[PS]Top Seal Bypass Risk along the Southern Flank of the Gippsland Basin, South-eastern Australia*

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Abstract

The Gippsland Basin is a potential site for large-scale carbon storage developments in the state of Victoria. The potential depends on regional top seal, the Lakes Entrance Formation, in providing a secure subsurface environment. GeoScience Victoria investigations confirmed generally good to excellent containment potential but the formation is locally affected by the Late Oligocene to Holocene tectonic phase with fault reactivation, inversion and folding. The deformation risks the sea integrity and efficiency of the formation because seal capacity of the rock matrix can be overruled by the enhanced permeability of the fracture systems. This risk is quantified by calibrating various deformation related parameters with the hydrocarbon leakage and seepage indicators in the basin.

Quantifying fault seal potential along the southern flank of the Gippsland Basin, Australia

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Summary

Victoria's Gippsland Basin has been identified as highly prospective for large-scale geological carbon storage. Much of the long term strategic storage potential in the basins is dependent upon the regional top seal, the Lakes Entrance Formation. Previous GeoScience Victoria investigations confirmed the suitability of the regional top seal for the containment of CO_2 but as the Lakes Entrance Formation is locally affected by late Oligocene to Holocene fault reactivation, inversion and folding, the resultant deformation requires investigation. This deformation may affect top seal integrity and efficiency as the relatively greater permeability of local fault systems has the potential to provide pathways for fluids regardless of the seal capacity of the unfaulted rock matrix. Fault seal potential is therefore quantified in this study by calibrating various deformation related parameters with hydrocarbon leakage and seepage indicators in the basin.

Rationale

The offshore Gippsland Basin (Fig. 1A) is a prolific hydrocarbon province with substantial brown coal deposits in the onshore Latrobe Valley. Resources from these areas will remain critical to Victoria's energy supply into the future. The long-term use of the fossil fuels will be contingent upon a reduction in the emitted greenhouse gases for which geological carbon storage is a key mitigation strategy. The efficiency and integrity of the top seal in the Gippsland Basin is important for the secure containment of stored CO_2.

Substantial subsurface data from the Gippsland Basin including extensive 2D and 3D seismic surveys and hundreds of wells and boreholes (Fig. 1C) form the basis for a robust regional assessment. Although the data distribution is biased by the location of the fields with most of data located in the Central Deep, the GDPI10 2D seismic survey, acquired in 2010, improves data coverage along the southern flank of the basin.

