

Combined on-fault and off-fault paleoseismic evidence

in the postglacial lacustrine sediments of Achensee (Austria, Eastern Alps)

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Research motivation:

- Hardly any paleoseismic record in the slow-deforming Eastern Alps
- Potentially active faults are unknown

Conclusions of this study:

The post-glacial sedimentary archive of Achensee unravels:

- 8 remote earthquakes by multiple coeval mass wasting
- 3 surface rupturing earthquakes as combined subaqueous faulting and mass wasting
→ First record of active faulting in Eastern Alps

Corresponding manuscript in review for publication in *Frontiers in Earth Science*, Research Topic: [Submarine Active Faults](#)

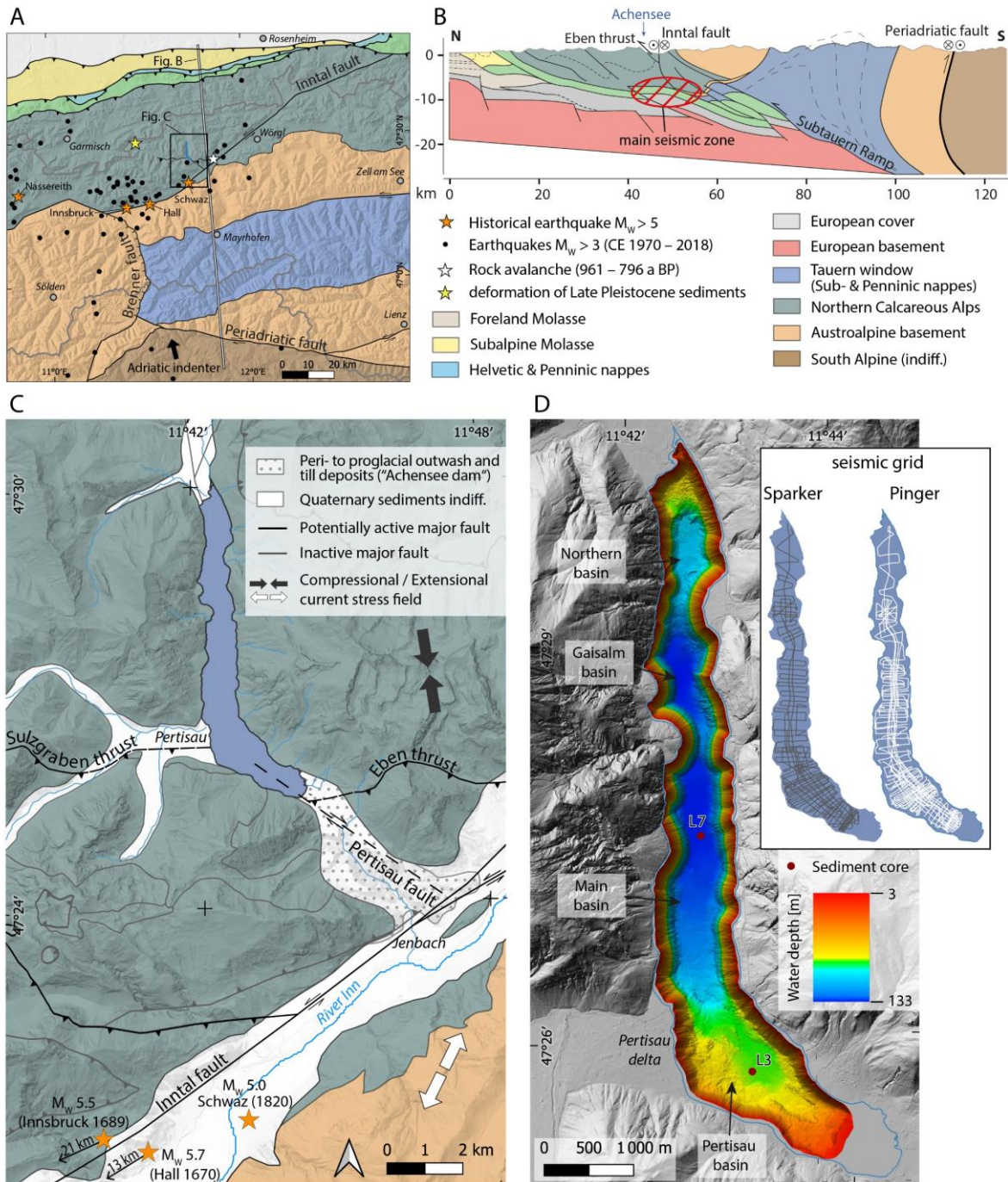


Figure 1

- A) Seismotectonic map of the central Eastern Alps including the main faults and faults relevant for this study, historical and recent earthquakes
- B) Simplified cross section across the Eastern Alps indicating the location and depth of the current seismic zone in respect to the major fault systems.
- C) Geological map of the surroundings of Achensee. The lake is located within the Northern Calcareous Alps and dammed in the Southeast by proglacial outwash and till deposits accumulated before the Last Glacial Maximum. The southern part of the lake is crosscut by the dextral strike-slip Pertisau fault separating the Sulzgraben and Eben thrusts. The sinistral Inntal fault obliquely crosscuts the Northern Calcareous Alps and separates them from the Austroalpine basement Southeast of Schwaz. The current stress field in this tectonic domain is generally compressional in NNW-SSE direction, but also a NE-SW extensional stress field occurs in the southern part of the study area.
- D) Bathymetry of Achensee showing the four sub-basins and the coring sites of this study. Inset shows the dense seismic grid using the pinger (grey) and sparker (white) seismic sources.

