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Giving perspective to cliff exposures with ground penetrating radar: Devonian lacustrine shore zone architecture

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The orbitally-controlled cyclic lacustrine successions of the Middle Devonian in Northern Scotland contains repeated developments of shore zone sandstones. However, due to the cliff-forming nature of the succession and the attitude of the sections through these sandstones, interpretation of this facies has been problematic. To better understand the shore zone systems, we carried out very high resolution sedimentary logging and constructed photo-panels which were combined with high resolution GPR profiling (250 MHz). To ensure close ties between the sedimentary logs and the GPR data, the cliffs were accessed using rope access techniques while GPR grids were shot directly above. The profiles were shot mainly in the strike direction of what was thought to be the shore elongation every 5-10 m and every 20-30 m in the dip direction. Shore zone systems of 3 different sequences have been imaged for a total of 1155 m of GPR profile collected. This configuration has allowed 3D visualisation of the architecture of the shore zone systems and, in combination with detailed sedimentology, provided insights into the generation of the dynamic shore zone environments.

The coastal cliffs of northern Scotland expose sedimentary cycles on average 16-m-thick which record deep lake, perennial lake and playa environments. The shore zone deposits reach 2 to 3.5 m in thickness. Loading and discrete channel forms are recognised in both the GPR data and sedimentary logs through the lower portion of the lake shore zone successions. Up-section the sandstone beds appear to become amalgamated forming subtle low angle accretionary bar complexes which although visible in outcrop, after careful investigation, can be fully visualised and examined in the GPR data. The 3D visualisation allowed mapping the architecture and distribution of the bars . The orientation of these features, recognised from the survey, is consistent with extensive palaeocurrent measurements from oscillation ripples. Further loaded sandstone beds and sand-filled shallow channel features overlie the bar forms. The channels are well imaged in the radargrams where their wider context can be gained.

Through the combination of high resolution GPR data and detailed sedimentological analysis determination of the processes through which the previously enigmatic lake shore zone sandstones has been possible. The shore zone sandstones overlie playa facies which contain abundant desiccation horizons, reflecting the most arid phase in the climatically-controlled lacustrine cycle. As climatic conditions ameliorated the rejuvenation of fluvial systems resulted in the transport of sand out into the basin. Initial deposition was limited to intermittent events where sediment was laid down on a water saturated substrate. Some of these may have occurred subaqueously as small scale turbidity flows. High resolution fluctuations in lake level resulted in periodic short-lived reworking events along the lake margin which produced amalgamated sands, forming low relief bars. Shore zone reworking is likely to have occurred over a wide area as the lake margin migrated back and forth, and gradually transgressed. Continued transgression forced fluvial systems back towards the basin margin.