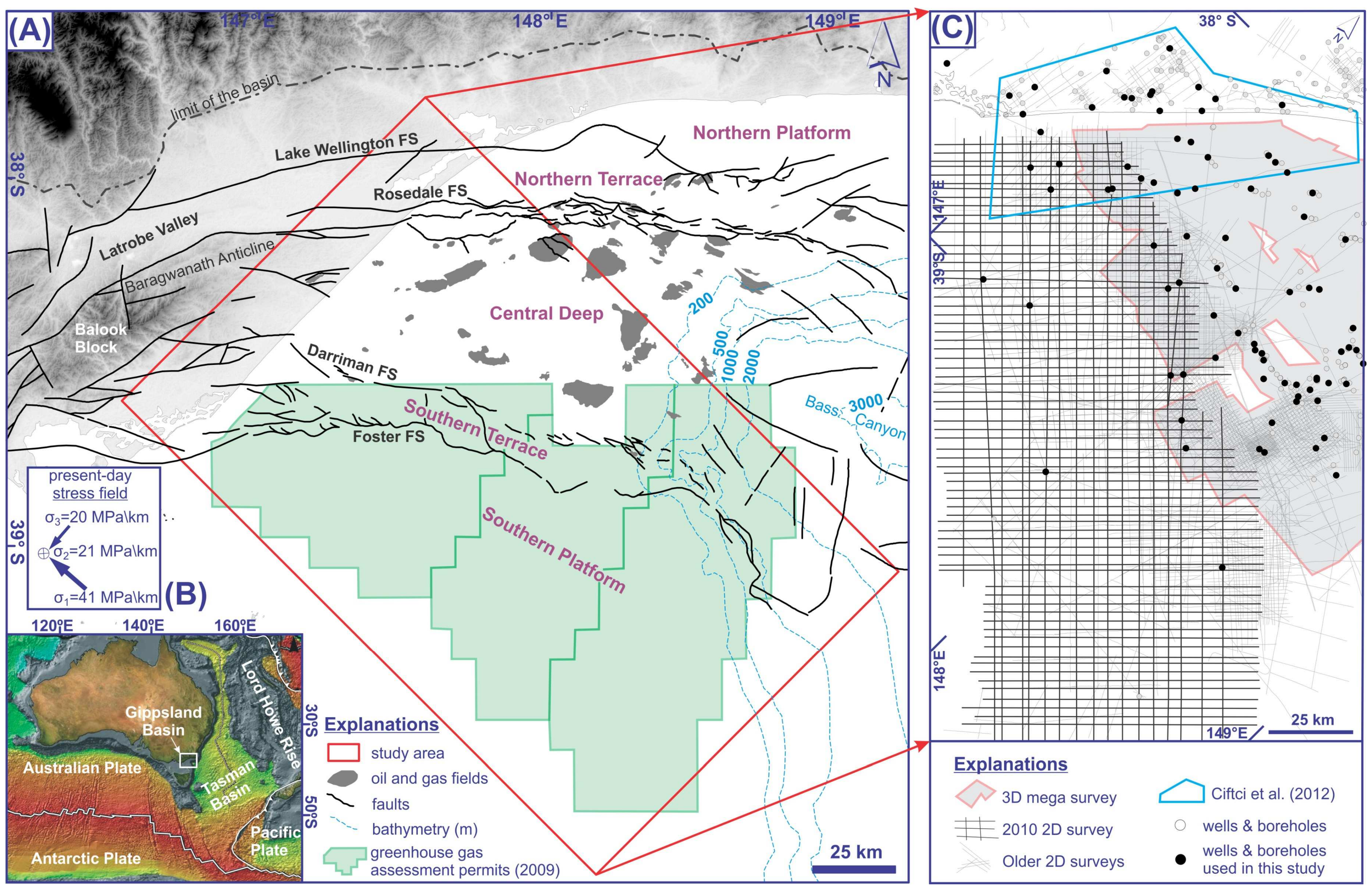

Figure 1: (A) A map of the Gippsland Basin showing the boundaries of the study area, the main fault systems, basin elements, major oil and gas fields and the greenhouse gas exploration blocks released in 2009; (B) Present-day stress tensor in the basin; and (C) The available subsurface data set in the study area.

Key Geological Points

- Multiple reservoir within the Latrobe Group have been confirmed through decades of oil and gas production (Fig. 2). These reservoirs are potentially suitable for geological carbon storage.
- The Lakes Entrance Formation is composed of fine grained clayey and calcereous lithologies and provides the ultimate regional barrier to the upward migration of buoyant fluids in the Latrobe reservoirs. Intra-formational seals are locally well developed but lack lateral continuity to be efficient at the basin scale (Fig. 2).
- The top seal has been affected by post Latrobe deformation during the TP-IV (Fig. 2) resulting in reactivation and inversion of the existing faults (Fig. 3).
- Natural seismicity confirms current activity along some fault segments (Fig. 3A).
- Previously reported hydrocarbon leakage and seepage indicators appear to be co-located with some of the fault zones (Fig. 3A).

