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Geological Setting of Natural “Gold” Hydrogen in the Pyrenees and Implications for Exploration Worldwide

Christopher Atkinson, Sandra García-Curiel,

Christopher Matchette-Downes and Ian Munro

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The H_2 Rainbow

Grey is how we make it today - steam methane reforming – (SMR).

Blue uses SMR, but with CCS.

Green uses renewable electricity to run electrolysers, which make H_2 and O_2 from water.

Turquoise is a pyrolysis treatment (chemical decomposition at high temperatures) of conventional natural gas, which produces H_2 and solid carbon as a by-product.

Gold or White is natural, molecular-free H_2 from the Earth

Presentation Outline

1. Natural/Gold Hydrogen (H2): a believer or non-believer?

2. Natural H2 in the Pyrenees

   - Iberian rotation, Pyrenean orogeny
   - Surface H2 seepage in the North Pyrenees
   - H2 presence in the South Pyrenees
   - Monzón-1 (1963) H2 discovery

3. Conclusions & Implications for SE Asia

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Natural H2: a believer or not?

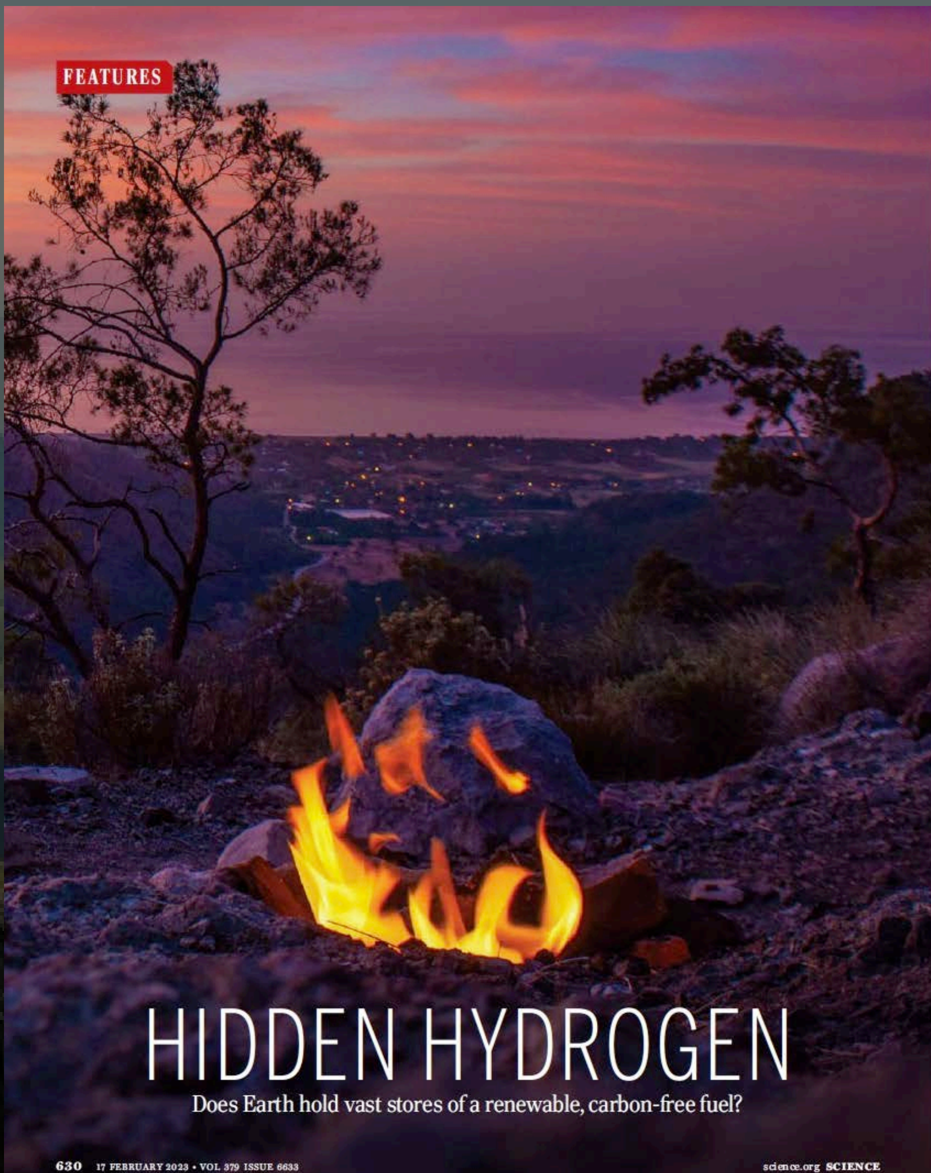
Of course it exists!

Hundreds of natural H2 seepages worldwide:

- Chimaera, Turkey 2500 years old!
- "Los Fuegos Eternos"discovered 200 years ago
- 1888 earliest published analysis of a natural gas containing H2!

HOWEVER concept of natural H2 exploration/production is embryonic and there is neither an exploration strategy nor any resource assessment for targeting natural H2 accumulations.

If still a non-believer....



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The occurrence and geoscience of natural hydrogen: A comprehensive review

Viacheslav Zgonnik

Natural Hydrogen Energy LLC, French branch: 31 rue Raymond Queneau, 92500 Rueil Malmaison, France

A R T I C L E I N F O

Keywords:
Hydrogen
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Faults
Earthquakes
Atmosphere
Microorganisms
Energy

A B S T R A C T

Using an interdisciplinary approach, this paper reviews current knowledge in the field of natural hydrogen. For the first time, it combines perspectives on hydrogen from the literature of the former Eastern bloc with that of the West, including rare hardcopies and recent studies. Data are summarized and classified in three main sections: hydrogen as a free gas in different environments, as inclusions in various rock types, and as dissolved gas in ground water. This review conclusively demonstrates that molecular hydrogen is much more widespread in nature than was previously thought. Hydrogen has been detected at high concentrations, often as the major gas, in all types of geologic environment. A critical evaluation of all the proposed mechanisms regarding the origin of natural hydrogen shows that a deep-seated origin is potentially the most likely explanation for its abundance in nature. By combining available data, an estimate of 23 Tg/year for the total annual flow of hydrogen from geologic sources is proposed. This value is an order of magnitude greater than previous estimate but most likely still not large enough to account for recently discovered worldwide diffusive seepages. Hydrogen could play a critical role in mechanisms taking place in both the shallow and deep geospheres and it can influence a very wide range of natural phenomena. Hydrogen is an essential energy source for many microorganisms. Sampling for hydrogen can be a useful tool in studying natural environments, geologic mapping, monitoring of earthquakes, plotting fault traces and resource exploration. Hydrogen of geologic origin has the potential to become the renewable energy source of the future, with exploratory projects ongoing at the present time. The topic of natural hydrogen is therefore relevant from many different perspectives.

1. Introduction

"*From a geological perspective, hydrogen has been neglected*". This was written by Nigel Smith and colleagues more than a decade ago in a 2005 paper, which appears to be the latest initiative in a review of natural hydrogen (Smith et al., 2005). In 2019 this statement still holds true. I suspect this is because of an existing prejudice that free hydrogen in nature is rare, and descriptions of the few known discoveries are anecdotal and for some reason garner very little notice. Therefore, if no one expects to find free hydrogen, no one samples for it. This prejudice influences the way gas samples are analyzed and sampled, but also the way detection systems are designed. The standard analytical approach for gas chromatography often uses hydrogen as a carrier gas (Angino et al., 1984). Because of this, if there is any hydrogen in a gas sample it will not be detected. It was reported that even in the 1990's, many surveys were not equipped to analyze for hydrogen (Smith, 2002). It still holds true, to this day, that only a few modern portable gas analyzers used in the natural sciences include a hydrogen sensor in their design. It is difficult to estimate how many times hydrogen has not been identified in H_2-rich samples because of the lack of a suitable detection technique to measure hydrogen concentrations.

