Control on Pleistocene shelf drainage by post-Eocene stratigraphy of the Gippsland Basin

Mark Bunch*
Australian School of Petroleum
University of Adelaide
mark.bunch@adelaide.edu.au

**presenting author asterisked*

SUMMARY

The Jemmys Point Formation – uppermost member of the cool-water carbonate Seaspray Group – records a terrestrial drainage system that traversed the now submerged continental shelf of the Gippsland Basin during the latest ice age. A partial network of large sinuous channels that includes a few diffuse areas of arced broadening (probably recording local slack-water lacustrine conditions), has been imaged by aeromagnetic survey data and now large-scale 3D exploration seismic data. Channels are well resolved in narrow-band quadrature phase exploration seismic data by a surface probe that runs along the first zero crossing of the seismic wavetrain. This corresponds closely with the modern-day bathymetric surface when assuming a seawater acoustic velocity of 1,500 m/s.

The stratigraphy of these channel features has not been ground-truthed despite the basin being a highly mature and productive petroleum province. In fact, it seems that their distribution is a 'negative' of the distribution of petroleum field areas. This fact leads to the consideration of two hypotheses: ongoing structural inversion of existing trapping structures at depth pushes channels away; or intervening zones of relatively high differential compaction subsidence pull channels towards them. No evidence was found to confirm the former hypothesis but this may be because the rate of local uplift does not outpace shelf-wide sedimentation (so cannot be resolved in seismic or seabed bathymetry data). By contrast, the loci of drainage channels appear to correspond well with regions of the thickest post-Eocene stratigraphy. This suggests that differential compaction subsidence has continued to hold the lowstand drainage system in place since a pre-cursor canyon head network was developed by the Mid-Miocene inversion maximum.

Key words: Gippsland Basin, Pleistocene drainage, river channels, 3D seismic data, compaction subsidence.

INTRODUCTION

The Jemmys Point Formation is the most recent stratigraphic unit present in the offshore Gippsland Basin. It is composed of alternating clastic limestone (grainstone) and siltstone (Mitchell et al., 2007). The top surface of this formation was traversed offshore during the latest glacial shelf exposure by a river channel drainage network imaged by first magnetic (Mitchell et al., 2007) and now 3D seismic survey data. None of the channel forms imaged has been sampled directly or intersected by a drillhole of any type so the composition of their fill material is unknown. Their acoustic properties however contrast sharply with background alluvial plain material – presumably Jemmys Point Formation proper – as their presence often causes a strong seismic polarity change, an amplification and a significant underlying seismic TWT push-down event. This implies opposite sign acoustic impedance contrasts with the overlying acoustic medium so both must be overlain by a thin, seismically irresolvable, veneer of post-Jemmys Point Formation sediment – perhaps a thin carbonaceous soil cover turned carbonaceous shallow marine mud – that separates them from the marine water column. Without precise information on their acoustic properties it is difficult to estimate their thickness though this could be inferred from channel widths.

All channels identified from seismic data appear to be extended reaches of rivers that discharge along the modern-day coastline. The imaged channel network however must be incomplete because it does not present as a recognisable modern drainage system (Figure 1). Most channels appear to discharge from north to south though there is a clear low-sinuosity west-to-east linkage that ultimately turns south before becoming seismically irresolvable. A main trunk channel measuring ~750 m wide developed in the south with deposits being thick enough that internal point-bar forms can be resolved. This appears to be the downstream outlet of one of three arced, broadened 'lacustrine' complexes to which both ancient Mitchell and Nicholson/Tambo rivers were tributaries. The trunk channel is seen to drain southwards and broaden again towards the edge of the Northern Fields seismic survey, before re-emerging as a large, confined, low-sinuosity channel that turns through ~90^{o} at the northern edge of the Bream 3D seismic survey area. It then continues ESE into the GAP04E survey where it is projected to converge with another, more highly sinuous channel arriving from the NW. These channels are seismically irresolvable prior to their confluence but their trajectory suggests they would emerge from the palaeo-shelf in the vicinity of the Anemone Canyon Head (Huang et al., 2014). The southernmost trunk channel is henceforth tentatively referred to as the 'Anemone River'.