References:

- A) Stucchi et al. (2013), Reiter et al. (2018), Brandner (1980), Bousquet et al. (2012), Geologische Bundesanstalt (2021a, 2021b)
- B) Ortner et al. (2006, 2015); Reiter et al. (2018)
- C) Reiter et al. (2018), Stucchi et al. (2013), Eisbacher and Brandner (1996), Moser (2008), Gruber and Brandner (2012), Kilian and Ortner (2019)

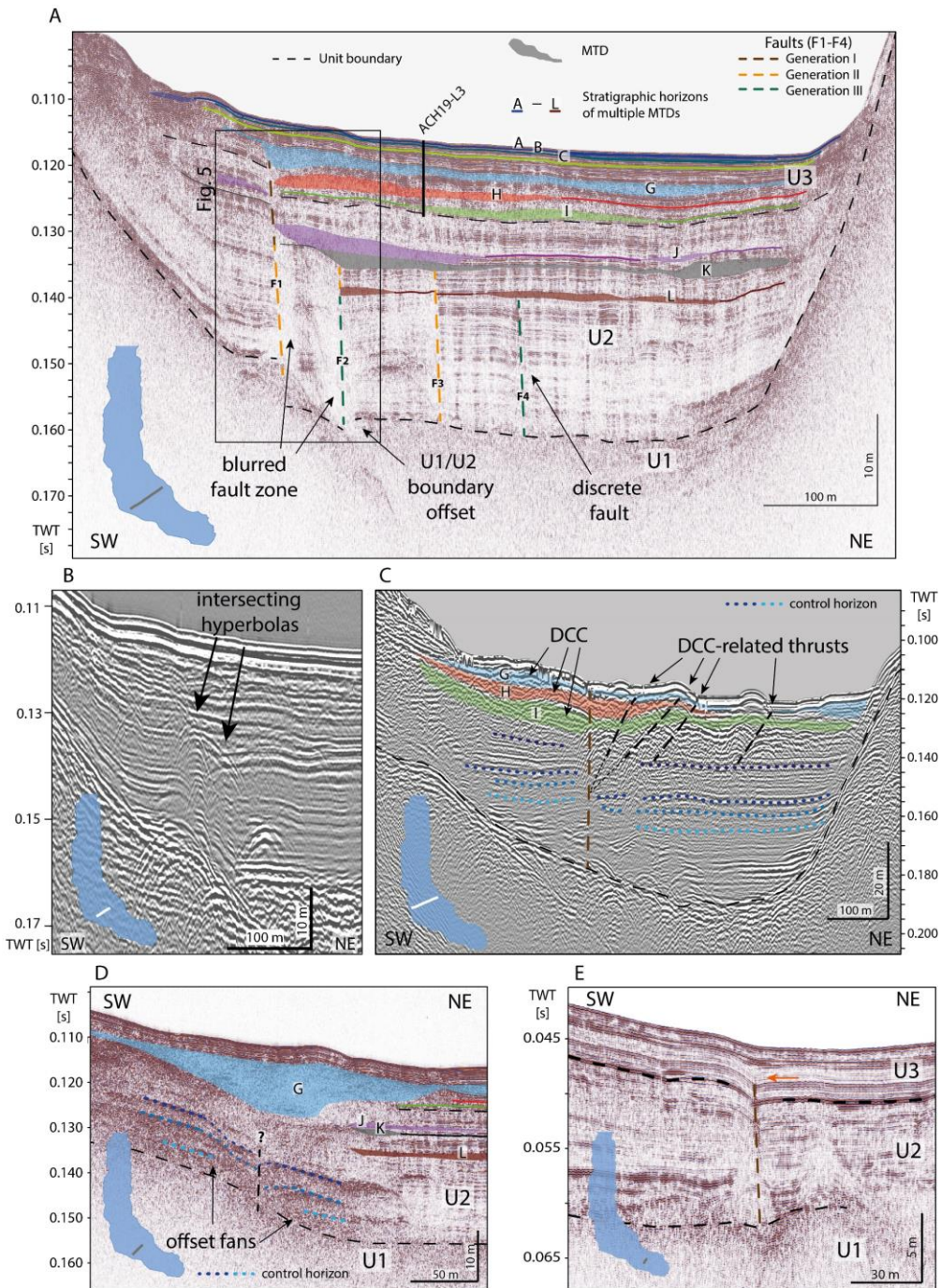


Figure 2: Seismic profiles with both on-fault and off-fault paleoseismic evidence

