

# The extent of ice sheet in the area of northern Reykjanes Ridge at maximum of the last glaciation: new insights



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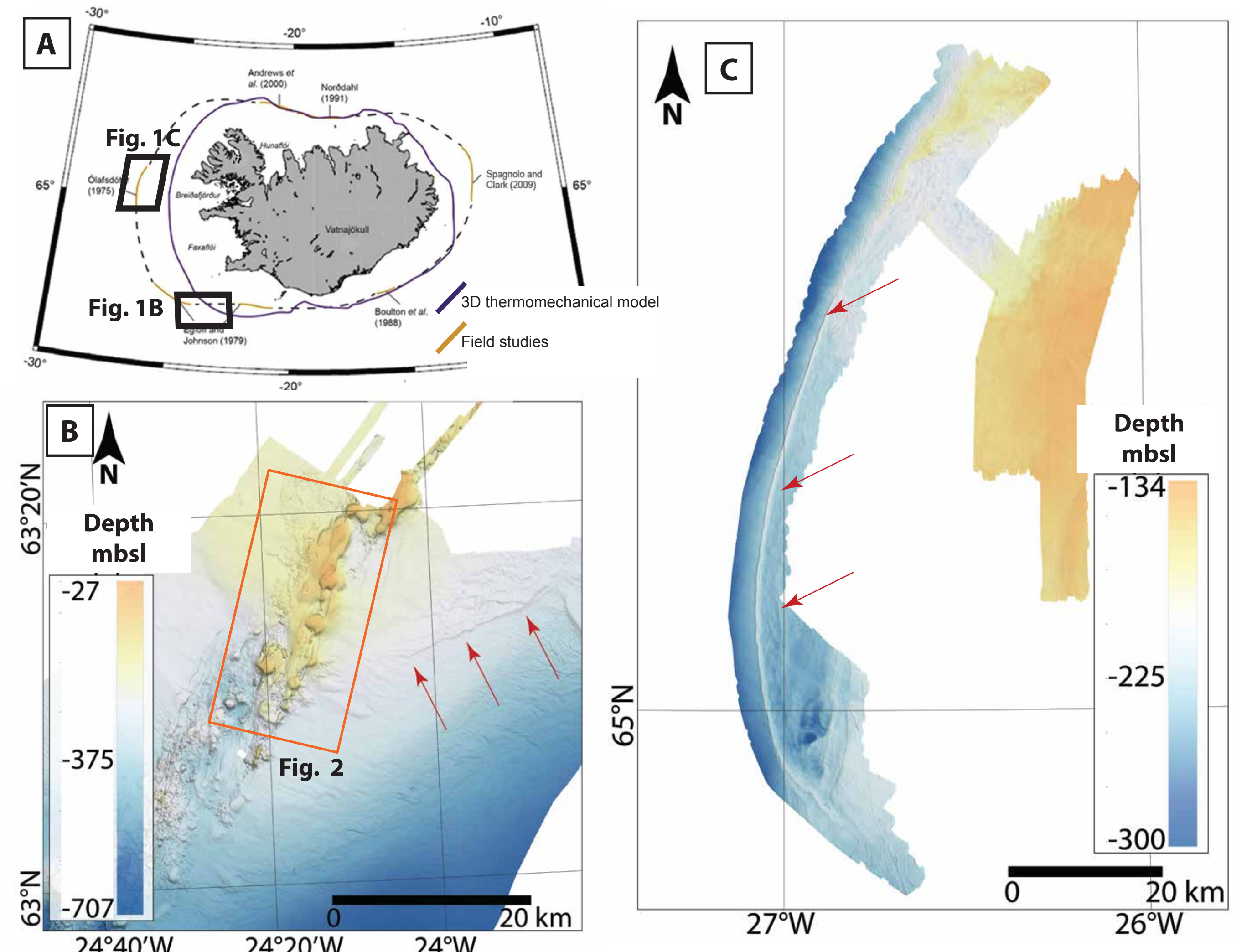
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## 1. Introduction and geological background