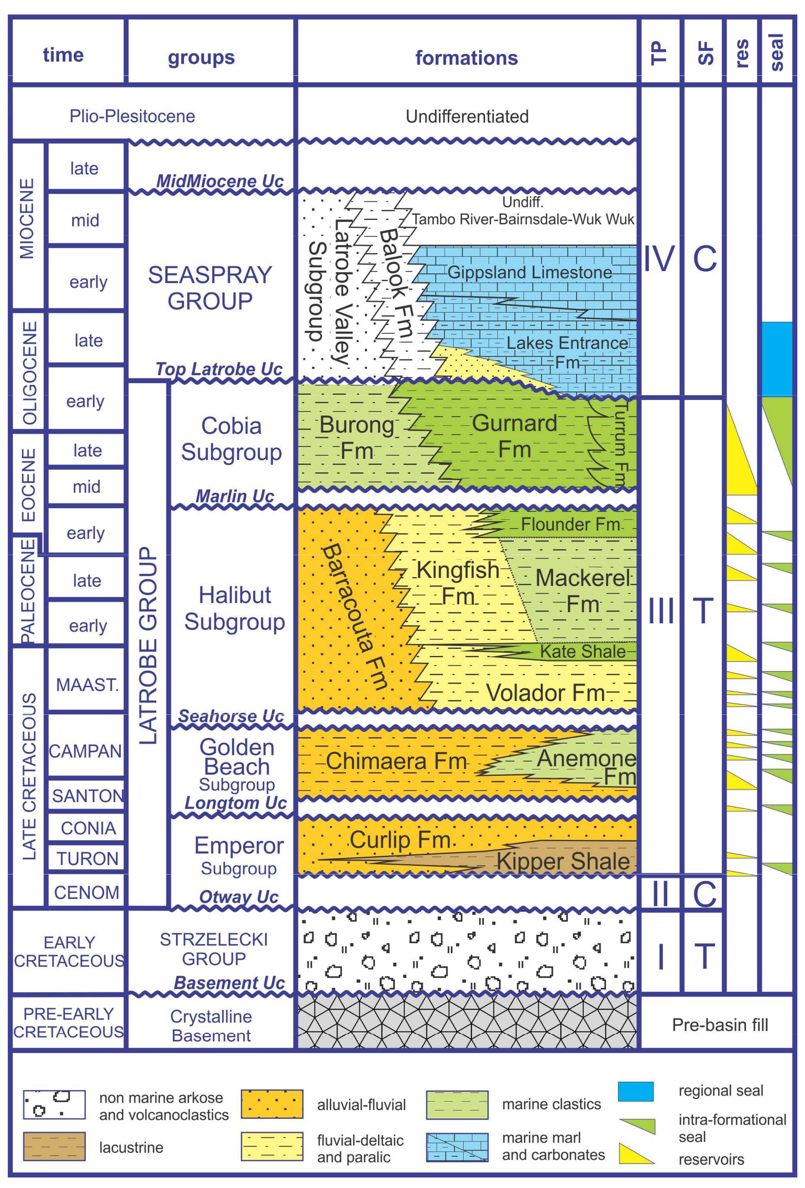

Figure 2: Generalized stratigraphic chart of the offshore Gippsland Basin. Abbreviations: TP – tectonic phase; SF – stress field; C – compressional; T – extensional.