- A) Pinger profile with four faults expressed as **blurred zones** or **discrete offsets**, which are subdivided in faulting generation I, II and III based on the stratigraphic level of their upper termination. Event horizons A-L depict stratigraphic **horizons with multiple MTDs**. The upper termination of fault generations I, II and III are directly overlain by MTDs of event horizons G, K and L. Vertical black line displays projected depth of core ACH19-L3.
- B) Fault zone expressed by **intersecting hyperbolas** in a sparker profile.
- C) A blurred fault zone offsetting seismostratigraphic control horizons (dark- to light blue) in a sparker profile. The fault terminates in the delta collapse complex (DCC). Transportation and emplacement of the DCC generated deformation and thrusting of basin sediments.
- D) The **Offset of fan delta deposits** locally characterizes the fault zone, where faulting horizons could not be assigned due to missing stratigraphic control between the MTD of event horizon G and the fan delta deposits. Pinger profile.
- E) A **discrete fault** terminating upwards in undeformed U3 (orange arrow) in the shallow SE-most part of the Pertisau basin. Pinger profile.

Faulting and mass-wasting are coeval

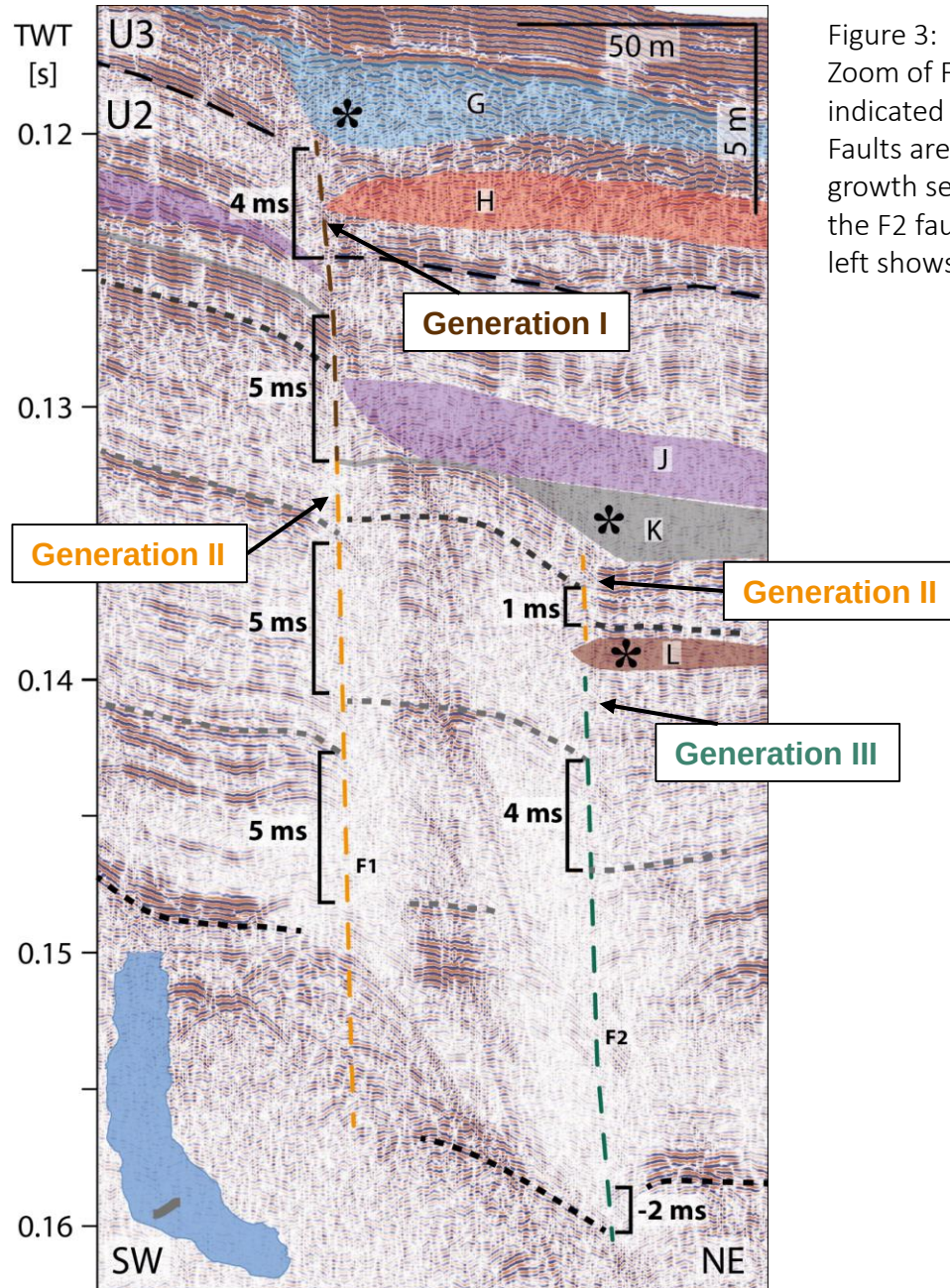
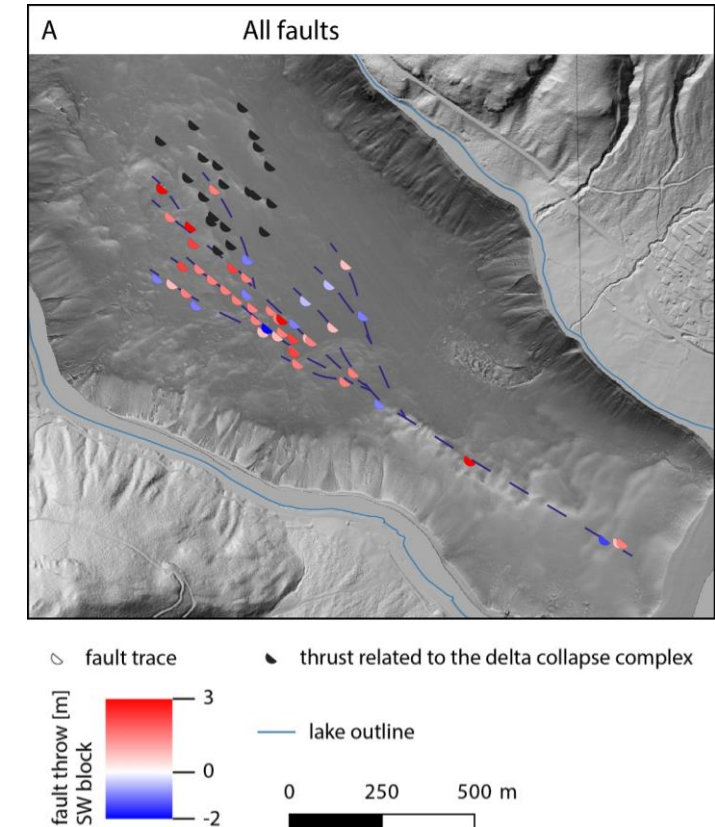


