Geology and 3D geological models for Queensland’s Surat and southern Bowen basins

Stratigraphic framework, data, methods and results

(OGIA/21/CD03/V1)

Version 1.0

December 2021

Office of Groundwater Impact Assessment

Version	Release date	Authorised by
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This publication has been compiled by the Office of Groundwater Impact Assessment, Department of Regional Development, Manufacturing and Water.

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1 Context

The Office of Groundwater Impact Assessment (OGIA) updates the Underground Water Impact Report (UWIR) for the Surat Cumulative Management Area (CMA) on a three- yearly basis, the latest update being the UWIR 2021 (OGIA 2021a). The Surat CMA incorporates parts of three large sedimentary basins: the southern part of the **Bowen Basin**, the **Surat Basin** and the western part of the **Clarence–Moreton Basin**. In the process of preparing and updating the UWIR, understanding of the geology and structural framework of the Surat and Bowen basins continues to evolve from the collective work undertaken by OGIA, the resource industry and research organisations, particularly since OGIA built the first geological model in 2021.

This companion document summarises the geological and structural framework of the component basins of the Surat CMA and details OGIA's approach and methodology in building the regional and sub-regional geological models to underpin various elements of groundwater conceptualisation and the reginal groundwater flow model (OGIA 2021b).

2 Evolution of geological knowledge in the Surat CMA

Understanding of the geology and structural framework of the Surat and Bowen basins continues to evolve. In 2019, OGIA prepared a detailed description of the geological understanding and geological modelling (OGIA 2019) to support the UWIR 2019. This was an update to the regional geological model from 2015, using wireline data from a further 2,700 new wells, new surface mapping by the Geological Survey of Queensland (GSQ) (Cranfield 2017) and a seismic dataset collated by the University of Queensland (UQ).

Since then, OGIA has further revised the geological model to support the next iteration of the UWIR in 2021. This revision is primarily driven by two factors: availability of a range of additional data and information; and a need for further refinement to support impact assessment from coal mining – an additional scope for the UWIR.

A summary of some of the key evolutionary stages in geological modelling and knowledge in the Surat Cumulative Management Area (CMA) are summarised in Table 2-1 below. The geological model was initially developed for the UWIR 2012 using existing datasets readily available at that time (GHD 2012) – including stratigraphic interpretations available via the Queensland Petroleum Exploration Database (QPED). Those interpretations had been developed by a number of different individuals and entities over a period of time, using multiple and often outdated stratigraphic schemas. The geological model for the UWIR 2016 was a major redevelopment, focused on the primary lithostratigraphic interpretation of geophysical logging of wells and bores to ensure consistency. Subsequent models by OGIA have used a similar approach, with addition of significant volumes of new data, more lithostratigraphic subdivisions, refinements in certain areas, more reliance on seismic data and an explicit representation of the major mapped faults in the Surat and Bowen basins.

Table 2-1: Evolution of geological knowledge in the Surat CMA

UWIR iteration	Key features of OGIA's geological models	Additional data and interpretation
2012	• Minex and Surfer model • 19 units • no faults • more than 5,000 wells used as input data	
2016	• Petrel model • 19 units • 750-m grid resolution • 17 active faults • about 5,000 wells • about 2,000 water bores	• regional lithostratigraphic interpretation from geophysical logs • regional fault systems • water bores data inclusion • nine-second digital elevation model
2019	• Petrel model • 21 units • 250-m grid resolution • 32 active faults • about 7,700 wells • about 24,500 water bores	• new geological outcrops from GSQ • 2,700 additional wireline-logged wells • remapping of the extent and thickness of the shallow Cenozoic units using information from water bore records • revised mapping of the geological faults • seismic dataset from UQ • revised mapping of the contact zones between the Bowen and Surat basins • one-second digital elevation model
2021	• same regional geological model structure as 2019, with the inclusion of the Walloon Coal Measures subdivision and revised Horrane Fault trace • sub-regional geological models – Northern Coal Area, New Acland and Horrane Fault	• Walloon Coal Measures subdivision created based on petroleum wells (drilled up to 2017) and coal hole data • revised Cenozoic extent using detailed surface geology – 1:100,000-scale mapping by GSQ • revised seismic interpretation and depth-conversion in the areas of the Horrane Fault and Hutton-Wallumbilla Fault

3 Geological basins

The Surat CMA incorporates parts of three large sedimentary basins: the southern part of the **Bowen Basin**, the **Surat Basin** and the western part of the **Clarence–Moreton Basin**. Geologic formations within the three basins mainly comprise various layers of sandstone, siltstone and mudstone that were primarily deposited by rivers and lakes, with occasional marine influences.

The geological basins and major structural elements in the Surat CMA are shown in Figure 3-1. The Bowen Basin is the deepest and oldest of the three basins, running north–south through the centre of the region. Overlying this is the Surat Basin, covering most of the central and southern parts of the Surat CMA. The sediments of the Clarence–Moreton Basin interfinger with those of the Surat Basin west of Dalby and Cecil Plains. Overlying these basins are extensive areas of unconsolidated younger alluvial sediments and volcanic basalts.

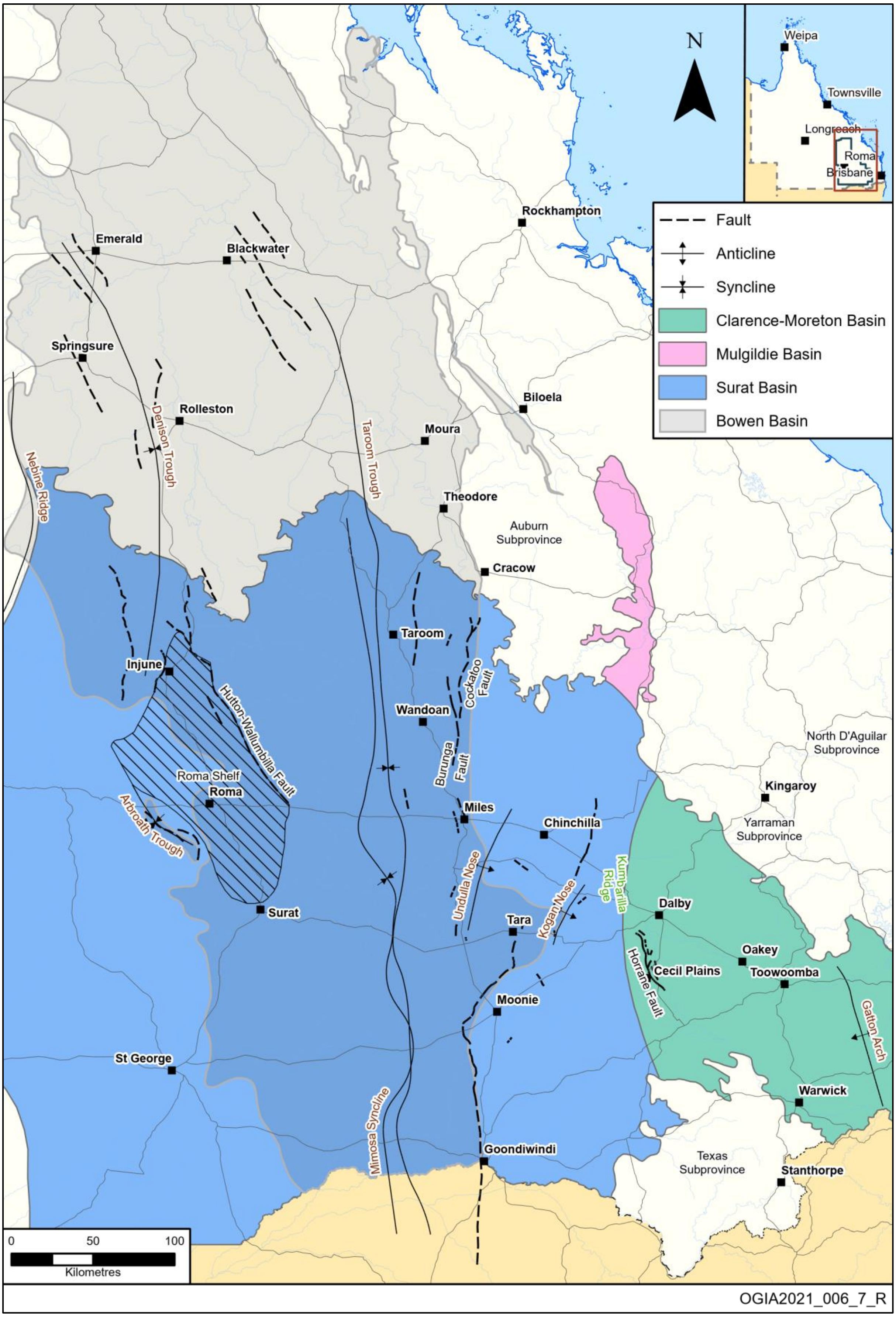

Figure 3-1: Geological basins and major structural elements in the Surat CMA

The most comprehensive summary of the stratigraphy of the study area is provided by Green et al. (1997) and is used by OGIA as the main guide in defining the hydrogeological units within the Surat CMA. A summary of the recognised stratigraphic units within the Bowen and Surat basins, within the Surat CMA, is provided in Figure 3-2.

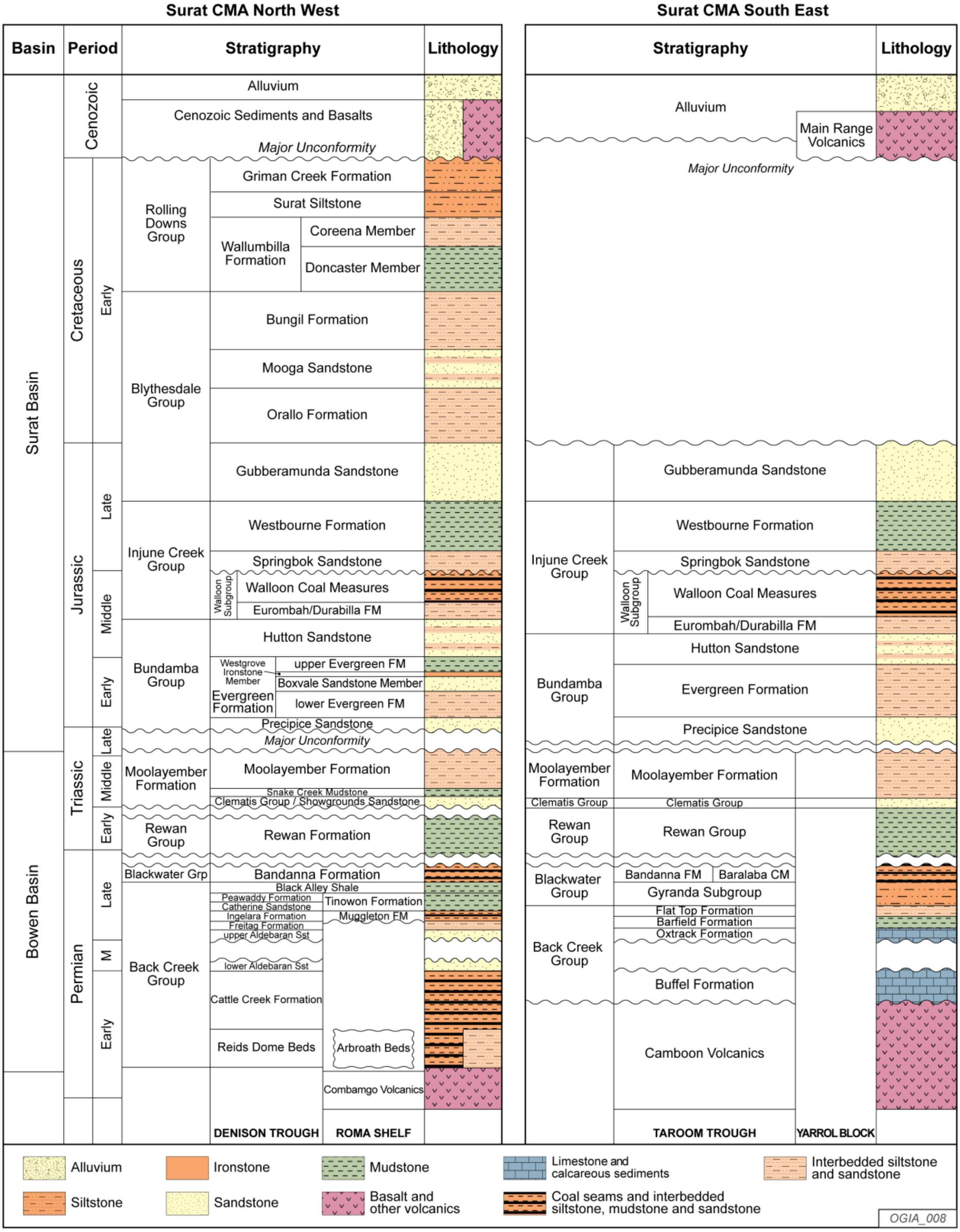

Figure 3-2: Stratigraphy of the Surat CMA (after Jell 2013)

The geology of the Bowen Basin is particularly complex and the stratigraphic formations have been simplified somewhat to represent unique hydrogeological units. The units of primary interest are the Late Permian CSG-producing coal seams of the Bandanna Formation and Triassic units above these coal seams, including the artesian aquifers within the Clematis Group and equivalents.

Within the Surat Basin, the stratigraphy of Green et al. (1997) is used with the following exception: the division between the Springbok Sandstone and Westbourne Formation is transitional and has in the past been inconsistently subdivided. OGIA has divided this into three consistent units: an upper siltstone/mudstone-dominated Westbourne Formation, a middle interbedded sandstone/siltstone/coal-dominated upper Springbok Sandstone, and a sandstone-dominated lower Springbok Sandstone. Throughout the remainder of the geological sequence, the recognised lithostratigraphic divisions have been used.

The Great Artesian Basin (GAB) is not a geologic basin; rather, it is a hydrogeological or groundwater basin comprising various parts of other geologic basins. Within the Surat CMA, the GAB includes: the Surat Basin sequences; the equivalent formations in the Cecil Plains Sub-basin of the Clarence–Moreton Basin (now considered to be an eastern hydrogeological extension of the Surat Basin (Ransley & Smerdon 2012)); and the upper sedimentary sequences of the Bowen Basin.

3.1 Surat Basin

The Surat Basin is one of the major basins forming the GAB, occupying an area of 440,000 km^2 (of which 180,000 km^2 is in Queensland). The Surat Basin is a large intra-cratonic basin, extending from north of Taroom in southeast Queensland to the Coonamble Embayment near Dubbo in New South Wales (Figure 3-3).

