Honeycomb structures and other intriguing geomorphological features in the North Falkland Basin

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North Falkland Basin (NFB)

The NFB, a Mesozoic-aged sedimentary basin located 40 km north of the Falkland Islands, is a rift system comprising a series of offset depocenters.

The NFB formed as a result of two rifting phases:

- Mid-Late Jurassic phase formed a series of NW-SE trending grabens;
- Late Jurassic to earliest Cretaceous phase overprinted the earlier phase in the central and northern NFB forming a series of N-S grabens.

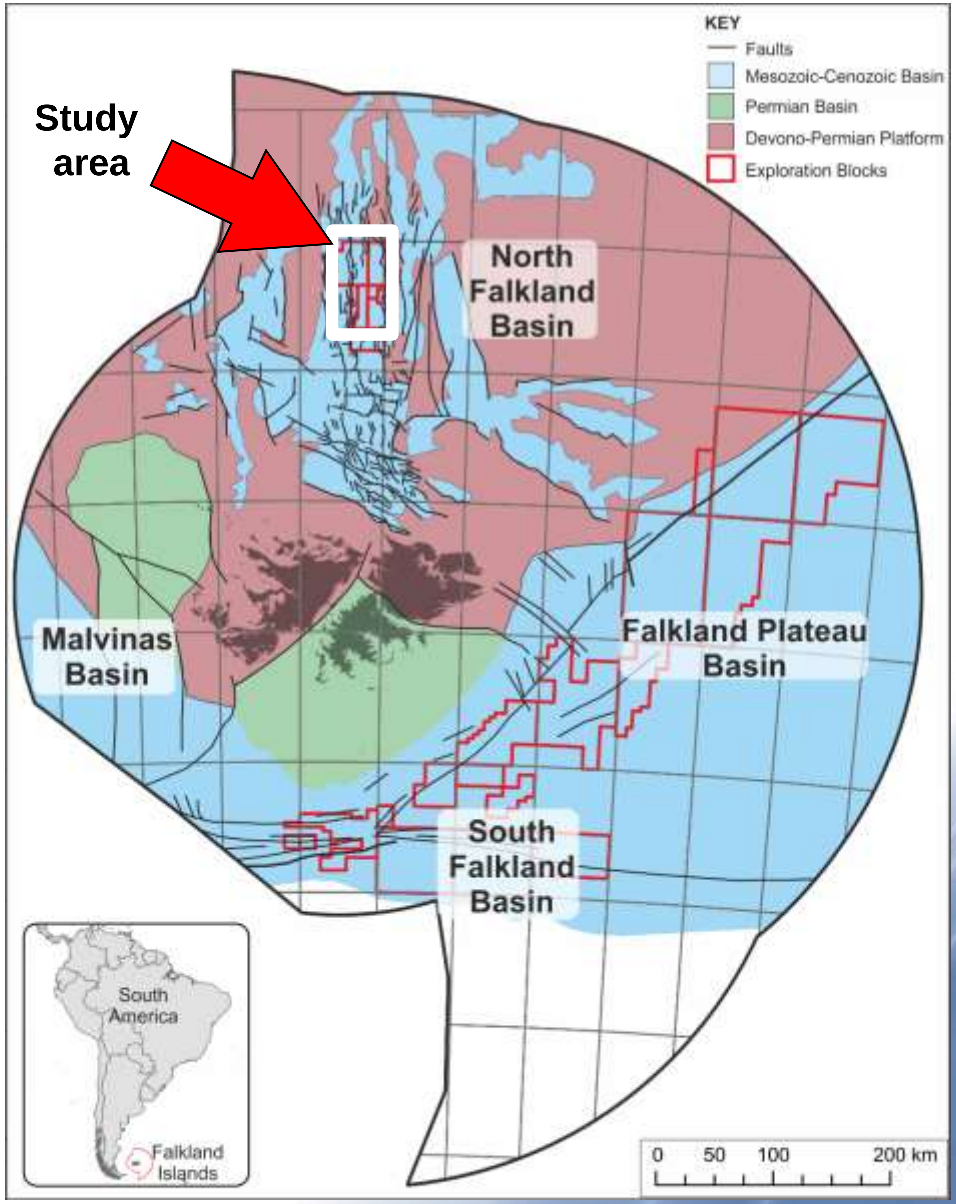


Figure 1.
Geological map of the offshore areas around the Falkland Islands.
Detailed fault interpretation of the North Falkland Basin (NFB) based on Lohr and Underhill (2015).
Modified from Jones et al. (2019).

Tectono-stratigraphy

Eight broad tectono-stratigraphic units have been identified across the Eastern Graben (*Richards and Hillier, 2000*):

- *Pre-Rift/basement;*
- *Early Syn-Rift;*
- *Late Syn-Rift;*
- *Transitional/Sag;*
- *Early Post-Rift;*
- *Middle Post-Rift;*
- *Late Post-Rift; and*
- *Post-Rift Sag phase.*

This presentation will focus on the shallow section of the Post-Rift Sag unit.

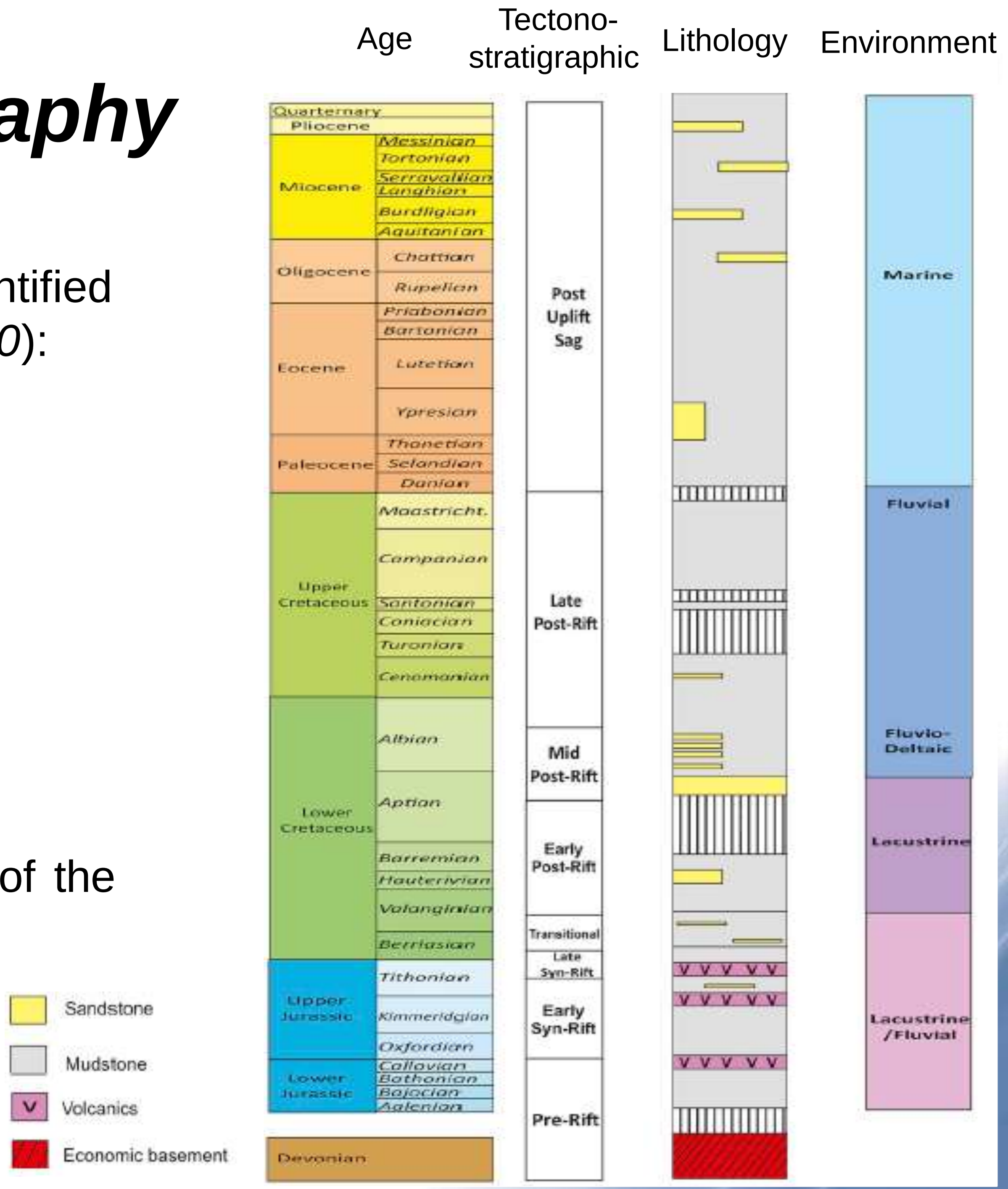
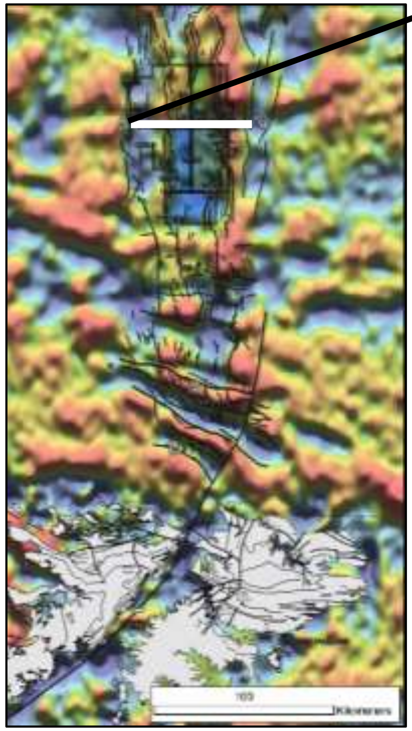


Figure 2. Geological summary chart for the North Falkland Basin from Devonian to recent times. Modified from Jones et al. (2019)