For example, hydrogen was not measured (de Boer et al., 2007; Hosgörmez, 2007) at a location in Turkey, where it is known to occur naturally at concentrations of up to 11.3%. The presence of hydrogen at this location has been confirmed by other studies (Hosgörmez et al., 2008; Vacquand, 2011). At the location in Turkey, hydrogen-rich natural gas seeps to the surface and burns spontaneously. The flames from this natural gas seep have been known since antiquity and are believed to be the source of the first Olympic flame. Another study reporting on the analysis of gas from Poison bay, New Zealand, did not include hydrogen (Lyon and Giggenbach, 1994) as a constituent, though it had been documented by others (Wood, 1972) to be at concentrations as high as 75.8%.

In view of the above, gas analyses from databases should be

Abbreviations: BTU, British thermal unit; c, concentration; MCFD, Million cubic feet per day; NH, Northern hemisphere; NR, not reported; PSIG, Pounds Per Square Inch Gauge; Tg, Teragram, equal to 10^{12} gram or 1 million ton.; SH, Southern hemisphere

E-mail address: zgonnik@nh2e.com.

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H2 source/generation

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From Hydroma, 2022

Serpentinization

Needs water

The alteration of ferromagnesian rocks (olivines and pyroxenes) that generates hydrogen from the oxydation reduction of water, especially in mafic rocks.

Rock crushing

Rock crushing along fault lines could be responsible for the generation of hydrogen gas as H_2 molecules diffuse out of freshly fractured mineral surfaces.

Radiolysis

Needs water

Earth's crust 's natural radioactivity that separates hydrogen and oxygen from water naturally.

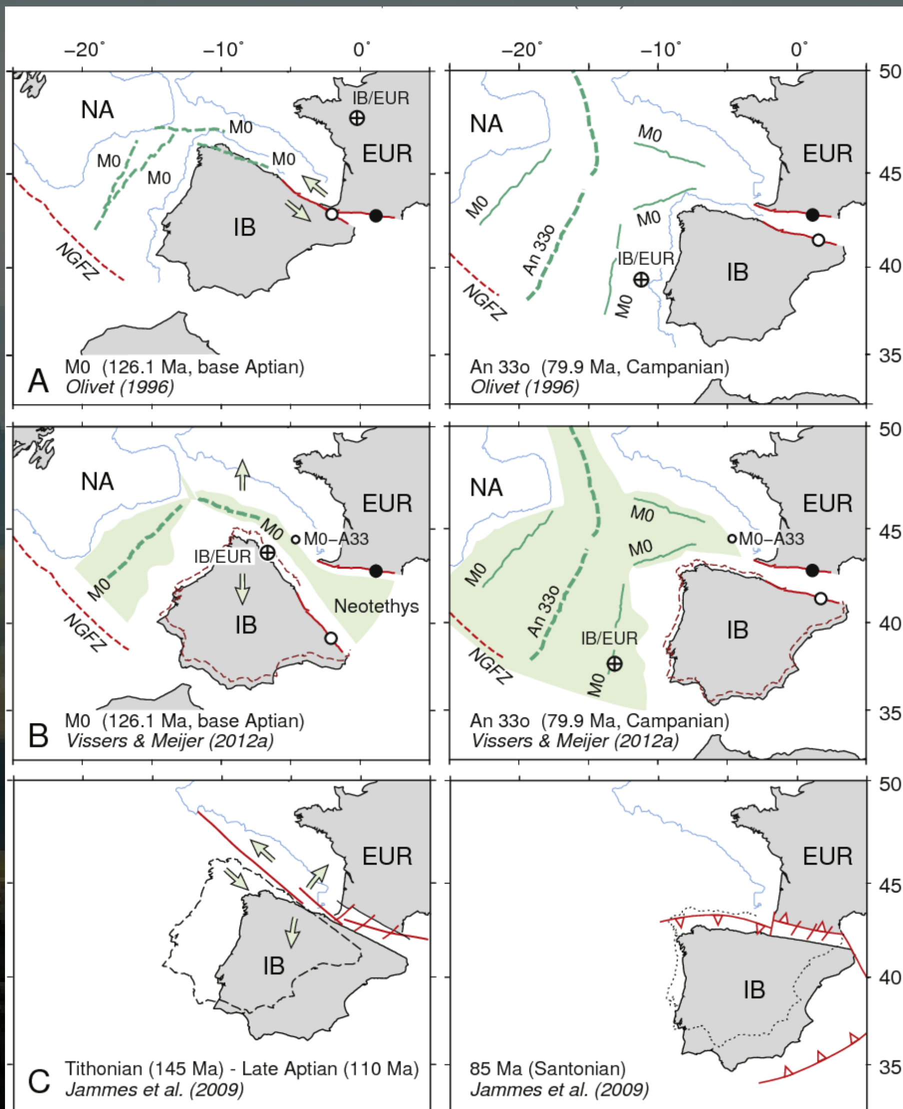
Degassing

Hydrogen stemming from the center of the earth's crust's (generated during the formation of the earth's core).