- A.** Iceland is the only part of the northern Mid-Atlantic Ridge elevated above the sea level where geological processes related to the divergent lithospheric plate boundaries and the formation of new oceanic crust can be directly observed<sup>1</sup>.
- B.** The location near the Arctic Circle has caused the Iceland to experience numerous glaciation periods, and during the Quaternary the extensive ice cover most likely covered the entire island<sup>2</sup>.
- C.** In the last 3 Ma Iceland experienced about 15 glaciations. During about 12 of them, the maximum extent of the ice sheet reached the coastline of the island, i.e. the sea level appropriate for given periods of maximum ice ages<sup>3</sup>.
- D.** The last glaciation most likely started at about 100 ka BP, with the Last Glacial Maximum of about 21 ka BP and the end of the glaciation period of about 10<sup>14</sup> ka BP<sup>2</sup>.
- E.** At the edges of the Icelandic plateau and along the Reykjanes Ridge, there is poor quality evidence from both field studies of the current seafloor (end moraines) and thermomechanical modelling, indicating the maximum extent of the ice sheets during the LGM (Fig. 1).
- F.** New empirical evidence from the seafloor of the northern part of the Reykjanes Ridge for the maximum extent of the Icelandic ice sheet during the LGM is presented.

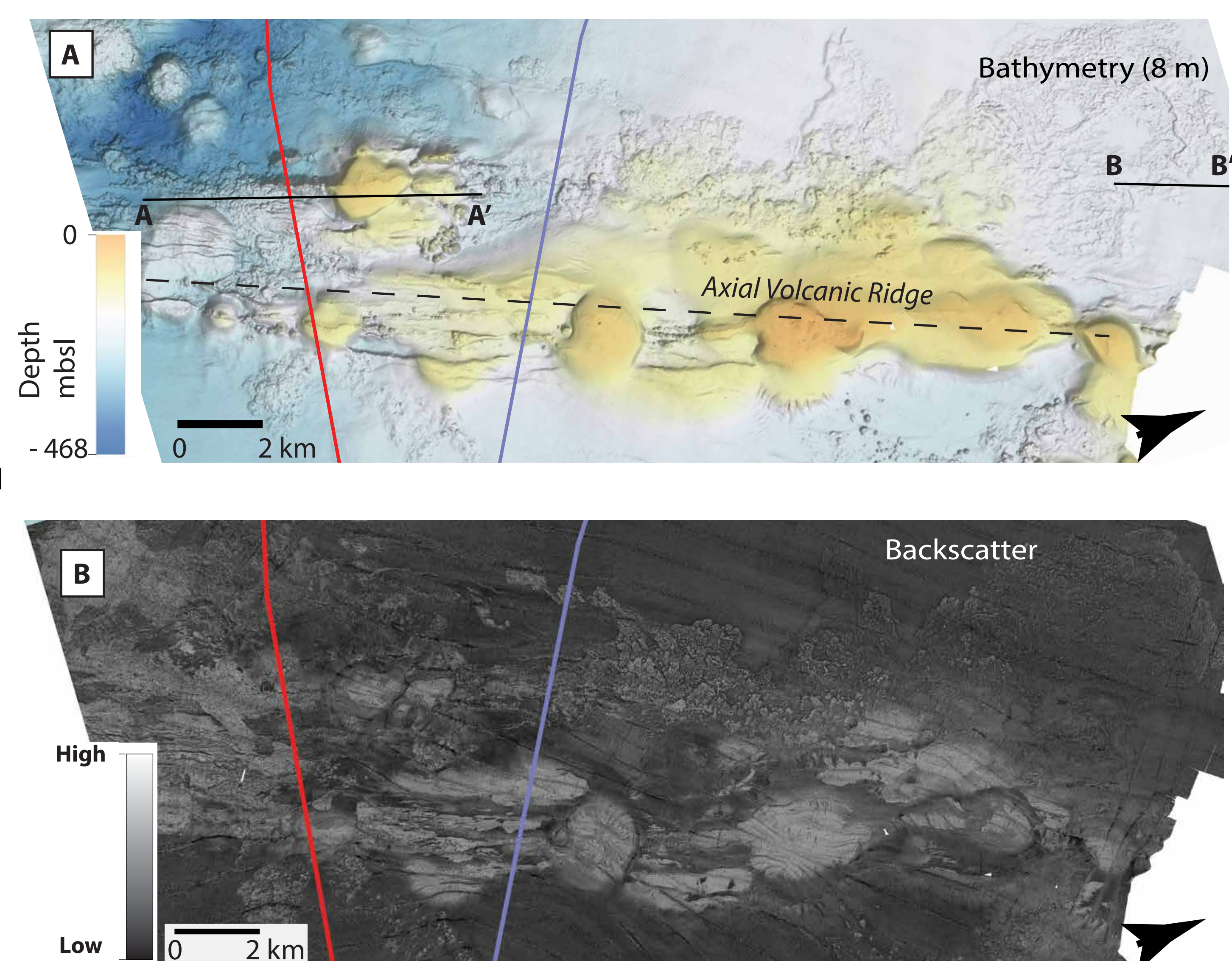
Fig. 1. Summary of field and modeled evidence (based on a 3D thermomechanical model) of the maximum extent of the Icelandic ice sheet at Last Glacial Maximum (A). Modified after <sup>2</sup>Brader i in., 2017; Low resolution (20m) bathymetry of the western Iceland shelf edge (B) and northern Reykjanes Ridge (C) showing end moraines (red arrows) interpreted as empirical evidence of the extent of the Icelandic ice sheet in the LGM. Modified from <sup>4</sup>Ólafsdóttir, 1975, <sup>5</sup>Egloff oraz Johnson, 1979, and <sup>6</sup>Pałgan et al., 2017.