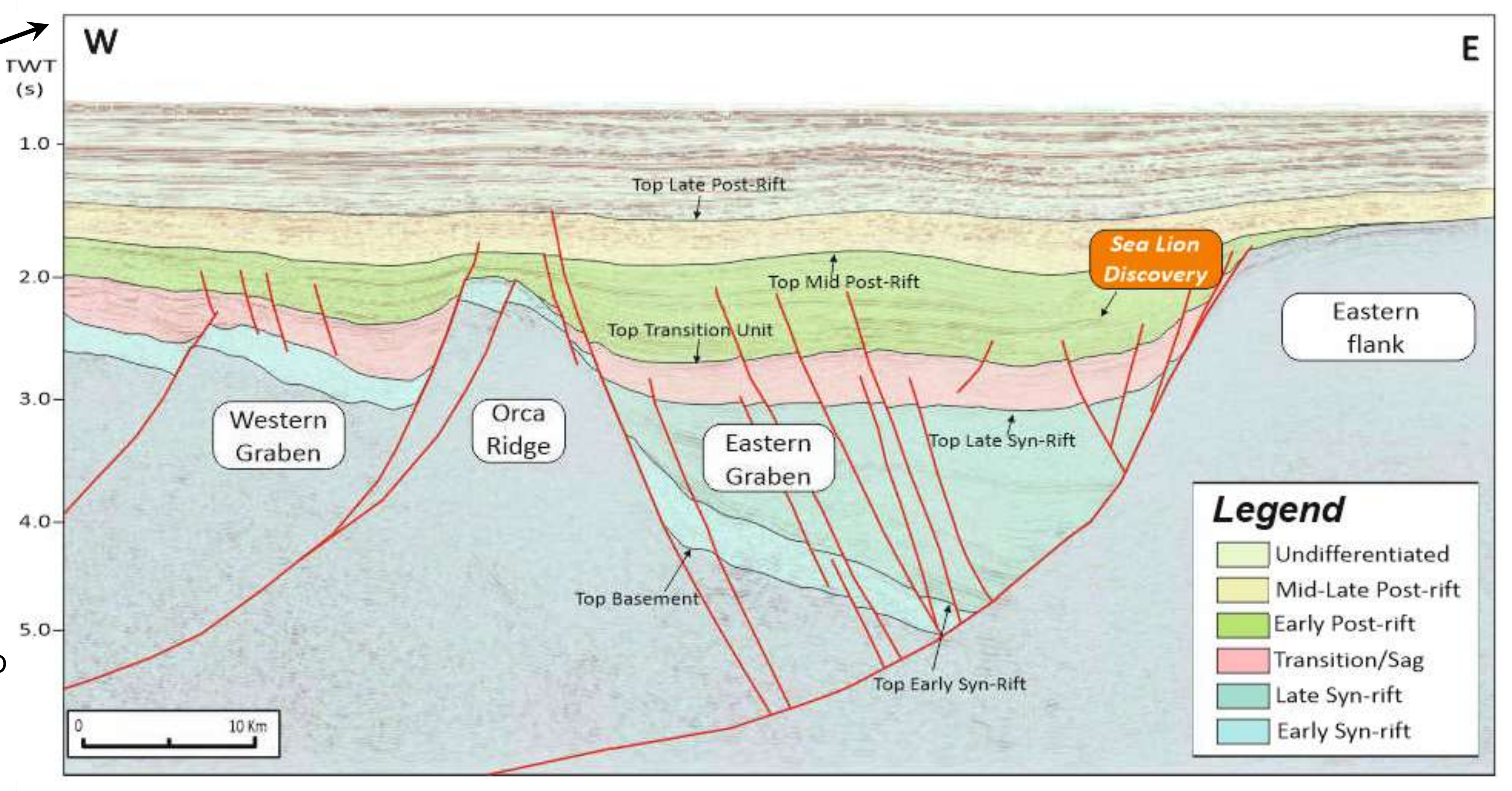


Figure 3. Representative seismic section from the NFB from a composite 3D survey. Adapted from Jones, et al. (2019).

Falkland Island Glacial Past

Although there is little terrestrial evidence of extensive glaciations (Hodgson et al., 2014), the seabed image obtained from the 3D seismic data have revealed numerous iceberg ploughmarks - formed where the keels of drifting icebergs gouge and scour the seabed (Brown et al., 2017).

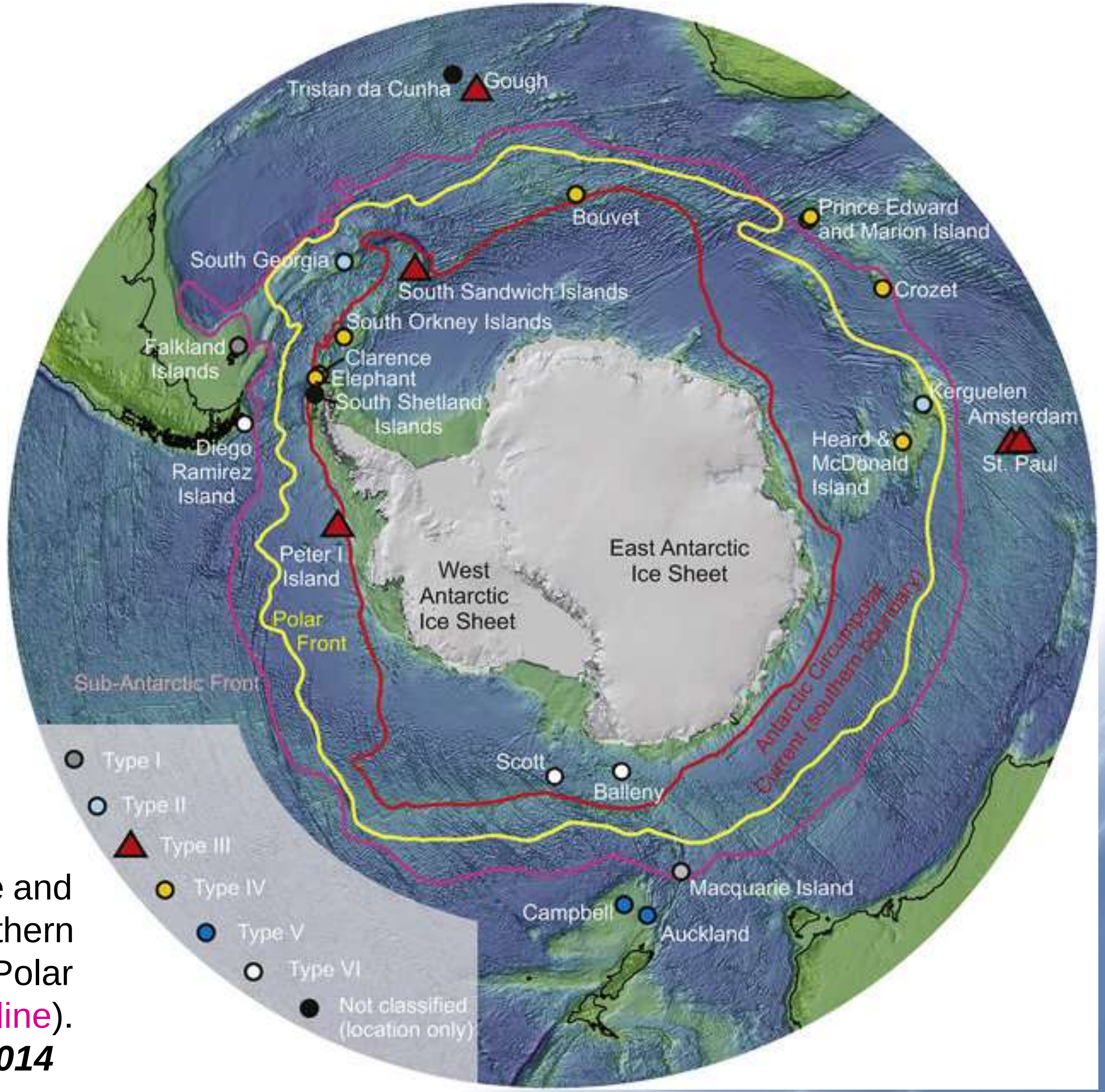


Figure 4. Map and classification of the glacial history of the maritime and sub-Antarctic Islands, shown in relation to the position of the southern boundary of the Antarctic Circumpolar Current (red line), Antarctic Polar Front (yellow line), and sub-Antarctic Front (pink line). Extract from **Hodgson *et al., 2014***

Dataset

The Eastern Graben of the North Falkland Basin is covered by three modern 3D seismic datasets that have been merged pre-stack to create one uniform survey.

The three input surveys were acquired in 1998, 2007, and 2011 by Fugro, CGG, and Polarcus respectively.

This composite 3D volume covers an area of 4500 km^2.

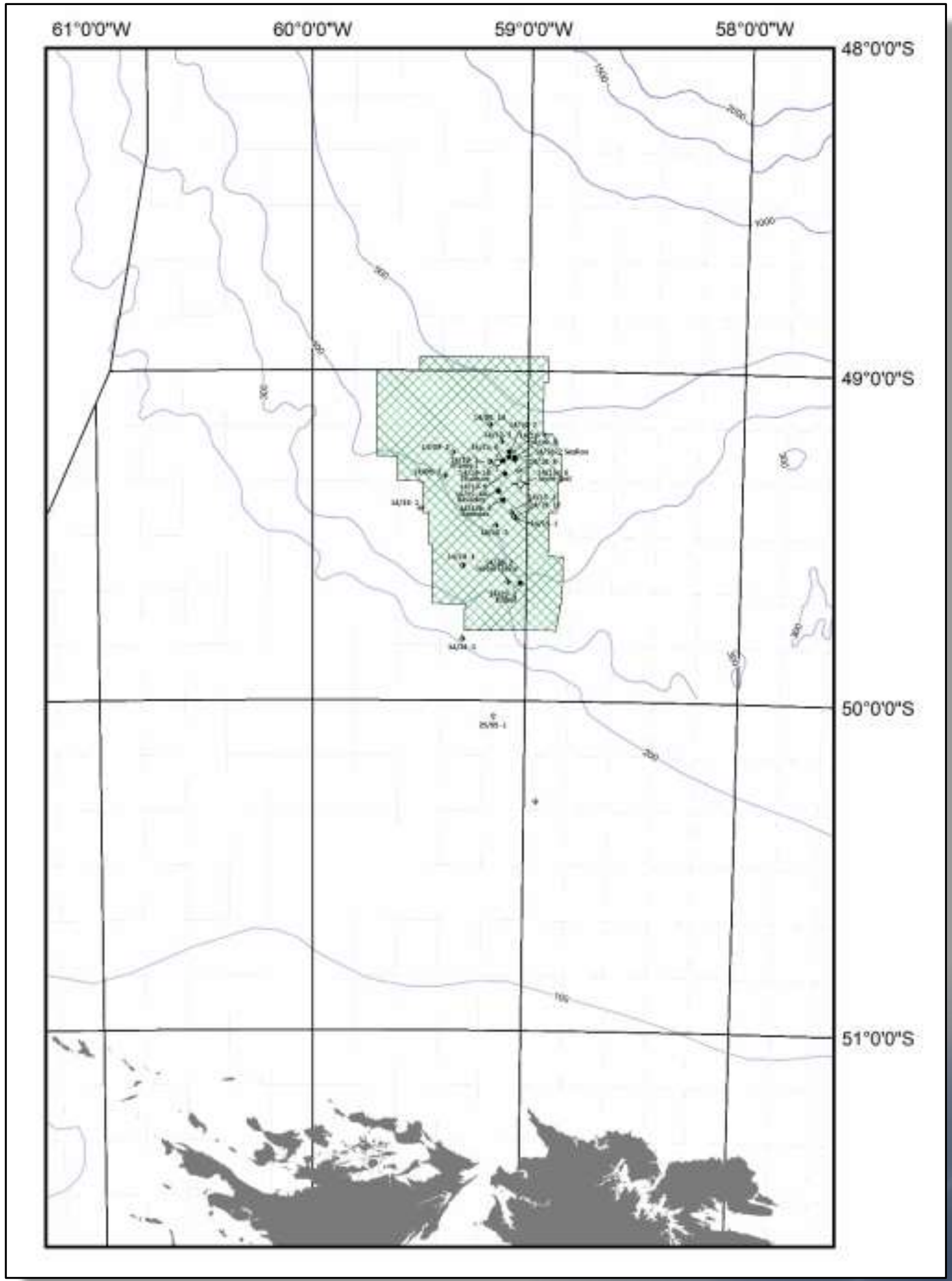


Figure 5. Location map of the 3D seismic dataset used for this study (in green).

In the shallow section, there are a selection of unusual features observable on 3D seismic data:

- At seabed: Numerous <u>iceberg ploughmarks</u> - formed where the keels of drifting icebergs gouge and scour the seabed.

- At H4: <u>Honeycomb structures</u> - densely packed oval to polygonal depressions found in northern area of H4. Pockmarks associated to these features are found in the overlying reflector H5.

  <u>Mini-mounds</u> - numerous mounds can be found in southern region of H4.

- At H2: <u>"Broken glass" fracture system</u> – network of fractures formed due to a sinistral shear were found in the south-eastern area of H2.