Figure 3:
Zoom of Figure 2A showing three **different faulting generations** directly overlain by MTDs indicated by stars. Fault throw is measured using seismic control horizons (narrow dashed lines). Faults are colored based on their upper termination as faulting generation I, II and III. A fault growth sequence is indicated by upward decreasing offsets. Note the reversal of fault throw of the F2 fault. Stratigraphic control horizons are shown as narrow dashed lines. Map inset in lower left shows position of the pinger profile.

Figure 6:
Trace map of subaqueous faults in seismic data colored with their respective fault throw, where positive values define uplifting of the SW block in respect to the NE block and vice versa for negative values. Thrust faults related to the emplacement of the delta collapse complex (DCC) are colored black. A potential interpretation of interconnected fault traces is shown by dark-blue dashed lines.



Fault activity for at least three times since ~ 18 ka BP

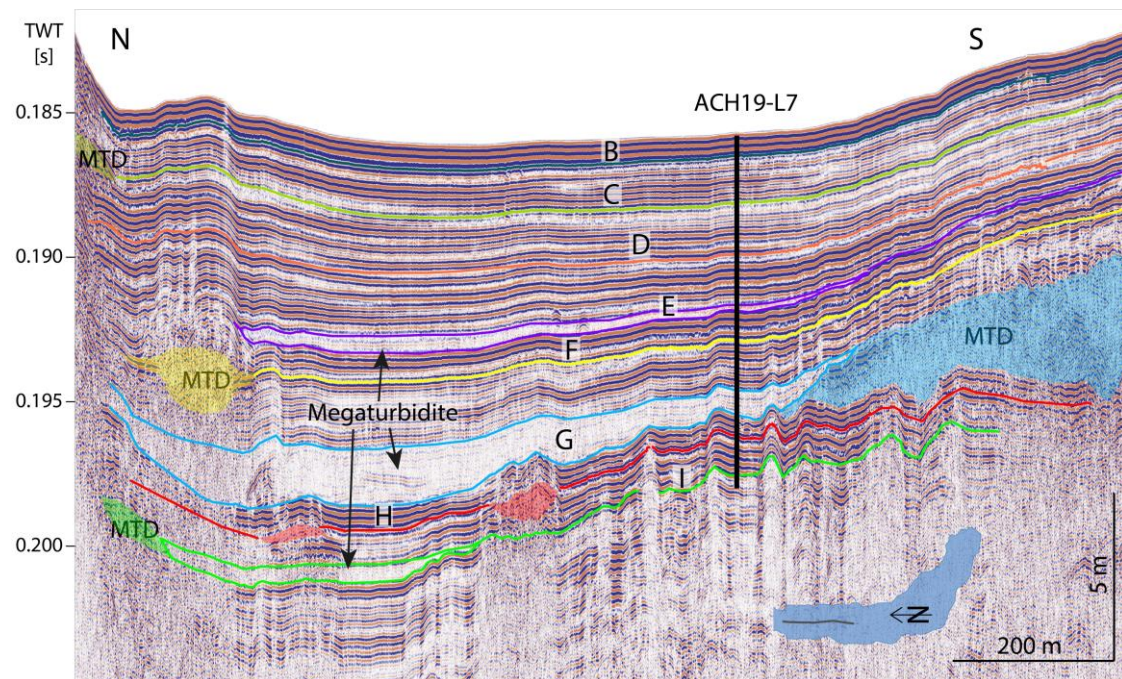
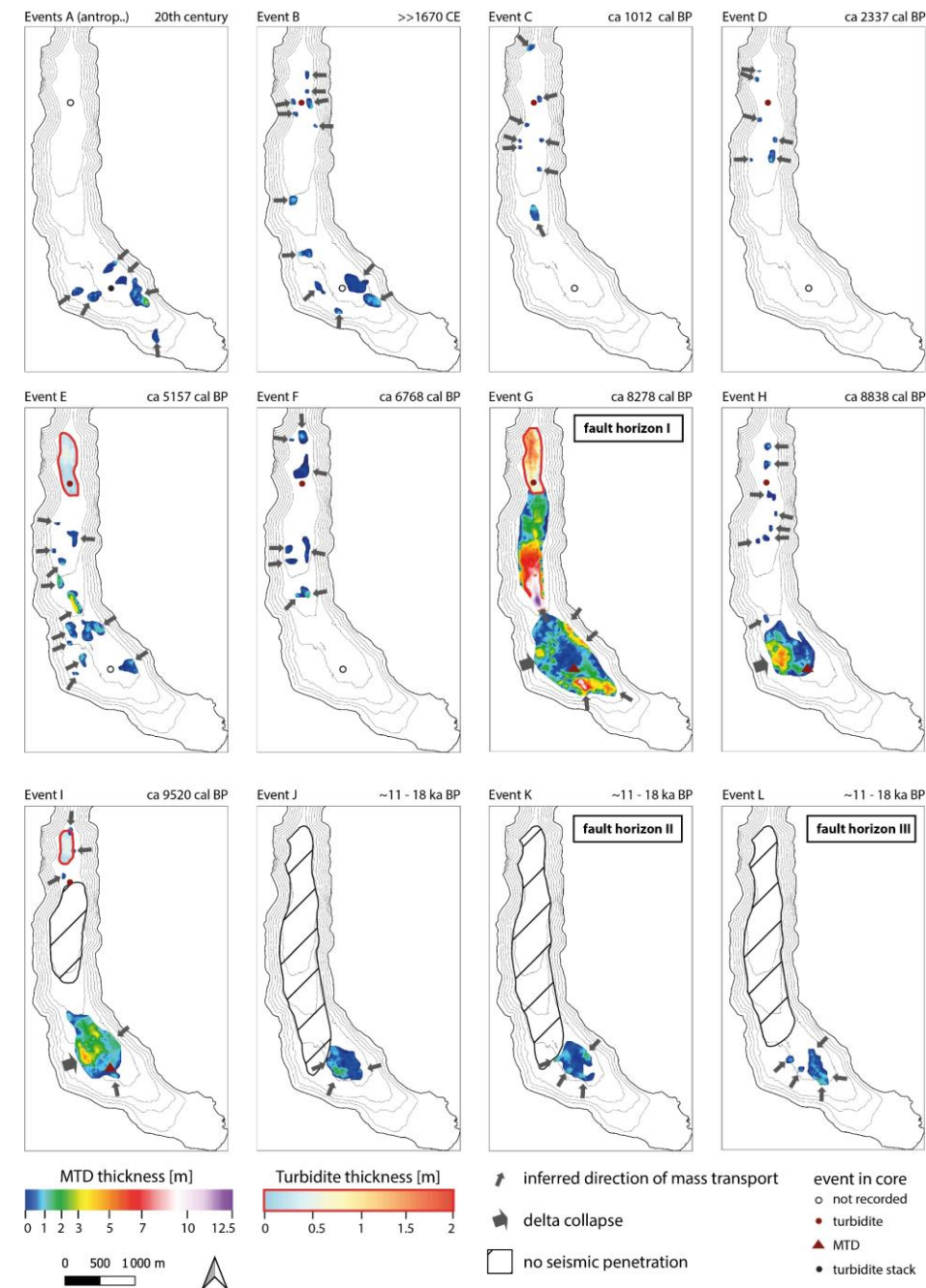


Figure 4: Pinger profile along the Main basin containing **event horizons (B-I)** with multiple MTDs. In event horizons G and I, MTDs are **directly overlain by megaturbidites** indicating their cogenetic formation. Vertical black line displays projected depth of core ACH19-L7 (see Fig. 6). Map inset indicates location of seismic profile.