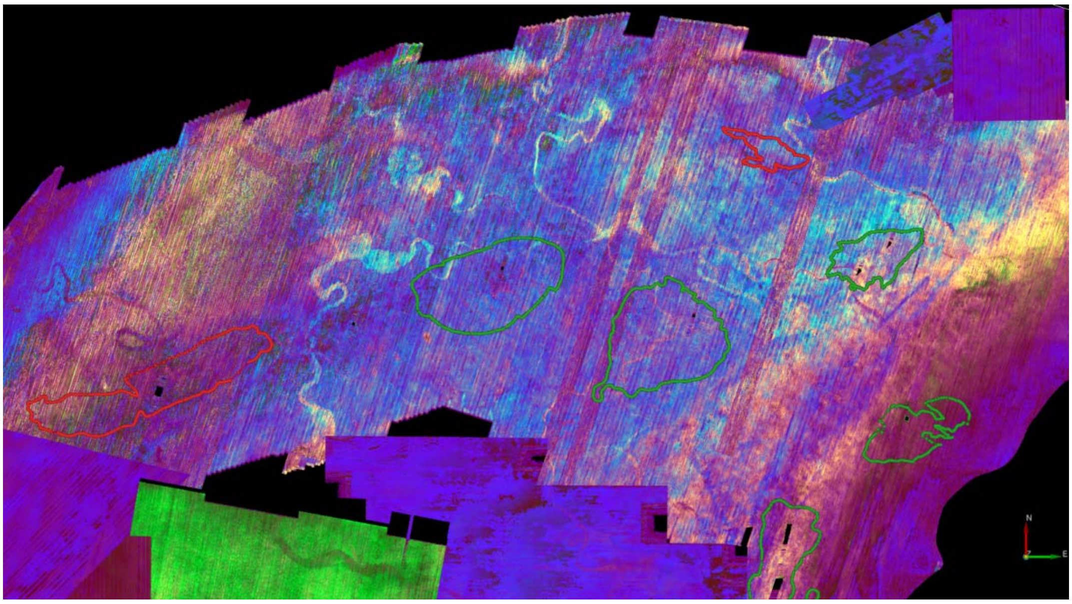

Figure 1: An attribute blend at the bathymetric surface of the 3DGeo Gippsland MegaSurvey. The blue channel is Instantaneous Phase, the green channel Instantaneous Amplitude and the red channel is the standard signed seismic amplitude. Key petroleum fields are shown by red (gas) and green (oil) polygons. The Pleistocene drainage channel network shows good contrast with the surrounding alluvial plain.

The striking feature of the distribution of imaged channels is that they do not cross petroleum field areas. There is one exception, a channel that crosses the Turrum/Marlin fields complex. This also happens to be the only channel (reach) identified without an eastward component to its trajectory. Even more striking are examples where channels appear to kink around the edges of field areas or divert to run between them (see Figure 1). Three of the four broadened reaches occur on the coastward (northern) side of a line linking Barracouta, Snapper and Longtom fields. If these broadened areas do represent a shallowing downstream discharge gradient that led to ponding of surface water, it is counterintuitive that they should occur landward of low sinuosity mid-shelf reaches. Seabed bathymetry indicates an essentially flat shelf that extends ocean-ward well beyond this area – further than backwater influence might be expected to extend. Both lines of evidence – channel diversions around fields and channel ponding upstream of fields – imply that the landscape overlying the fields themselves had developed subtle elevated features during the last glacial shelf exposure that formed an obstacle to surface drainage. A cause of this could have been ongoing regional neotectonic inversion that began in the Miocene-Pliocene (Dickinson et al., 2002) subsequent to Mid-Miocene structural inversion that formed petroleum traps at Latrobe Group level (McLean & Blackburn, 2013). A complementary mechanism of differential compaction subsidence may have operated between field areas that could have provided extra sediment accommodation to concentrate surface drainage flow.