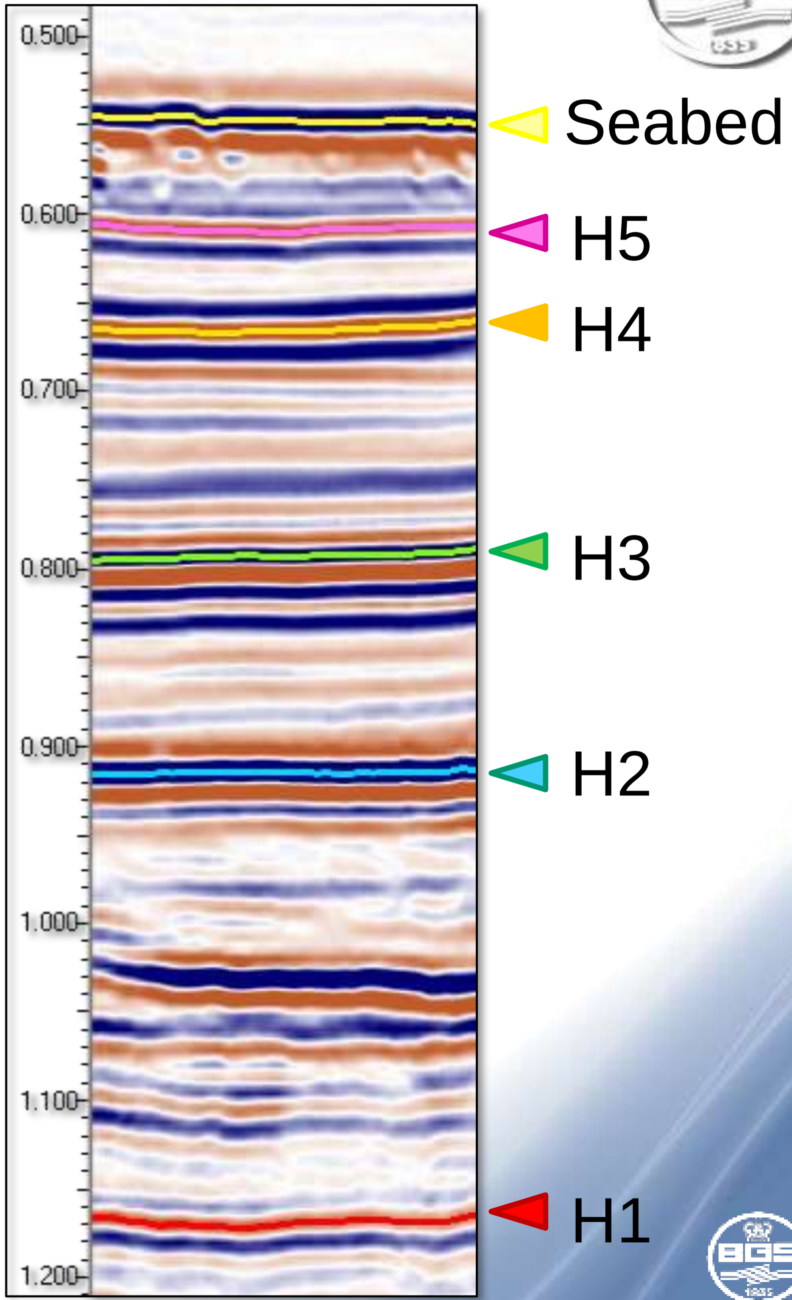


Figure 6. Segment of a representative seismic section showing the 6 horizons mapped for this study.

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Seabed

Iceberg ploughmarks

The seabed is scoured by numerous iceberg ploughmarks. They occur in various sizes and shapes, generally exhibiting linear or curvilinear geometry although ‘wandering’, sinuous and tear-shape have all been observed (Fig. 7A).

The major ploughmarks have a predominant direction of SW-NE, whereas smaller ploughmarks present various predominant direction and can even crosscut pre-existing features (Fig. 7B).

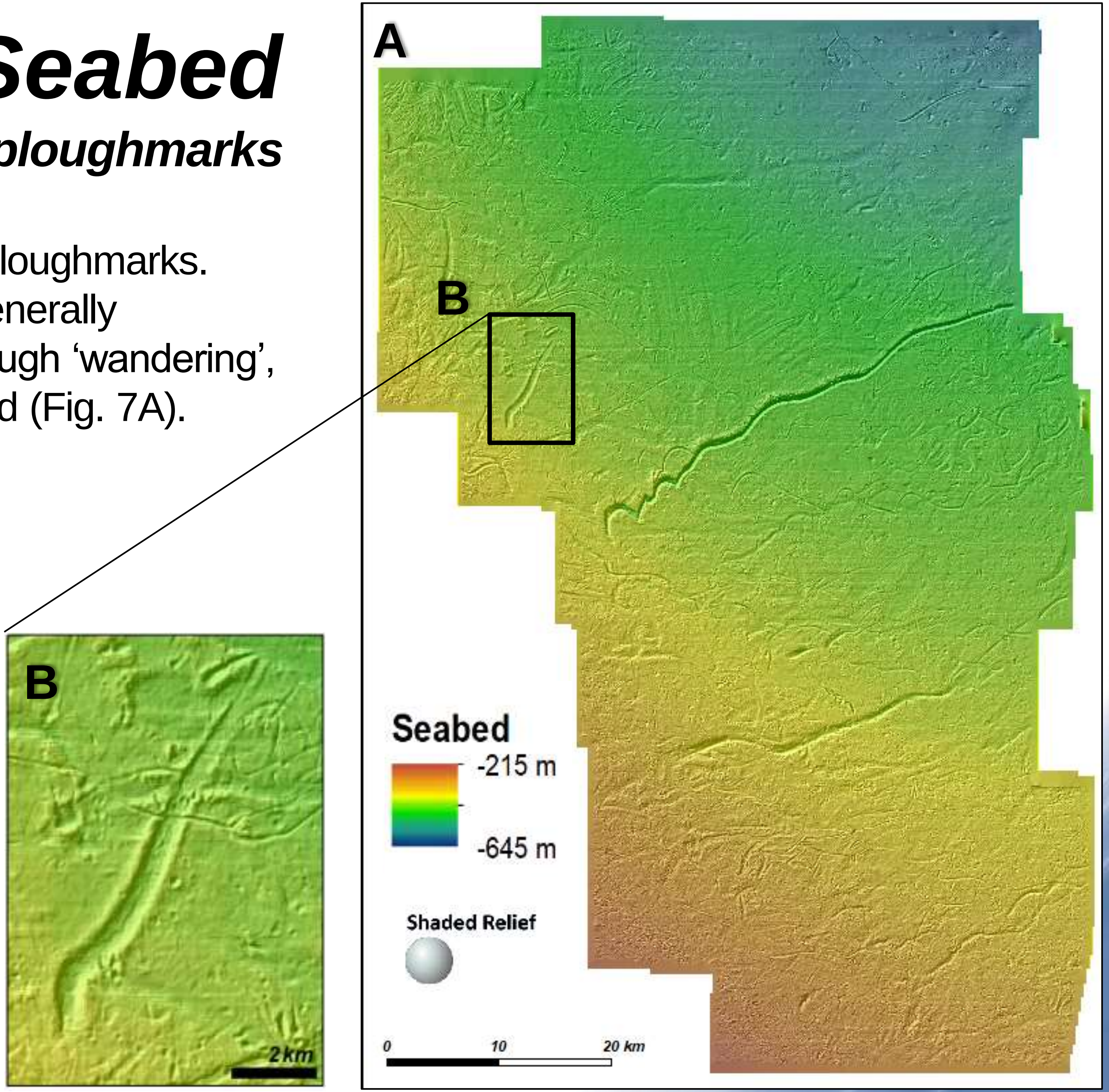


Fig 7. A) Shade-relief map of the seabed (depth converted to meters) showing numerous iceberg ploughmarks. **B)** Detailed of the shade-relief map of the seabed showing crosscutting relationship between two iceberg ploughmarks found in the study area.

Seabed

Iceberg ploughmarks

Some ploughmarks present exactly the same geometry several kilometres apart. One of these sets of parallel ploughmarks is the set of five tear-shape ploughmarks shown in Figure 8.

This group of tear-shape iceberg ploughmarks had to be formed either by a large individual iceberg with uneven keel or by keels of several deep-keeled grounded icebergs drifting uniformly while trapped within a thick multiyear sea-ice floe.

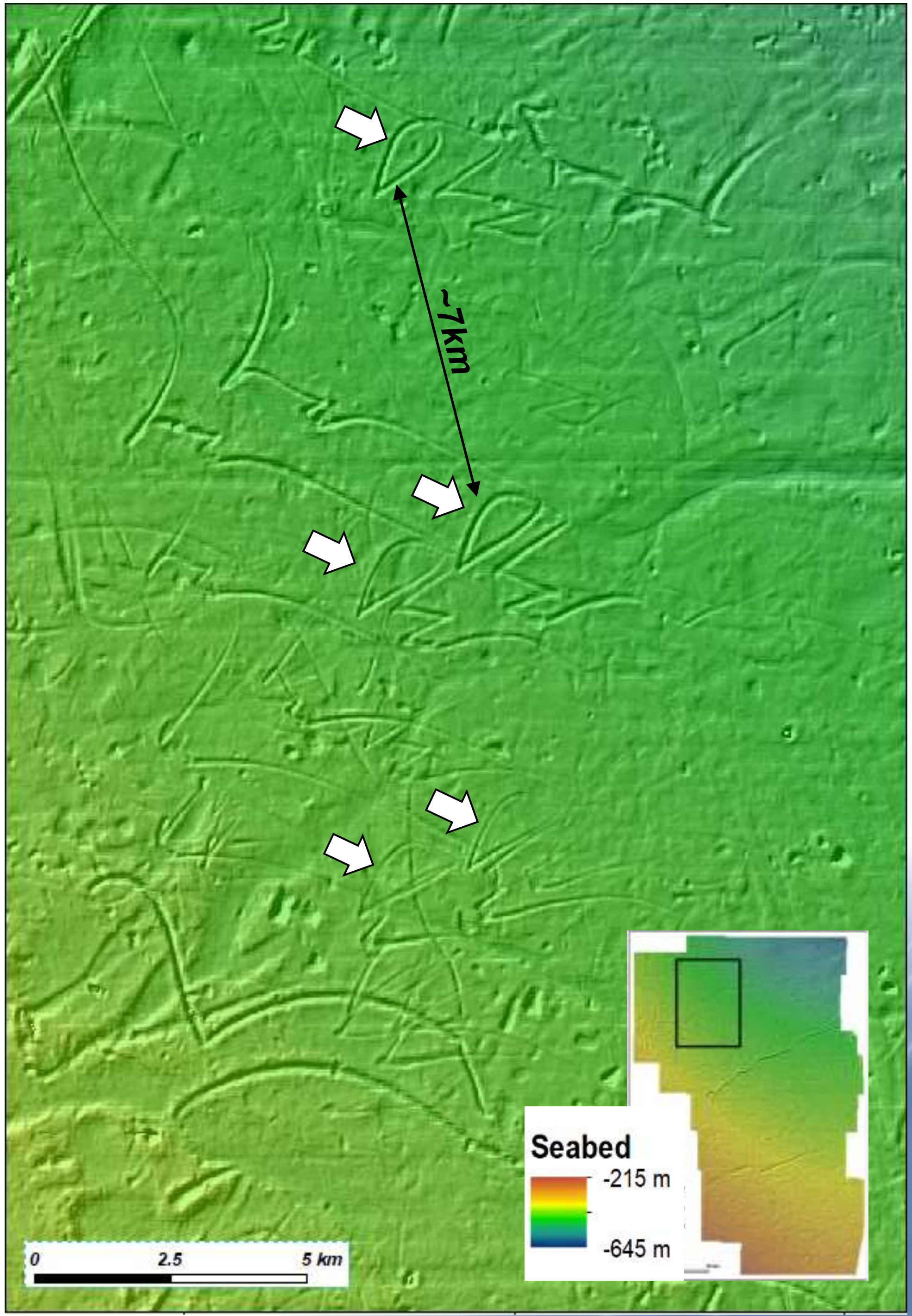


Fig 8. Detail of seabed shade-relief map showing ploughmarks with the same geometry repeated multiple times (white arrows).

