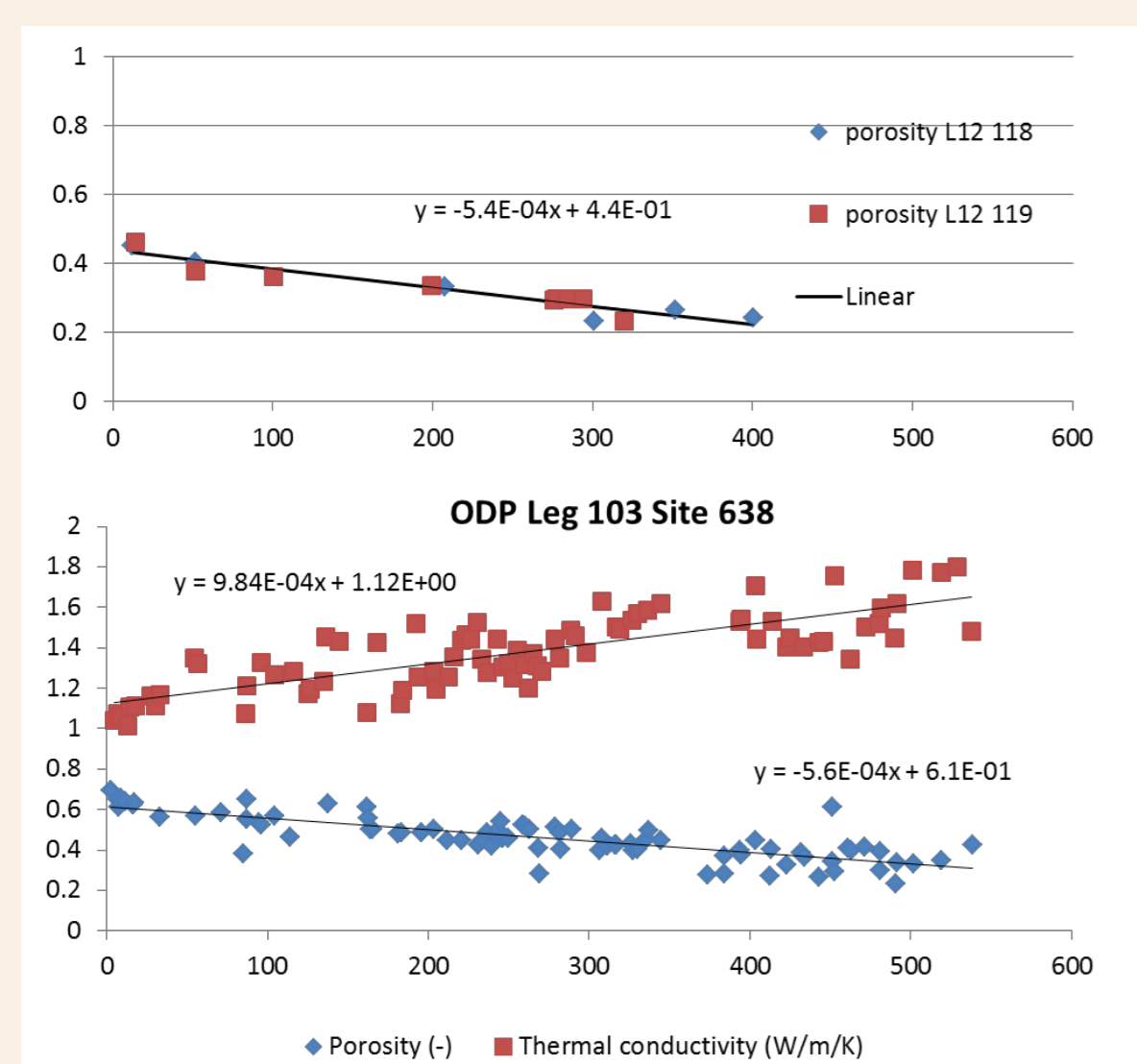
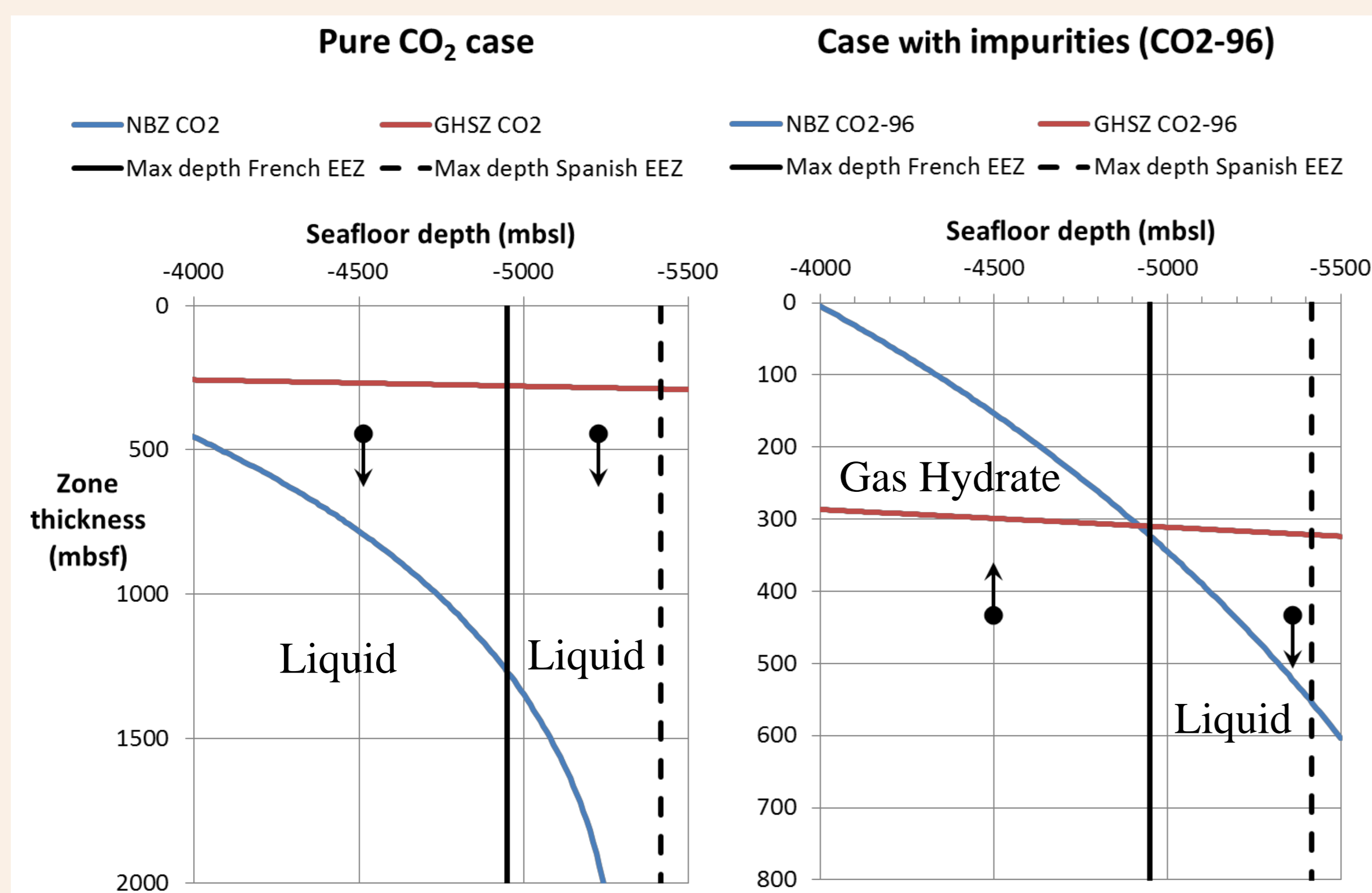
Sediment Thickness > 800 m
color legend=isopachs in meter (NCEI's global ocean sediment thickness grid version 2).

