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Deformation structures in lake ice – a natural analogue for joint formation, propagation and faulting in rocks

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Stable periods of winterly high-pressure weather with little or no snowfall allow lakes and ponds to freeze with transparent ice covers and extremely smooth surfaces. We observed fault structures and cracks within the ice the frozen Neusiedlersee, Burgenland, Austria, in January 2009, after 16 days of daily average temperatures below zero degrees and minimum temperatures partly below minus 10 degrees (http://www.zamg.ac.at).

The ice cover has an average thickness of 10-15 cm, however, characteristically for this lake, there are always many areas of open water, up to several tens of meters long, even after long periods of frost. The whole ice surface is crosscut by a complex network of cracks, most of them extending several tens up to hundreds of meters laterally, and transecting the entire ice sheet vertically. Generally, four types of fractures can be observed within the ice:
(1) Opening mode fractures, with obvious extension up to 0.5 m along them and abundant ice crystals with a preferred orientation of syntaxial growth perpendicular to the fracture walls.
(2) Thrust faults cutting the ice at $\tilde{3}0°$, with 10-30 cm of shortening.
(3) Strike-slip faults with contractional as well as extensional stepovers accommodate strain between the tips of parallel fault segments, where relay ramps show either upward or downward vertical movements, respectively. Straight segments of strike-slip faults are frequently associated with secondary en echelon fractures (Riedel and/or P-shears), which are decorated by small air inclusions.
(4) Isolated, conjugate and en-echelon joints without any obvious offset, which are recognized by the planar alignment of sub-mm sized air bubbles.

The wealth of structures observed in the lake ice documents a continuous dynamic process of relative movements between and within ice plates, which may be regarded as an analogue of joint formation, propagation and development of Andersonian type of faults at all scales.