Figure 5: **Distribution and thickness maps of MTDs and megaturbidites** of seismic-stratigraphic event horizons A-L. Symbols and color code of the coring sites provides information on the sedimentary imprint of the event in the cores.



Off-fault paleoseismic evidence (11 times) since ~ 18 ka BP

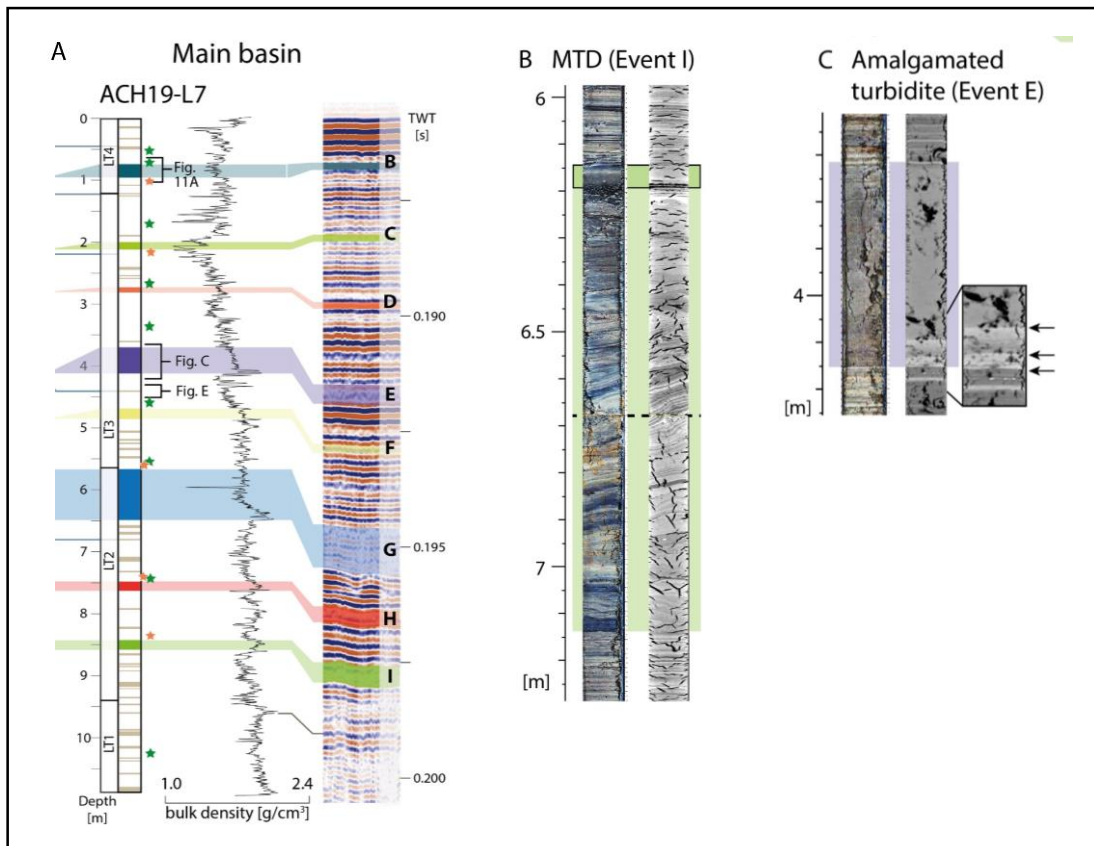


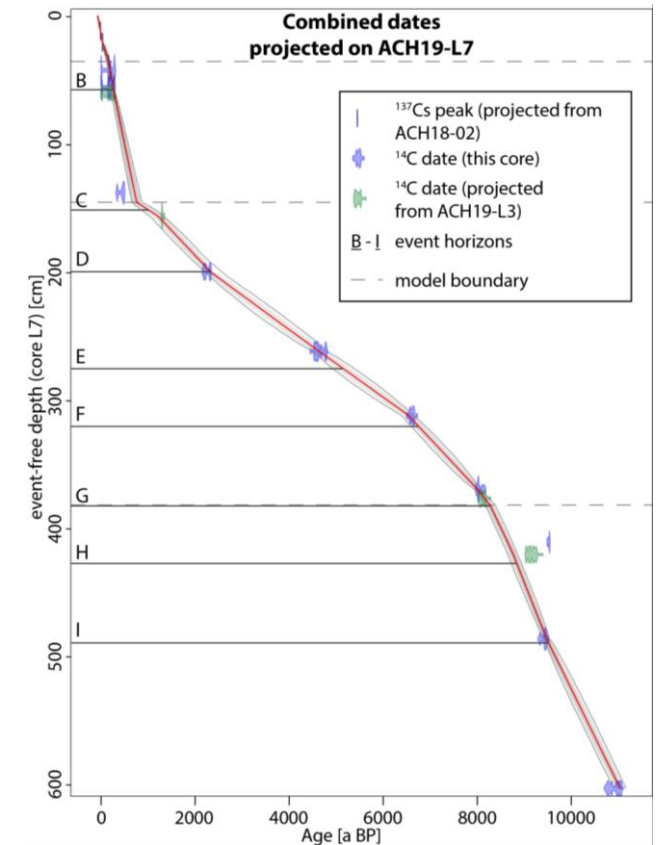
Figure 6: Core data from the the Main basin (core ACH19-L7).