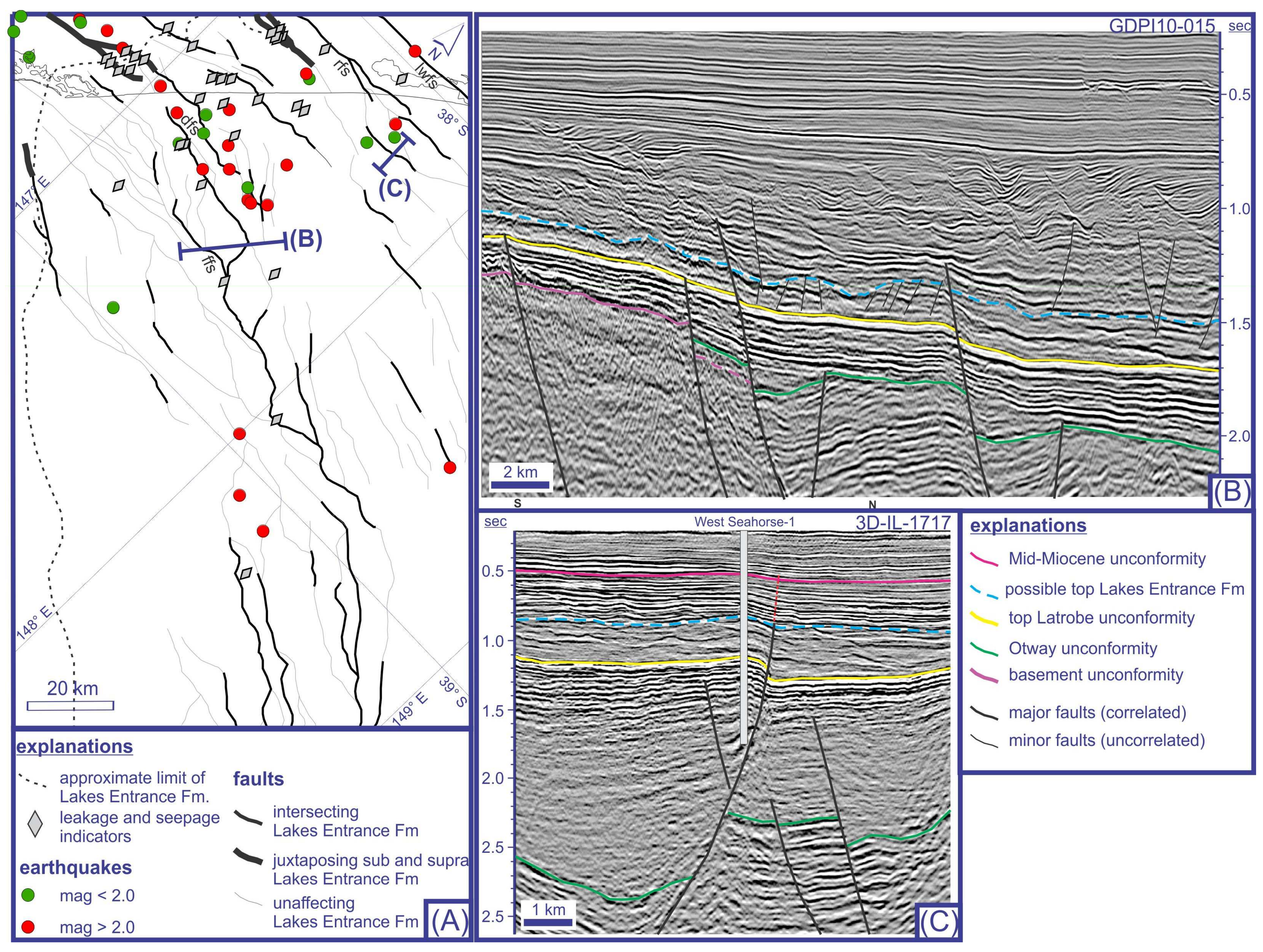

Figure 3: (A) Map showing fault segments affecting the Lakes Entrance Formation, historical earthquake records (Geoscience Australia, 2012) and the location of hydrocarbon leakage and seepage indicators (Goldie Divko et al., 2010); (B) Representative seismic profile illustrating the style of faulting and displacement of key horizons along the southern flank; and (C) Representative seismic profile illustrating the evidence of inversion and reverse offsets in the Lakes Entrance Formation.

Working Hypothesis

Faults may provide local fluid pathways through the top seal and may result in decreased ability of the top seal to contain reservoir fluids. The level of deterioration is related to: (i) Intensity of deformation; (ii) membrane seal capacity of the fault rocks; and (iii) the critical stress state on the fault plane. The fault seal efficiency can be quantified based on the investigation of these factors using various geological parameters calibrated against leakage and seepage indicators.

FOR FURTHER INFORMATION
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Results