These mechanisms have been observed to influence surface drainage loci elsewhere. In a modern example, abandoned concave meander loop scars evident in LandSat imagery show how the Taz River, a tributary to the Ob River Estuary in Siberia, has migrated northward away from an anticline developing in response to the collision of the Indian tectonic plate with the Eurasian tectonic plate 1000s of kilometres to the SSE (Allen and Davies, 2007). The arced, broadened channel areas of the shallow Gippsland Basin probably record the superposition of successive meander loops of a similar scale that record diversion of drainage while the overall drainage direction was consistently towards the lowstand shoreline.

Similar drainage effects have been recorded within seismic data. Maynard (2006) interpreted continual avulsion of smaller-scale surface drainage features in response to neotectonic elements developing nearby that influenced the same stratigraphic level (drainage converged obliquely towards accommodation provided by an active normal fault front). This resulted in an overall lateral shift of acoustically distinct material that records the loci of the trunk channel feeding an alluvial braidplain or alluvial fan feature.

METHOD AND RESULTS

The sensitivity of drainage systems to variations in substrate surface gradient is not well constrained. Surface gradients for natural river systems occur up to 0.5^{o} (Blair and McPherson, 1994), equivalent to ~9-in-1000. The Gippsland Basin shelf slope in the general direction of drainage (SE) is less (Figure 2). Pleistocene channels so far identified have a sinuosity of 1.15-2.15 so thalweg elevation gradients are incredibly low. These channel forms are therefore definitely not extensions of canyon heads feeding Bass Canyon (Huang et al., 2014). Their planform architecture is also incompatible with that of a canyon head system that, given time, would incise and dissect the shelf area when fully exposed (Huang et al., 2014). Changes in drainage network morphology occur in response changes in the balance of sediment transport dynamics, which are controlled by channel head profile and sediment load. Local neotectonic uplift would act to reduce the upstream head gradient and increase the downstream head gradient (assuming flow is not completely diverted). Constant inflow rate river channels compensate in the short-term by lengthening upstream and shortening downstream, i.e. they become more sinuous upstream and less sinuous downstream. In lengthening, they reduce their head and thalweg gradients, so sediment transporting capacity reduces. When a river can no longer canabilise alluvial plain sediments, the flow broadens and shallows. The 'Anemone River' occurs in an extensive gap downstream of the notional line that links major field areas and demarcates the hypothesised landscape obstacle that may have caused the ponded broadened reaches and high sinuosity channels on the inner-shelf. It is large, low sinuosity, shows evidence of active sedimentation (stepping through seismic slices shows snapshots of point bars that appear to have migrated longitudinally) but does not run parallel to median shelf slope azimuth (135^{o}). These are all geomorphological arguments to suggest local neotectonic effects influenced surface drainage across the Gippsland Basin shelf during the last glaciation.

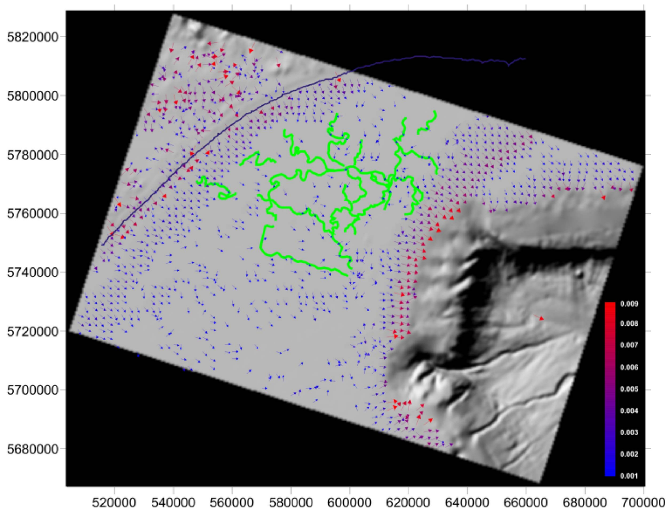

Figure 2: Shaded relief image of Gippsland Basin bathymetry. Vectors show maximum surface gradients in the range 1-in-1000 to 9-in-1000 (the limit of natural rivers). Vectors are missing on the shelf where it is too flat to register, a band which coincides with the Pleistocene channels interpreted from 3D seismic data.