## 2. Results and observations

- A.** A new high resolution (8 m) bathymetric map of the northern Ridge of Reykjanes was created from the data collected during the A200608 expeditions from 2006 carried by former Marine Research Institute in Reykjavik, on board R/V Árni Friðriksson (using multibeam echosounder Kongsberg EM712 75 kHz (Fig. 2A). Sub-bottom profile (Fig. 3B) was done using Kongsberg Maritime TOPAS PS18
- B.** The acoustic backscatter of the multibeam data (Fig. 2B) combined with local topography allowed to distinguish three types of seafloor in this area:
  - **Rough/high backscatter** - representing neovolcanic areas (young seafloor built of relatively young lavas, i.e. Holocene, with fissure, conical and hummocky volcanoes),
  - **Smooth/low backscatter** - representing areas with medium or significant sediment cover (older seafloor, i.e. Pleistocene or older), sediment structures observed (channels or sand waves),
  - **Smooth/high backscatter** - representing areas with hard but smoothed outcrops of lavas.
- C.** The seafloor typical for divergent plate boundary in the northern part of the Reykjanes Ridge (Fig. 2A, SW from the red line) is characterized by a rough, hummocky terrain with many fissure, conical and flat-topped volcanoes.
- D.** Near the neovolcanic zone (central part of Axial Volcanic Ridge (or AVR), NE from the red line), where the plate boundary separating North American and Eurasian plates is located, the dominance of a smooth seafloor with a high backscatter (Fig. 2B) is observed.
- E.** The flat-topped volcanoes, which are located on and around AVR, are characterized by extremely high smoothness, despite their location within or very near the neovolcanic zone. Some such volcanoes are also observed further away from the neovolcanic zone and AVR axis.
- F.** Numerous lava flows have been observed in the area, with extent up to several kilometers beyond the neovolcanic zone.