The Surat Basin is bounded to the northeast by the Auburn Arch and to the southeast by the Texas Block. Sediments of the Surat Basin interfinger with those in the Eromanga Basin in the west, across the Nebine and Eulo ridges and the Cunnamulla Shelf, and with those in the Clarence–Moreton Basin across the Kumbarilla Ridge. The northern margin of the Surat Basin has been exposed and extensively eroded due to uplift during the Cenozoic, and the sediments generally dip in a south-westerly direction (Exon 1976). The basin continues south into New South Wales where it is bounded by the Lachlan Fold Belt (Ransley & Smerdon, 2012).

The northern boundary of the Surat Basin is well defined by the outcrop areas of the deeper sediments. However, the location of the buried ridges between the Surat Basin and the Eromanga and Clarence–Moreton basins is not so well defined. A broad and complex high, comprising the anticlinal Nebine Ridge and the faulted granitic dome of the Eulo Ridge, separates the Eromanga Basin and the Surat Basin (Ransley & Smerdon, 2012). While the Nebine Ridge is well developed in its northern extent at the outcrop areas in Queensland, gravity data suggest that the southern extension of the ridge into northern New South Wales is terminated by cross-faulting and diminishes into the Roma and Cunnamulla shelves. Sediments of the Surat Basin grade to the west over the Nebine Ridge into the Eromanga Basin; however, the deeper Jurassic formations pinch out over the basement high towards the southwest, and the Jurassic and Cretaceous sequence does not fully cover the crest of the Eulo Ridge (Ransley & Smerdon, 2012).

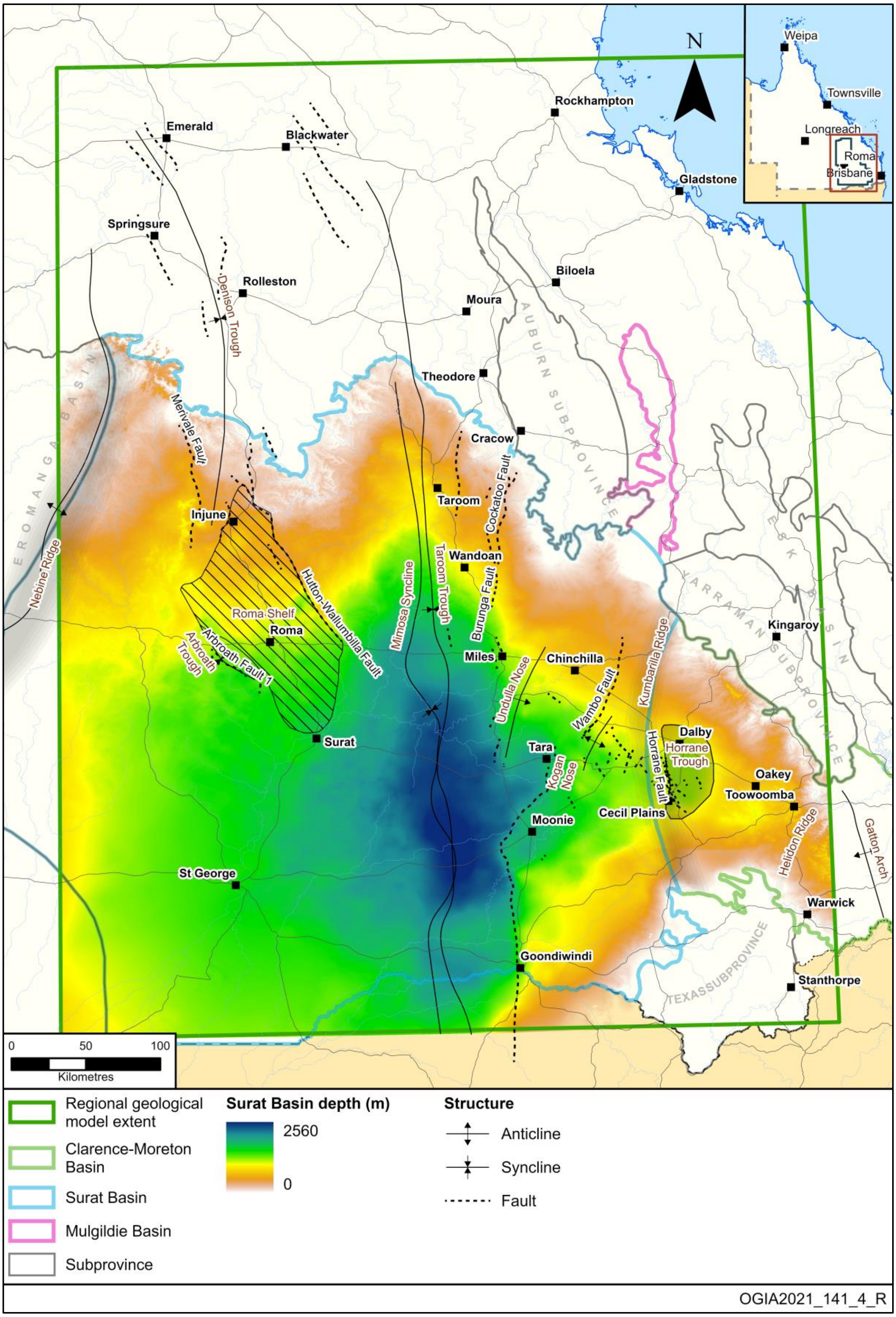

Figure 3-3: Structural elements of the Surat and Clarence–Moreton basins (after Ransley & Smerdon 2012; Geological Survey of Queensland 2012; Esterle & Sliwa 2002; Cadman, Pain & Vukovic 1998)

The boundary between the Surat and Clarence–Moreton basins to the east was historically considered to be the Kumbarilla Ridge (Draper 2013), a broad basement structure with a location that is poorly defined and difficult to determine accurately. However, Day, Bubendorfer and Pinder (2008) consider the eastern boundary of the Surat Basin to be the Toowoomba Strait, equivalent to the present-day line of the Great Diving Range through Toowoomba. Day, Bubendorfer and Pinder (2008) argue that the sedimentary sequences in the Cecil Plains Sub-basin, the western-most sub-basin of the Clarence–Moreton Basin, are more comparable to the sediments in the Surat Basin than to the remainder of the Clarence–Moreton Basin to the east of the Toowoomba Strait.

Similarly, Ransley and Smerdon (2012) identify the Kumbarilla Ridge as being neither a geological nor a hydrological boundary between the Surat and Clarence–Moreton basins. They also suggest a clear lithostratigraphic correlation between the sediments of the Surat Basin and the Cecil Plains Sub-basin. This correlation was also evident when undertaking the lithostratigraphic interpretation of the geophysical wireline data. A common lithostratigraphic subdivision was therefore made across the Surat Basin and Cecil Plains Sub-basin when preparing the geological model for the UWIR 2019. In addition, Ransley and Smerdon (2012) identify the groundwater divide to be coincident with the Main Range for the younger Jurassic formations and likely to be at the Helidon Ridge for the basal Jurassic sequences.

The shape and structure of the Surat Basin is controlled by the underlying basement structures of the Bowen Basin and older rocks (DNRM 2005) such that the structural features of the Bowen Basin are generally reflected, but subdued, in the Surat Basin structures. Hence, the axis of the Mimosa Syncline (Figure 3-3), the main depocenter of the basin, generally follows that of the Bowen Basin's Taroom Trough (Figure 3-4) but the syncline is much broader and shallower than the underling trough (Ransley & Smerdon 2012). At the top surface of the Evergreen Formation, basement topography is still evident, although significantly subdued; however, by the base of the Wallumbilla Formation, the structure is very subdued and barely evident (Ransley & Smerdon 2012).

To the east, as shown in Figure 3-3, the Mimosa Syncline is bounded by the north-to-south trending Burunga–Leichhardt Fault in the north and Goondiwindi–Moonie Fault in the south (Power & Devine 1970). Between the faults and the Kumbarilla Ridge is the Chinchilla–Goondiwindi Slope. The Surat Basin sediments on this slope dip shallowly (less than 1°) towards the Mimosa Syncline, where the dip then steepens over the faults and edge of the Bowen Basin (Exon 1976). Between the western extent of the Mimosa Syncline and the Nebine Ridge is the St George – Bollon Slope.

The Surat Basin is filled by Jurassic clastic continental sedimentary rocks and Early Cretaceous marine rock units, which attain a maximum thickness of 2,500 m (Babaahmadi, Sliwa & Esterle 2015; Hoffmann et al. 2009). The result is a highly heterogeneous mix of alternating layers of sandstones, siltstones, mudstones and coal lenses. The sediments unconformably overlie the Permian-to-Triassic Bowen Basin in the Taroom Trough and basement rocks of the Tasman Fold Belt (Goscombe & Coxhead 1995).

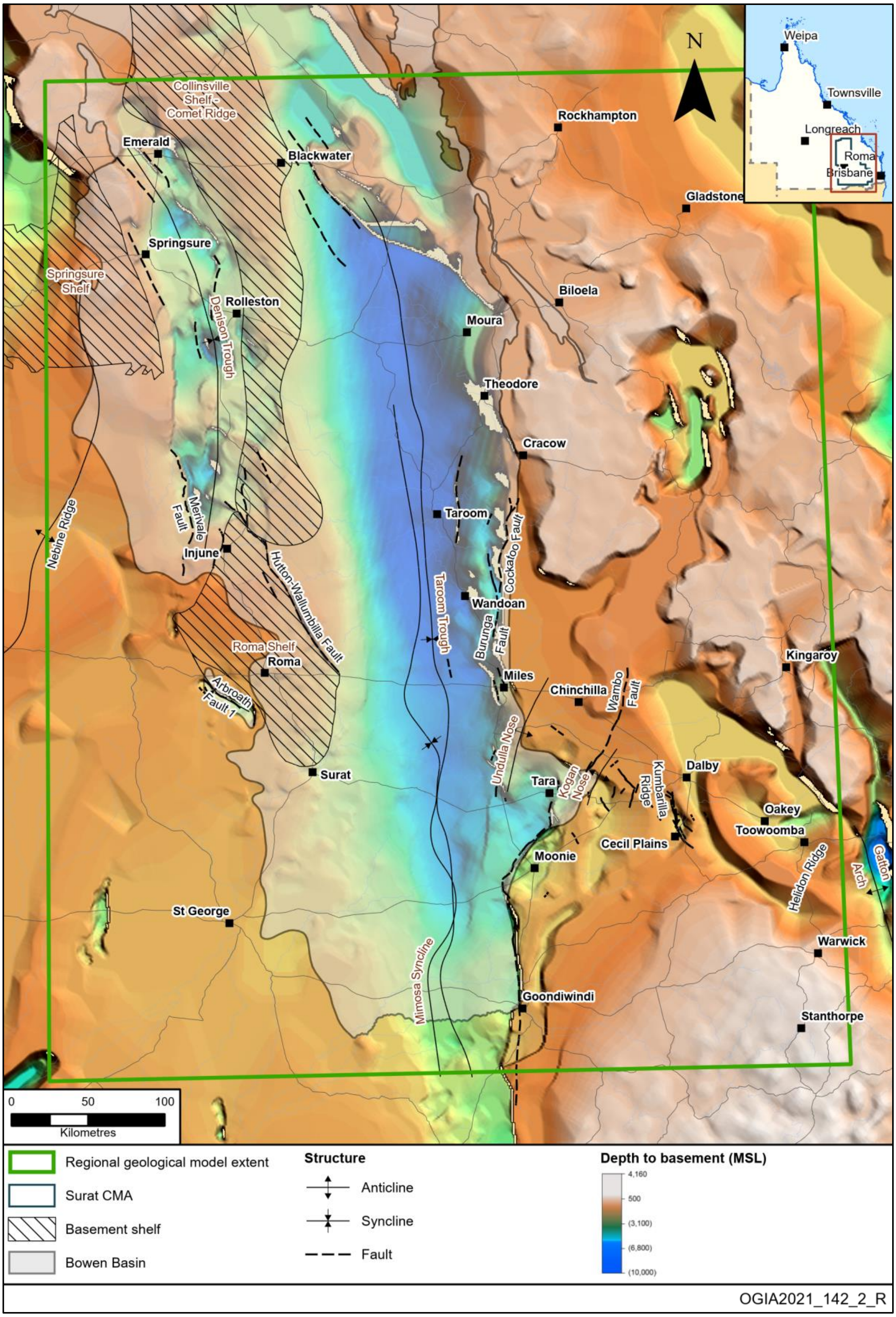

Figure 3-4: Structural elements of the Bowen Basin (after Esterle & Sliwa 2002; FROGTECH 2014; Geological Survey of Queensland 2012; Ransley & Smerdon 2012; SRK Consulting 2008)

3.2 Clarence–Moreton Basin

The Clarence–Moreton Basin underlies southeast Queensland and northeast New South Wales. The basin contains a thickness up to 3 km (~1.3 km in the Cecil Plains Sub-basin in Queensland) of continental sediments of Late Triassic to Late Jurassic, covering approximately 27,000 km^2 (O'Brien et al. 1994). Sediments of the Clarence–Moreton Basin unconformably overlie the Ipswich and Nymboida basins (Goscombe & Coxhead 1995).

The Clarence–Moreton Basin consists of three main centres of sedimentary deposition or sub-basins – the Cecil Plains, Laidley and Logan sub-basins – and the small Yamba Trough, which extends offshore from the Logan Sub-basin (O'Brien & Wells 1994). The westernmost sub-basin, the Cecil Plains Sub-basin, is the only sub-basin which falls within the Surat CMA (O'Brien et al. 1994), as shown in Figure 3-3.

The Cecil Plains Sub-basin is a broad, relatively undeformed depression, which overlies the Horrane Trough: a graben about 20 km wide and 35 km long, bounded on its western side by a steep, east-dipping fault. The Cecil Plains Sub-basin extends from the Kumbarilla Ridge to the Toowoomba Strait in the east. The sediments in the Cecil Plains Sub-basin reach a maximum thickness of approximately 1,300 m in a subdued depocentre, overlying the western part of the Horrane Trough (O'Brien et al. 1994).

As previously discussed in section 3.1, while the younger Cretaceous sequences of the western Surat Basin are eroded and the lowermost Triassic sediments of the eastern Clarence–Moreton Basin are missing over the Kumbarilla Ridge, there is a clear lithostratigraphic correlation between the Jurassic sequences in the Surat and Clarence–Moreton basins (Donchak 2013). The deepest Jurassic unit, the Precipice Sandstone, interconnects around the northern end of the Kumbarilla Ridge (Ransley & Smerdon 2012). The upper unit of the Woogaroo Subgroup, the Ripley Road Sandstone (previously termed the Helidon Sandstone), is the equivalent of the Precipice Sandstone, while the upper part of the Marburg Subgroup, the Marburg Sandstone, is the equivalent of the Hutton Sandstone.