Also shown are the isopachs of 800 m that have been used to define the CO₂ storage zone

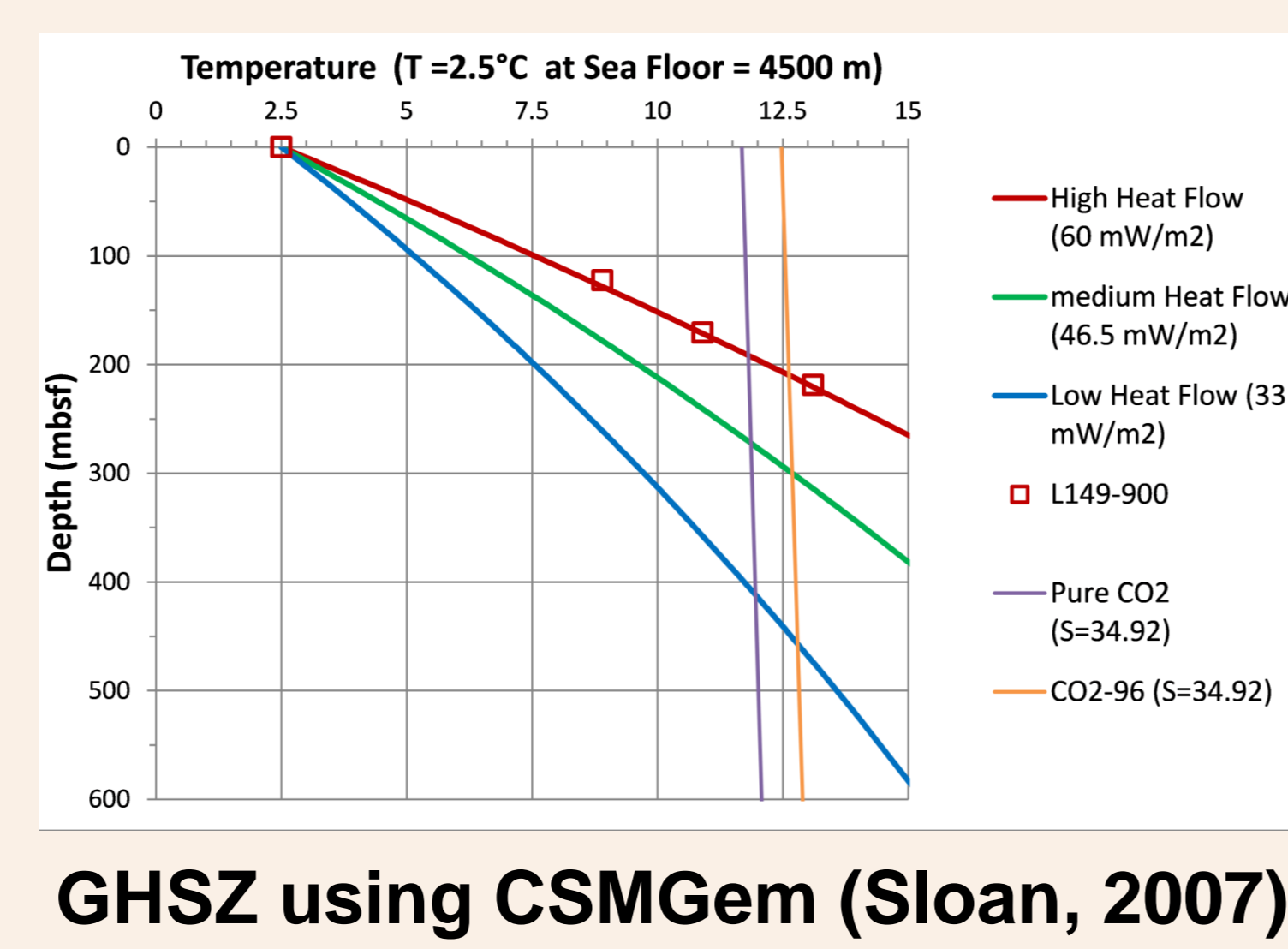
Source: GHFD09 (re-calculated)	L149	L149	L149	L103 638	CH5	CH9	CH13	CH15	BD17	BD9	BD21
Surface Thermal Conductivity Wm ⁻¹ K ⁻¹	1.1	1.3	1.1	1.12	1.17	1.05	1.06	1.14	0.913	0.95	0.96
Heat Flow mW m ⁻²	49.5	52 (53.8)	60	nd	33 (33)	40 (46.3)	50 (52.4)	46 (45.5)	58.	31.4 (33)	48.6 (48.8)

Thermal Conductivity of surface sediments is almost constant: $TC = 1.1 \text{ Wm}^{-1}\text{K}^{-1}$
Heat Flow in the studied zone varies between two extreme values: **Low HF = 33 mW/m² High HF = 60 mW/m²**

CO₂ storage as liquid or gas hydrate (medium Heat Flow 46.5 mW/m²)



$PORO = 0.6 - 0.0006 \cdot Z$
 $TC = 1.1 + 0.001 \cdot Z$



GHSZ using CSMGem (Sloan, 2007)
 $TEMP = 2.5 + HF \cdot \ln(TC/1.1)$

	Surface (km ²)	Mean thickness (m) ^a	Mean Porosity (%)	Theoretical Storage Volume (km ³)	Storage efficiency factor ^b (%)	Density (g/cm ³)	Storage capacity (GtCO ₂)	
French EEZ (CO ₂ -100)	Liquid	55 443	1213	0.3	20 173	2	1.045	422
French EEZ (CO ₂ -96)	Gas Hydrate	55 442	115	0.53	3422	2	0.3	20.5
Spanish EEZ (CO ₂ -96)	Gas Hydrate	70 569	52	0.45	1728	2	0.3	10.4
	Liquid	36 720	153	0.39	1972	2	1.045	41.2

^a as a liquid, the thickness is twice the depth difference between the neutral buoyancy level and the gas hydrate formation level; as gas hydrate, the thickness is the difference between the hydrate formation level and the neutral buoyancy level
^b a conservative estimate of 2% as explained in (Burnol et al., 2015)

Conclusions

- Physical conditions (P, T, depth, sediment thickness) in French/Spanish EEZ are favorable for a CO₂ storage in deep-sea sediments (deep offshore option)
- The Negative Buoyancy Zone (NBZ) and Gas Hydrate Stability Zone (GHSZ) are calculated using the bisection method in a new code called GASCO₂ (Burnol et al., 2015)
- GMT is then used to calculate the storage volume and capacity in both EEZ
- French EEZ theoretical storage volume (3422 km³) is of the same order of magnitude as the total storage volume in the Spanish EEZ (3700 km³)
- Storage capacity estimate as Gas Hydrates is two times higher in the French EEZ (20.5 Gt) than in the Spanish EEZ (10.4 Gt)
- Total storage capacity in the Spanish EEZ (Gas Hydrates + Liquid) is higher than the storage capacity in the French EEZ (only Gas Hydrates)