www.hydroma.ca

Natural H2 in the Pyrenees

Atlantic opens, Iberia rotates & Pyrenees form



Various models proposed

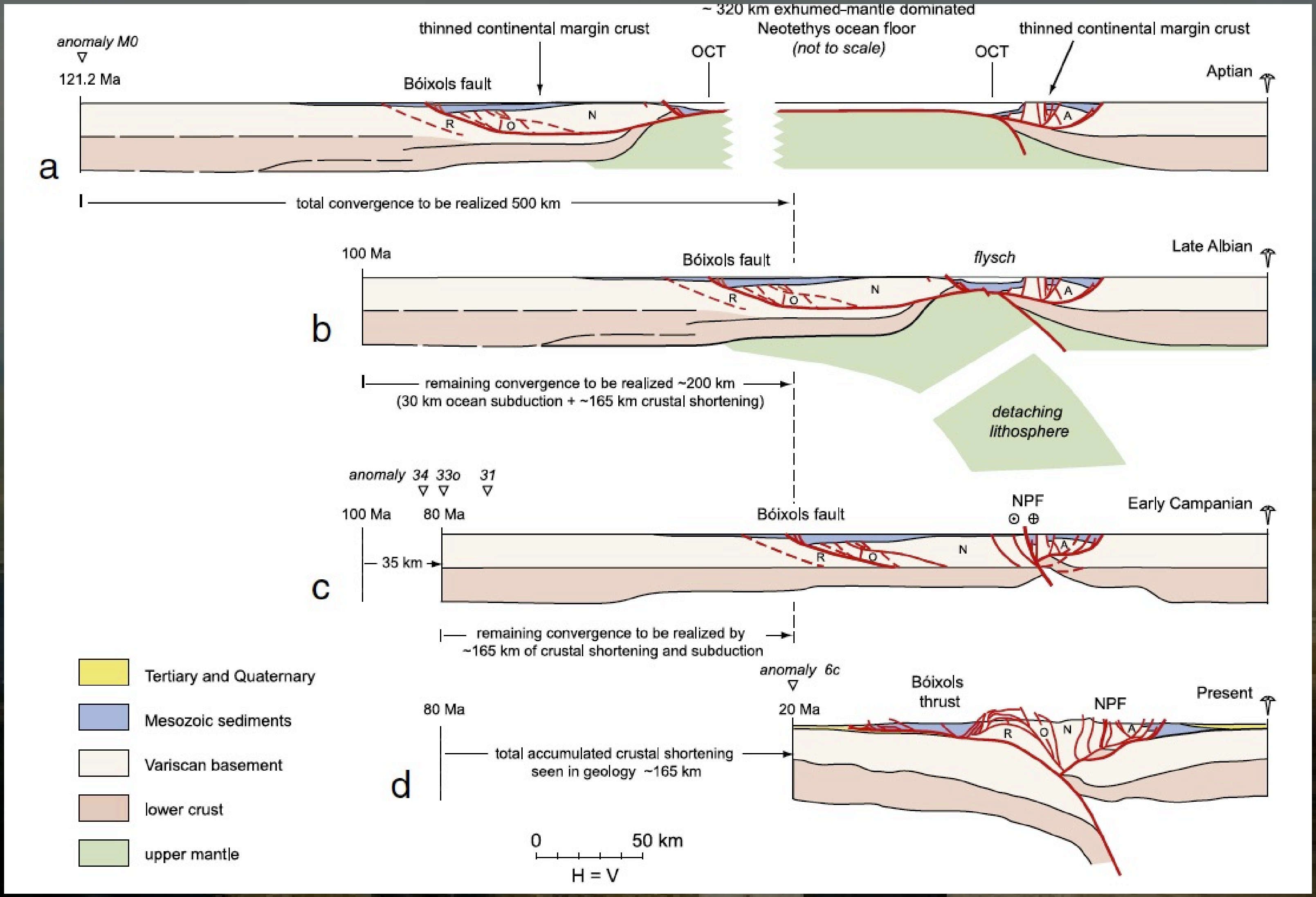
All involve Iberian rotation & crustal extension in Pyrenean region in mid Cretaceous

Followed by N-S shortening associated with Africa collision and subsequent uplift of Pyrenean mountain belt in late Cretaceous/Tertiary.