The Walloon Coal Measures are present within both the Surat and Clarence–Moreton basins, representing a widespread (>500 km) episode of deposition of river, lake, swamp and marsh sediments. The formation has been either partly eroded, or exposed, over much of the eastern part of the Clarence–Moreton Basin (Goscombe & Coxhead 1995).

3.3 Bowen Basin

The Bowen Basin is an elongated, north-south-trending basin extending over an area of 160,000 km^2 from central Queensland, south beneath the Surat Basin, and into New South Wales where it connects with the Gunnedah and Sydney basins.

This basin contains broadly folded Permian to Triassic sediments, which attain a maximum thickness of approximately 9,000 m in the Taroom Trough (Cadman, Pain & Vukovic 1998; Draper 2013) as shown in Figure 3-4. Within the Surat CMA, the Bowen Basin has two main centres of sedimentary deposition, the Taroom Trough to the east and the Denison Trough to the west, which are separated by the Comet Ridge.

To the east, the Bowen Basin is bound by the Gogango Thrust Zone, an area of heavy deformation of the Bowen Basin and underlying volcanics rocks, and a series of north to south oriented faults extending south of the Auburn Arch. These faults comprise the Chinchilla–Goondiwindi, Moonie and Leichhardt–Burunga fault zones (Draper 2013). Although remnants of the Permian sequence are found to the east of these faults (e.g. east of Tara), erosion during the Triassic period has largely restricted the occurrence of the Permo-Triassic sediments to the Taroom Trough (Cadman, Pain & Vukovic, 1998).

Towards the north of the Taroom Trough and to the east of the Comet Ridge is a region of intensely deformed and tightly folded Permian sedimentary rocks, termed the Dawson Folded Zone. This zone separates the gently folded sedimentary rock in the Taroom Trough from the much more folded and faulted rocks in the Nebo Synclinorium to the north (Draper 2013).

To the west, the Bowen Basin is bound by the Nebine Ridge, Anakie Inlier and the Collinsville, Springsure and Roma shelves (Totterdell 1990). The east-dipping Merivale Fault and the southwest dipping Arbroath Fault form the western limit of the Roma Shelf and Denison Trough (Cadman, Pain & Vukovic 1998; Geoscience Australia 2015).

The southern extent of the Comet Ridge is delineated by the north-northwest trending Hutton–Wallumbilla Fault, which downthrows to the southwest and separates the Comet Ridge from the Roma Shelf. The displacement on the fault is up to around 450 m in the Bowen Basin sequences, but less than 100 m in the overlying Surat Basin strata (Draper 2013).

To the southwest, the margins of the Bowen Basin are less sharp and not well defined (Draper 2013). Here, sediments deposited on the St George – Bollon Slope onlap and thin to the west, and shallowly dip to the east towards the Taroom Trough. Further west, the Bowen Basin sequence thins across the Nebine Ridge and interfingers with sediments of the Galilee Basin across the Springsure Shelf. To the south, deposition between the Bowen, Gunnedah and Sydney basins was probably continuous (Cadman, Pain & Vukovic 1998).

The depositional history of the Bowen Basin is complex. Due to varying rates of uplift and subsidence, the periods of sedimentation were not always consistent across the basin and the geological units are not always laterally extensive or easy to correlate (Draper 2013). Deposition in the basin commenced during the Early Permian, with fluvial and lacustrine sediments and volcanics being deposited in the east and a thick succession of coals and non-marine sediments in the west (Geoscience Australia 2015). The basin then entered a thermal subsidence phase that extended from the mid Early Permian to the Late Permian, during which deltaic and shallow marine sediments and extensive coal measures were deposited (Mallet et al. 1995).

In the Late Permian, the basin entered an extensive period of foreland loading, resulting in accelerated subsidence that allowed the deposition of a thick succession of Late Permian marine and fluvio-deltaic sediments, including coal and Early to Middle Triassic fluvial and lacustrine sediments (Draper 2013). The sediments deposited in the last cycle – the Bandanna Formation, Rewan Group, Clematis Group and Moolayember Formation – along with the early Permian Cattle Creek Formation, are most relevant to assessing the impacts of CSG extraction and are therefore the only Bowen Basin units explicitly represented within the geological model.

Sedimentation in the Bowen Basin ceased in the Late Triassic, followed by a period of widespread erosion prior to deposition of the Surat Basin sediments (Cadman, Pain & Vukovic 1998).

4 Structural framework

The Surat and Bowen basins have a significant deformation history which has resulted in the occurrence of multiple structural features. The Bowen Basin is structurally very complex, with extensional fault systems, volcanic activity and thrust faults as well as repeated reactivation of structures. For example, east of the Taroom Trough, a series of north-to-south orientated Triassic thrust faults have formed, including the Chinchilla–Goondiwindi, Moonie and Leichhardt faults (Cadman, Pain & Vukovic 1998). In the northwest, the regionally significant Hutton–Wallumbilla Fault separates the Comet Ridge Platform from the Roma Shelf (Cadman, Pain & Vukovic 1998).

The shape and structure of the overlying Surat Basin is largely controlled by the underlying basement structures of the Bowen Basin and older rocks (DNRM 2005). The structural features of the Bowen Basin are generally reflected in the overlying Surat Basin sediments in a subdued manner (OGIA 2016). However, in some areas, the reactivation of the Permo-Triassic fault systems of the Bowen Basin and basement rocks – following deposition in the Surat Basin – has caused displacement of the overlying Jurassic-Cretaceous sequence. Renewed thrusting on these faults has led to the propagation of some of the faults up into the Surat Basin succession, but more commonly, the deformation was principally by folding and uplift of the Surat succession above the reactivated fault (Copley et al. 2017; Korsch et al. 2009; R J Korsch & Totterdell 2009).

Sedimentation in the Bowen Basin was terminated in the Middle to Late Triassic by the Goondiwindi event (R J Korsch & Totterdell 2009) which resulted in major regional compression and significant extensional and thrust faults in the Bowen Basin strata. This was followed by a period of widespread erosion prior to deposition of the Surat Basin sediments (Cadman, Pain & Vukovic 1998).

Sedimentation in the Surat Basin was then initiated by subsidence in the Early Jurassic. This resulted in several episodes of fluvial-lacustrine deposition as the basin continued to subside into the Early Cretaceous (Ryan et al. 2012).

During the Middle Cretaceous, a regional uplift and tilting event terminated deposition in the Surat Basin and resulted in large-scale erosion of Jurassic-Cretaceous sediments (Raza, Hill & Korsch 2009). Often referred to as the Moonie event (R. J. Korsch & Totterdell 2009), this event caused only minor deformation, with reactivation of Triassic thrust faults generally manifested as folding in the Surat Basin succession (QGC 2012).

Following this, a regional extensional event occurred, associated with the cessation of rifting in the Tasman Sea. Both extensional and transtensional styles are observed in the Surat Basin associated with this event (Ryan et al. 2012). A subsequent uplift and compression event in the Late Cretaceous caused significant folding and small-scale faulting. Fault displacements associated with this event are generally less than 50 m (Copley et al. 2017).

The major regional faults present within the Surat CMA are easily interpreted across multiple seismic lines, as the damage and deformation zones associated with these faults may be up to several kilometres. The basement or Pre-Permian deformation controls, in part, the orientation of structures within the Bowen Basin (Esterle & Sliwa 2002). In turn, many of the structures in the Surat Basin have formed and are spatially controlled by the reactivation of deeper structures or zones of weakness in the Bowen Basin and basement (Copley et al. 2017; DNRM 2005).

4.1 Eastern faults

As mentioned previously in section 3.3 and shown in Figure 3-4, the present day Bowen Basin is bounded in the east by the north- and northeast-trending Goondiwindi–Moonie–Wambo and Leichhardt–Burunga–Cockatoo fault zones (Draper, 2013; Korsch et al., 2009). While some researchers suggest these represent ancient normal faults that were reactivated (Power & Devine, 1970), others suggest these are new thrusts linked to the growing thrust wedge in the New England Orogen to the east (Korsch et al., 2009). The latter theory is supported by remnants of the Bowen Basin sediments existing to the east of the faults (Fielding, Stephens & Holocombe 1997).

The geometries of these faults show considerable variation along strike (Korsch et al., 2009). The Bowen Basin sediments are displaced, thrusting the Carboniferous units of the Texas Beds and Palaeozoic basement rocks over the Bowen Basin rocks, with fault throws reaching 1400 m (Sliwa 2013).

The Surat Basin has suffered only minor levels of deformation in comparison to the underlying Bowen Basin sequence within these eastern fault zones, with most of the deformation observed to be folding of the Surat Basin sediments. As shown in Figure 4-1, these eastern fault systems have a strong influence on the Bowen Basin sediments, with large throws and significant offset and folding of Permian strata. The overlying Surat Basin formations also steepen to the west across this regional structure. Folding of Surat Basin strata over these structural features has resulted in the evolution of the Undulla Nose, Kogan Nose and Wandoan Anticline.

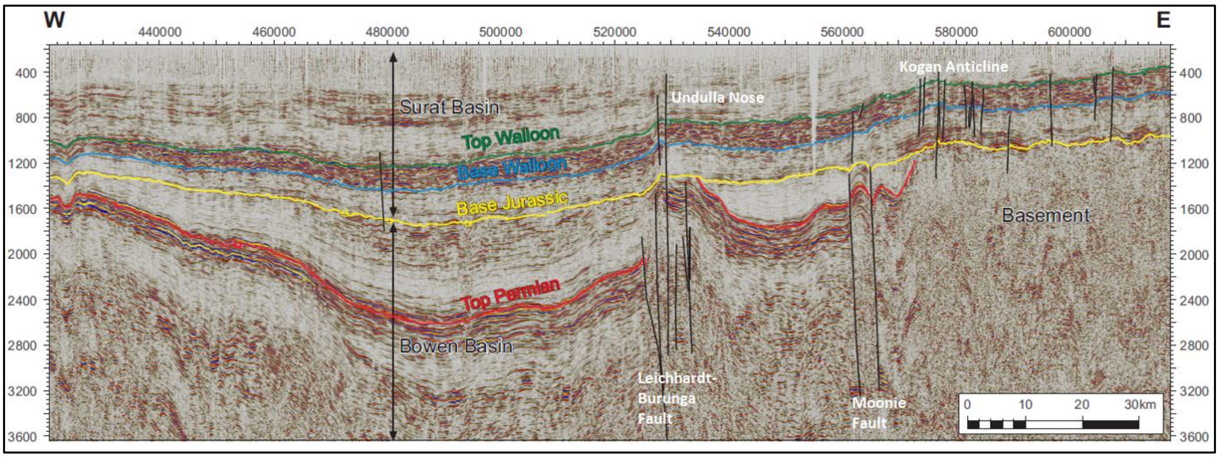

Figure 4-1: Regional seismic section (BMR84-14) in the Surat Basin (Ryan et al. 2012)

In addition to the major regional fault systems described above (shown in Figure 3-3 and Figure 3-4), Figure 4-2 shows other faults interpreted as part of the SBEA modelling work (Dixon, Hoffmann & Simpson 1993; Wells et al. 1992), the Bowen and Surat Basins Regional Framework Study (SRK Consulting 2008), Eastern Surat Basin Structural Framework from 2D Seismic Interpretation for Arrow Energy Limited (Sliwa 2013) and the UQ Faults and Fractures project (Copley et al. 2017).

This fault mapping suggests a concentration of northwest- and northeast-striking lineaments and faults in the south-eastern part of the Surat CMA, located in the highly deformed area of the Texas Orocline. These features are thought to be associated with the Early to Middle Permian reactivation of the Texas Orocline. This oroclinal bending is thought to have resulted in the rotation of some major faults, such as the Moonie–Goondiwindi faults.

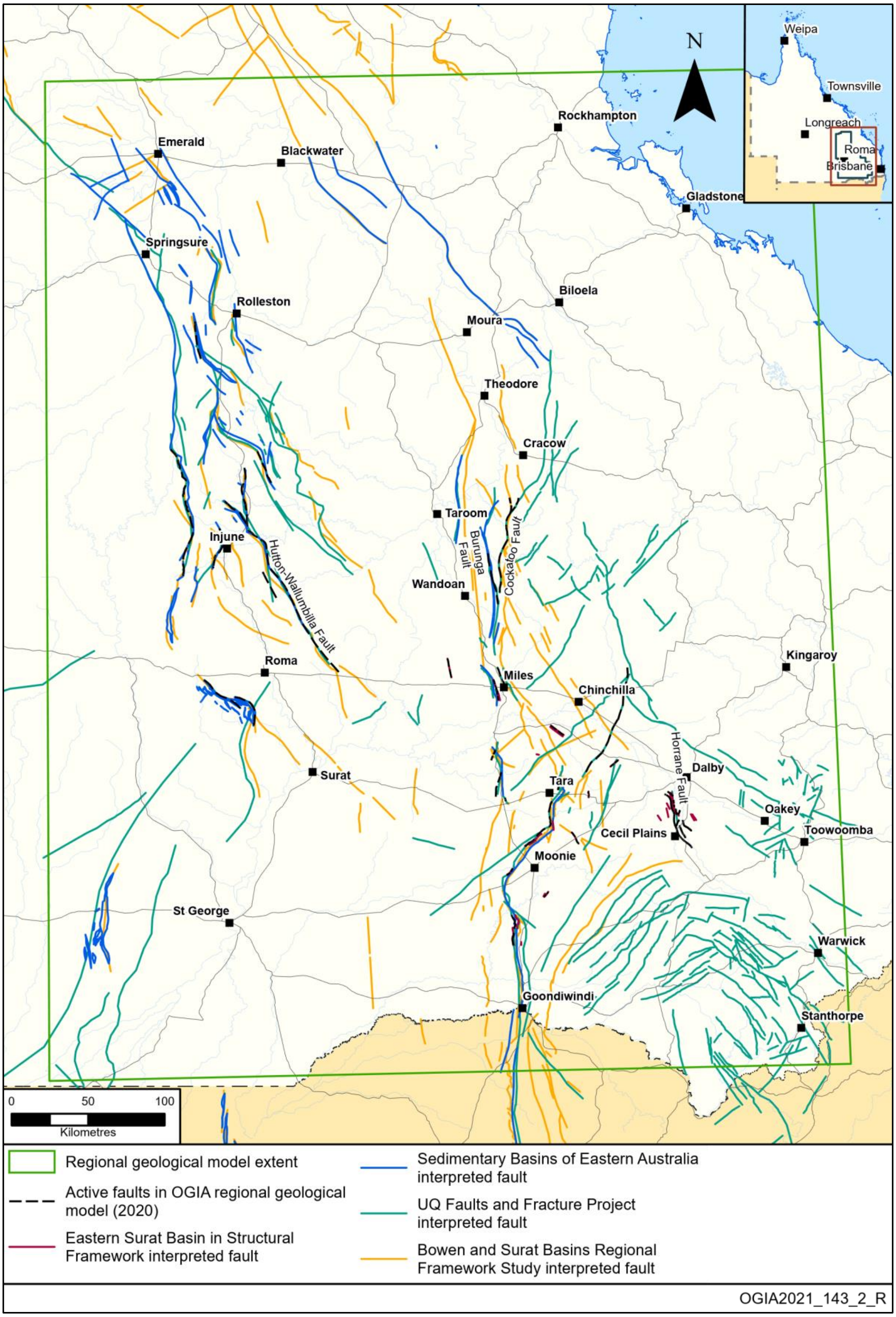

Figure 4-2: Regional fault mapping

4.2 Western faults

The key structural features in the western portion of the Surat CMA are the Hutton–Wallumbilla, Merryvale and Injune thrust faults. These are generally north-northwest-striking features (Babaahmadi, Sliwa & Esterle 2016) (Figure 4-2).