Fig. 2. (A) High resolution bathymetric map (8 m) of the northern Reykjanes Ridge, Iceland. Raw data was collected using Kongsberg multibeam echosounder EM712 75 kHz. Post-processing was performed in QPS Chimera software. Global Mapper 21 and Terrain Texture Shading techniques were used to compile the map. The red line represents suggested empirically extent of the LGM<sup>4,5</sup>, while the purple line indicates the extent but suggested by thermomechanical model work<sup>2</sup>; (B) Acoustic backscatter indicating the hardness of seafloor. A bright backscatter represents hard seafloor (i.e. bedrock), and a dark represents soft (sedimented) seafloor. The map was created in the QPS FMGT and compiled in Global Mapper 21 software. Red and purple lines like in 2A.



## 2. Discussion

### Assumptions

- Axis of the AVRs represent plate boundaries.
- Significant portion of seafloor along the northern Reykjanes Ridge was formed along the plate boundary.
- Young seafloor along the divergent plate boundaries is characterized by high roughness and high backscatter, hence the occurrence of different types of volcanoes and lava flows.
- The studied area is affected by low sedimentation rate of shallow areas (<<1mm/year) and the presence of strong near-bottom currents.

### Discussion

- A.** Both the 3D thermomechanical model and the new data from the seafloor are clearly compatible, i.e. they both accurately indicate the extent of the ice sheet during the LGM.
- B.** Sedimentation (mainly terrigenous originating from Iceland) cannot be the only geological process affecting the smoothing of the shallow neovolcanic and near-neovolcanic zone in the northern Reykjanes Ridge.
- C.** Only ice sheet could lead to such a strong smoothing of the terrain (Fig. 3A). This occurred during the retreat of the ice cap during the deglaciation and the progressive exarication of the seafloor - in this area - the neovolcanic and near-neovolcanic zone of the Reykjanes Ridge.
- D.** New bathymetric data confirm previous observations by Egloff and Johnson<sup>5</sup>. In the area SW from the red line in Fig. 2, there is no very smooth seafloor within the neovolcanic zone.
- E.** The presence of large lava flow (e.g. Fig. 2A, NW corner) indicates volcanic activity during the Holocene period, after ice sheets retreated. If pre-LGM, they would be eroded by ice sheet.
- F.** Sub-bottom profile AA' shows seafloor with no sediment pockets (Fig. 3B). Summit of flat-topped volcano has thin, strongly reflecting layer. Typical sediment-lava transition and sediments stratification is seen in profile BB' (Fig. 3C).