Seabed

Iceberg ploughmarks

The longest of these features extends for more that 47 km (beyond the study area), starting at -407 m water depth and extending up to water depth of more than -485 m (Fig. 7A).

This ploughmark can reach widths of ~500 m and be up to 25 m deep (Fig. 7B). It shows asymmetric ploughmarks rims, with a higher northern rim.

A

B

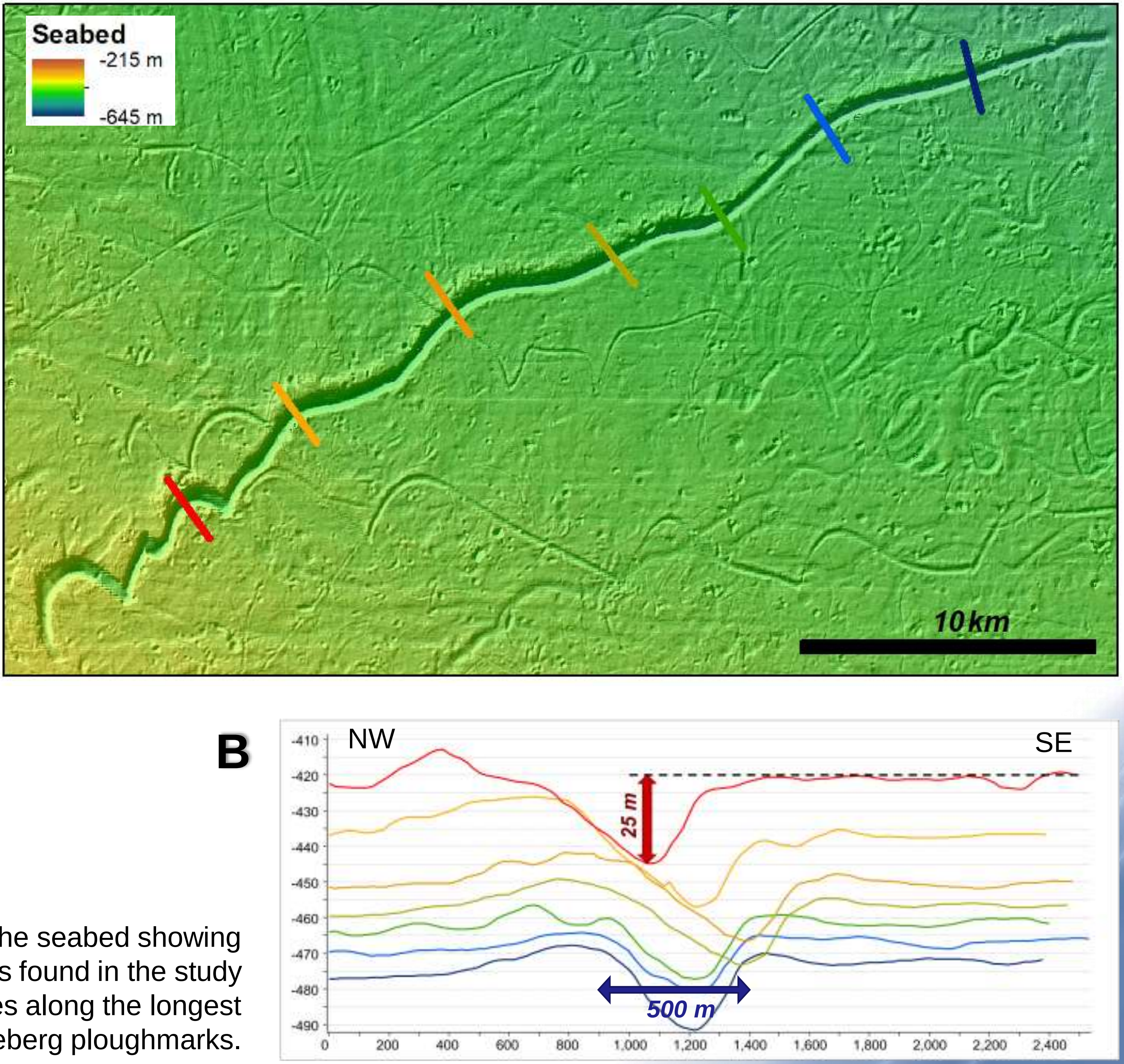


Fig 9. A) Shade-relief map of the seabed showing the longest iceberg ploughmarks found in the study area. **B)** Bathymetric profiles along the longest iceberg ploughmarks.

Honeycomb structures (H4)

These structures are observed at time-depths of ~680-760 ms twt (~60-150 ms twt below present seabed) and appear to be limited stratigraphically, occurring within two reflectors.

The honeycomb structures (HSs) appear as densely packed oval to polygonal depressions, typically 450-650 m in width.

They are mostly present on the northern section of the study area, mainly in to two areas: the **Western HSs Field** (Fig. 10A) and the **Eastern HSs Field** (Fig. 10B).

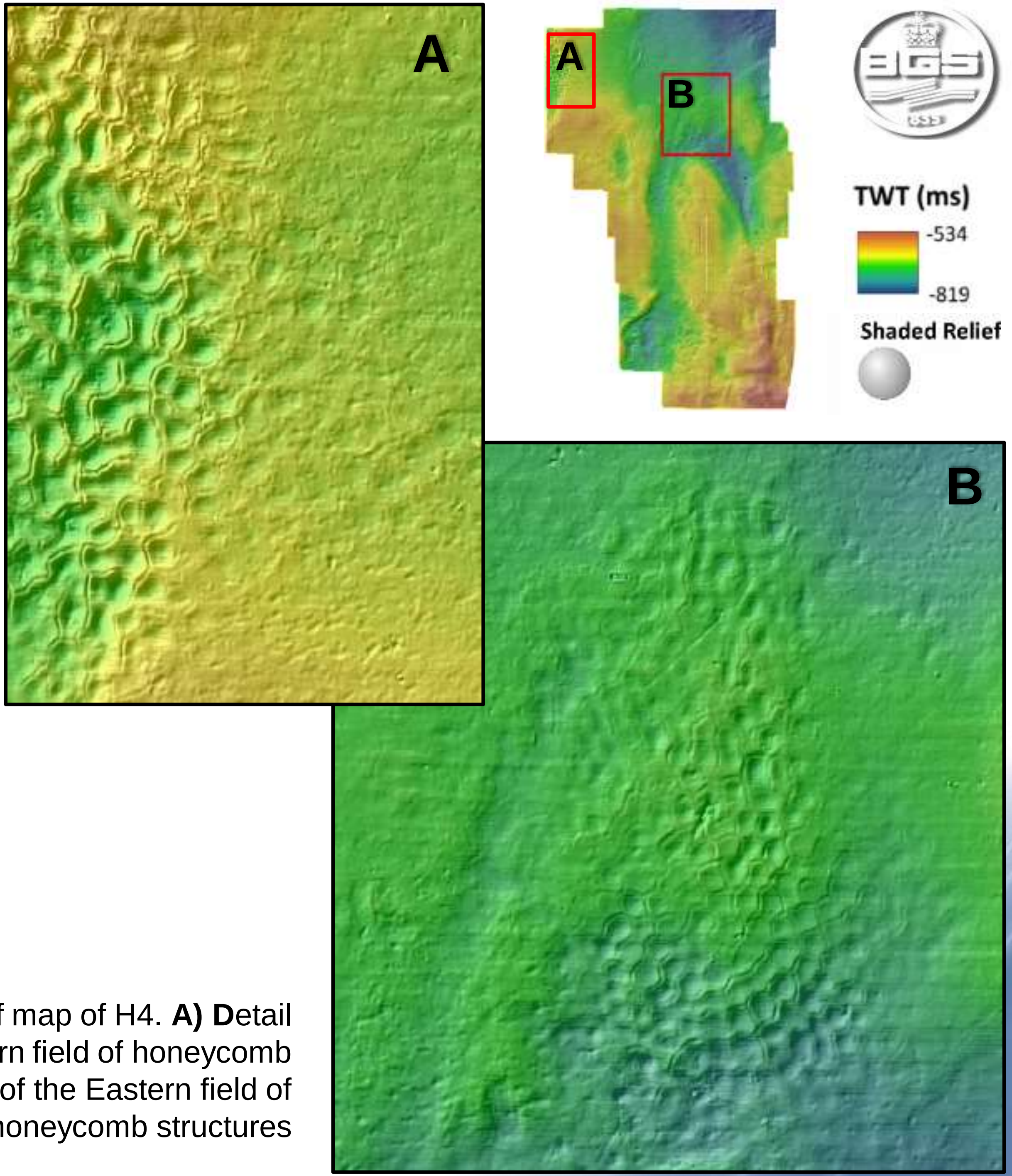
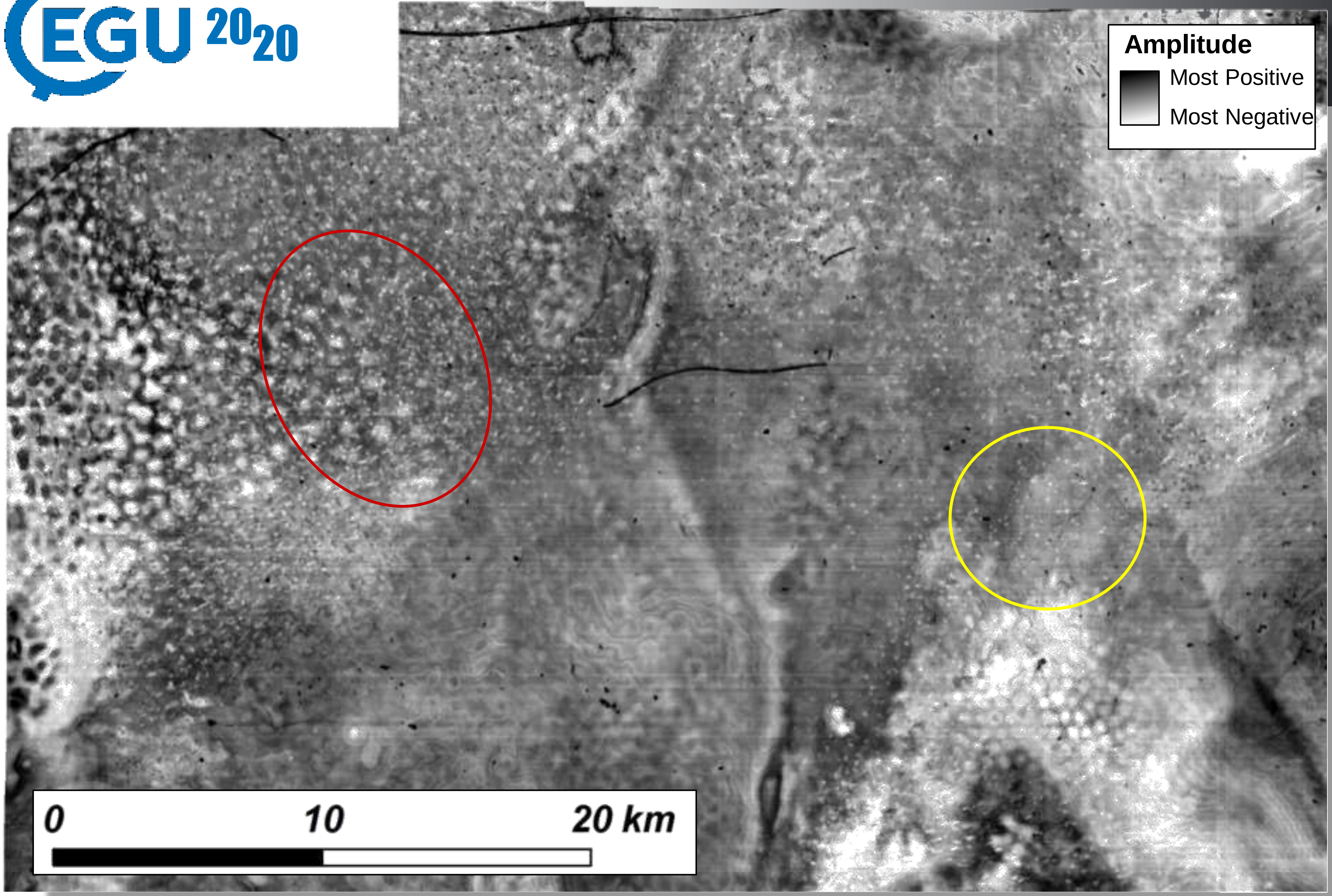