The Hutton–Wallumbilla Fault is more than 150 km long and separates the Comet Ridge from the Roma Shelf (Figure 3-4). Major deformation occurred in the late Triassic and resulted in a complex fault morphology (Copley et al., 2017). Uplift is dominantly vertical on the west, displacing the Permo-Triassic succession of the Bowen Basin and causing the development of a propagation fold in the Triassic sediments (Babaahmadi, Sliwa & Esterle, 2016; Copley et al., 2017).

Figure 4-3, along seismic line 86-P8a, indicates the Hutton–Wallumbilla Fault is dipping northeast and there is significant displacement of the Bowen Basin sequence, in the order of 200–350 m. However, the Surat Basin sequence appears to be gently folded over the fault (Babaahmadi, Sliwa & Esterle, 2016). The lack of any significant thickening of the shallower strata suggests that reactivation of the fault occurred after the deposition of the Surat Basin sediments. Hence, Copley et al. (2017) suggest that the fault was reactivated in the Cenozoic, but with only a small fraction of the amplitude of the Triassic deformation. Interpreting seismic line 86-P20 (to the south of line 86-P8a), as shown in Figure 4-4, the same authors point to significant displacement of the Bowen Basin sequences, but only minor movement within the Surat Basin, leading to the formation of keystone faults or flower structures, which appear to be typical of faults observed in the Surat Basin (refer to section 4.3).

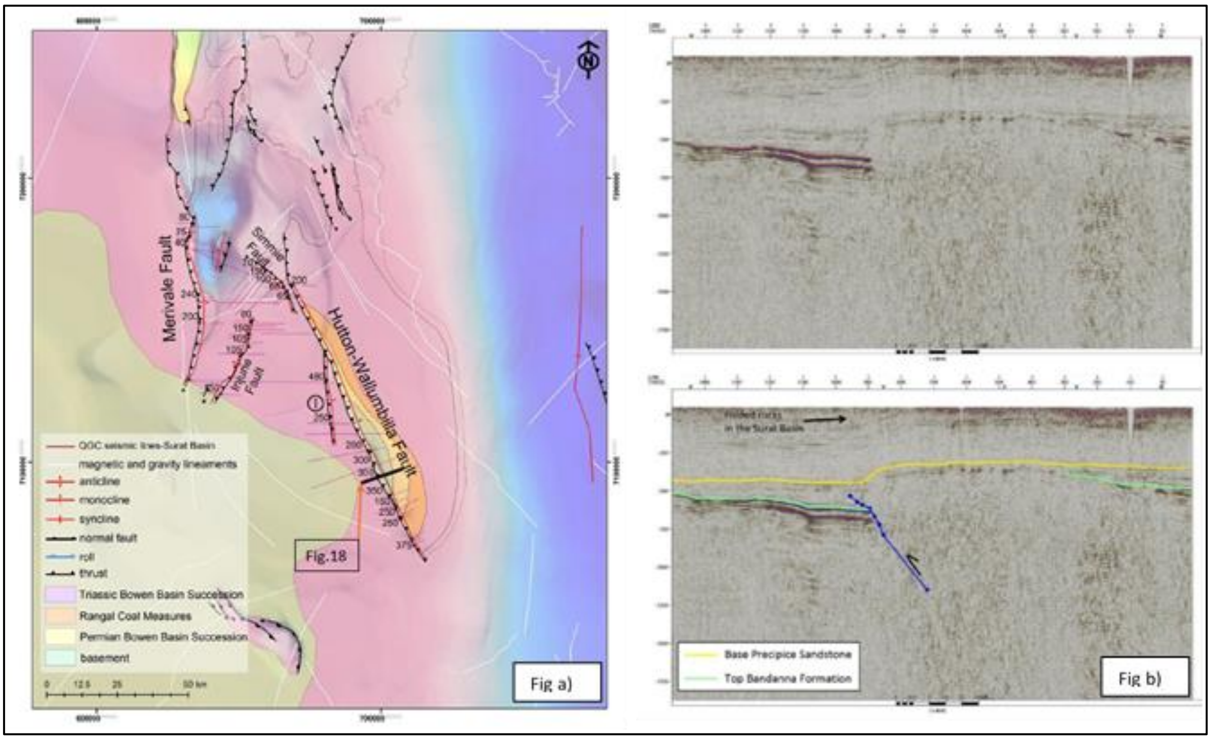

Figure 4-3: a) Basement map with major fault structures, b) Seismic line (86-P8a) showing the Hutton–Wallumbilla Fault (Babaahmadi, Sliwa & Esterle 2016)

To the west of the Hutton–Wallumbilla Fault is the north-striking Merrivale Fault. Similar to the Hutton–Wallumbilla Fault, it dips to the east and significantly displaces the Permo-Triassic Bowen Basin sequence, with throws approximating 240 m. This fault is thought to have been active as a boundary fault during the early Permian extensional regime, controlling the Early Permian sedimentation in the

Denison Trough before being reactivated as a reverse fault during the Middle Permian to early Late Triassic Hunter–Bowen Orogeny (Babaahmadi, Sliwa & Esterle, 2016). Again, the Surat Basin sediments are gently folded over the fault with little or no observable displacement (Babaahmadi, Sliwa & Esterle, 2016; Copley et al., 2017).

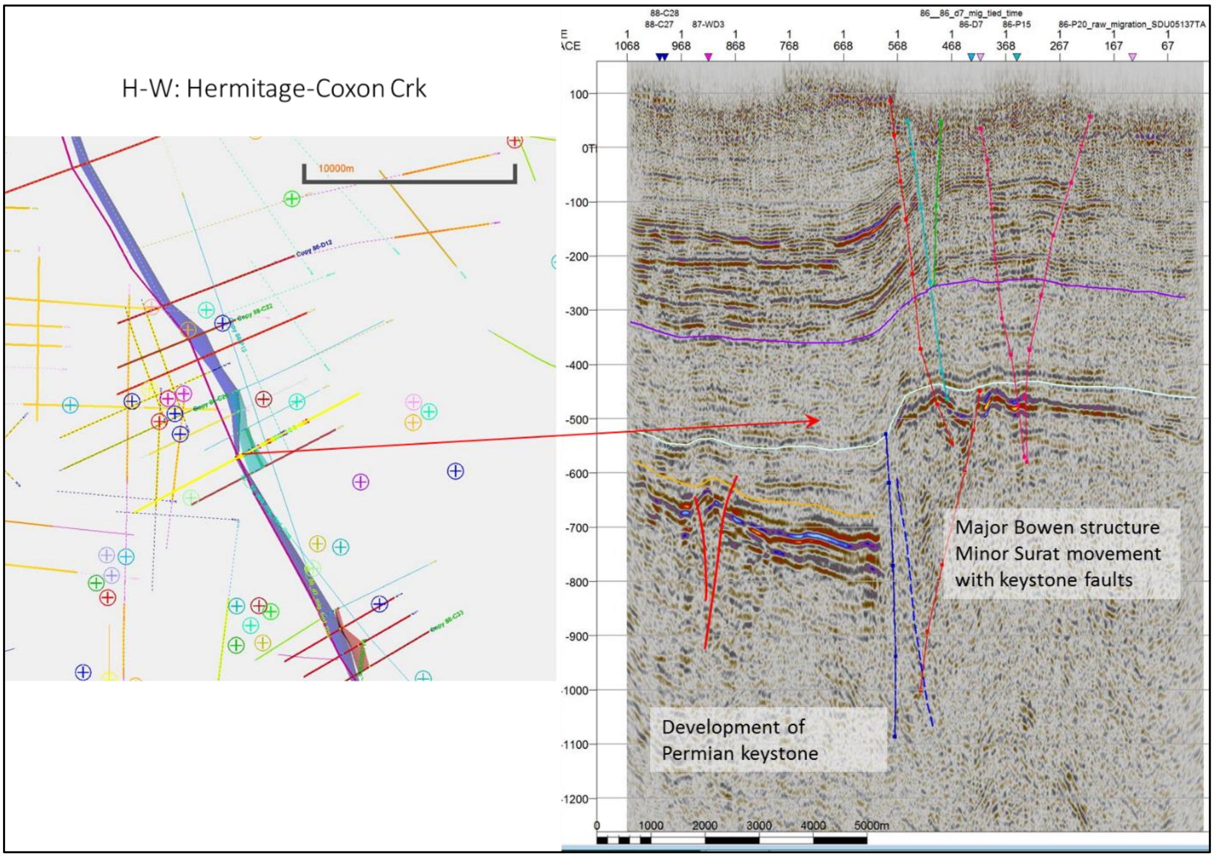

Figure 4-4: Seismic line (86-P20) showing the Hutton–Wallumbilla Fault and faulting in the Surat and Bowen sequences (Copley et al. 2017)

Between the Hutton–Wallumbilla and Merrivale Faults is the Injune Fault. Babaahmadi, Sliwa and Esterle (2016) interpret this fault as a north-northeast-striking thrust fault. The fault dips west-northwest and displaces the Permo-Triassic Bowen Basin sequence. The same authors also suggest that this fault developed during the mid-Triassic episode of the Hunter–Bowen Orogeny as there is little evidence of the fault extending into the underlying Permian strata.

4.3 Faulting in the Surat Basin

As discussed above in relation to a number of the major regional fault systems, reactivation of the Permo-Triassic fault systems of the Bowen Basin and basement rocks following deposition in the Surat Basin, in general caused only minor displacement of the overlying Jurassic-Cretaceous sequence. Renewed thrusting on these faults led to the propagation of some of the faults a short distance up into the Surat Basin sequence, but more commonly the deformation was principally by folding and uplift of the Surat sequence above the fault (Korsch et al., 2009; Korsch & Totterdell, 2009b).

Where present, faulting in the Surat Basin sediments is mostly evident in seismic data as flower structures, originating from deeper basement thrust faults (Figure 4-5). These flower structures are characterised by upwardly diverging pairs of steeply dipping faults with opposite movement. The centre of these structures is typically a down-dropped graben or 'keystone' block, usually tightly folded, with varying degrees of internal complexity (Copley et al., 2017). There is generally little net offset across the faulted zone, with fault displacement averaging 20 m and rarely being greater than 50 m.

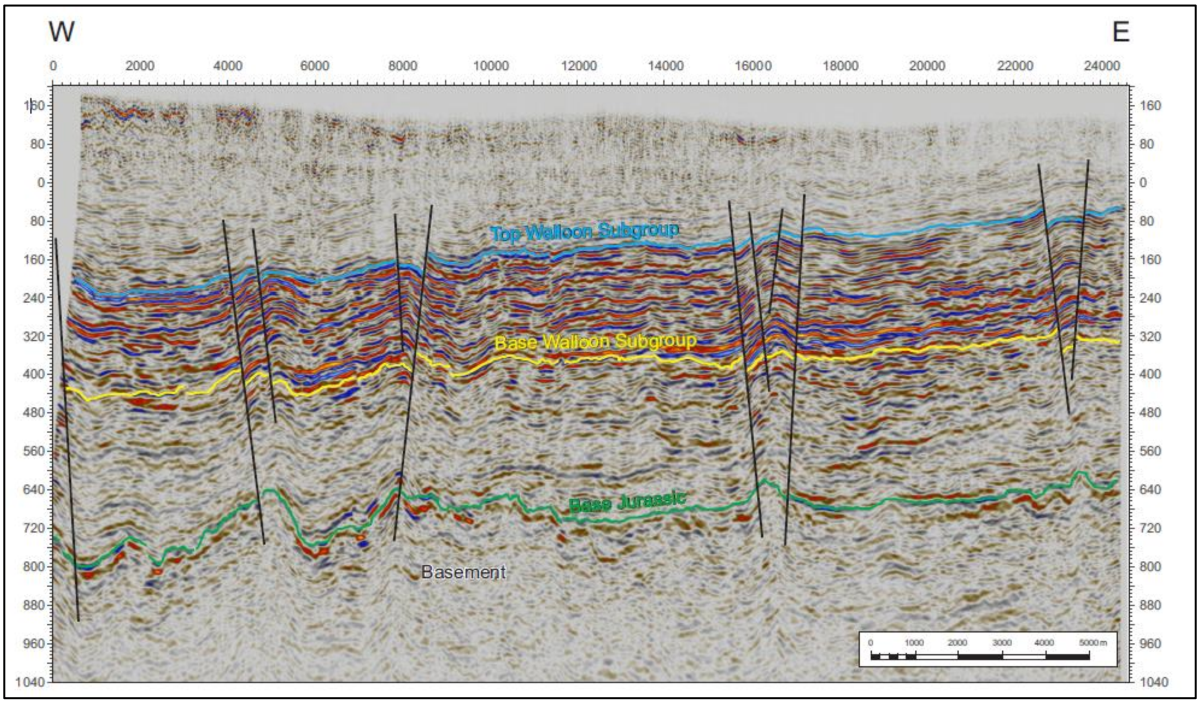

Figure 4-5: Example of flower structures in the Surat Basin on seismic section (Jen10-7) to the west of Dalby (Ryan et al., 2012)

In some cases, these features can have a lateral extent of 5–10 km following a deeper trend of weakness, but individual faults are generally discontinuous and are not typically seen on more than one seismic line (Copley et al., 2017). As such, spatial correlation is difficult and the orientation and length of each fault cannot typically be assessed with a high degree of accuracy. However, the majority of faults are understood to be generally less than 2 km in length and typically occur as graben structures 800–1,000 m wide (Babaahmadi, Sliwa & Esterle, 2016).

The lower frequency of faults observed in the Surat Basin sediments in the central part of the area, where the Surat Basin is underlain by the Bowen Basin (Figure 4-2), suggests that the underlying sediments may act as a buffer for fault propagation. Conversely, towards the southeast of the CMA, the Surat Basin sediments directly overlie the basement rocks of the Tasman Fold Belt and faulting is more common. Several negative extensional structures are present in the southeastern Surat Basin and these are thought to be influenced by the underlying Texas Orocline, which is a major high-strain zone in the region (Babaahmadi, Sliwa & Esterle, 2016).

