Onshore-offshore hydrological characterisation of the Canterbury margin (New Zealand) based on geophysical and modelling techniques

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1 Introduction

Vast offshore bodies of fresh and moderately brackish groundwater (offshore freshened groundwater, or OFG) have been documented up to 100 km from modern shorelines and down to 4.5 km below the seafloor (bsf). In this study we integrate offshore time-domain controlled-source electromagnetic (CSEM) data with multichannel seismic reflection data, borehole data and hydrological modelling to quantitatively characterise an OFG system at high spatial resolution. The objectives of our study are to: **(i) constrain the 3D geometry, extent, dimensions, hydraulic and age characteristics of the OFG system; (ii) infer the origin and emplacement mechanisms of the OFG; (iii) identify the controls of the OFG system and its characteristics.**

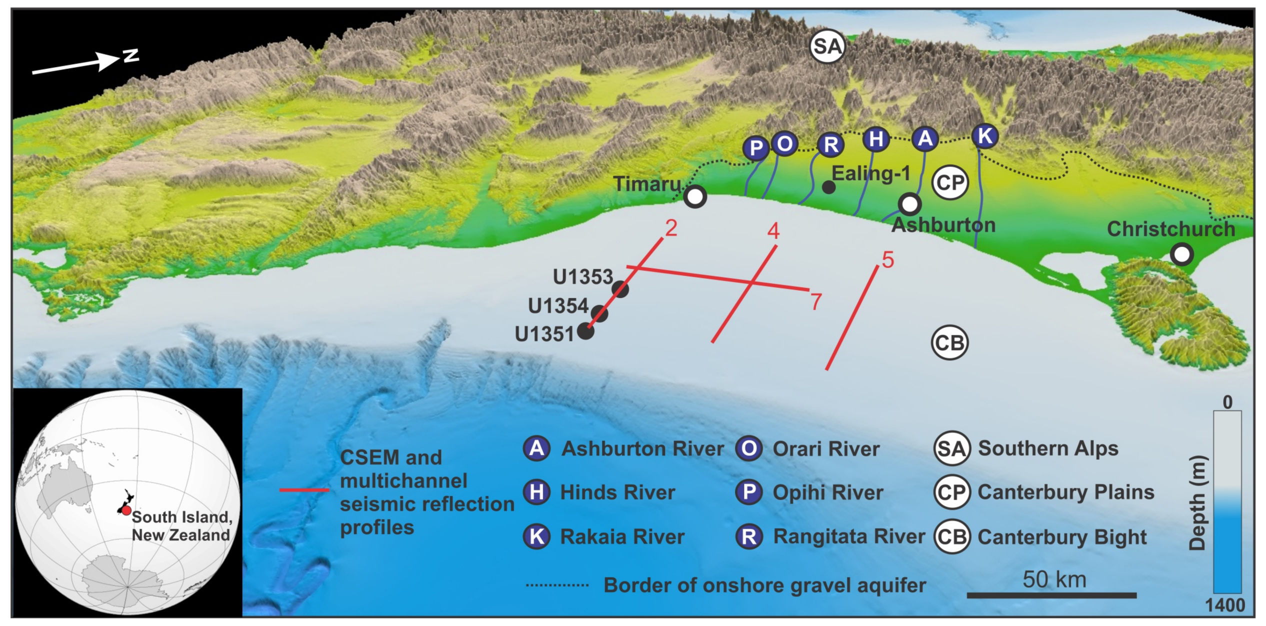
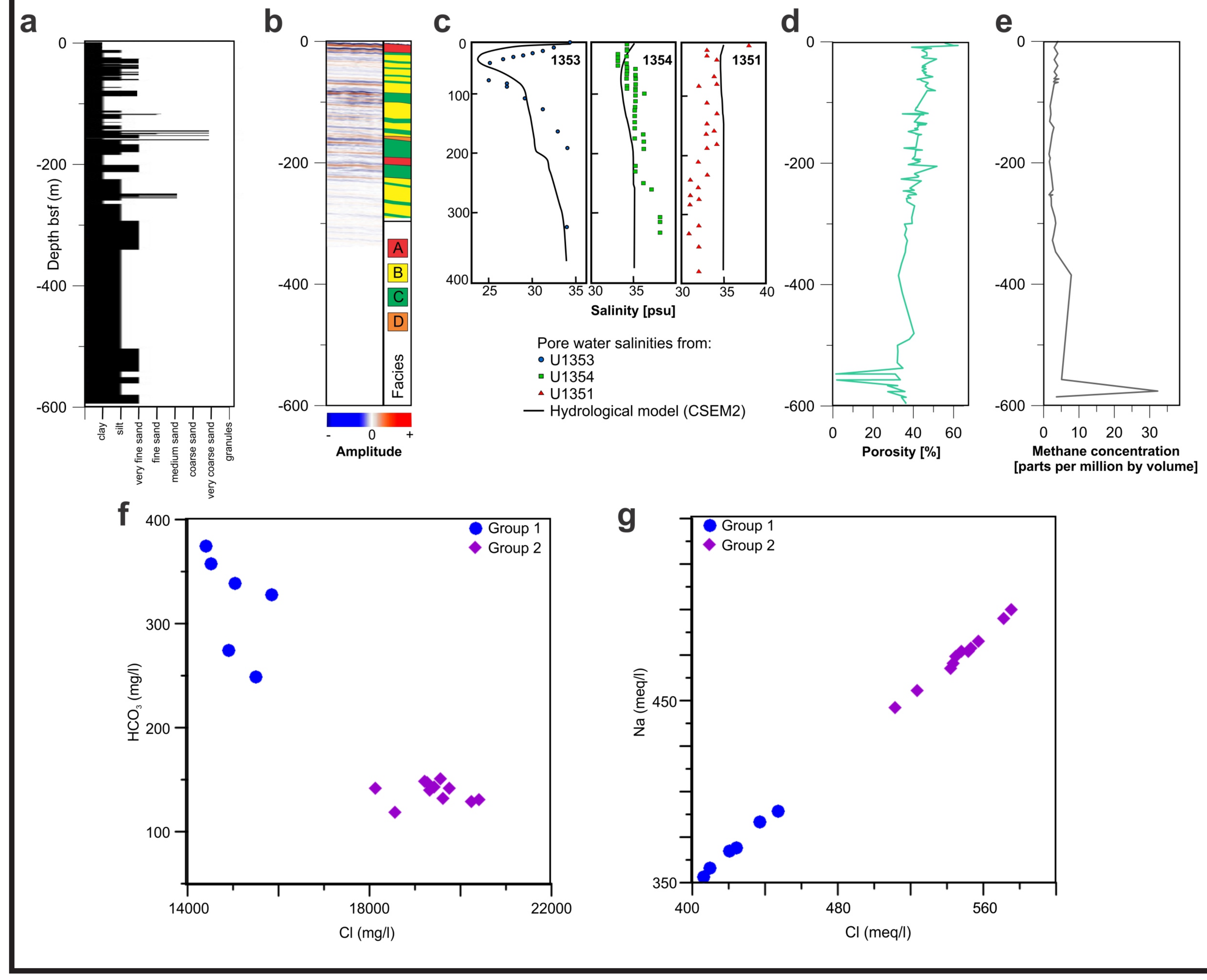


Fig. 1: Study area. Three dimensional digital elevation model of the Canterbury Basin. The location of the rivers, onshore gravel aquifer, onshore well Ealing-1, CSEM and multichannel seismic reflection lines, and boreholes U1351, U1353 and U1354, is shown.