SGR | Strain | Slip tendency

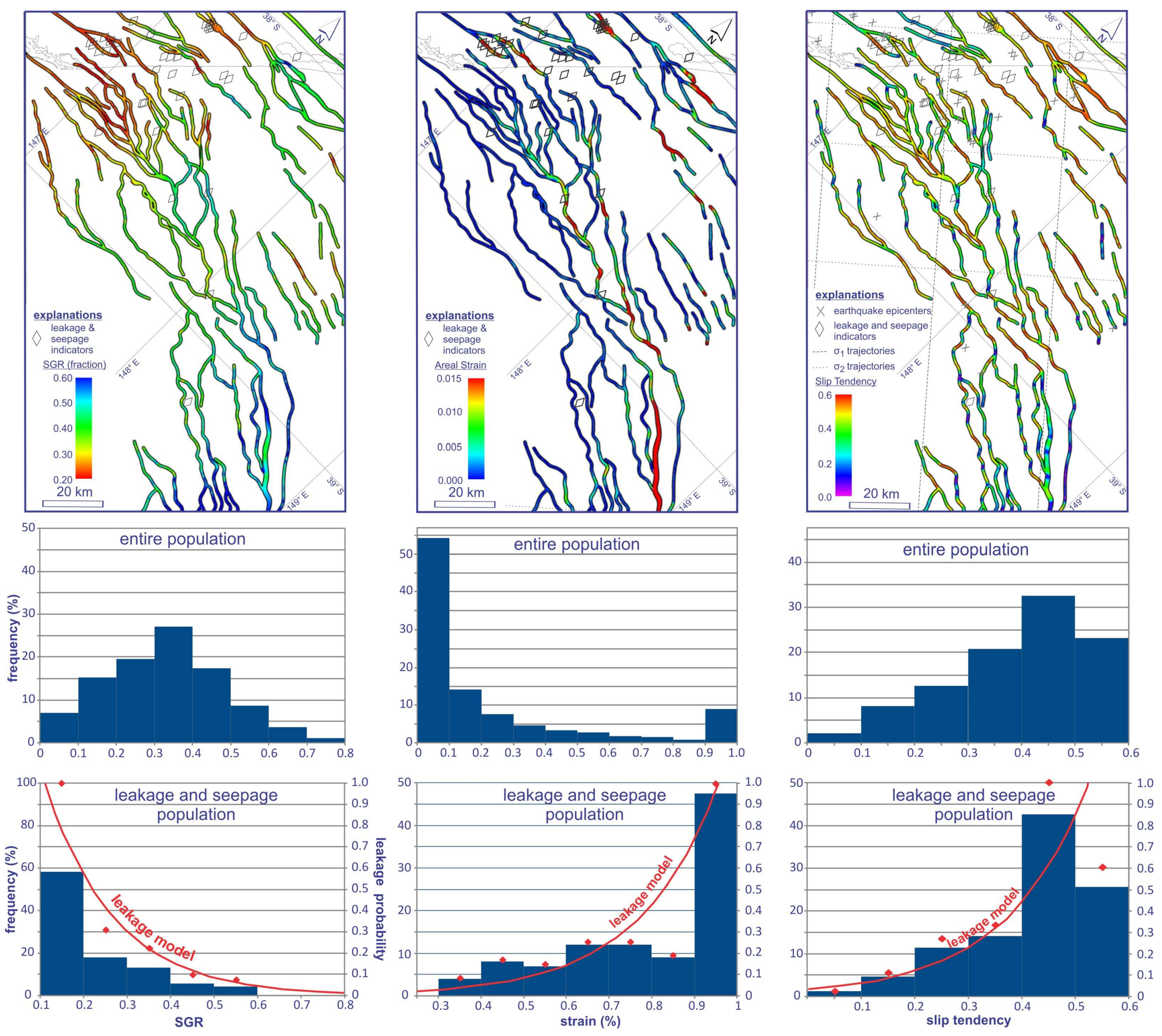

Figure 4: Shale gouge ratio (SGR), strain and slip tendency parameters were found to correlate to the locations of the known hydrocarbon leakage and seepage indicators in the basin. Top row – maps of SGR, strain and slip tendency in the study area; middle row – distribution of the entire population of the parameters; and bottom row – distribution of the parameters only at the hydrocarbon leakage and seepage indicator locations. Leakage probability models were defined for each parameter based on these distributions.