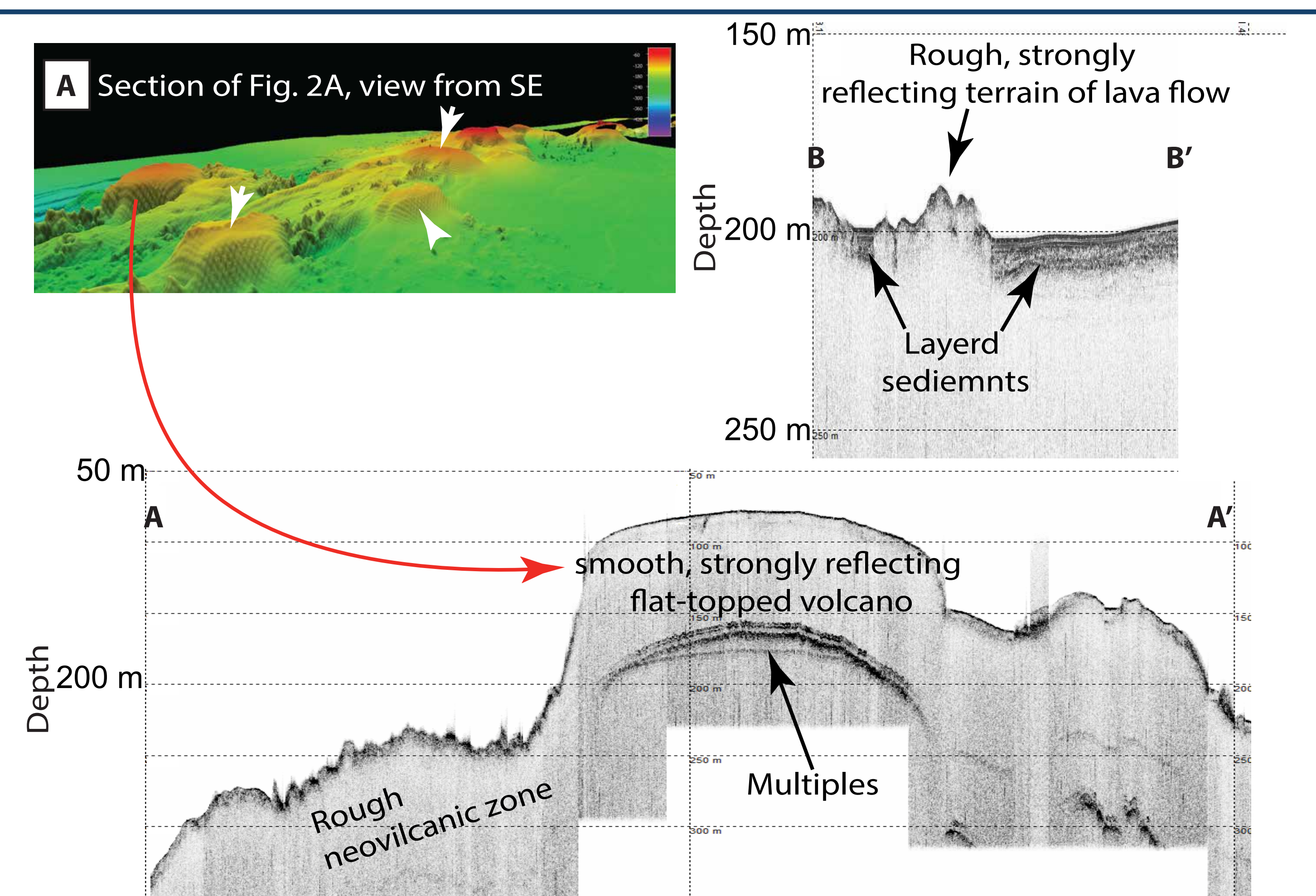


Fig. 3. (A) 3D view of the bathymetry from Fig. 2A. The arrows point to the volcanoes smoothed by the ice sheets; (B) Przekrój ZZ' oznaczony w Rys. 2A, czerwona linia wskazuje wygładzony wulkan; (C) Przekrój przez typową strefę neowulkaniczną Grzbietu Reykjanes. Czarne strzałki to wulkany szczelinowe, linia fioletowa to wulkan kraterowy, brązowa to płaskowierzchołkowy;

<sup>1</sup>Saemundsson, K., 1979, Outline of the geology of Iceland: Jökull, v. 29, p. 7-28  
<sup>2</sup>Brader, A. i in., 2017, Postglacial relative sea-level changes in northwest Iceland: Evidence from isolation basins, coastal lowlands and raised shorelines: Quaternary Science Reviews, 169, 114-130  
<sup>3</sup>Einarsson, T. oraz Albertsson, K. J., 1988, The glacial history of Iceland during the past three million years: Philosophical Transactions of the Royal Society, 318, 637-644  
<sup>4</sup>Ólafsdóttir, T., 1975, Jökulgardur a sjavarbotni ut af Breidafirði (English summary: A moraine ridge on the Iceland shelf, west of Breidafjörður): Náttúrufræðingurinn, 45, 247-271  
<sup>5</sup>Egloff, J. oraz Johnson, G.L., 1979, Erosional and depositional structures of the southwest Iceland insular margin: thirteen geophysical profiles, w: Watkins, J.S., Montadert, L., oraz Dickerson, P.W. (Ed.), Geological and Geophysical Investigations of Continental Margins, AAPG, Tulsa, Oklahoma, pp. 43-63  
<sup>6</sup>Pałgan, D. i in., 2017, Volcanism and hydrothermalism on a hotspot-influenced ridge: Comparing Reykjanes Peninsula and Reykjanes Ridge, Iceland, Journal of Volcanology and Geothermal Research, 348, 62-81