5 Geomodelling approach and framework

5.1 Overview of OGIA's modelling approach

OGIA developed a 3D regional-scale geological model (geomodel) to support structural and conceptual framework for regional groundwater modelling, and to support aquifer interconnectivity investigations and management strategies.

The regional geological model is a 3D representation of the extent and thickness of the geological units in the Surat/Clarence–Moreton and Bowen basins and overlying Cenozoic sediments that are relevant to the current conceptualisation of the hydrogeological system within the Surat CMA. A lithostratigraphic approach was used to define the geological units, delineating the boundaries between the units based on their lithological properties and stratigraphic relationships derived from geophysics logs and other key dataset interpretations.

The 3D geological model is developed using the Schlumberger's Petrel modelling platform. The first model iteration was developed by OGIA in 2015 and has since been progressively revised in 2018 and 2020 in response to availability of new data and to add additional features of interest. Details of the model construction, input data, underlying stratigraphic framework and results for the 2018 regional-scale geological model are available in a separate report (OGIA 2019). Key elements of the modelling approach and the models' evolution are summarised in the following sections.

For the UWIR 2021, additional sub-regional models were developed to support assessment of coal impacts at the northern and eastern coal areas, as well as for conceptualisation investigation, such as the Horrane Fault characterisation. In total, four geological models were created or updated. These are as follows:

- A regional-scale geological model covering all major geological units of the Surat and southern Bowen basins – 450×650-km domain; 21 units; and 250-m grid resolution.
- A sub-regional model for the Northern Coal Area (NCA) with revised geology in the Surat Basin to include coal holes – 150×115-km domain; 7 layers; and 250-m grid resolution.
- A sub-regional model for the eastern Surat Basin, around the New Acland coal mine – 75×65-km domain; 8 layers; and 100-m grid resolution.
- A local-scale model around the Horrane Fault – 25×40-km domain; 10 layers; and 100-m grid resolution.

Table 5-1 summarises the geological model characteristics and purposes and Figure 5-1 shows their extents.

Table 5-1: Summary of OGIA's geological model iterations

Geological model	Iteration	Area (km^2)	Basin	Faulted	Primary dataset	Primary purpose
Regional	3rd	~300,000	Surat and Bowen	Yes	Wells and water bores	Framework of groundwater flow model, aquifer attribution and conceptualisation
NCA	1st	17,750	Part of Surat	No	Wells and coal holes	Framework of groundwater flow model, aquifer attribution and conceptualisation
New Acland	1st	4,875	Part of Surat and Cenozoic	Yes	Coal holes, wells and water bores	Fault characterisation, conceptualisation, and aquifer attribution
Horrane Fault	1st	960	Part of Surat and Cenozoic	Yes	Wells and water bores	Fault characterisation and conceptualisation

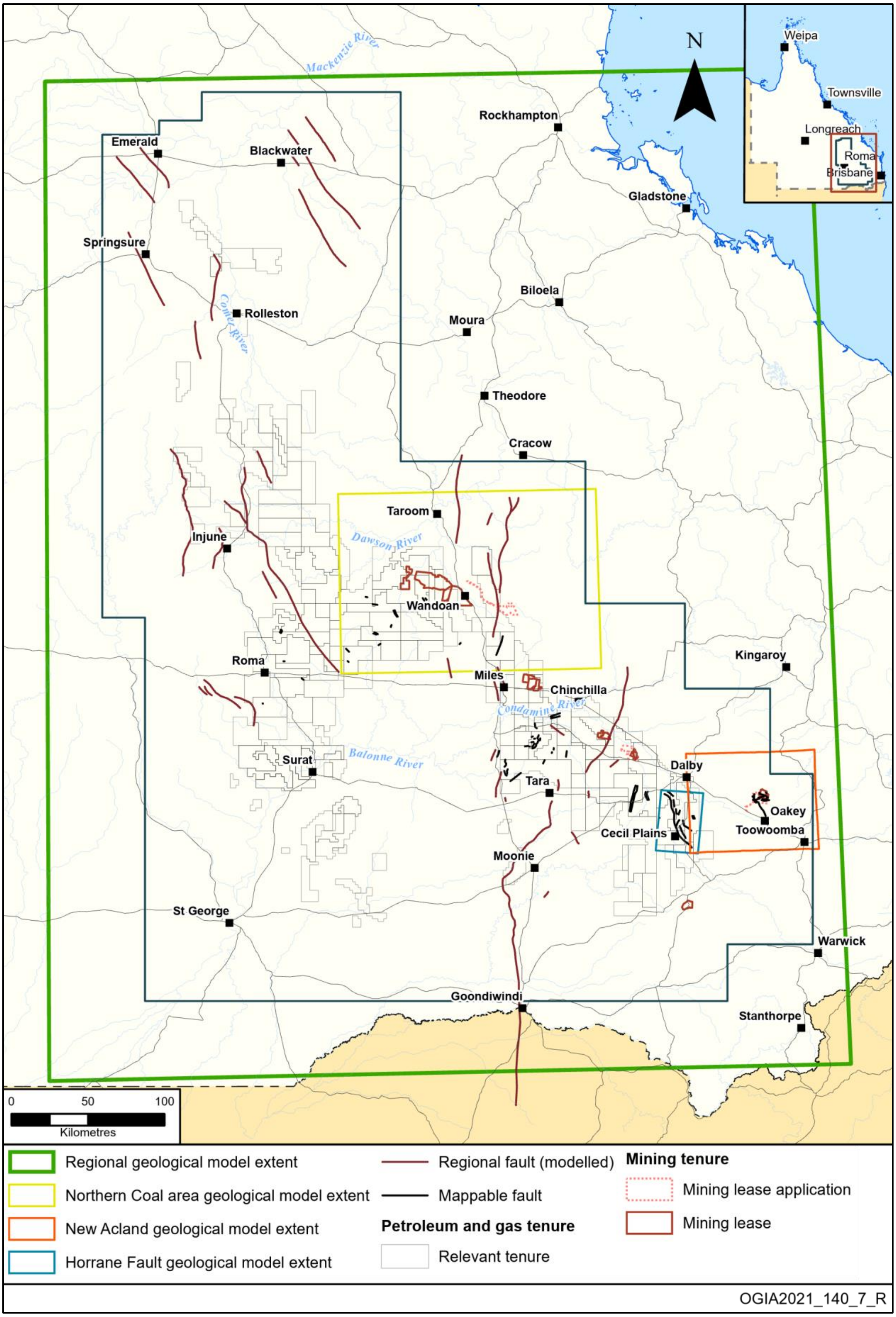

Figure 5-1: Regional and sub-regional geological model locations

5.2 Improvements since the last iteration

Model iteration is driven by three key factors:

- availability of additional data or information that may result in changes to the model
- known issues or limitations in the model
- specific conceptualisation or groundwater flow modelling needs.

Since the last model, more than 1,700 new petroleum wells have been drilled in the Surat CMA. The vast majority of these are extensions of current development areas with some in-fill drilling. Additionally, with the inclusion of coal mines in the Surat CMA, geophysical log data has become available to OGIA from about half of the approximately 18,000 coal holes that have been drilled.

A known limitation of the past geological models is the absence of alluvium coverage in some areas, particularly in the NCA. This led to some shallow bores being wrongly attributed to Surat formations instead of alluvium, promulgating impact prediction errors in the near-surface. The recent GSQ detailed surface geology mapping (1:100) was used to address this issue.

Revision and refinement of the geology around coal mines was required as part of the groundwater modelling strategy and conceptualisation, resulting in two sub-regional geological models that include coal hole data and interpretation and further characterisation of the surficial units, such as the alluvium and Main Range Volcanics (MRV). The extent and outcrop of the MRV – an important aquifer system with high usage for stock and domestic purposes – was revised. The interpretation of the MRV extent includes new available datasets: regional airborne magnetic survey, GSQ detailed surface geology mapping (1:100), data from the tenure holder New Hope Group and Groundwater Database (GWDB) water bores.

A long-term project that started in the lead-up to the UWIR 2021 is the revision and depth-conversion of 2D seismic interpretations. This information is highly valuable to improve geologic modelling confidence and advanced fault characterisation, particularly where well data is sparse. An initial project was conducted in the Horrane Fault area where depth-converted faults and horizons interpretations were used to generate a local-scale geological model that provides useful information on local fault systems that may have implications for groundwater flow and on the prediction of impacts.

The key improvements made to the geological models that underpin the UWIR 2021 are summarised below:

- inclusion of the Walloon Coal Measures subdivisions (upper and lower Juandah Coal Measures and Taroom Coal Measures) based on previously interpreted petroleum wells (drilled up to 2017) and newly collected data from about 1,000 coal holes (limited coal holes penetrate a full subdivision), see section 5.5.4
- development of sub-regional geological models for the northern and eastern part of the Surat Basin for better representation of the Walloon Coal Measures and surficial units – Cenozoic and/or MRV in these areas
- revision of the alluvium, with a more detailed extent (1:100,000 scale)
- revision of the Horrane Fault trace.

5.3 Modelling workflow

The geological models are developed using Petrel software (Schlumberger) and involve the following main modelling steps common to all geological models:

1. Incorporate and review key input data: borehole data, stratigraphic markers, seismic data, fault structures, geological boundaries, topography, trend surfaces and other data.
2. Generate stratigraphic depth surfaces and isochores – main inputs to the modelling process – primarily from stratigraphic markers together with mapped and interpreted geological unit boundaries and structures, and trend surfaces. Each surface is created independently.
3. Build the structural geological model by assembling the key input datasets, using a 'corner point gridding' workflow subdivided into the following processes:
    - Define the model extent.
    - Determine the appropriate horizontal (lateral) grid resolution, using regular grid spacing, also called 'corner point gridding'. The horizontal or lateral resolution should be selected according to the best use of the data (and computing limitations).
    - Perform fault modelling (Petrel): The model skeleton and associated pillar architecture are designed based on the shape of the faults defined in this step. The faults in the regional geological model are represented using vertical pillars, to ensure a regular grid for integration with the groundwater modelling package (MODFLOW USG).
    - Define the vertical (layering) grid resolution. The objective for the regional model is to represent each hydrostratigraphic unit – the vertical resolution represents the unit or formation level (further subdivisions will be done for dynamic modelling purpose but are not based on stratigraphic relationships). The vertical (or layering) modelling step incorporates the stratigraphic depth surfaces and thickness maps into the model structure by adjusting and mating them to each other while accounting for erosional rules, thickness and accommodation space, stratigraphic markers and other controls. The Petrel processes involved are Pillar Gridding, Make Horizons and Make Zones, as detailed in OGIA (2019).

The main elements of the workflow are illustrated in Figure 5-2.

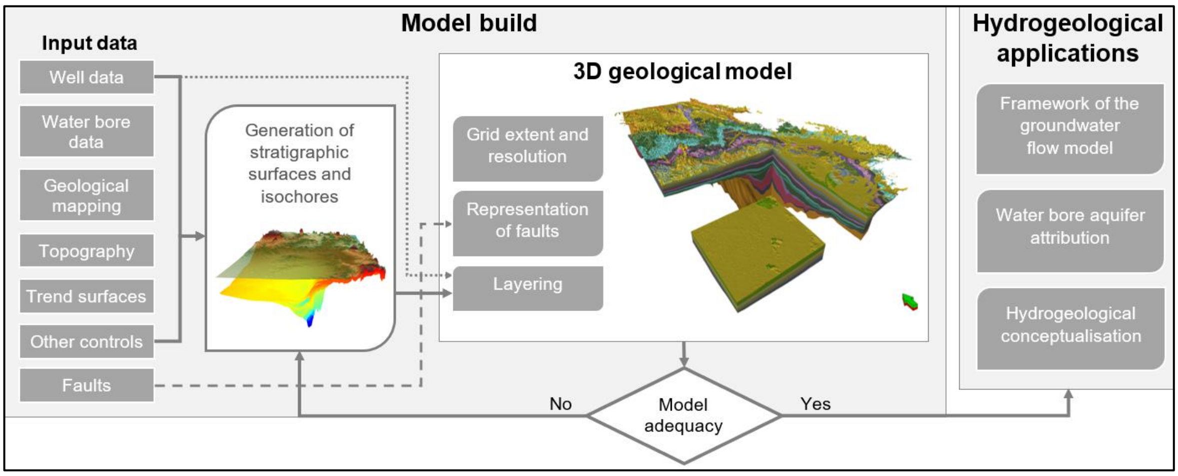

Figure 5-2: Structural geological model workflow

The model was progressively reviewed through each step to ensure that the resulting 3D grid corresponded to the geological conceptualisation. For example, cross-sections were created around features of interest, like faults and springs, to confirm that the model reasonably reflected the conceptualisation at these features.

Models are reviewed internally within OGIA and externally by the OGIA Technical Advisory Panel. The regional geological model (supporting the UWIR 2019) also had critical milestones peer-reviewed by the University of Queensland.

5.4 Input data

The following types of input data were used in the geological models:

- **Well markers** (also referred to as stratigraphic markers or formation tops) represent the position of stratigraphic or geological boundaries (e.g., formation tops and bottoms) in wells, based on measured depth from ground surface. Their delineation relies on the interpretation of geophysical wireline logs from primarily petroleum wells and coal holes across the study area. For the generation of the several geological models associated with the UWIR 2021, over 9,000 petroleum wells and over 9,000 coal holes with log files were quality checked/reviewed and standardised to produce clean representative logs. Gamma ray and density were the most abundant logs available for interpretation. These datasets were regionally correlated to produce a confident and consistent subset of over 45,000 stratigraphic markers that became the primary model input.
- **Water bores**; as geophysical wireline logs coverage is lacking for shallow units, interpretation of these units, and especially the base and extent of the Cenozoic, is primarily based on lithological descriptions from water bores. Drillers' logs of water bores from the GWDB were manually reviewed. Nearly 24,500 water bores had relevant information for defining the base of the unconsolidated sediments and basalts, and the top of the underlying Surat or Bowen basin sediments (see section 4.3 - OGIA 2019). The Cenozoic sediments include several alluvial groundwater resources, and the quantity of water bore data available is generally directly related to the level of groundwater development in each unit.
- **Faults**; only regional fault systems evident in seismic and well data are represented in the regional geological model - primarily mapped by the UQ faults and fractures study (Copley et al. 2017). In the regional geological model, all faults are represented as vertical and laterally defined as 'zig-zag' structures to maintain a regular grid alignment. A total of 44 faults or fault segments were incorporated, but only 32 have units displaced (active faults) in the regional geological model (as in the UWIR 2019).
- In 2020, two newly available datasets were included in the revision of the mappable faults data (OGIA 2020). Smaller-scale faults were interpreted across multiple 2D seismic lines, 3D seismic and coal holes:
    - Extensive coal holes information became available with the inclusion of coal mines in the Surat CMA. The density of drilling in mining leases is sufficient in some areas to delineate faults using edge detection method.
    - OGIA revised and depth converted seismic interpretations in two specific areas of interest for faults characterisation – the Horrane and Hutton–Wallumbilla faults.