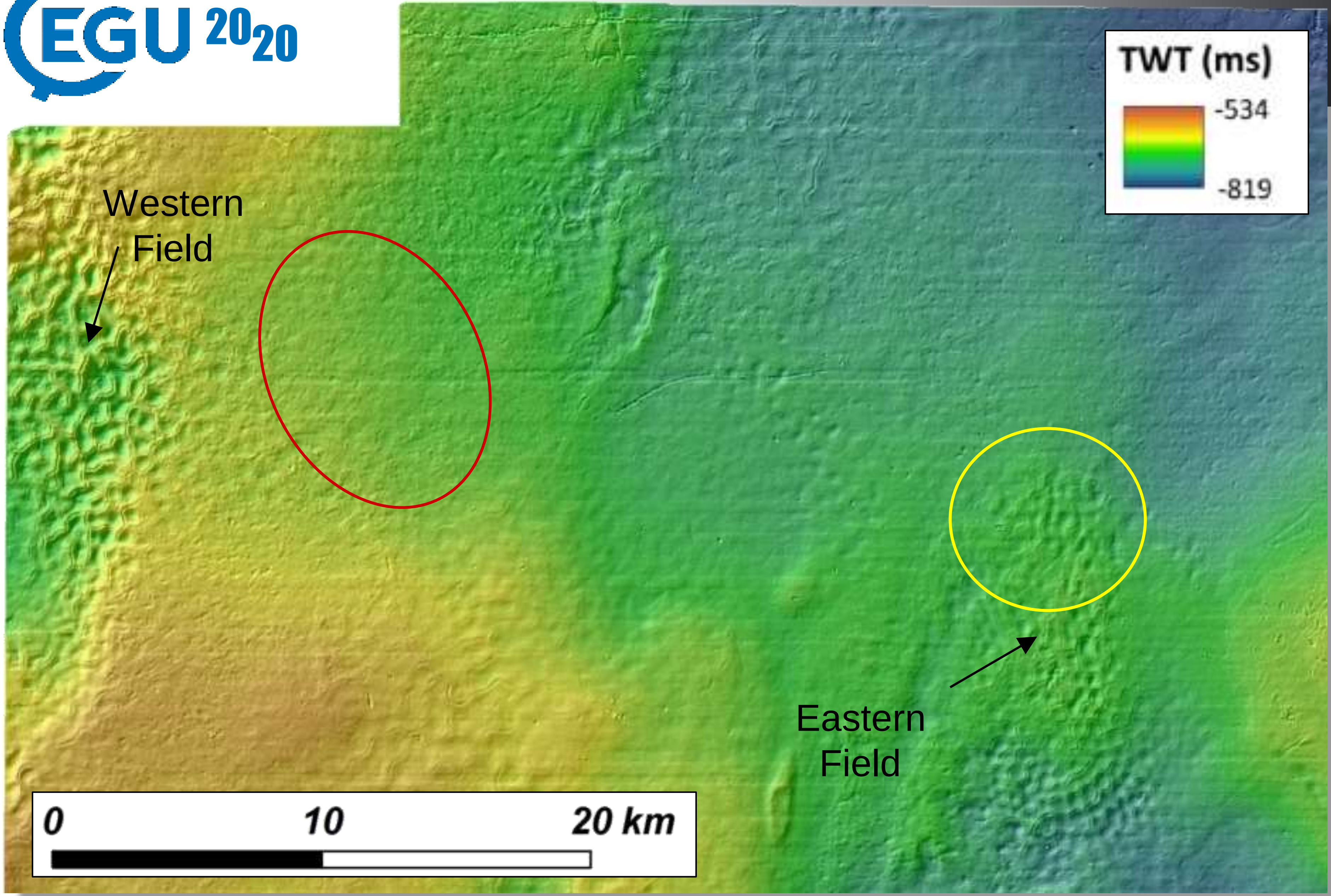
Fig 10. Shade-relief map of H4. **A)** Detail showing the Western field of honeycomb structures. **B)** Detail of the Eastern field of honeycomb structures



Honeycomb structures (H4)

The H4's amplitude map (Fig. 11) reveals that these structures affect a larger area (circle in red) than what is recognisable on the depth map.

Fig 11. Amplitude map of H4, showing both the western and eastern fields of honeycomb structures.



Honeycomb structures (H4)

However, some features visible in the depth map (Fig. 12) are not evident in the H4's amplitude map (circle in yellow).

Fig 12. Shade-relief map of H4, showing both the western and eastern fields of honeycomb structures.

Eastern Honeycomb Structures Field (H4)

The honeycomb structures in the eastern field present a regular hexagonal geometry, truly resembling honeycombs.

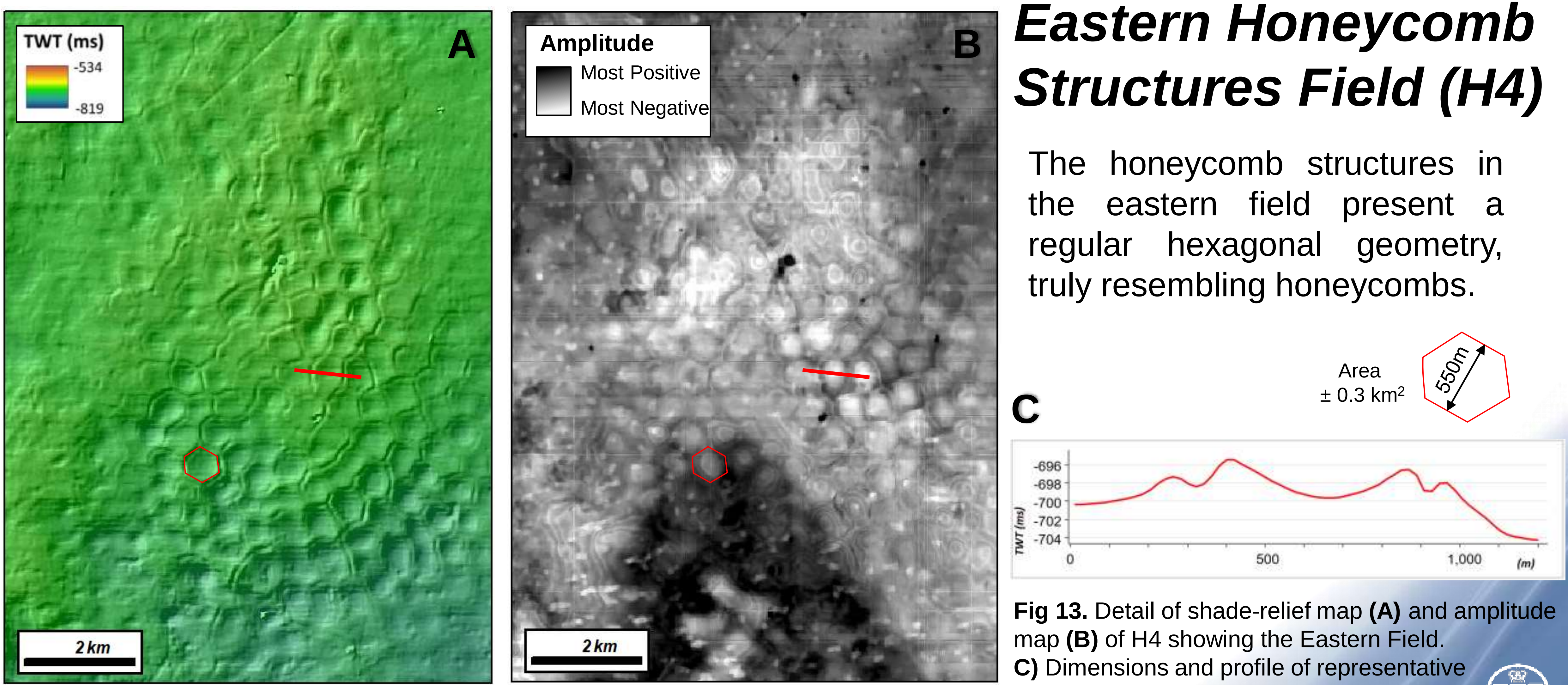
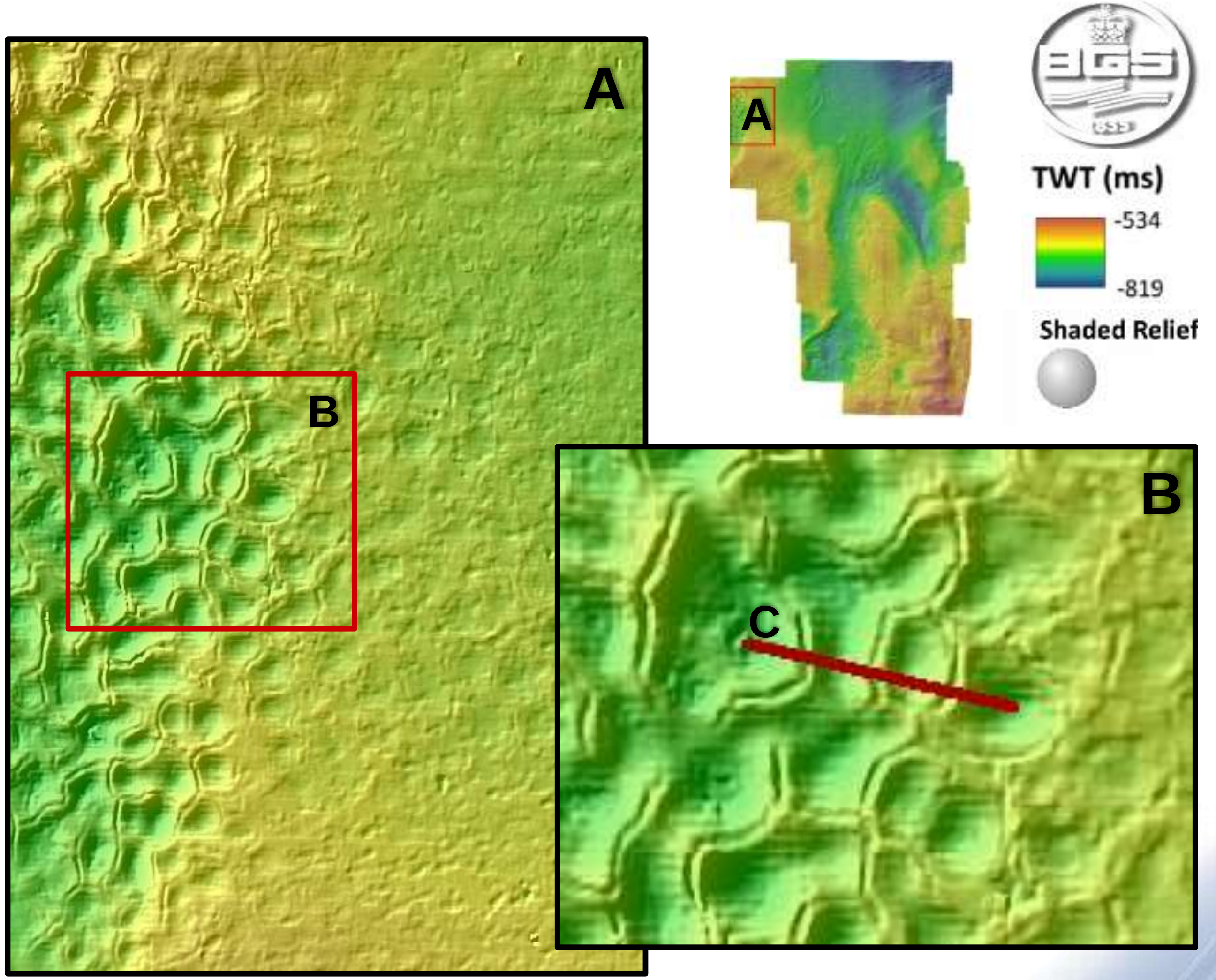