A) Correlation of seismic event horizons with sediment core log. Seismic event horizons correlate to MTDs and cogenetic turbidites in the sediment core.

B) Core image and CT scan of a **MTD** showing folded and distorted strata, shear zones and a turbidite on top.

C) Core image and CT scan of an **amalgamated turbidite** consisting of ~3 individual sedimentary pulses (black arrows; event E). Each of these pulses has an internally homogeneous character. This amalgamated turbidite corresponds to the megaturbidite interpreted in seismic data (Figure 7).

Figure 7: Age-depth models of core ACH19-L7 based on combined ¹³⁷Cs peaks and ¹⁴C dates. Events corresponding to seismic event horizons B-I are indicated by horizontal black lines.



Sediment cores: Investigating the earthquake origin of seismic-stratigraphic event horizons and dating the events

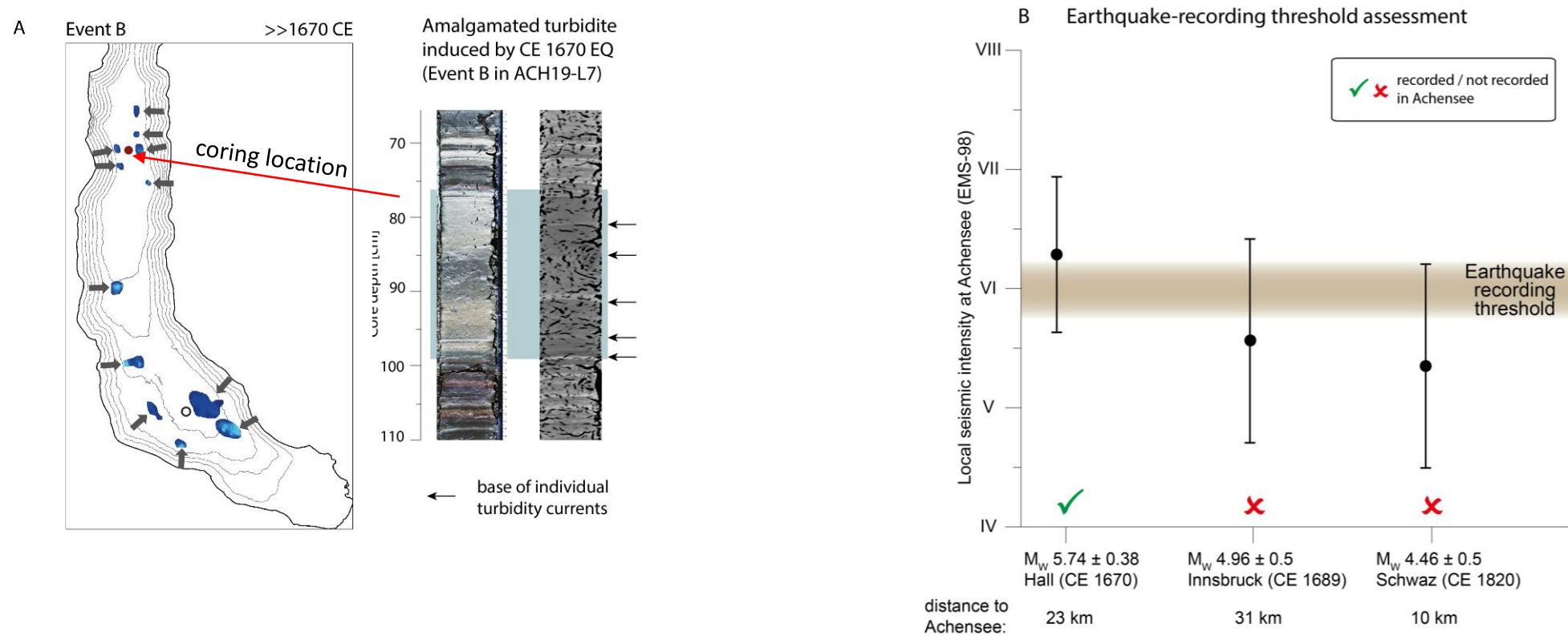


Figure 8: Calibration of the earthquake imprint in Achensee.