- **Geological mapping**; each lithostratigraphic unit's lateral extents – outcrop and subcrop – of were developed from existing geology mapping (Cranfield 2017) when available, with some adjustments to match the well interpretations. In some instances, the extent corresponds to the outcrop/subcrop limit of the base of the formation; in others, such as the Precipice Sandstone that onlaps against the Surat basement surface towards the southwest of the area, the extent represents a combination of the outcrop limit and the estimated line of onlap.
- **Trend surfaces** are used in Petrel to help guide the shape of a stratigraphic surface being generated. For example, a trend surface guides the shape of a stratigraphic surface between the well markers of that surface. A trend surface does not force the position of the stratigraphic surface to exactly match the position of the trend surface but rather makes the stratigraphic surface mimic the shape of the trend surface. The trend surfaces used in the model were derived from seismic data interpretation or from existing model surfaces (section 3.8, OGIA 2019).
- **Isochore surfaces** are thickness grid maps for given intervals, based on isochore points (from borehole data) and formation extents.
- **Control markers** are artificial points created to control model behaviour where actual data is lacking or where the model doesn't behave as expected. They may be placed in existing wells or as isolated markers that are not tied to wells; for example, near stratigraphic unit outcrop boundaries, or towards the south-western corner of the model, where there are sparse well picks and a number of strata are thought to pinch out across the Nebine Ridge.

5.5 Regional geological model

5.5.1 Key features

The regional geological model was developed to represent the lithostratigraphic-based conceptualisation of the Surat and Bowen basins. During the modelling process, substantial efforts were invested to represent the following key features:

- Surat Basin units cropping out along the northern and eastern Surat Basin margins
- main regional faults effects on the Surat and Bowen units
- subcrop of the Surat Basin units against the Cenozoic units, primarily the Condamine Alluvium and MRV
- the unconformity at the base of the Springbok Sandstone
- onlap of the Surat Basin units against the basal Jurassic unconformity along the western margins of the model
- subcrop of the Bowen Basin units against the basal Jurassic unconformity
- the geological conceptualisation at springs
- contacts between the Bandanna Formation and Surat Basin units near the Hutton–Wallumbilla and Burunga faults.

5.5.2 Modelling approach

The upper limit of the geological model is the topographic surface taken from the SRTM-derived 1-second digital elevation model (1" DEM) (Gallant et al. 2011). The uppermost model layer represents the Cenozoic units present within the area and is delineated by the topographic surface and the base of the Cenozoic. The contact between the Cenozoic and the underlying Surat and Bowen basin units is erosional. The base Cenozoic combines the Condamine Alluvium and other alluvium sediments, the MRV, and the Tertiary basalts and sediments. The erosional surface that represents the base of the Cenozoic was created by subtracting developed thickness maps from the DEM surface (section 5.7.2, OGIA 2019).

The stratigraphy of the Surat and Bowen basins has been simplified for the purpose of the geological model, whereby only thicker or regionally extensive formations are included, without internal subdivisions. The exception to this is the subdivision of the Evergreen Formation into the upper and lower Evergreen, separated by the Boxvale Sandstone Member.

The Walloon Coal Measures subdivision into upper and lower Juandah and Taroom coal measures, from coal and petroleum well picks, has been included for the UWIR 2021. The subdivision occurs after the completion of the regional geological model in Petrel. The isochore (or thickness) grids used for the subdivision of the Walloon Coal Measures were generated in Petrel. The Walloon Coal Measures subdivision approach is further explained in section 5.5.4.

The Surat Basin section of the geological model contains 14 stratigraphic layers, from the basal Precipice Sandstone through to the Wallumbilla Formation. The Bowen Basin section contains five stratigraphic layers, from the undifferentiated lower Bowen through to the Moolayember Formation. The model structure is created by developing surfaces for the top of each modelled formation and inserting these into the model grid to create the main horizons. Subdivision between these horizons, such as the Evergreen Formation to Precipice Sandstone division, is then done by inserting isochores or thickness maps between the horizons.

Stratigraphic depth surfaces and thickness maps are incorporated into the structure of the model via the Make Horizons and Make Zones processes, building the vertical layering of the model, as summarised in Table 5-2. In these processes, the input horizons and thickness maps are anchored to the stratigraphic markers and others information, and are adjusted in relation to each other to fit the available accommodation space between horizons.

During development of the geological model, horizons representing ground surface (DEM), base of Cenozoic, base of Springbok Sandstone or top of Walloon Coal Measures (SPUNCON), and the base of Surat Basin (BUNCON), were all set as erosional horizons, the modelled basement was set as a basal horizon, and all other horizons were set as conformable horizons (Table 5-2). Horizons conformably overlie the underlying horizons or are cut by erosional boundaries. The input surfaces for conformable horizons were clipped within the geological model to more cleanly represent onlap and erosional boundaries at the formation extents.

After the completion of the Petrel geological model, some formations are subdivided for the purpose of the groundwater flow model (section 6, OGIA 2019), like the subdivision of the Springbok and Hutton sandstones into upper and lower units and the insertion of the Cattle Creek Formation into the undivided lower Bowen Basin geological model layer.

Table 5-2: Data and processes summary for the regional geological model (UWIR 2021)

Age	Basin	Stratigraphic surface	Code	Stratigraphic markers count	Formation extent	Previous model surface	Additional control	Comment	Surface type	Update from UWIR 2019 geomodel	Modelling process
		Ground elevation (mRL)	00_DEM_1sec	NA	NA	NA	DEM 1"		Erosional	No	Petrel - Make Horizons
Cenozoic		Base of Cenozoic	Cenozoic	>20,000	1	1	Revised to use GSQ 1:100,000-scale mapping in some area	Combine: Condamine Alluvium, the MRV, other Cenozoic basalts and sediments.	Erosional	Local changes	Petrel - Make Horizons
Cretaceous	Surat Basin	Top Wallumbilla Formation	W130_ COREENA	283	1	1			Conformable	No	Petrel - Make Horizons
Cretaceous	Surat Basin	Top Bungil Formation	W210_BUNGIL	558	1	1			Conformable	No	Petrel - Make Horizons
Cretaceous	Surat Basin	Top Mooga Sandstone	W220_MOOGA	610	1	1			Conformable	No	Petrel - Make Horizons
Jurassic	Surat Basin	Top Orallo Formation	W230_ ORALLO	724	1	1			Conformable	No	Petrel - Make Horizons
Jurassic	Surat Basin	Top Gubberamunda Sandstone	W240_ GUBBERA	1,749	1	1			Conformable	No	Petrel - Make Horizons
Jurassic	Surat Basin	Top Westbourne Formation	W310_ WESTBOURNE	2,217	1	1			Conformable	No	Petrel - Make Horizons
Jurassic	Surat Basin	Top Springbok Sandstone	W330_ SPRINGBOK	3,501	1	1			Conformable	No	Petrel - Make Horizons
Jurassic	Surat Basin	Top Walloon Coal Measures	W410_ SPUNCON	5,369	1	1		Previous models were used to control and trend this surface (2012 GHD Model and Dixon et al. 2011)	Erosional	No	Petrel - Make Horizons
Jurassic	Surat Basin	Top Lower Juandah Coal Measures	W420_ JUANLOW	4,759	1	0	From petroleum wells and coal holes	Isochore was created in Petrel from petroleum wells (drilled up to 2017) and coal hole data	Conformable	New	Model integration in Python
Jurassic	Surat Basin	Top Taroom Coal Measures	W470_ TAROOM	5,708	1	0	From petroleum wells and coal holes	Isochore was created in Petrel from petroleum wells (drilled up to 2017) and coal hole data	Conformable	New	Model integration in Python

Age	Basin	Stratigraphic surface	Code	Stratigraphic markers count	Formation extent	Previous model surface	Additional control	Comment	Surface type	Update from UWIR 2019 geomodel	Modelling process
		Top Durabilla Formation	W480_ DURABILLA	5,879	1	1			Conformable	No	Petrel - Make Horizons
		Top Hutton Sandstone	W510_HUTUP	1,110	1	1	Control points	Some industry markers were added to constrain the surface	Conformable	No	
		Top Upper Evergreen Formation	W540_EVERUP	1,115	1	1		Base Hutton depth surface from Dixon et al. (2011) was used to trend previous model's surface.	Conformable	No	Petrel - Make Zones
		Top Boxvale Sandstone	W552_ BOXVALE	383	0	1	Control well data - Zero thickness (228 points)		Conformable	No	
		Top Evergreen Formation	W555_ EVERLOW	1,065	0	1			Conformable	No	
		Top Precipice Sandstone	W580_ PRECLOW	1,248	1	1	Control well data - Zero thickness (290 points)		Conformable	No	
Triassic		Base Surat Basin / Top Bowen Basin / Top Moolayember Formation	W610_ BUNCON	1,715	1	1		Base Surat depth surface from Dixon et al. (2011) extended to the Nelson et al. (2012) data set were used to trend previous model's surface	Erosional	No	Petrel - Make Horizons
	Bowen Basin	Top Clematis Group	W650_CLEM	1,468	1	1			Conformable	No	
		Top Rewan Group	W710_REWAN	1,841	1	1			Conformable	No	
Permian		Top Bandanna Formation	W810_PCTOP	1,955	1	1		Control points from GHD Model (2012) for the Top Rangal depth were used to constrain previous model's surface.	Conformable	No	
		Base of Bandanna Formation	W820_PCBOT	1,833	1	1			Conformable	No	
		Base Bowen	W910_ BASEMENT	829	1	1		SEEBASE was used to trend the previous model's surface.	Erosional base	No	

5.5.3 Model results

The regional model represents the primary lithostratigraphic units in the Surat/Clarence–Moreton and southern Bowen basins. The model comprises 22 stratigraphic surfaces, defining 21 units (Figure 5-3 a)); including 32 active fault segments. The model accounts for the two major aquifers systems – the Great Artesian Basin and Condamine Alluvium; and encompasses CSG reservoir targets – the Walloon Coal Measures and the Bandanna and Cattle Creek formations. Other modelling achievements are the representation of key geological features and relationships (Figure 5-3b and c and section 5.5.1).

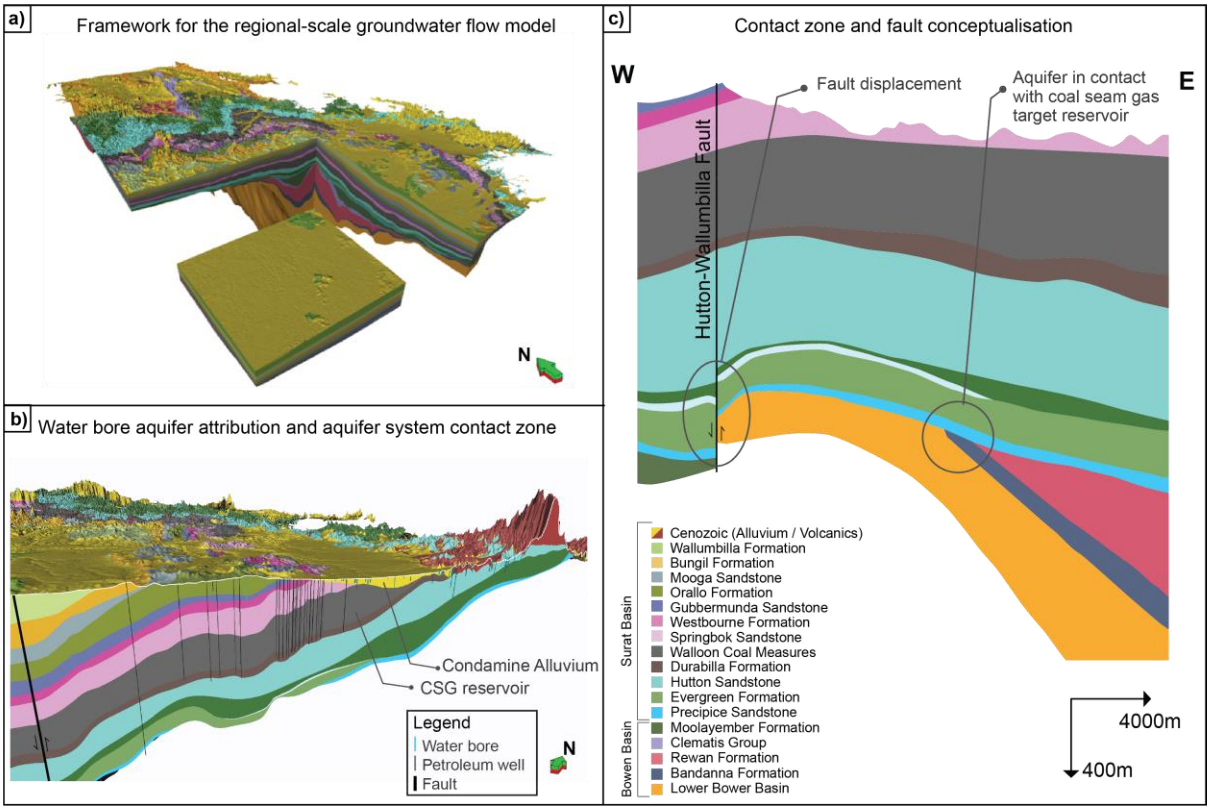

Figure 5-3: Regional geological model – key modelling outputs

Further model results are presented in Appendix 1, as well as chapter 7 and the appendix of OGIA (2019). A video showing the model outputs is also available at the following link: https://www.business.qld.gov.au/industries/mining-energy-water/resources/landholders/csg/surat-cma/location-geology

5.5.4 Walloon subdivisions

The integration of existing and proposed coal mines into the assessment of cumulative impacts within the Surat CMA necessitated a revision of the subdivision of the Walloon Coal Measures. CSG extraction occurs through the depressurisation of wells open across multiple coal seams as well as the interburden between, whereas coal mining targets specific coal seams. The Walloon Coal Measures was subdivided into three layers to better represent: the geology and the clustering of coal seams targeted in coal mining; flow between units within the formation; and the potential propagation of impacts from the deeper CSG production areas into the shallower coal mining areas.