Fig 13. Detail of shade-relief map **(A)** and amplitude map **(B)** of H4 showing the Eastern Field.
C) Dimensions and profile of representative HSs (indicated in red on A and B).

Western Honeycomb Structures Field (H4)

The honeycomb structures in this area present a irregular geometry and can have time-depths of 10-20 ms (Fig.14C), two times deeper than what observed in the Eastern field (Fig.13C).

Each depression is delineated by wide ridges, characterised by the presence of a rift along the ridges centreline. The centreline rifts have long steep parallel walls and can be a few TWT ms deep (Fig.14C)



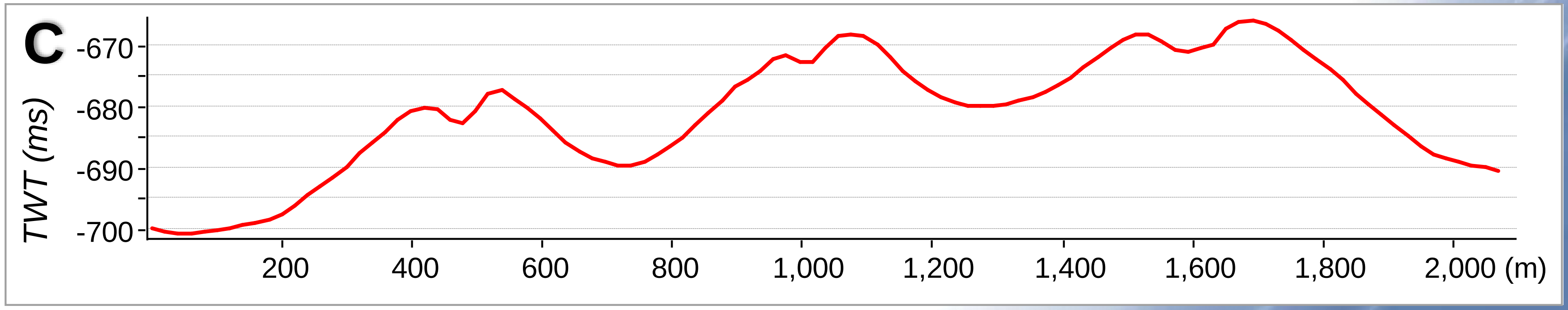


Fig 14. Shade-relief map of H4. **A)** and **B)** Detail showing the western field of honeycomb structures. **C)** Topographic profile (in TWT) of the profile indicated in B.

Western Honeycomb Structures Field (H4)

The geometry HS in this area becomes progressively more irregular west of the red line in Fig. 15A.

The change in geometry also coincide with a inversion of the amplitude values on the centre of the depressions (from negative values to positive values).

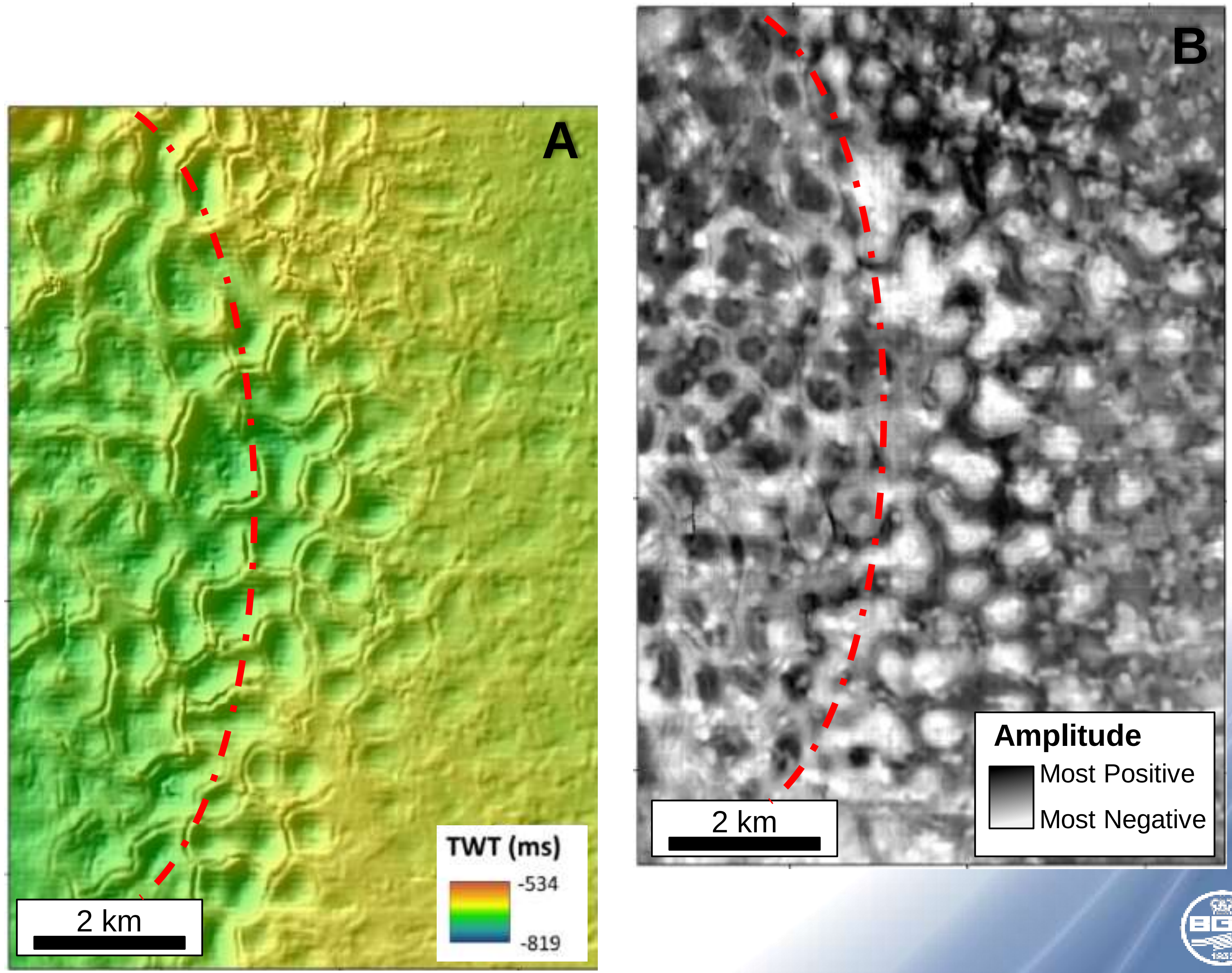


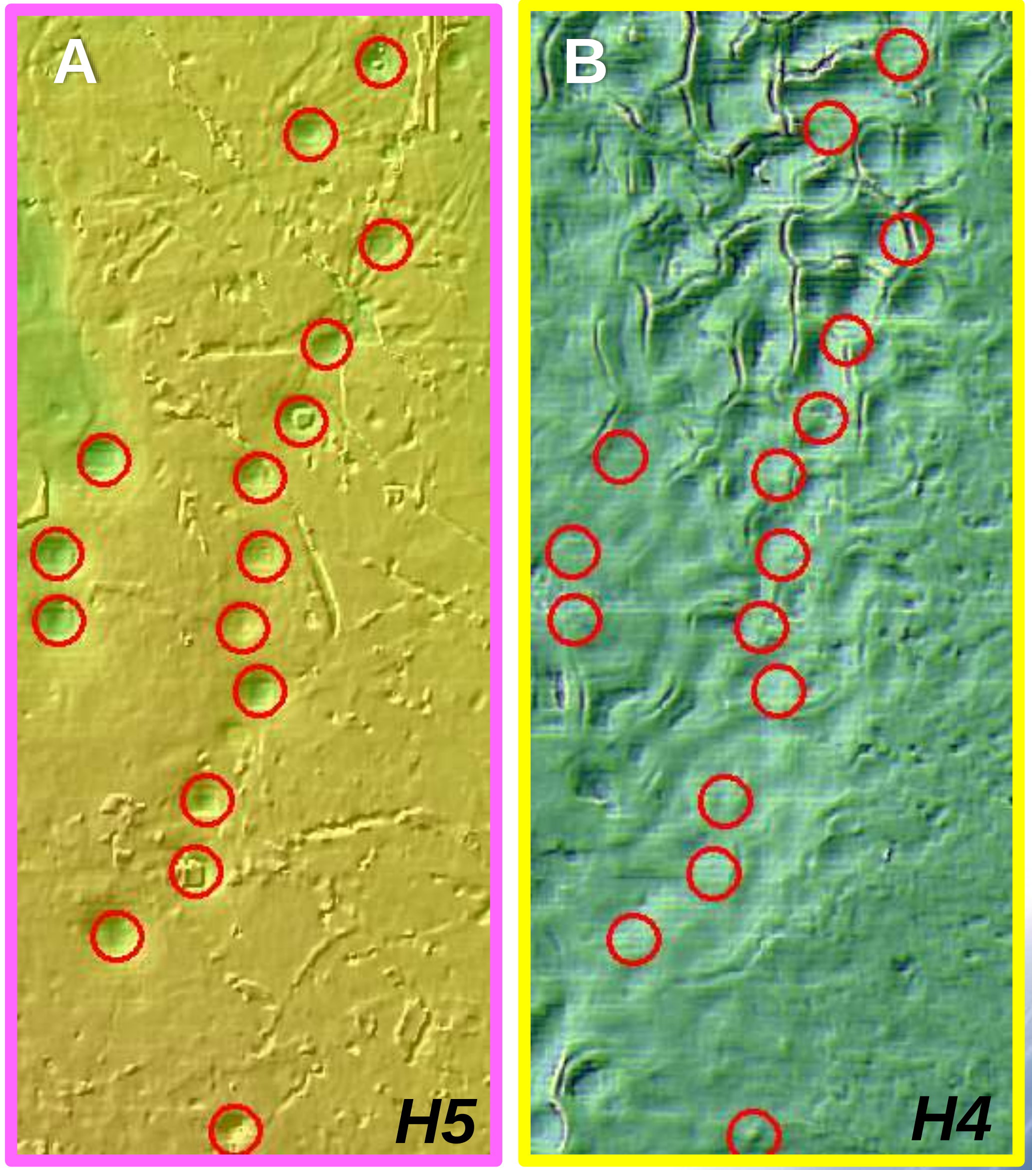
Fig 15. Detail of shade-relief map **(A)** and amplitude map **(B)** of H4 showing the western field of honeycomb structures.