Top seal potential | Volume of shale | Fracture density

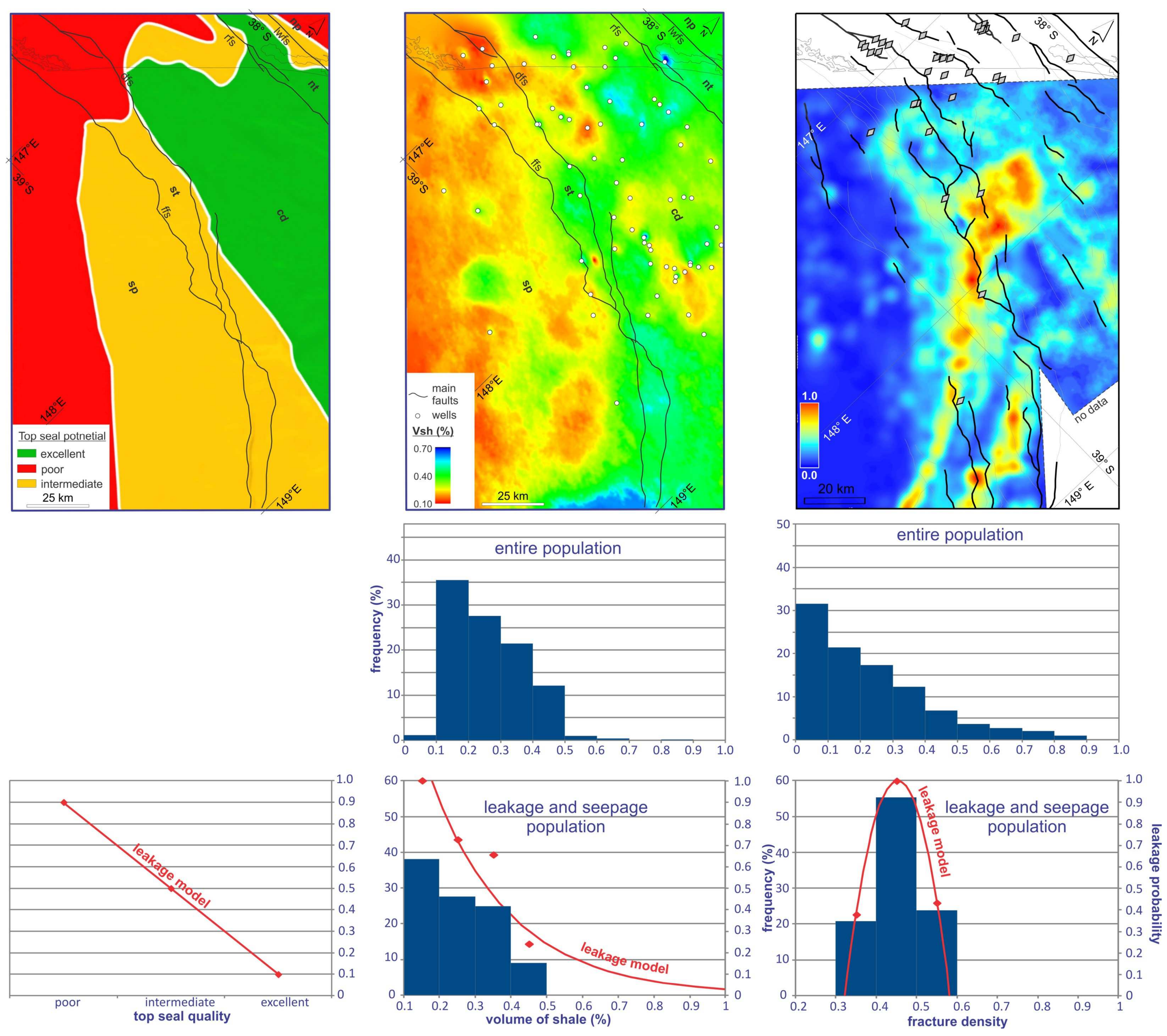

Figure 5: Top seal potential, average volume of shale fraction and fracture density of the Lakes Entrance Formation. These attributes potentially affect the seal efficiency of the formation. Top row – maps of top seal potential, volume of shale and fracture density of the Lakes Entrance Formation; middle row – distribution of the entire population of the attributes; and bottom row – distribution of the attributes only at hydrocarbon leakage and seepage indicator locations. Leakage probability models were defined for each attributes based on these distributions.