It is often difficult to pick the boundaries between the various internal subdivisions and apply these consistently across the Surat CMA. Therefore, the subdivision was created based on different coal seam and interburden distributions that can, in general, be correlated regionally (Figure 5-4). The Walloon Coal Measures model-unit was subdivided into three layers (Figure 5-4 and Figure 5-5):

- **Upper Juandah Coal Measures:** interval between the Springbok Unconformity (W410_SPUNCON) and the last mudstone below a sandy interval, W420_JUANLOW marker falls between Iona and Argyle seams (R. Sliwa, 2020)
- **Lower Juandah Coal Measures (including Tangalooma Sandstone):** Interval between the W420_JUANLOW boundary and the top of the thicker Taroom coal seams – W470_TAROOM.
- **Taroom Coal Measures:** From the top of the thicker coal seams to the top of the Durabilla Formation – W480 DURABILLA, which is defined as the base of the last coal seam in the lower Taroom Coal Measures. Since it is relatively easy to pick coal in wireline logs, this pick can be made consistently and with some confidence (see section 4.2.3 - OGIA 2019).

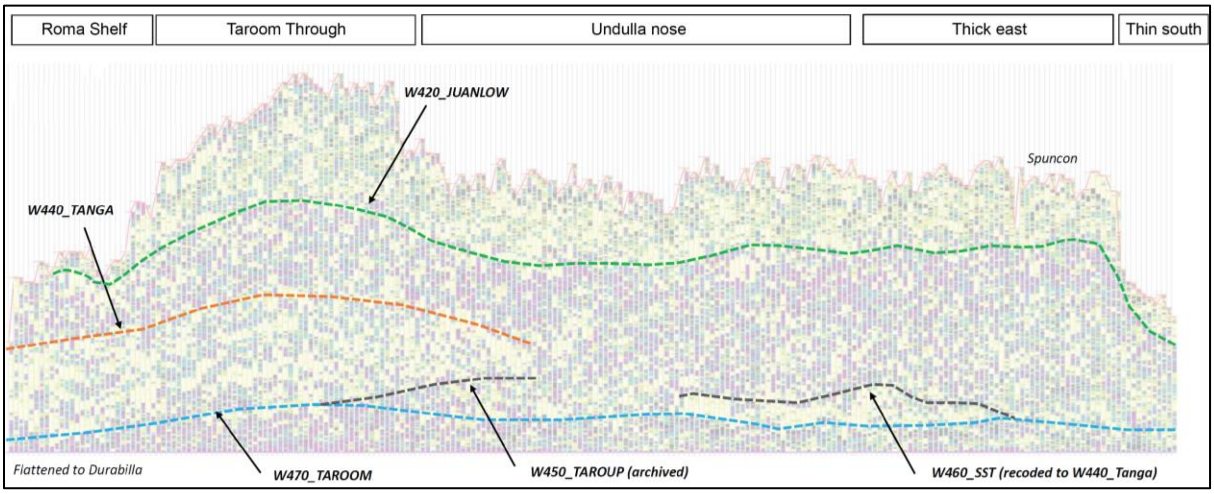

Figure 5-4: Walloon subdivision regional interpretation from wireline logs (Sliwa 2020)

The Juandah Coal Measures typically comprises upward-fining sequences of fine- to medium-grained lithic and feldspathic sandstone, siltstone, mudstone and coal (Nelson et al. 2012) and is further subdivided into an upper interval, which is characterised by a relatively sandy coal seam interburden, and a lower interval with a mudstone/siltstone dominated interburden. The boundary between the upper and lower units is generally picked at the base of a blocky high-resistivity sandstone above the last occurrence of mudstone, referred to as the W420 JUANLOW marker. The base of the lower Juandah Coal Measures is marked by the Tangalooma Sandstone. In areas where the Tangalooma Sandstone does not exist, the lower Juandah Coal Measures cannot easily be differentiated from the underlying Taroom Coal Measures. The Tangalooma Sandstone shales out in the southern part of the Taroom Trough and towards the southeast of the Surat CMA. As the lowermost coal seam package, the Taroom Coal Measures typically comprise thick coal seams and fine-grained interburden. Individual coal seams in this interval tend to be thicker than seams higher up in the Walloon Coal Measures, and the interburden is typically locally sandier.

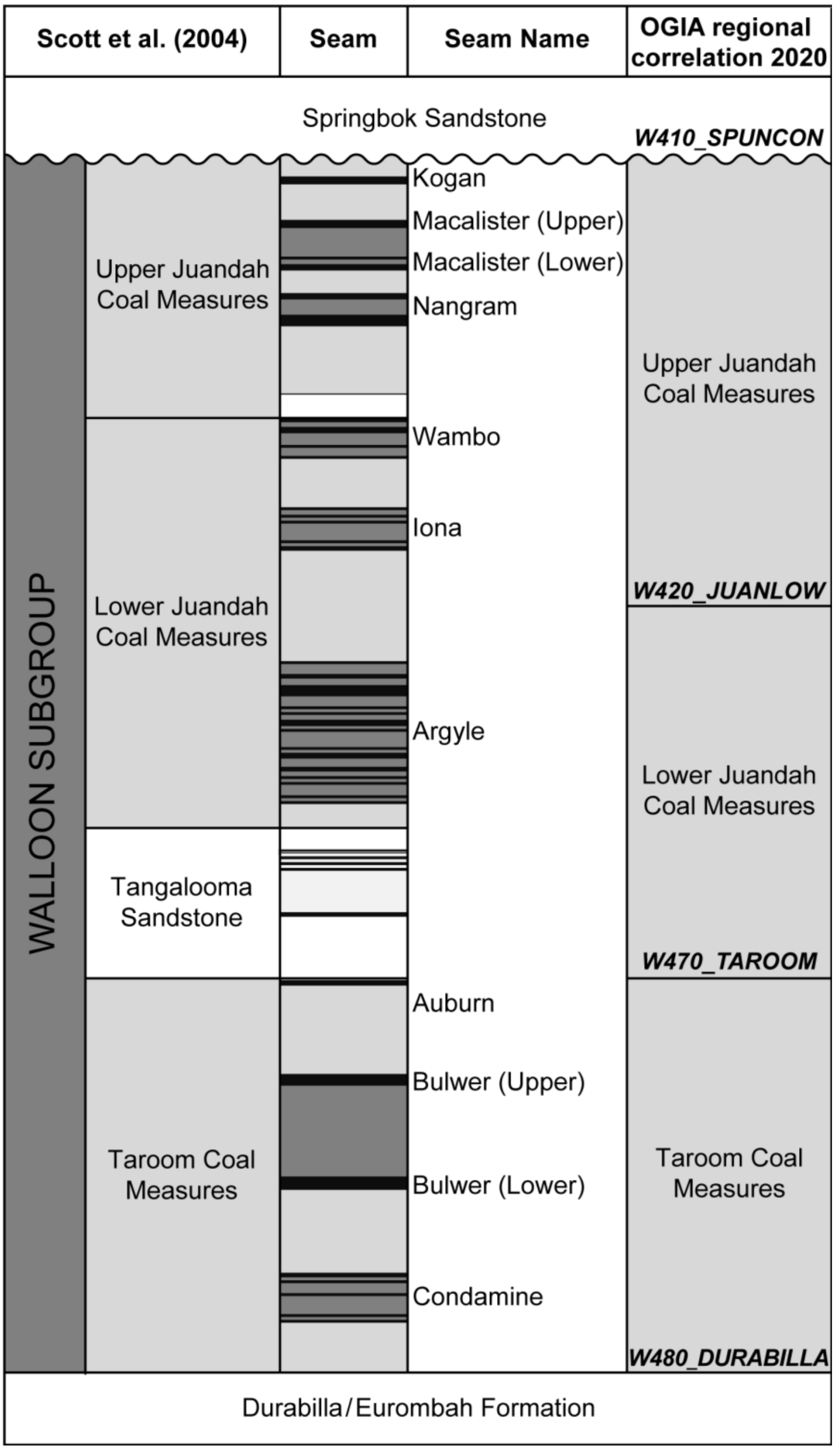

Figure 5-5: Stratigraphy of the Walloon Coal Measures

The regional stratigraphic markers dataset was revised in 2020 to includes newly available coal holes from coal mine tenures. R. Sliwa undertook stratigraphic interpretation of wireline logs for 9,100 coal holes with gamma ray and density logs and provided 18,596 stratigraphic makers from these holes. Stratigraphic makers from coal holes were combined to the existing markers from petroleum wells interpretation (drilled up to 2017) and this became the primary input dataset for the isochore (or thickness) maps generation. New stratigraphic markers derived from petroleum wells drilled between 2017 and 2020 were not ready at the time of isochore creation (end of July 2020) but were used in sub-regional geomodel construction.

To subdivide the Walloon Coal Measures, several steps occurred:

- Regional interpretation to delineate the stratigraphic boundaries for W410_SPUNCON, W420_JUANLOW and W470_TAROOM using new coal holes and revising the existing petroleum wells, accounting for new information.
- Creation of a new formation extent for the Lower Juandah and Taroom coal measures, these formation extents were created by interpolating W420_JUANLOW and W470_TAROOM stratigraphic markers into an elevation surface (mAHD) and intersecting it with the 1" DEM. These limits were adjusted by consideration of other layer extents.
- Creation of an isochore (thickness) points dataset and quality checking the information. Only a small subset of the coal holes could be used for that purpose as most of the coal holes do not penetrate a full sub-unit. Table 5-3 summarises the number of isochore points for each of the Walloon sub-units used in the isochore maps creation. A more detailed description of the process used to generate the isochore maps is presented in Appendix 2.

Table 5-3: Isochore points derived from stratigraphic markers

Stratigraphic interval	Marker defining the interval	Marker count
Upper Juandah Coal Measures	W410_SPUNCON to W420_JUANLOW	4,479
Lower Juandah Coal Measures	W420_JUANLOW to W470_TAROOM	4,759
Taroom Coal Measures	W470_TAROOM to W480_Durabilla	5,705

5.6 Northern Coal Area geological model

5.6.1 Key features

Developed to support assessment of coal mining impacts in the northern part of the Surat Basin, the Northern Coal Area (NCA) geological model was used for both conceptualisation and groundwater modelling. The following key features and datasets were represented in this geological model:

- Surat units relevant to Walloon Coal Measures coal mining and CSG extraction – reservoir, overlying and underlying aquifers, including Walloon Coal Measures subdivisions
- outcropping Surat Basin units
- coal holes and new petroleum well data
- absence of regional faults

5.6.2 Modelling approach

The upper limit of the model is the 1" DEM topographic surface (Gallant et al. 2011). The model includes only regionally extensive formations: the Springbok Sandstone, subdivided Walloon Coal Measures, Durabilla Formation and Hutton Sandstone. The Walloon Coal Measures is subdivided into Upper Juandah, Lower Juandah and Taroom coal measures, from coal and petroleum well picks (drilled up to 2020). The stratigraphy of the shallower formations was simplified in this model, where all formations shallower than the Springbok Sandstone were lumped into a single unit referred to as the overburden.

The same modelling workflow (see section 5.3) used for the regional geological model was applied to the construction of the NCA model. A series of stratigraphic depth surfaces (mAHD) were created for each formation boundary and integrated into the model via the Make Horizons process (Petrel). Due to the limited control for the top of Hutton Sandstone, the Durabilla formation and Hutton Sandstone were modelled based on isochore (or thickness) maps in the Make Zones process. These two modelling steps bring together all input data, adjusting them to accommodate each other, accounting for thickness and spacing accommodation and anchoring them to the stratigraphic well and control markers. Table 5-4 summarises the data and processes used in the generation of the NCA geological model.

Similar to the development of the regional geological model, horizons representing ground surface (DEM) and base of Springbok Sandstone or top of Walloon Coal Measures (SPUNCON) were all set as erosional horizons. All other horizons were set as conformable and, hence, either conformably overlie the underlying horizon or are cut by erosional boundaries (Table 5-4). The stratigraphic boundary representing the top of the Durabilla Formation is well constrained (from well data) and delineated (from GSQ mapping), and therefore, was used as a trend surface to guide some of the other surface boundaries.

Table 5-4: Data and processes summary for the NCA geological model (UWIR 2021)

Age	Basin	Stratigraphic surface	OGIA's reference name	Stratigraphic markers count	Formation extent	Primary input	Comment	Surface type	Modelling process
		Ground elevation	00_DEM_ 1sec	NA	NA	1" DEM		Erosional	Make Horizons and Make Zones
Jurassic	Surat Basin	Top Springbok Sandstone	W330_ SPRINGBOK	1,932	Same as 2018 geological model	Petroleum wells	Based on 2018 regional model output adjusted to new compiled well data	Conformable	
		Top Walloon Coal Measures	W410_ SPUNCON	3,952	Same as 2018 geological model	Petroleum wells and coal holes	Surface based on the new compiled well data and trend surface from the previous geological model output	Erosional	
		Top Lower Juandah Coal Measures	W420_ JUANLOW	3,411	New – created	Petroleum wells and coal holes	New stratigraphic surface using new compiled well data and NCA Top Durabilla as trend surface	Conformable	
		Top Taroom Coal Measures	W470_ TAROOM	3,782	New – created	Petroleum wells and coal holes	New stratigraphic surface using new compiled well data and NCA Top Durabilla as trend surface	Conformable	
		Top Durabilla Formation	W480_ DURABILLA	3,948	Updated	Petroleum wells and coal holes	Surface based on the new compiled well data and trend surface from the previous geological model output	Conformable	
		Top Hutton Sandstone	W510_ HUTUP	307	Updated	Petroleum wells and coal holes	Build from isochore	Conformable	
		Top Upper Evergreen Formation	W540_ EVERUP	428	Same as 2018 geological model	Petroleum wells	Based on 2018 regional model output adjusted to revised well data	Conformable	

5.6.3 Model results

The NCA geological model focuses on the Walloon Coal Measures subdivisions – the target of coal mines and CSG, and its adjacent formations. It covers an area of 17,750 km^2, extending 150 km east-west and 115 km north-south, and encompassing major CSG fields such as Roma (Santos), Reedy Creek (Origin), Ross and Cam (QGC), and three coal mines – Elimatta, Wandoan Coal Project and The Range, see Figure 5-6. The model contains seven stratigraphic layers, from ground elevation to Hutton Sandstone, with a grid resolution of 250 m. It provides a revised geology accounting for new petroleum wells (drilled up to 2020) and coal holes. No regional faulting was identified in the area, therefore the model does not contain any faults.

The Walloon subdivision into Upper Juandah, Lower Juandah and Taroom coal measures, the outcrop of the Surat Basin units along the northern margins and the unconformity at the base of the Springbok Sandstone are some of the key geological features represented in this geological model.