Vissers & Meijer (2012) matches the true geology the best

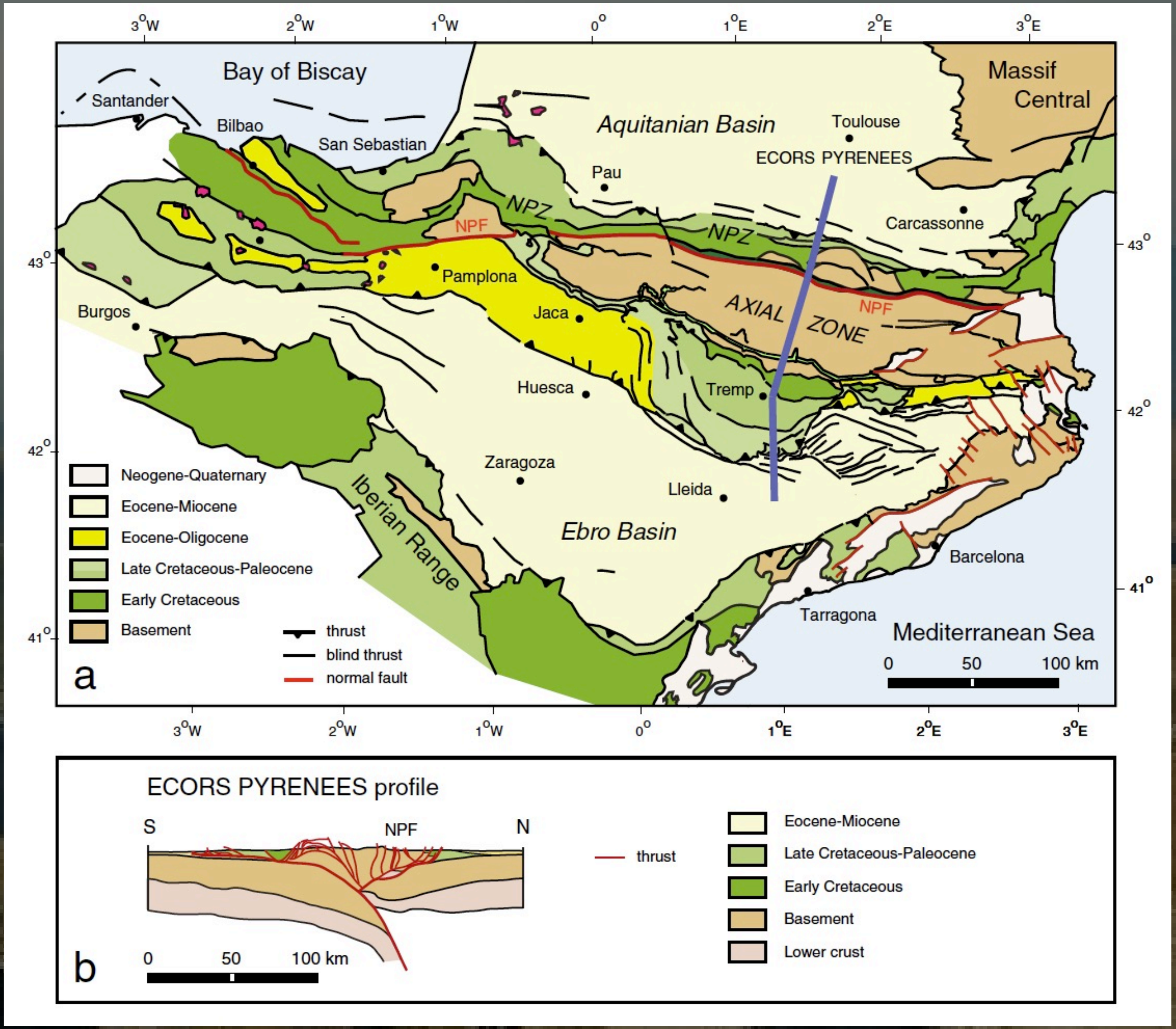
For H2 the Upper Mantle is key

From Vissers & Meijer, 2012



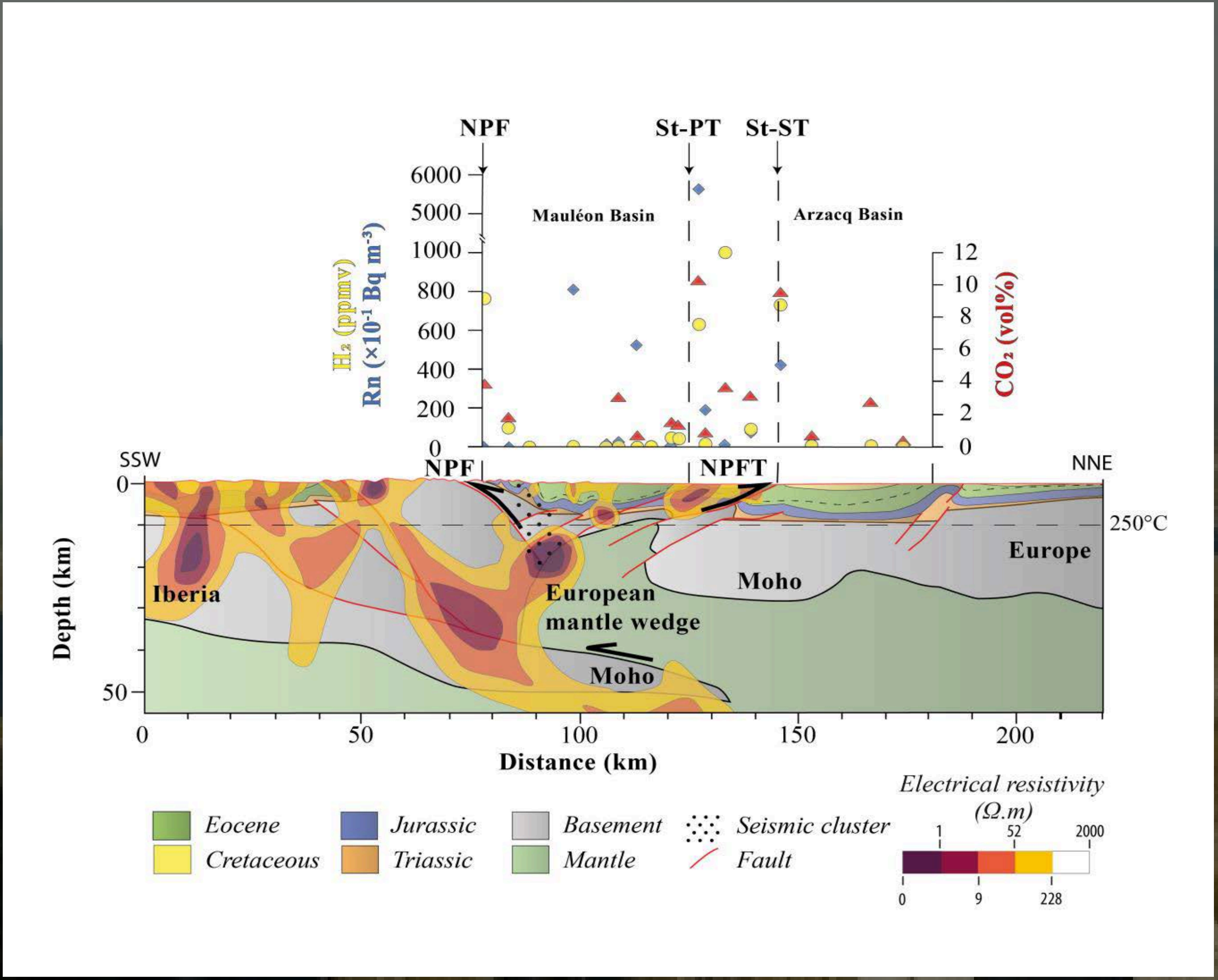
Pyrenees Geology

From Vissers & Meijer, 2012



North Pyrenees anomalous H2 seepage

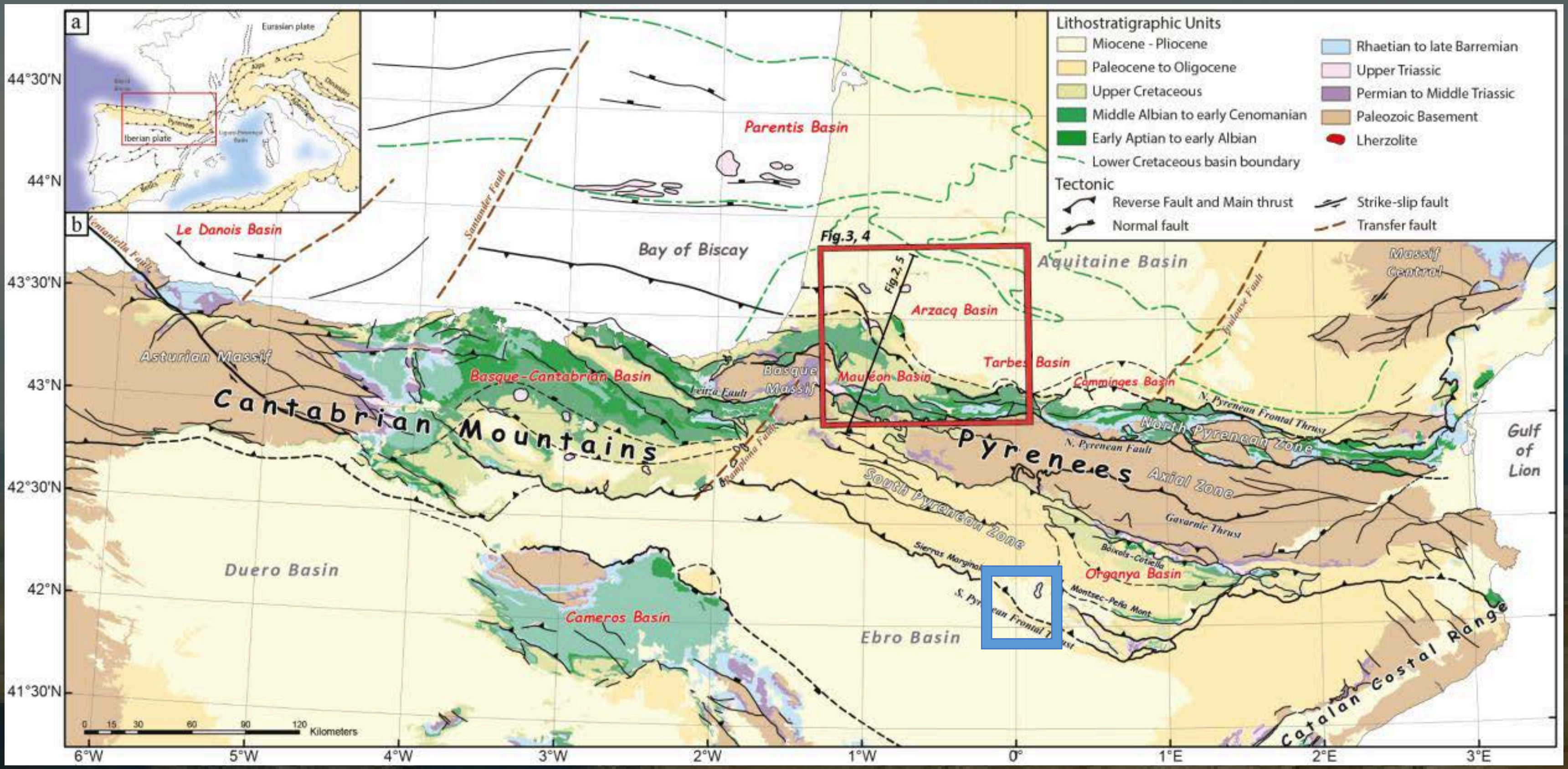
From Lefeuvre et al, 2021



NFT - North Pyrenean Fault

NPFT - North Pyrenean Frontal Thrust

H2 in the South Pyrenees, Spain



Lefeuvre et al (2021) illustrated importance of natural H2 seepage along the North Pyrenean Fault zone at southern edge of Aquitaine Basin (red). Note the symmetry of location of the Permit area (blue) on the northern edge of the Ebro Basin in the South Pyrenees.