Differential neotectonic movements that might have controlled the distribution of shelf surface drainage should be revealed by subtle offlapping seismic reflectors and thickening of strata between areas overlying uplifted blocks. These features are not present within the Gippsland Mega Survey dataset. Figure 3 below shows a section through the data running along an arbitrary line linking through Barracouta, Snapper and Longtom fields. The modern bathymetric surface runs along the first zero crossing, which is pushed down in two-way time by material deposited in three of the post-glacial channel features interpreted in the shallowest part of the data. The three channels coincide spatially with local troughs of the mid-Miocene unconformity surface.

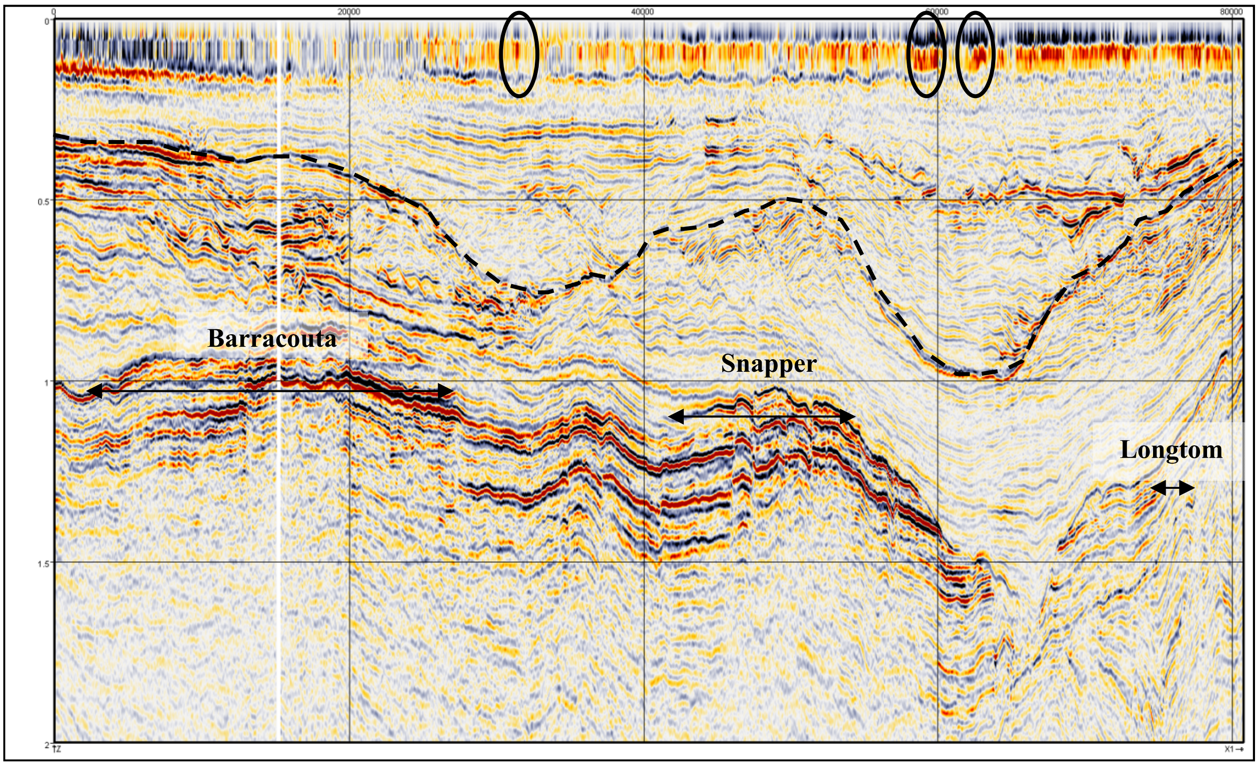

Figure 3: An arbitrary line through the 3DGeo Gippsland MegaSurvey that links through Barracouta, Snapper and Longtom field areas. These fields sit within Latrobe Group reservoirs (high amplitude). Pleistocene channels are indicated by ovals highlighting signal amplification (high acoustic impedance contrast) and TWT push-down near the top of the section. The Mid-Miocene unconformity is shown by the dashed line.

Figure 4 implies that local troughs in the Mid-Miocene unconformity surface are a proxy and perhaps the primary control on the distribution of the Pleistocene channel system. The topology of the unconformity partially mimics the Top-Latrobe Group surface associated with the majority of petroleum fields in the basin. Latrobe Group trapping structures developed during the middle Miocene when compression and structural growth peaked following cessation of seafloor spreading in the Tasman Sea (McLean & Blackburn, 2013). The creation of negative accommodation led to a canyoning phase that ate down into what was then a cool-water carbonate shelf, and this exaggerated structural dissection of the then bathymetric surface. Canyon heads of the proto-Bass Canyon were active in the mid-shelf area of today (Maung and Cadman, 1992; McLean & Blackburn, 2013) and may have been transitioning into river channels since then during periods of exposure as the shelf began to build and prograde (see Figure 4 below).