2 Study area



We have chosen the Canterbury Bight, located offshore of the eastern coast of the South Island of New Zealand (Fig. 1), as our study area because this continental margin potentially hosts one of the shallowest OFG systems globally, as indicated by a pore water salinity anomaly recorded in borehole U1353 from IODP expedition 317 (Fig. 2c) .

Fig. 2: Borehole U1353 data. Depth profiles of (a) sediment grain size, (b) seismic reflection data (from TAN1703 survey) and interpreted facies, (c) pore water salinity, (d) porosity, (e) methane concentration, (f) plots of HCO3 vs. Cl and (g) Na vs. Cl. Pore water salinity profiles, derived from the hydrological models for the site of boreholes U1353, U1353, and U1354, are included (c).

3 Results

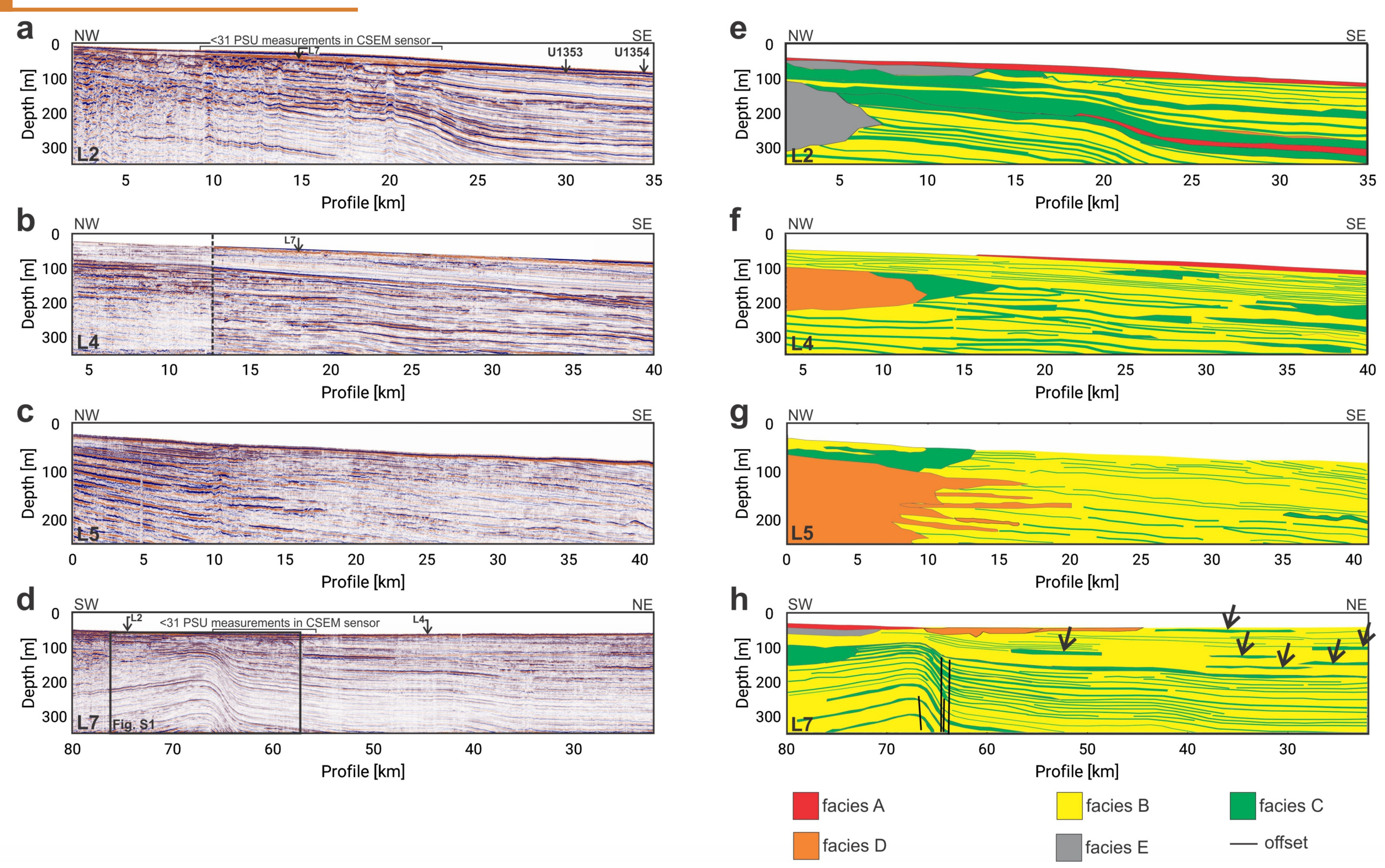


Fig. 3: Multichannel seismic reflection profiles. (a-d) Processed seismic reflection profiles along lines 2, 4, 5 and 7. (e-h) Interpreted facies. Offsets in seismic reflectors in line 7 are marked by black lines. Black arrows denote interpreted buried valleys infilled by coarse-grained sediments.

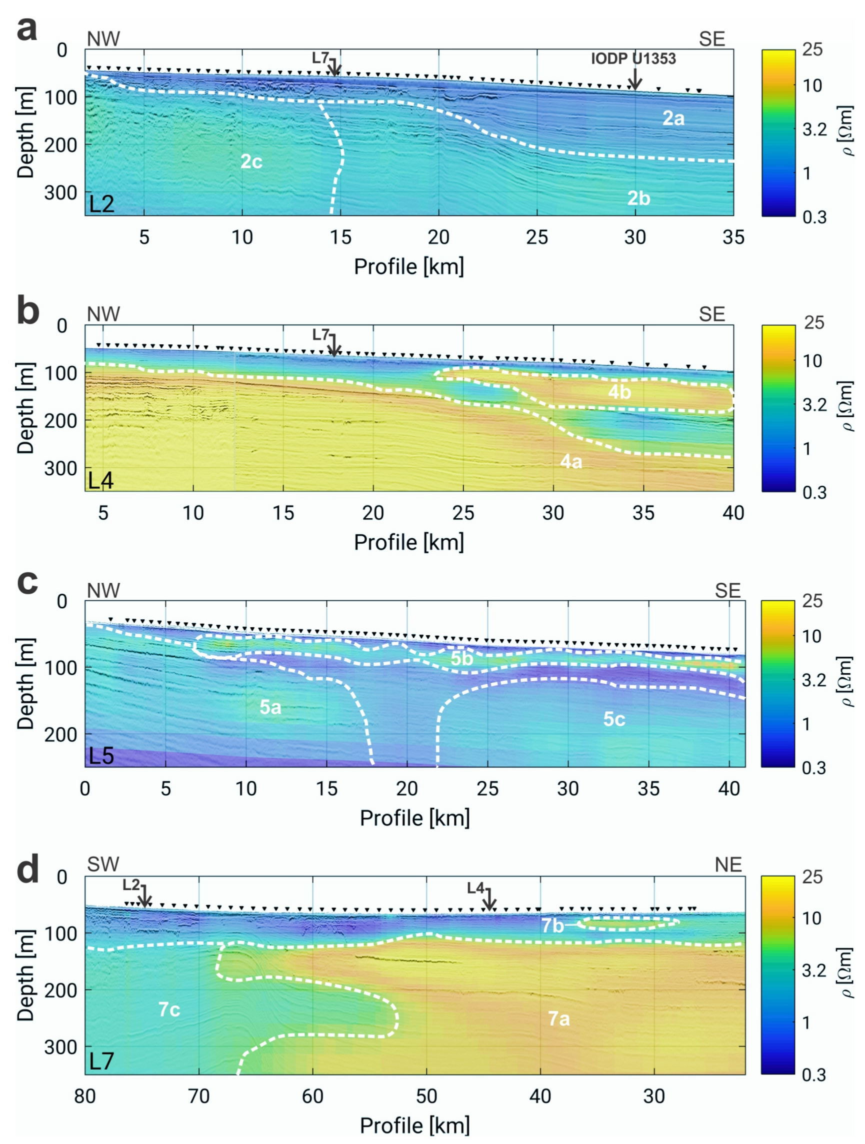


Fig. 4: CSEM lines. Interpreted resistive features from the data acquired along lines 2, 4, 5, and 7, overlaid on seismic reflection profiles.