H2 in existing wells, Ebro Basin, Spain

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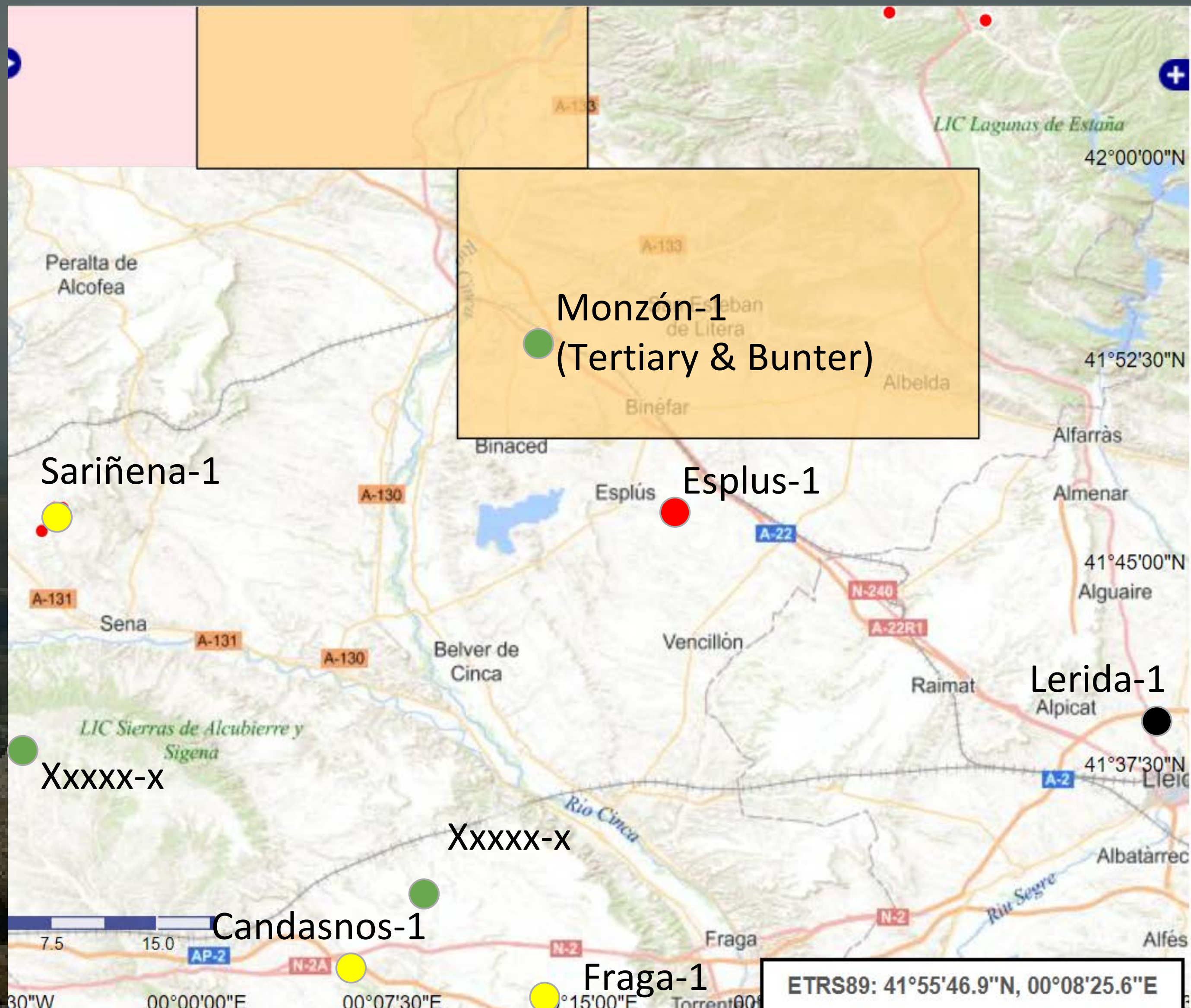
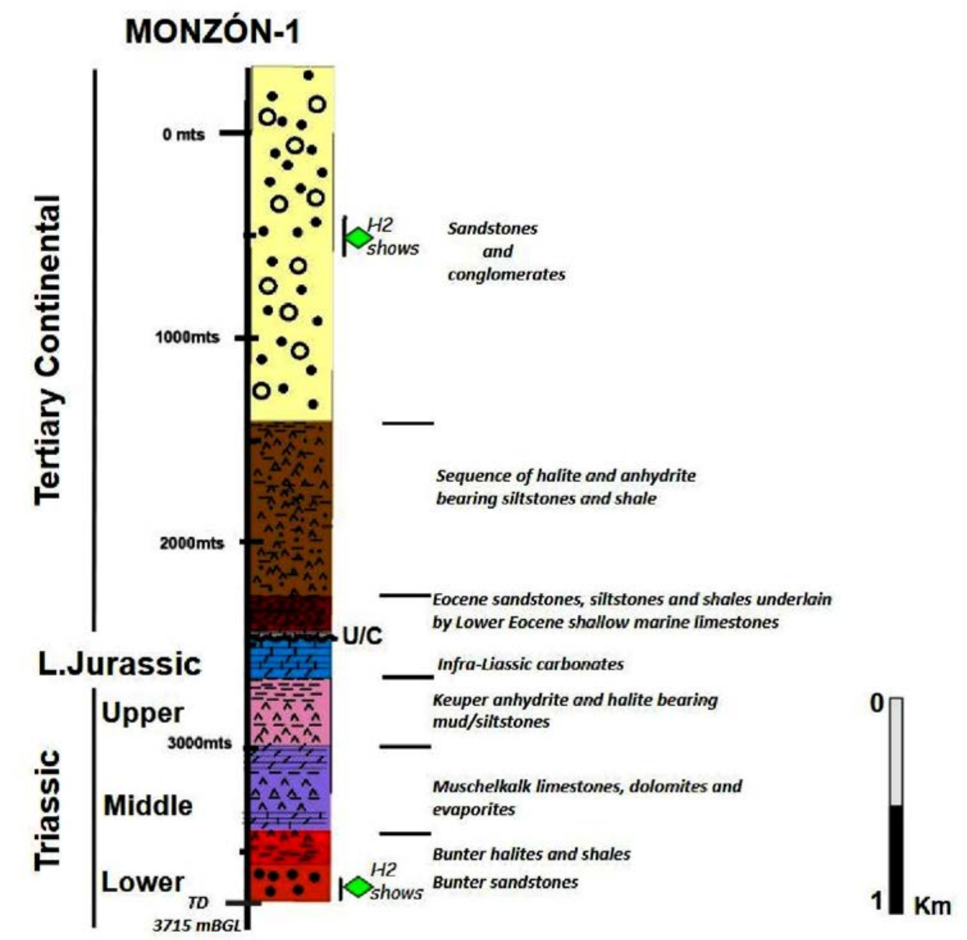
- H2
- CH4
- No Gas
- No info



H2 in the Monzón-1 Well



TD 3715m in Triassic Bunter Sandstone

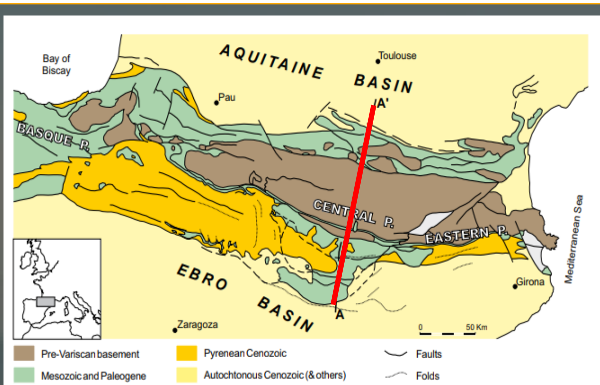
Bunter Sandstone 56m thick

Overlain by:

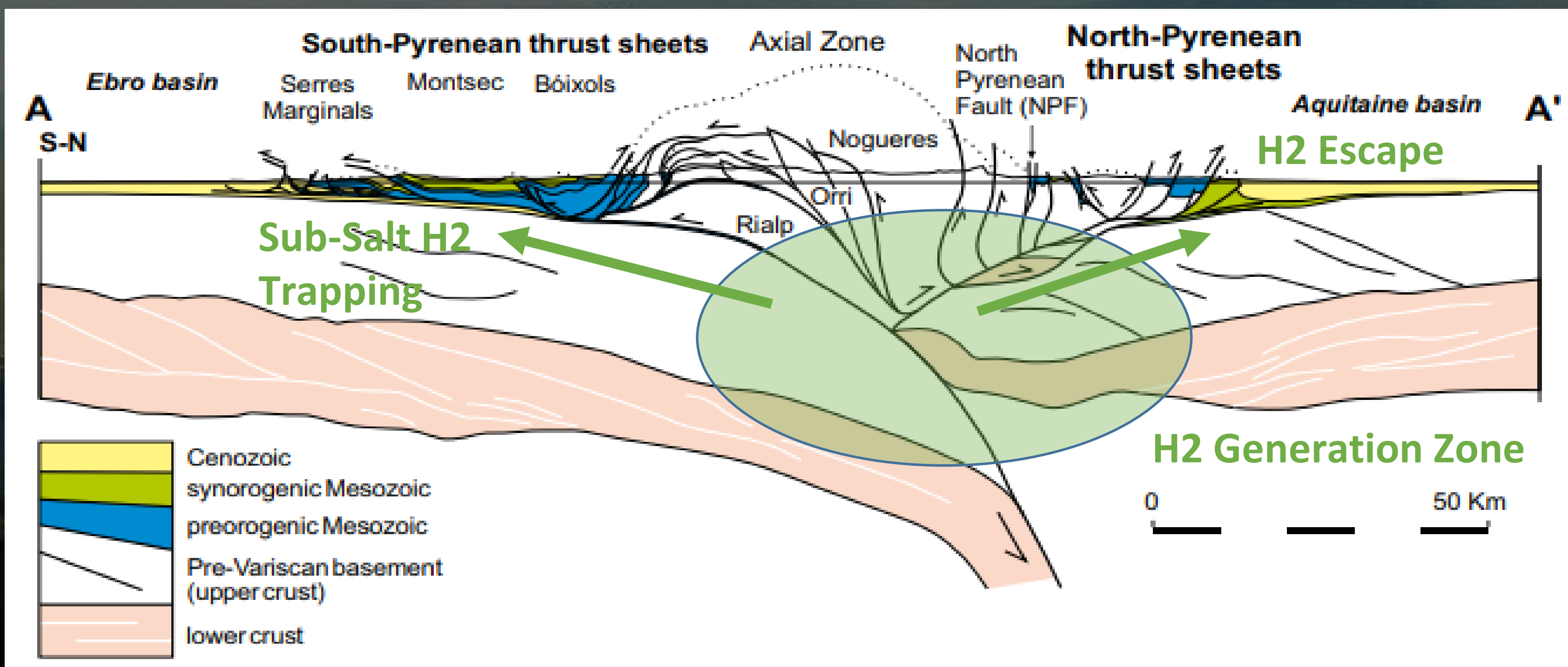
Rock	Depth (m)
Evaporite bearing Bunter Shale	185
Röt Halite	60
Muschelkalk & Keuper halite & evaporite bearing shales	533
Tertiary aged halite and evaporite bearing shales	1,000+
Total	~1,780

VERTICAL TOTAL of 1780m of halite & evaporite bearing shales above the Bunter Sandstone

H2 escape vs trapping in the Pyrenees



Presence of thick Mesozoic/Tertiary cover sediments in the South Pyrenees favours H2 trapping compared to the North Pyrenees where this cover is largely missing.