Fault leakage factor

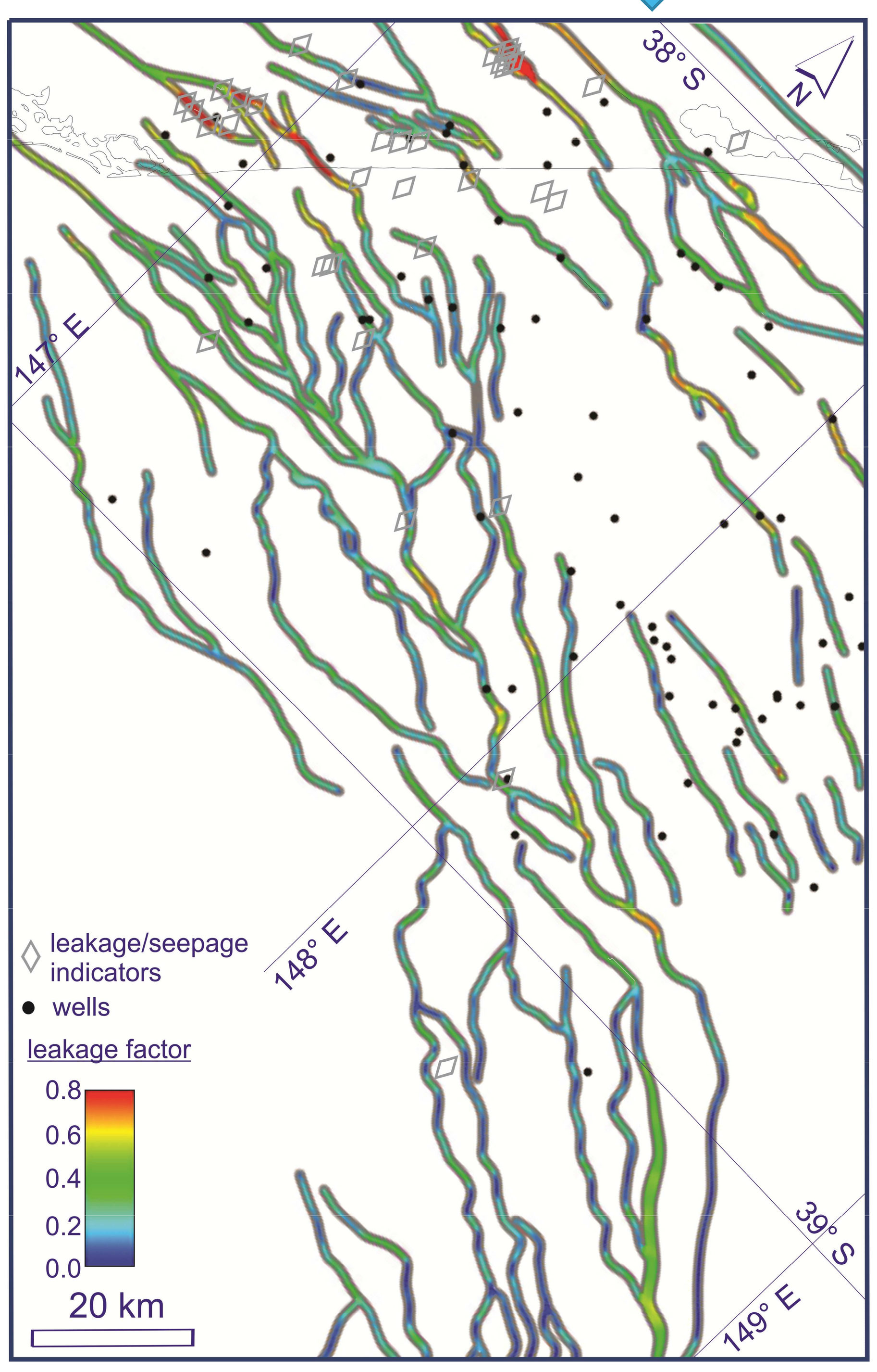

Figure 6: The fault leakage factor map is calculated by averaging the leakage probabilities modelled based on the SGR, strain and slip tendency parameters (Fig. 4).