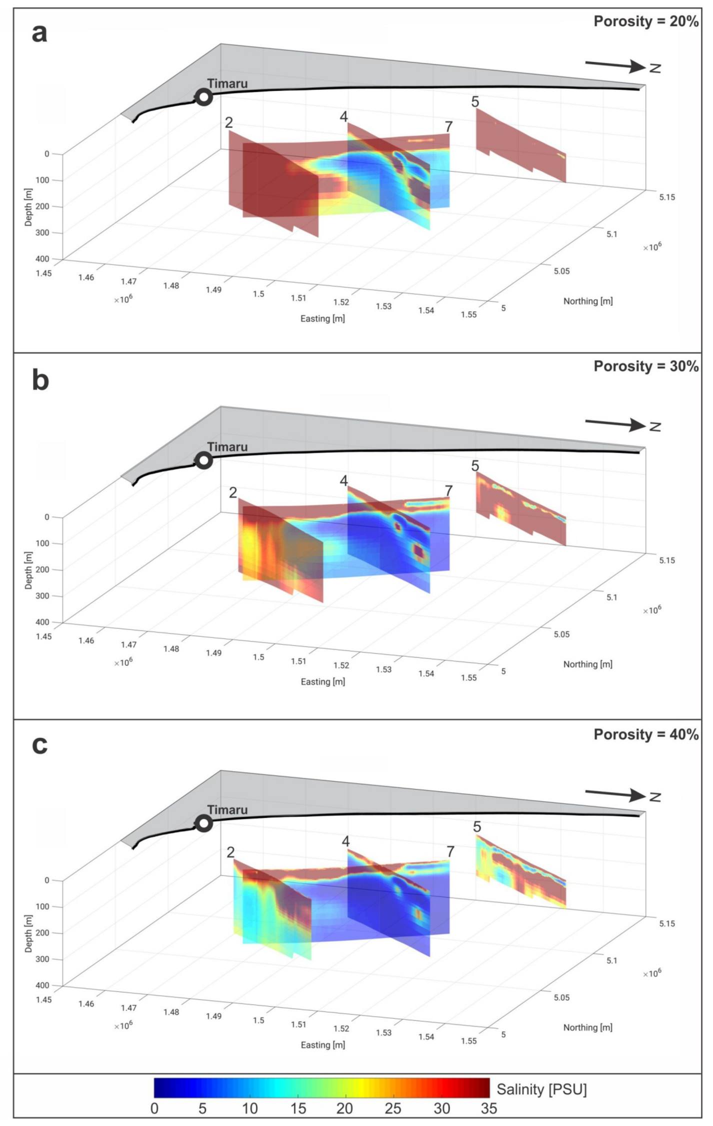


Fig. 5: Models of estimated sub-seafloor pore water salinity derived by applying Archie's Law and the Fofonoff and Millard algorithm. We used constant porosities of (a) 20%, (b) 30% and (c) 40%.