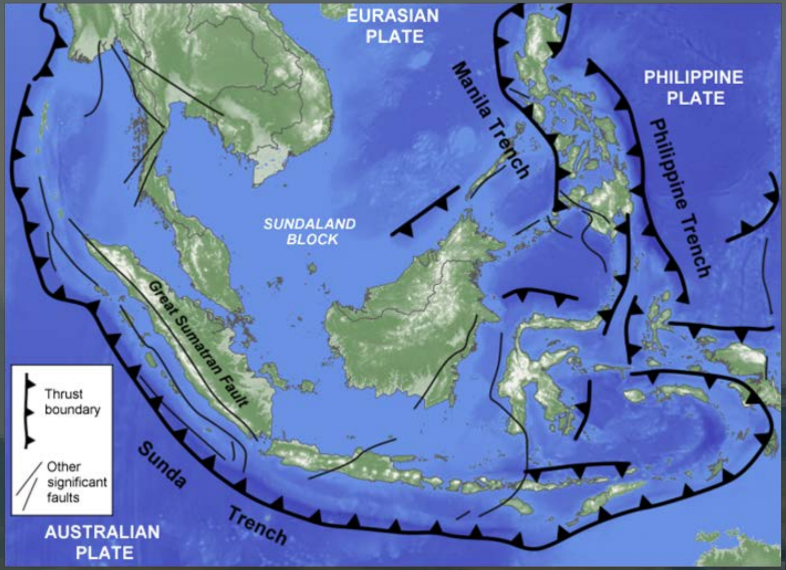


Geological cross-section of the Central Pyrenees. From Muñoz et al 2018

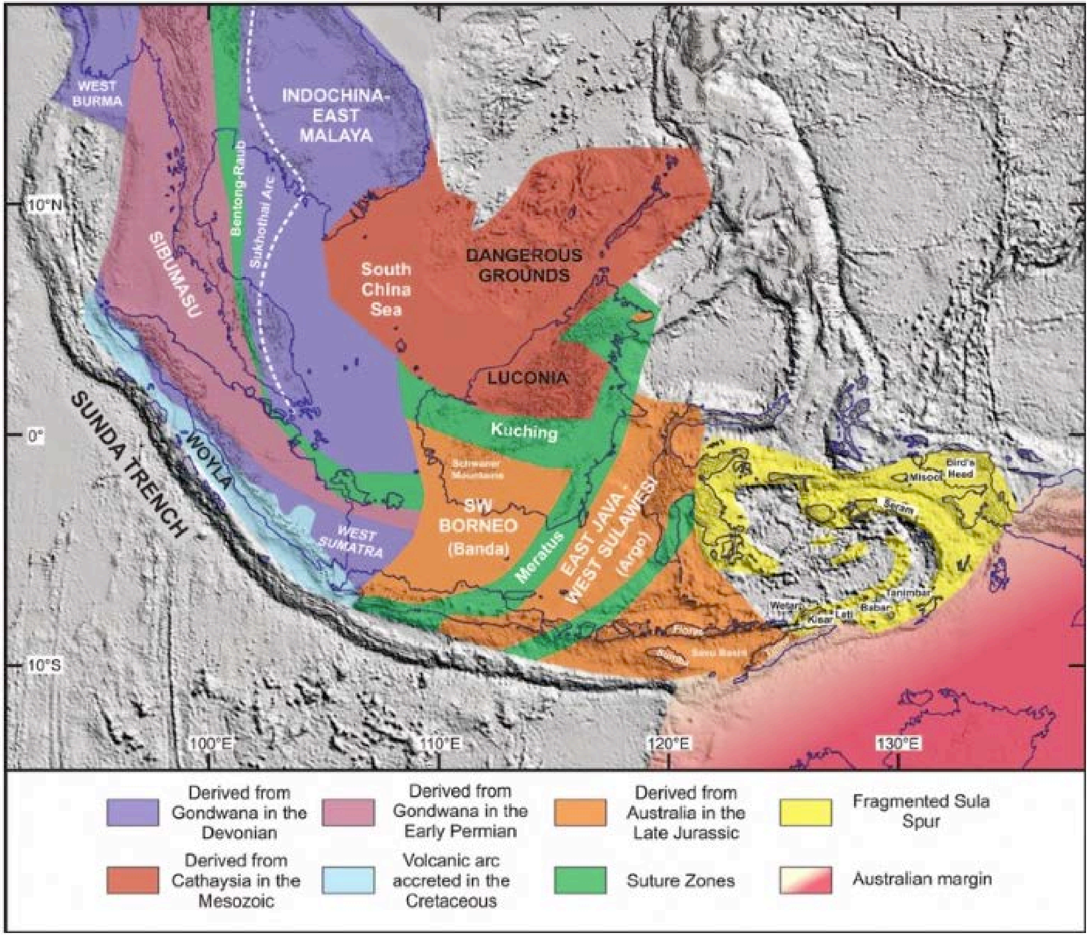
Conclusions

- Natural/Gold Hydrogen (H2) exists and occurs extensively throughout the World!
- H2 is associated with the Pyrenean orogenic belt probably due to the presence of shallow upper mantle rocks
- Active H2 seepage is observed in the North Pyrenees and H2 is observed in wells in the South Pyrenees.
- The Pyrenees are unlikely to be unique.
- Areas with complex collision/subduction histories and elevated upper mantle rocks should be examined for natural H2 presence.

SE Asia plate boundaries/sutures



Geologically SE Asia could be a very happy hunting ground for natural H2!



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ADDITIONAL MATERIAL

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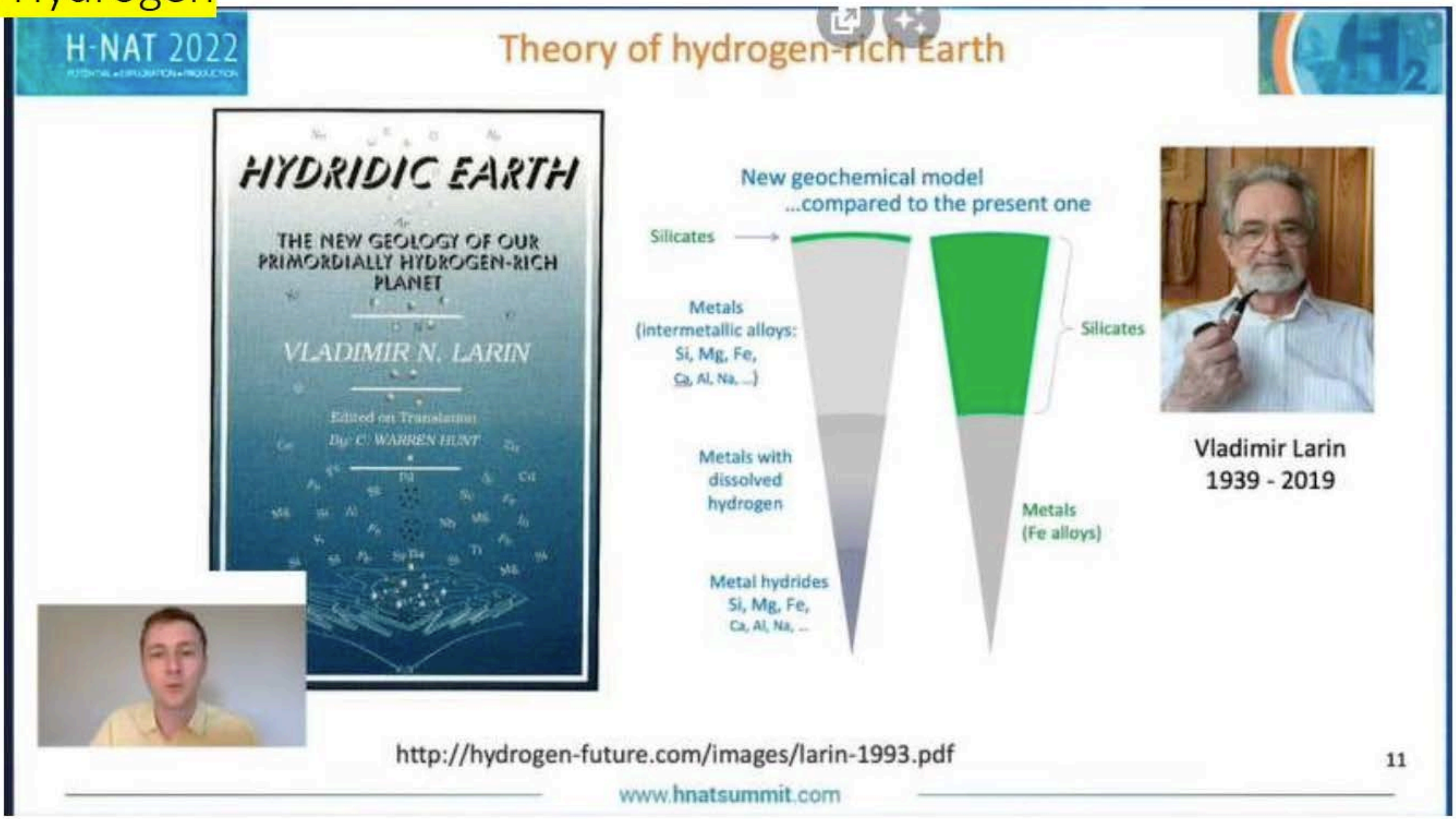
Concept of deep H2 & Earth de-gassing