Honeycomb Structures (H4)

The formation of honeycomb structures have been attributed to diagenetic processes (Morley et al., 2017).

Immediately above the western field of honeycomb structures, there is a series of pockmarks (Fig. 16A) that may be related to gas or fluid expulsion from the honeycomb structures.

The depths at which they are found and the evidence of fluid expulsion suggests this could be due to the opal-A/CT transition.



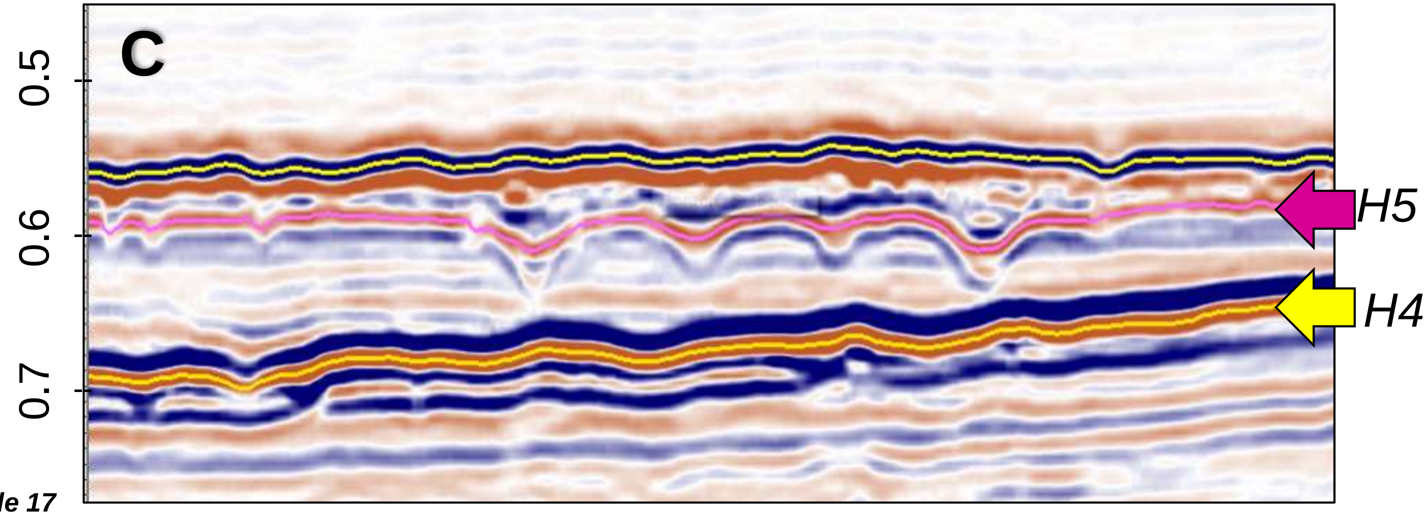


Fig 16. A) Shade-relief map of H5, showing the distribution of pockmarks. **B)** *Landform* derived layer of H4 showing the western field of honeycomb structures. Red circles show the location of the pockmarks in both A and B. **C)** Reprehensive seismic line.

Mini-mounds (H4)

Numerous mounds can be found densely packed in certain areas of the H4 surface (Fig. 17). They tend to occur preferentially in areas of higher slope facing towards West.

They are typically 150–250 m in width and 2–5 ms high.

In seismic profiles, the first few horizons directly below the mounds show small centres of acoustic disturbance.

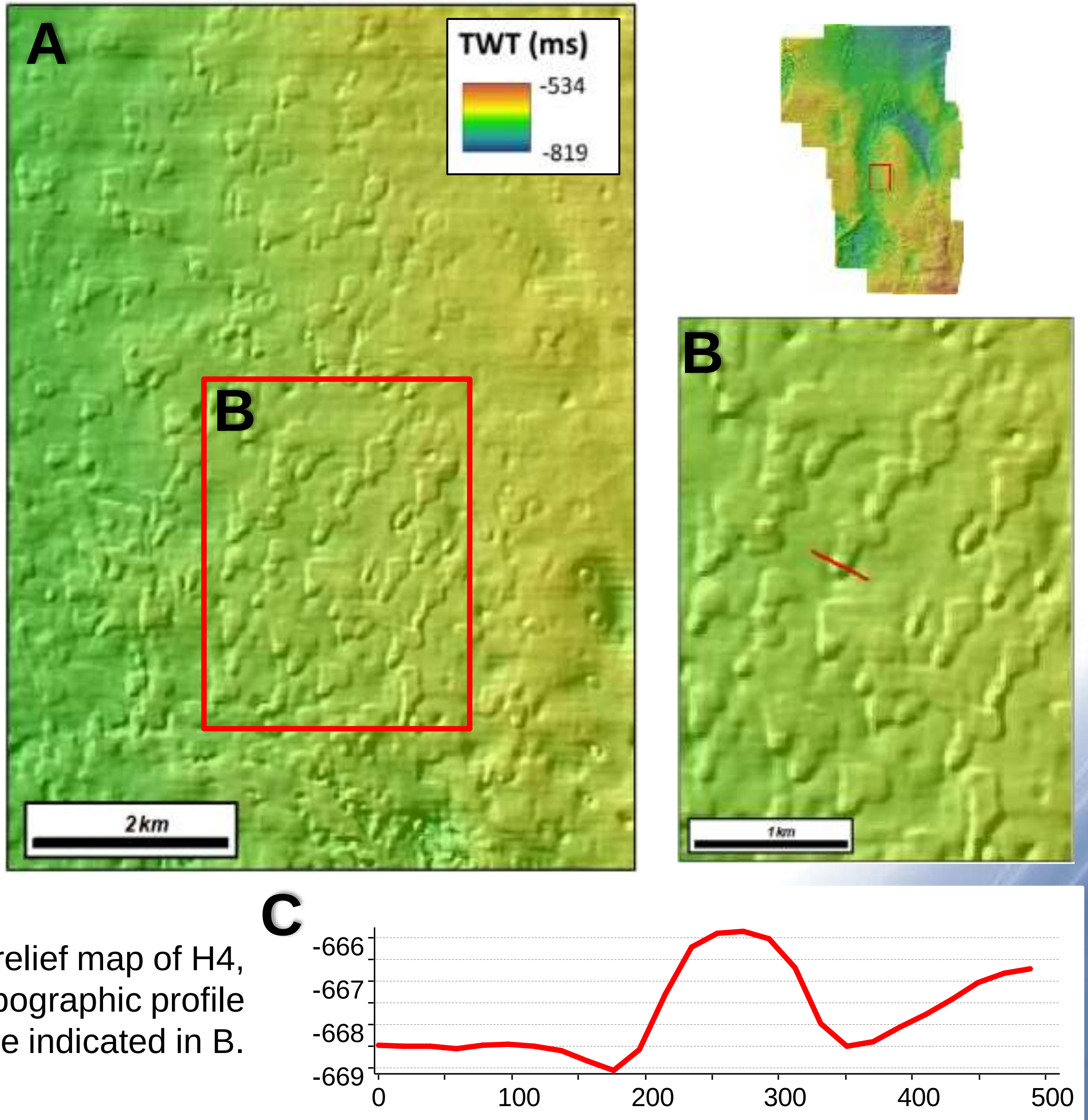


Fig 17. A) and **B)** Shade-relief map of H4, showing the mini-mounds. **C)** Topographic profile (in TWT) of the profile indicated in B.

Mini-mounds (H4)

In the H4 amplitude map, the mounds are characterised by circular areas of higher amplitudes.

The vast majority of the mounds also presents an “acoustic shadow” towards NW that can extend for a few hundred meters.

We suggest that these mini-mounds could be buried coral mounds and that the “acoustic shadows” would result of the coral rubble being preferentially deposited NW of the mounds by the predominant currents.