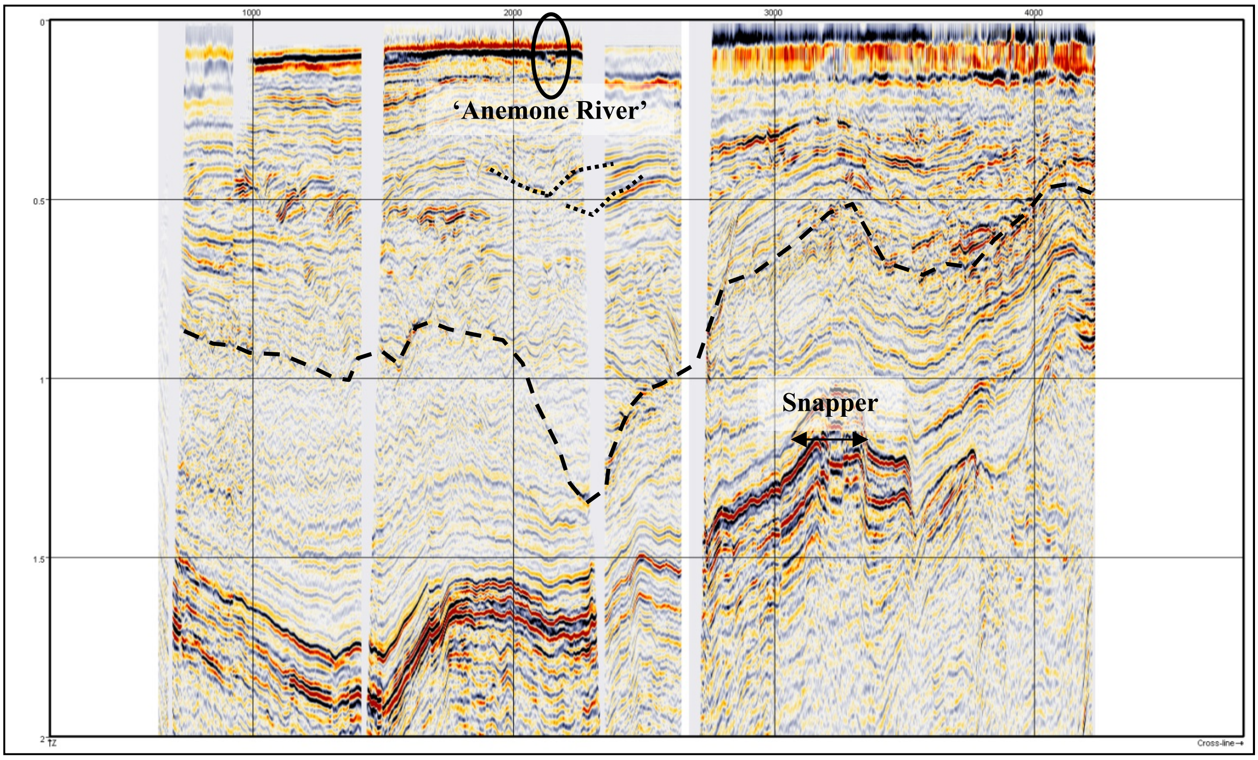

Figure 4: Inline 2807 from the 3DGeo Gippsland MegaSurvey. The Snapper oilfield is shown. The 'Anemone River' is indicated by an oval highlighting TWT push-down near the top of the section. The Mid-Miocene unconformity is shown by the dashed line. Two pre-cursor canyon head surfaces are dotted in the same lateral vicinity as the modern 'Anemone River'. All three channel forms overlie a sharp local trough in the Mid-Miocene unconformity surface.

What it is that controls the persistent location of Pleistocene river channels atop an essentially flat lowland area when the modern shelf was exposed, must be the ongoing process of differential compaction subsidence. This occurs ostensibly within those pre-determined intra-field areas. A quick test of this idea was conducted by gridding isopachs of major post-Eocene stratigraphic packages bounded by the Mid-Miocene unconformity surface. Figure shows these in relation to the distribution of interpreted Pleistocene drainage channels (Figure 5).