From Czado, 2023

Deep Hydrogen

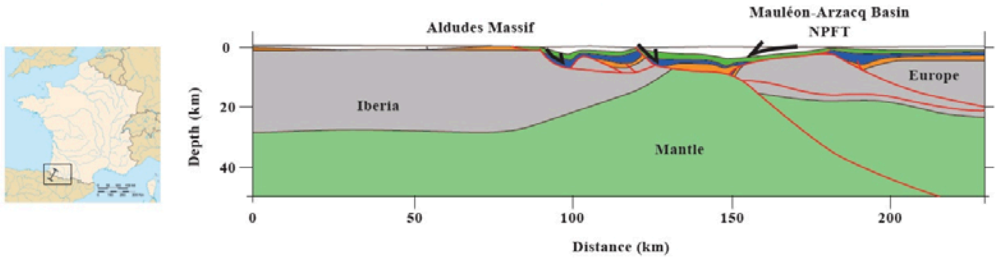


Mantle wedge is key to H2 generation

From Lefeuvre et al, 2021

3. Geological setting

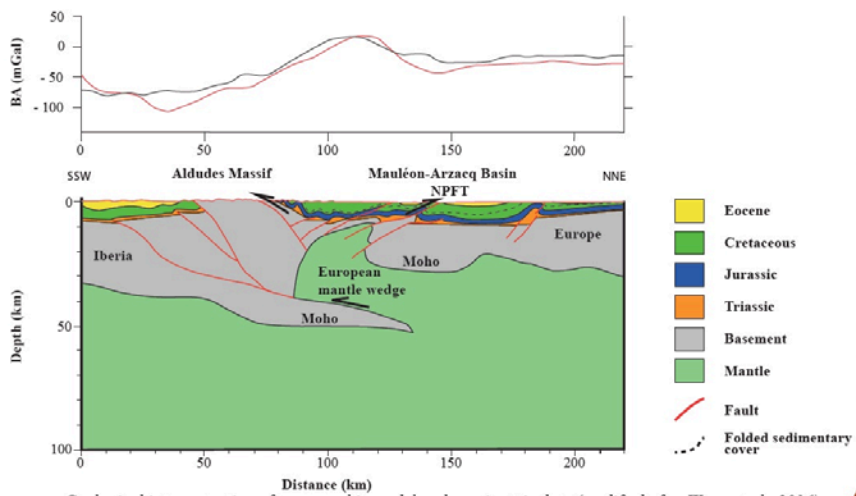
- **The Pyrenees is located in Southwest Europe,** form an intracontinental orogen that result from the **tectonic inversion of a rifted margin system (Early Cretaceous)** between the Iberian and European plates (Wang et al., 2016).



Cretaceous Hyper-extended rifting (after Gomez-Romeu et al 2019)

- **Mantle bodies were higlighted by geophysic data (Seismic, Gravimetric, Magnetic) at shallow depth**:
  - Bodies of exhumed mantle **inherited from the pre-collisional hyper-extended rift system.**
  - Mantle is **connected to the surface by two deep rooted faults** North Pyrenean Frontal Thrust (NPFT) to the north and North Pyrenean Thrust (NPF) to the south (Wang et al., 2016; Gomez-Romeu et al., 2019).

- Major fault can have two behavior (1) **drain water to the depth** (Taillefer et al., 2017; 2018) (2) **fluid migration pathway to the surface**. **Water at depth will serpentinize mantle rocks**



Geological interpretration of tomographic model and gravimetric data (modified after Wang et al., 2016)

H2 emanations in the north Pyrenees relate to the alteration of near surface iron rich mantle rocks and obducted and uplifted oceanic crust.

Trapping and sealing mechanisms are largely absent on the northern flanks of the Pyrenees and H2 easily escapes.

H2 detection via satellite data, Ebro Basin, Spain

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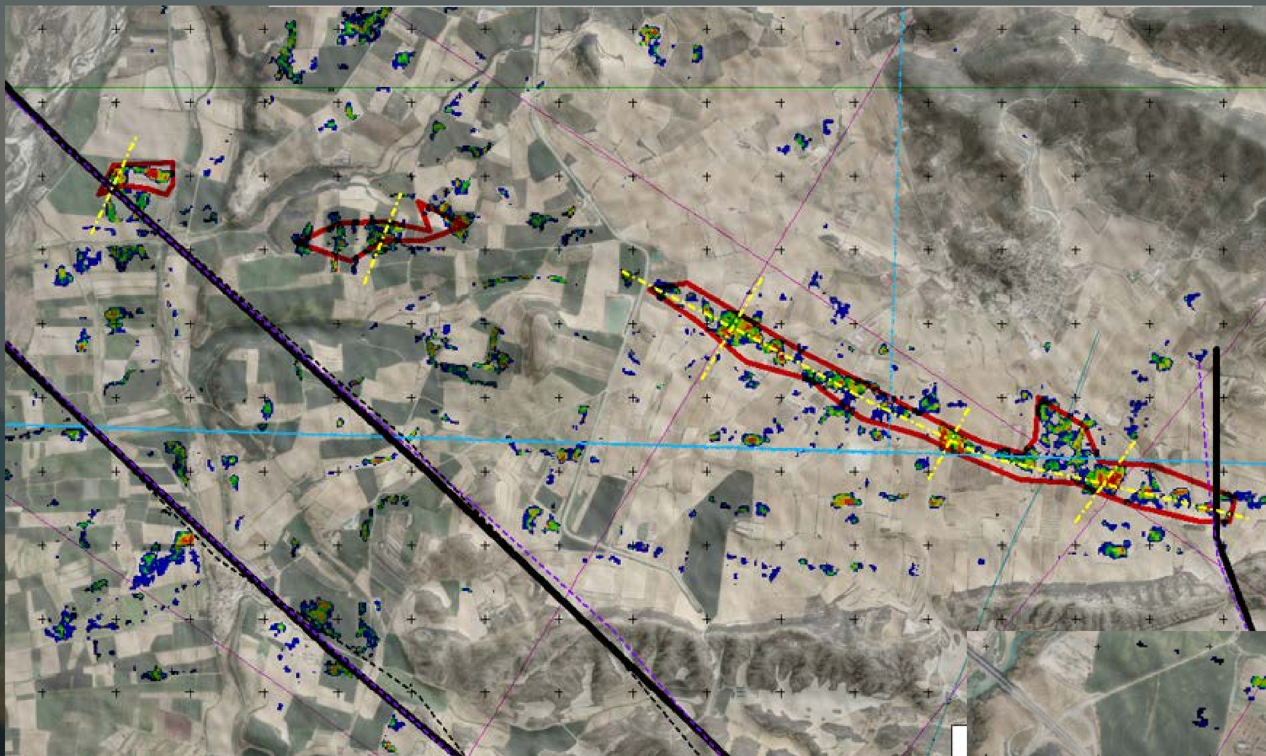

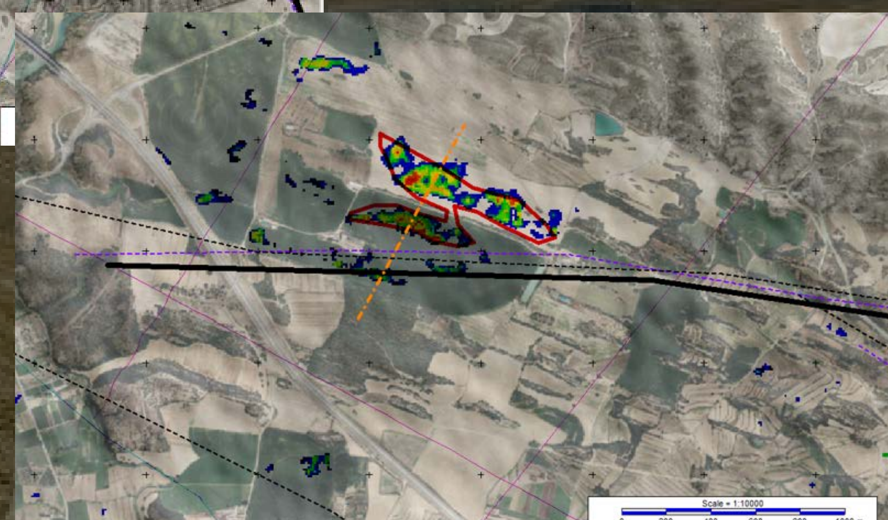

Example data from Barbastro/Monzon Permits, Helios Aragon

(Dirt Exploration, 2021)