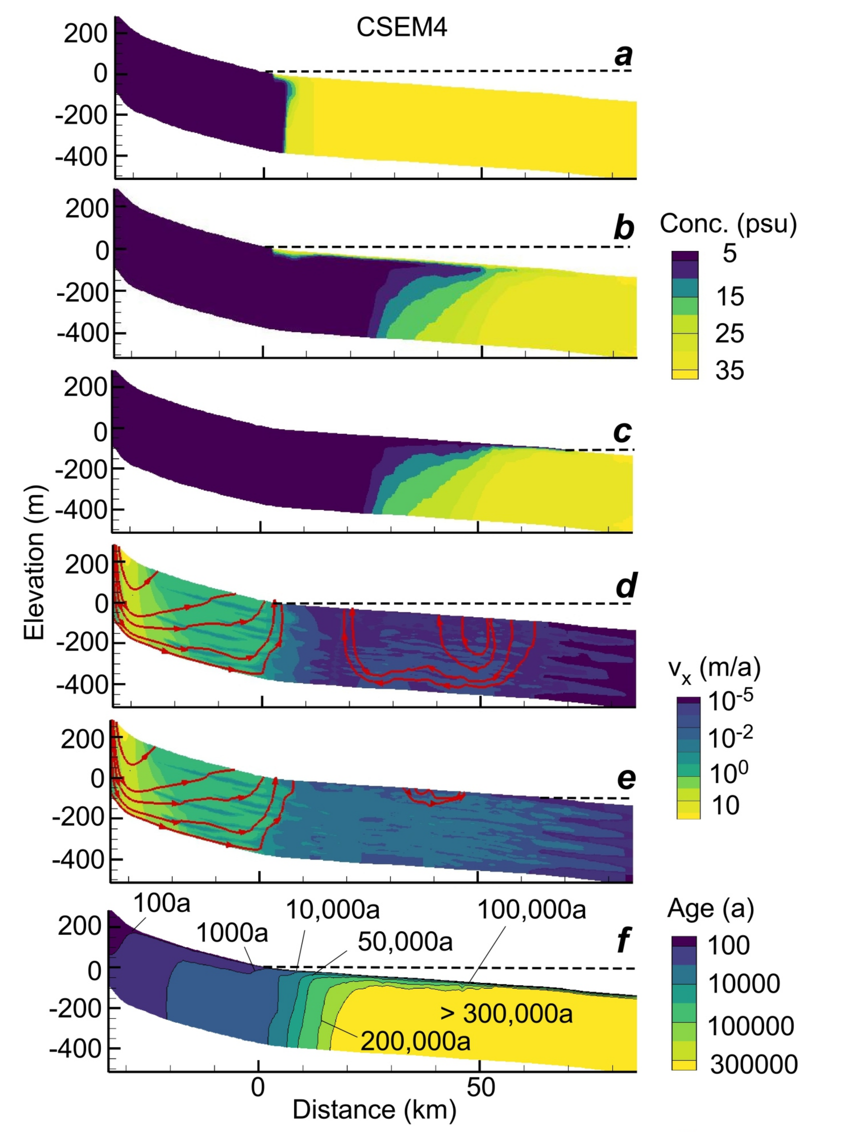


Fig. 6: Hydrological model results for line 4. (a) Computed present day salinity after 1 Ma using fixed, modern sea level conditions. (b) Computed present day salinity after 1 Ma using time-varying sea level conditions. (c) Computed salinity conditions at the last glacial maximum. Computed groundwater velocities (vx) from transient scenario today (d) and during the last glacial maximum (e). The red arrows in (d) and (e) are the groundwater streamlines. Computed present-day mean groundwater residence times from the transient simulation are shown in (f).

4 Conclusions

1. **Integration** of CSEM with seismic reflection data and hydrologic modelling, and constrained by borehole data, is a **powerful** approach to quantitatively characterise OFG.
2. The OFG system extends up to **60 km** wide and exhibits a **complex 3D structure**.
3. **Variability** of OFG salinity along-shelf is attributed to **multi-scale heterogeneity in the sedimentary and permeability architecture** of the shelf. **Normal faults** appear to constitute a flow barrier.
4. A **meteoric origin** and present-day connection to onshore aquifers are inferred.
5. OFG emplacement has mainly taken place during the last 3 glacial cycles via topographically driven flow.
6. Application of our approach in active margins with their steep topographies, is likely to **significantly revise** global volumetric estimates of OFG.