Integrated leakage factor

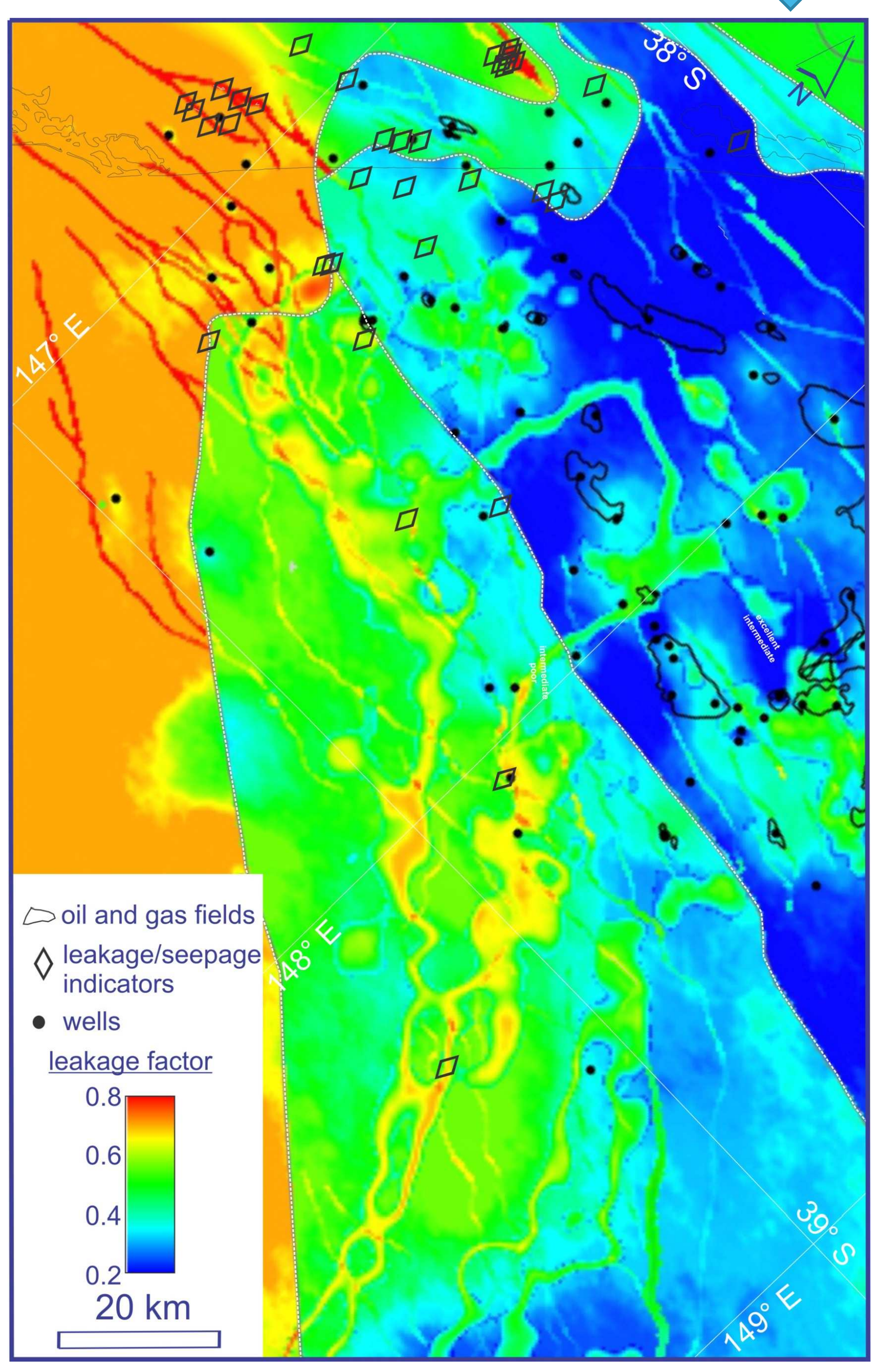

Figure 7: The integrated leakage factor map incorporates the top seal potential, volume of shale and fracture density attributes of the Lakes Entrance Formation (Fig. 5) with the fault leakage factor map (Fig. 6). It is a first-order basin-scale map depicting the overall top seal efficiency in the Gippsland Basin.

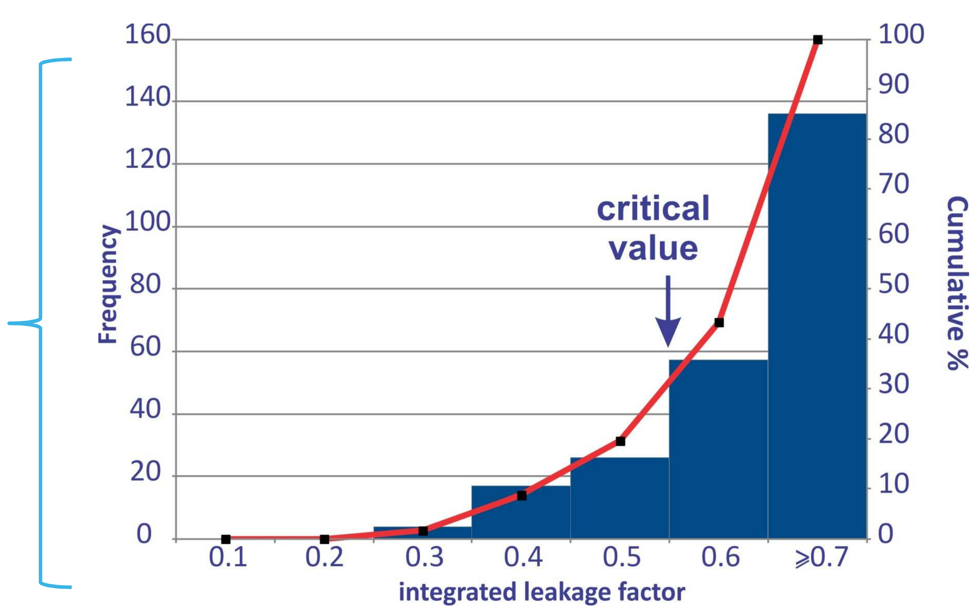

Figure 8: Distribution of the integrated leakage factor at the sites of hydrocarbon leakage and seepage indicators. The values above 0.6 suggest high potential for seal inefficiency.

Conclusions

The leakage factor maps provide a first order assessment of the fault and top seal efficiency in the Gippsland Basin and depicts critical areas where the hydrocarbon leakage probability over geological time is high and further in-depth analyses are required. However, these maps may not be directly applicable to reservoir scale considerations due to lack of sufficient detail on fault geometry and segmentation as well as local stress field perturbations.

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