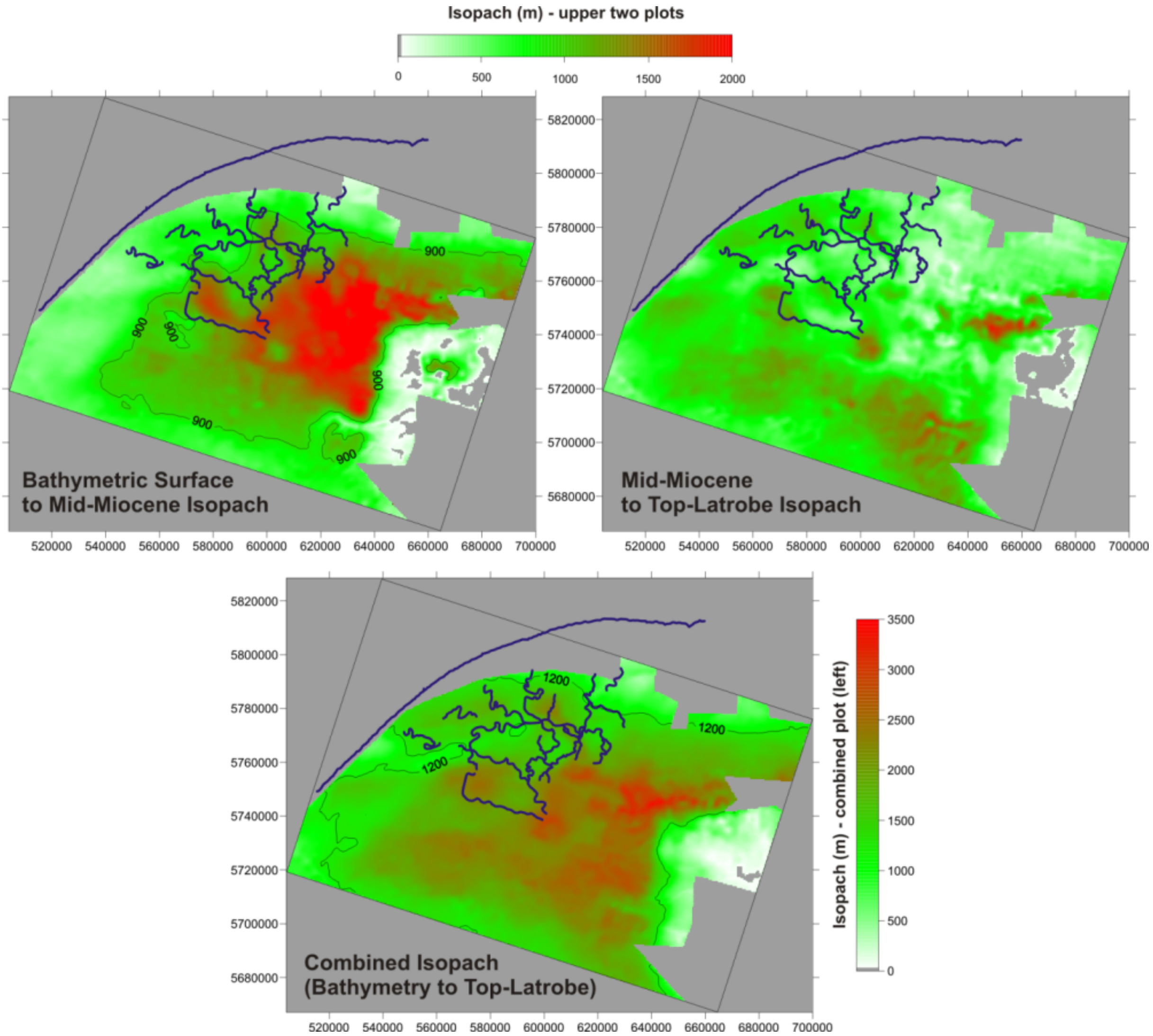

Figure 5: Isopachs generated according to McLean & Blackburn (2013). The modern coastline and interpreted Pleistocene river channels are shown in dark blue. A single isopach contour is included for the purposes of clarity, where appropriate.

Figure 5 demonstrates a compelling argument to suggest that the loci of Pleistocene drainage at last shelf exposure was pre-determined by the thickest post-Latrobe Group succession. Some channels diversions are explained by a tendency to follow the thickest post-Mid-Miocene package, some by a similar tendency to follow the thickest early Seaspray Group succession (Mid-Miocene to Top-Latrobe). All are explained by a combination of the two. Disconnected channel reaches sit within what would have been local high accommodation zones on the inner-shelf where local compaction subsidence rates were greatest and therefore preservation potential was greatest. High coordination number channel confluences appear to occur at the knickpoints of proto-canyon heads while broadened, ponded areas occur where individual channels flowed towards thin isopach areas with low compaction subsidence accommodation rates. Lastly, the sharp ~90^{o} turn of the ‘Anemone River’ (the southernmost channel) is accounted for by its flow towards a similar low compaction subsidence barrier and the draw of a high compaction subsidence, combined isopach high to the east. Cases where a channel trajectory runs sub-parallel to a combined isopach high but not directly over it can be accounted for by lateral migration as a result of autocyclic lateral accretion of clastic channel bodies.

CONCLUSIONS

A Pleistocene drainage network has been imaged by 3D exploration seismic data acquired across inner and mid-shelf areas of the Gippsland Basin. The river channel system operated during the last continental shelf exposure and is detectable thanks to sediment backfilling during the latest post-glacial marine transgression. The distribution of the channel network was pre-determined by structural dissection and erosion of basin stratigraphy resulting from the Mid-Miocene inversion maximum. Though later, more regional Miocene-Pliocene inversion may exploit some of the same neotectonic elements locally, the effect is thought to be relatively subdued. The key control on the distribution of the Pleistocene drainage network is deduced to be high differential compaction subsidence, which is greatest where the post-Eocene stratigraphic package is thickest. Stratigraphic volume loss caused by carbonate diagenesis may also play a role, given these area areas where the post-Eocene carbonate succession is thickest. Such a mechanism would reinforce the effect of relatively high differential compaction subsidence, which provides a reason why nearly all identified channels do not encounter operating petroleum field areas where their stratigraphy might have been ground-truthed.

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