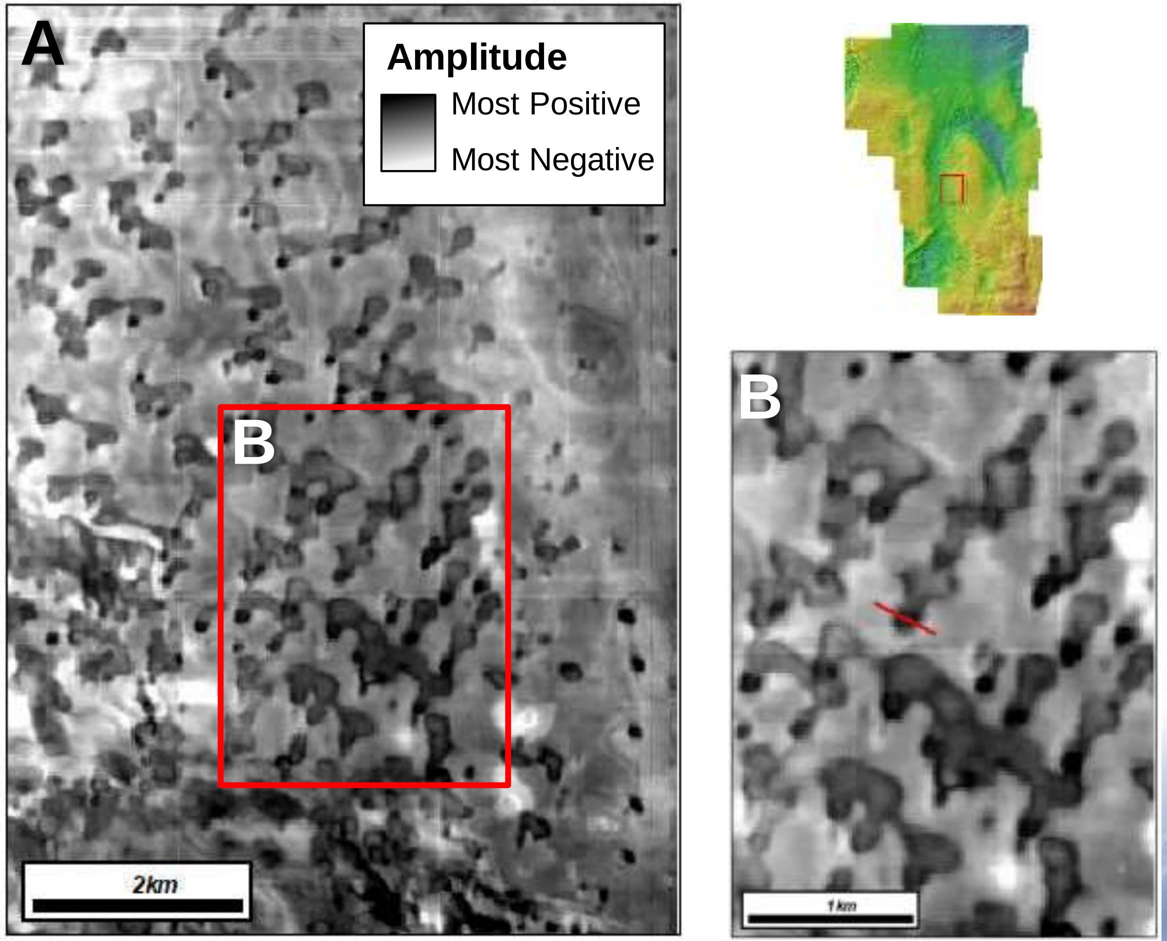
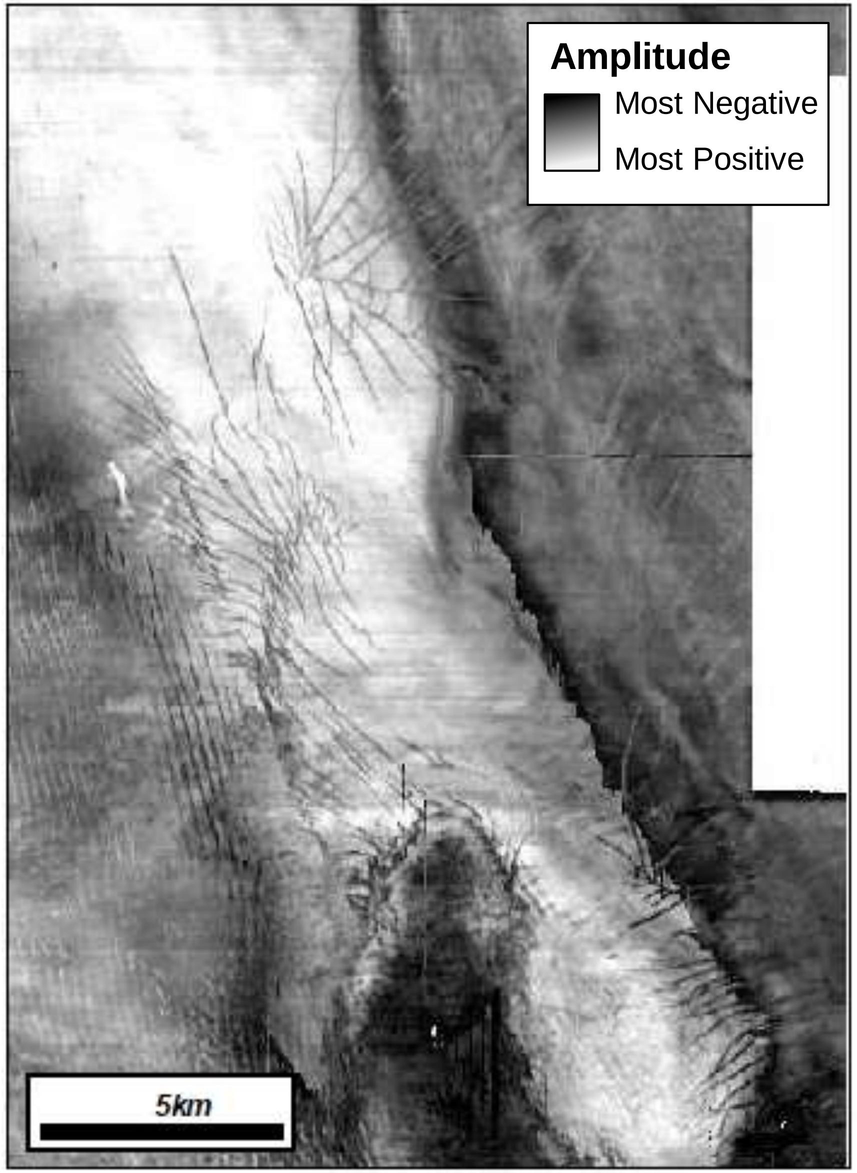


Fig 18. A) Amplitude map of H4, showing mini-mounds. **B)** Detail of the H4 amplitude map showing “acoustic shadow” NE of the centre of the mini-mounds.

"Broken glass" fracture system (H2)

A fracture system resembling broken glass can be recognised on H2 (Fig. 19A) at time-depths of ~780-945 ms twt.

This fractures are visible on the amplitude map (Fig.19B). A total area of ~290 km^2 is affected by a network of fractures that can extend for more than 8 km.



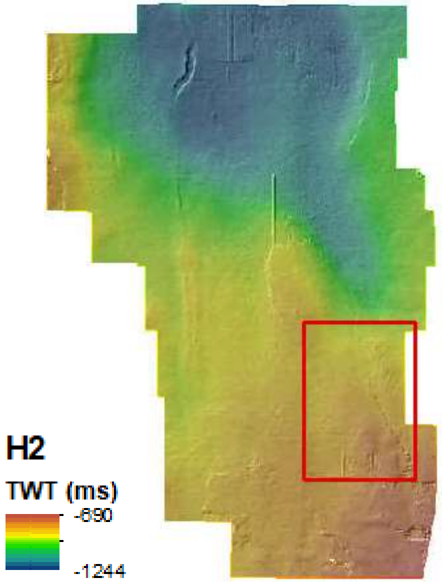


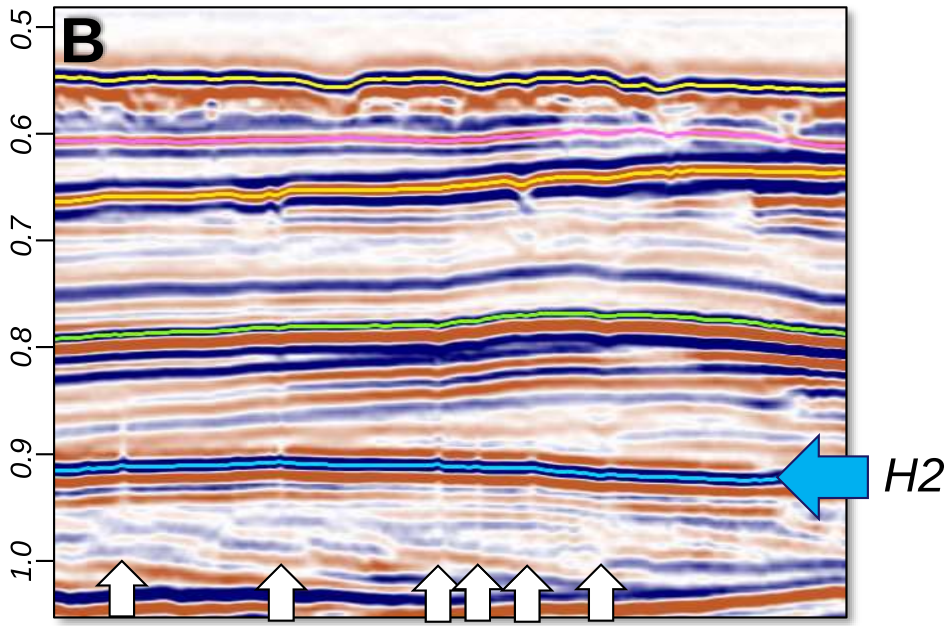
Fig 19. A) Shade-relief map of H2, the location of the "broken glass" fracture system. **B)** Amplitude map of H2, showing the "broken glass" fracture system.

"Broken glass" fracture system (H2)

These fractures appear to be formed in response to sinistral shear in transtensional regime.

The northernmost fracture swarm appears to have formed due to a near instantaneous deformation event. Although there does appear to be some overstepping.

The fractures can also be identified on seismic profiles, both above and below H2 (Fig. 20B).



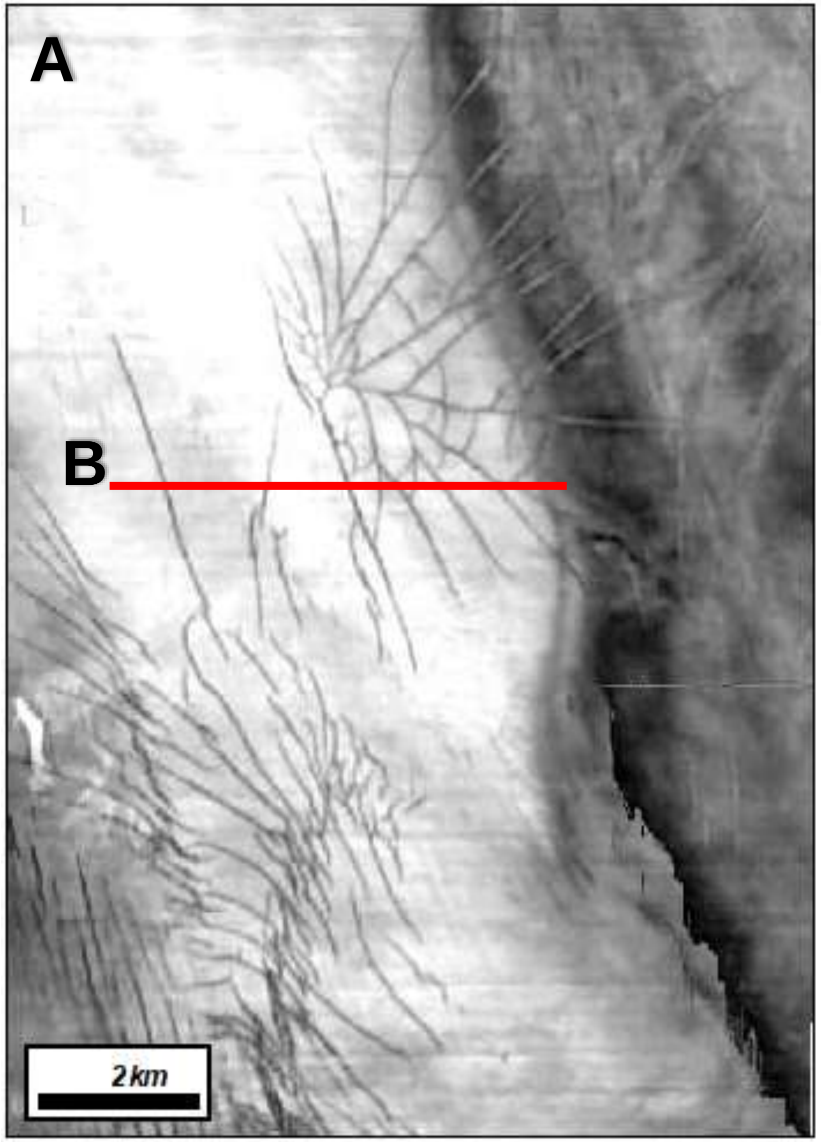


Fig 20. A) Amplitude map of H2, showing the "Broken glass" fracture system. **B)** Seismic section through the fracture system.

Conclusions

- Iceberg ploughmarks at seabed

  Formed where the keels of drifting icebergs gouge and scour the seabed. These features were formed when global sea levels were >100 m lower than at present and can provide insights into paleo oceanic currents and/or dominant wind patterns.

- Honeycomb structures (H4)

  The features were initially attributed as sub-seismic polygonal faulting, but after more detailed investigation they appear to be very similar to honeycomb structures observed in the Great South Basin of New Zealand (Morley et al., 2017). The formation of honeycomb structures in the Great South Basin have been attributed to diagenetic processes. The depths at which the honeycomb structures here presented are found and the evidence of fluid expulsion suggests this could be due to the opal-A/CT transition.

Conclusions

- Mini-mounds (H4)

  Numerous mounds can be found in southern region of H4. We suggest that these mini-mounds could be buried coral mounds and that the “acoustic shadows” would result of the coral rubble being preferentially deposited NW of the mounds by the predominant currents. In contrast to tropical corals, which live in shallow waters bathed with light, cold-water corals are found in water depths of hundreds or even a thousand meters.

- “Broken glass” fracture system (H2)

  A large area of H2 show evidences of a network of fractures with a spatial distribution that resemble a broken glass effect. These fractures were probably formed in the post-rift phase, possibly in a sinistral transtension regime.

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