- A) Multiple MTDs in seismic data and an amalgamated turbidite** consisting of five individual homogeneous pulses (black arrows) in core data are interpreted as the sedimentary imprint of the $M_w 5.7 \pm 0.4$ Hall earthquake.
- B)** Calculated seismic intensity at Achensee based on the magnitude range of historical earthquakes (Stucchi et al. 2013). An earthquake-recording threshold for Achensee at local intensity $IL \sim VI$ results in recording the strongest historical earthquake in Hall CE 1670, but not the other two.

Calibrating the off-fault paleoseismic record by historical events

Remark: magnitudes of historical EQ differ from abstract due to: use of a different event catalog, differences in M_L and M_w and large magnitude uncertainty of historic events (up to ± 0.5)

Table 1: Paleoseismic record of Achensee combining both on-fault and off-fault paleoseismic evidence

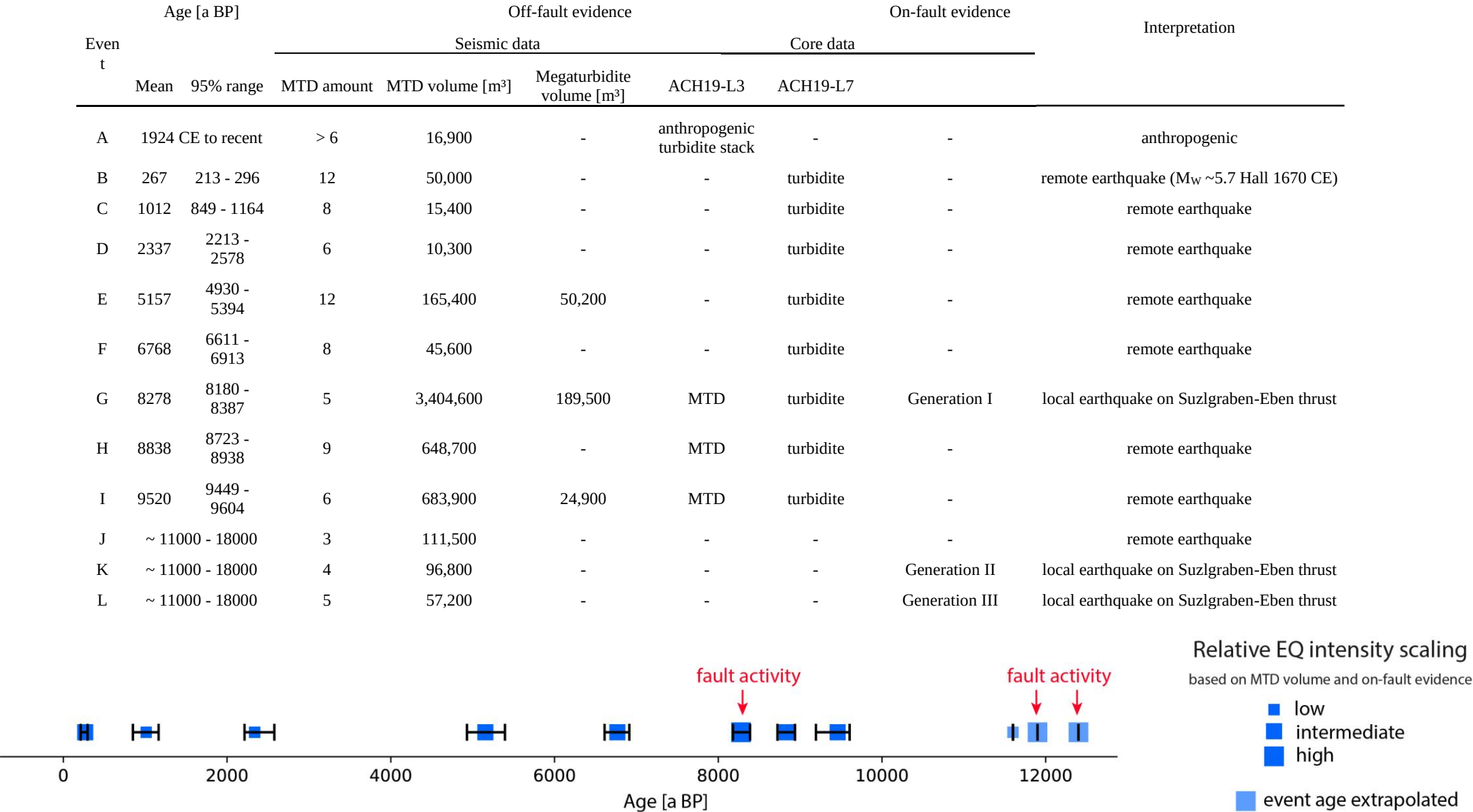


Figure 9: Paleoseismic record of Achensee combining both on-fault (red arrows) and off-fault paleoseismic evidence (blue square)

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