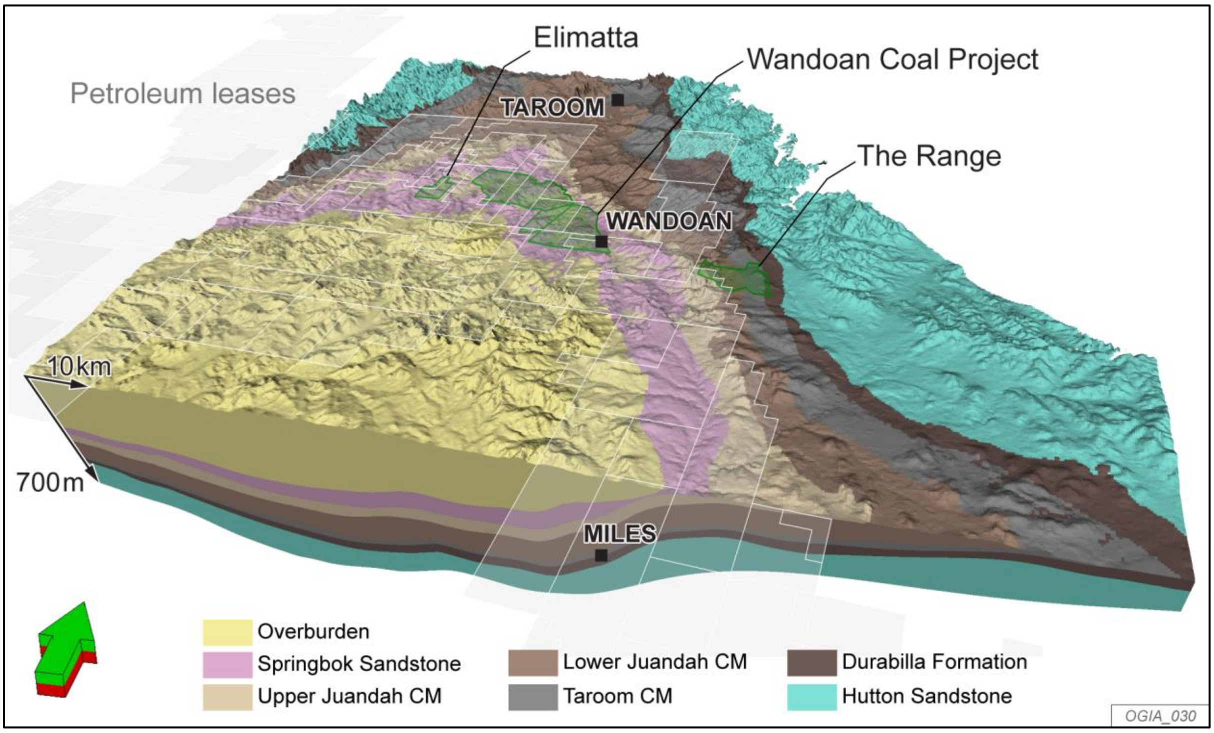

Figure 5-6: Northern Coal Area geological model

5.7 New Acland geological model

5.7.1 Key features

The New Acland geological model was developed to support fault characterisation and conceptualisation of the groundwater system to improve predictions of the associated impacts of coal mining around the New Acland mine.

The following key features were represented in this geological model:

- revised geology of the Surat units relevant to Walloon coal mining – reservoir, overlying and underlying aquifers
- separation and adjustment of the Cenozoic alluvium and MRV

- data from coal holes and new petroleum wells (drilled up to 2020)
- mapped and modelled faults from coal hole data
- Walloon Coal Measures subdivisions
- the identified potential juxtaposed area between reservoir and aquifer from fault displacement.

5.7.2 Modelling approach

In the area surrounding the New Acland mine, the confidence of the regional geological model is low, as limited data control was available in this part of the Surat Basin prior to the inclusion of the coal mines in the Surat CMA. New Hope provided extensive geology datasets (drillholes, geophysical survey, local geology model, etc.) that were used to revise the understanding of the geology of the area.

The same modelling workflow (see section 5.3) used for the regional geological model and the NCA geological model was applied to the construction of the New Acland geological model, with the difference of using angular faults, rather than vertical faults, as pillars of the model within the Pillar Gridding process. A series of stratigraphic depth surfaces (mAHD) were created for each formation boundary and integrated into the model via the Make Horizons process (Petrel). Due to the limited control for the Top Hutton Sandstone, the Durabilla formation and Hutton Sandstone were modelled based on isochore (or thickness) maps in the Make Zones process. These two modelling steps bring all input data together, adjusting them to accommodate each other, accounting for thickness and spacing accommodation. Table 5-5 summarises the data and processes used in the generation of the New Acland geological model.

The two uppermost layers modelled are the Cenozoic alluvium and the MRV. These two units have an erosional contact with the underlying formations. The alluvium in some areas sits on top of the MRV.

The base of Cenozoic surface was created for the purpose of the regional geological model by first developing a thickness map (based on stratigraphic picks from water bores) of the unit and then subtracting this thickness from the DEM surface to generate the erosional base of Cenozoic surface. For the New Acland geological model, the Cenozoic extent was revised for the extent of the alluvium only using GSQ detailed surface geology 1:100,000 mapping, and coal holes – base of alluvium markers.

One of OGIA's projects was to further characterise the MRV to include newly available datasets: regional airborne magnetic survey, detailed GSQ surface geology (1:100,000 mapping), New Hope data and GWDB water bores. Results from this project were used to revise outcrop and subcrop extents and produce a thickness map to define the erosional base of the MRV.

For the Surat units, the model includes the Springbok Sandstone, the subdivided Walloon Coal Measures, the Durabilla Formation, and the Hutton Sandstone. All Surat units are outcropping or subcropping toward the east.

The coal holes dataset provides good control on the stratigraphic boundaries. Furthermore, the high-density drilling in the mining area also informs fault characterisation, as faults can be mapped and displacements estimated from offsets between stratigraphic markers.

Table 5-5: Data and processes summary for the New Acland geological model

Age	Basin	Stratigraphic surface	OGIA's reference name	Stratigraphic marker count	Formation extent	Primary input	Comment	Surface type	Petrel process
		Ground elevation	00_DEM_ 1sec	NA	NA	1" DEM		Erosional	Make Horizons (and Make Zones)
		Base Cenozoic	Base_ Alluvium	1,080[a]	Updated	Water bore and coal holes	Same method as the regional geomodel with a refined alluvium extent from GSQ - 1:100,000 scale	Erosional	
		Base MRV	Base_MRV	1,544[b] +712[c]	New - created	Water bore, coal holes and magnetic survey	Surface output from the MRV characterisation project	Erosional	
Jurassic	Surat Basin	Top Springbok Sandstone	W330_ SPRINGBOK	None within model extent	Same as 2018 geomodel	Petroleum wells	Based on 2018 regional model output (no new data available)	Conformable	
		Top Walloon Coal Measures	W410_ SPUNCON	4	Same as 2018 geomodel	Petroleum wells	Based on 2018 regional model output (no new data available)	Erosional	
		Top Lower Juandah Coal Measures	W420_ JUANLOW	5	New - created	Petroleum wells and coal holes	From newly compiled markers and smoothed Top Durabilla trend surface	Conformable	
		Top Taroom Coal Measures	W470_ TAROOM	1,518	New - created	Petroleum wells and coal holes	From newly compiled markers and smoothed Top Durabilla trend surface	Conformable	
		Top Durabilla Formation	W480_ DURABILLA	459	Updated	Petroleum wells and coal holes	From newly compiled markers (primary input) and Balgowan sequence floor (secondary input)	Conformable	
		Top Hutton Sandstone	W510_ HUTUP	17	Updated	Petroleum wells and coal holes	Build from isochore using regional data	Conformable	
		Top Upper Evergreen Formation	W540_ EVERUP	2	Same as 2018 geomodel	Petroleum wells	Based on 2018 regional model output (no new data available)	Conformable	

Notes:

a. Cenozoic confident dataset (OGIA 2017) within extent derived from GSQ 1:100,000 geological mapping
b. MRV confident dataset (OGIA 2020) within extent derived from GSQ 1:100,000 geological mapping
c. MRV reference dataset (OGIA 2020) within extent derived from GSQ 1:100,000 geological mapping

5.7.3 Model results

The New Acland geological model focuses on the surficial formations (alluvium and MRV) and the Taroom Coal Measures – the target of New Acland coal mine. It contains eight stratigraphic layers, from ground elevation down to the Hutton Sandstone, with a grid resolution of 100 m.

The model (Figure 5-7) is built around the New Acland coal mine, on the western slope of the Great Dividing Range within the Clarence Moreton Basin. It covers an area of about 4,875 km^2 (75 km by 65 km) and provides a revised geology of the area, including significant newly available data – primarily from coal holes.

Key geological features of the New Acland geological model are the outcropping of the Surat units toward the eastern edge. Strata above the Taroom Coal Measures has been mostly eroded and then partially covered by Tertiary basalts of the MRV and Cenozoic alluvium. The Durabilla Formation is consistently present underneath the Taroom Coal Measures. The Durabilla Formation is underlain by the Marburg Sandstone, an equivalent to the Hutton Sandstone in the Surat Basin. Within the extent of the mining leases, ten faults were modelled with four that show potential for juxtaposition between the lower part the Taroom Coal Measures and the Hutton Sandstone, as shown in Figure 5-8 and Figure 5-9.

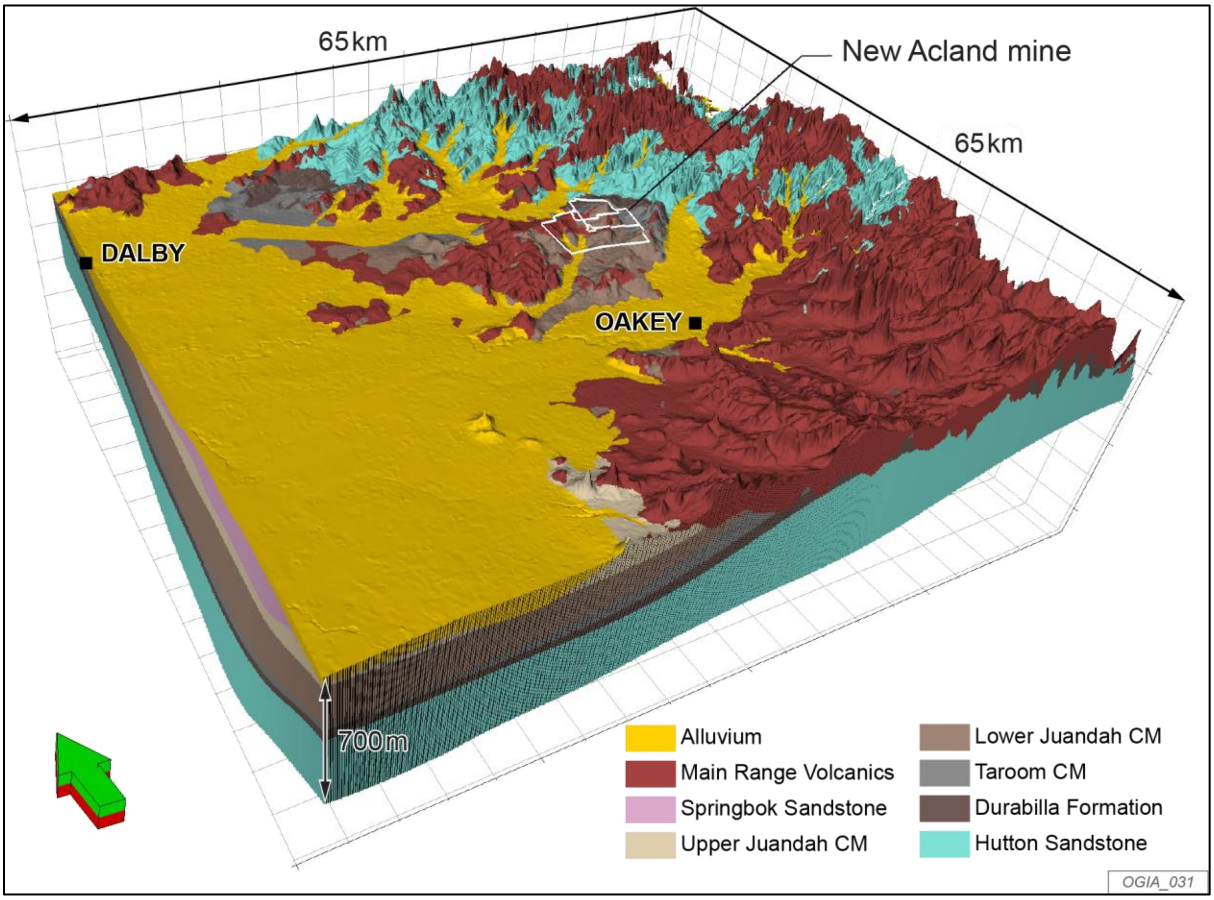

Figure 5-7: New Acland 3D geological model

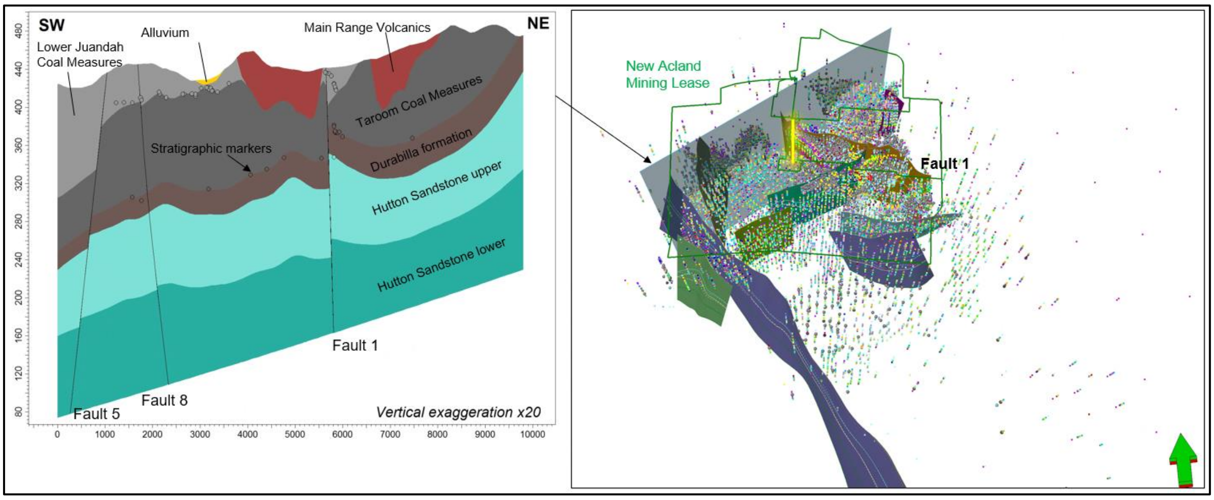

Figure 5-8: Geological cross-section (left) and 3D view (right) of the faults network modelled in the New Acland geological model (2020)

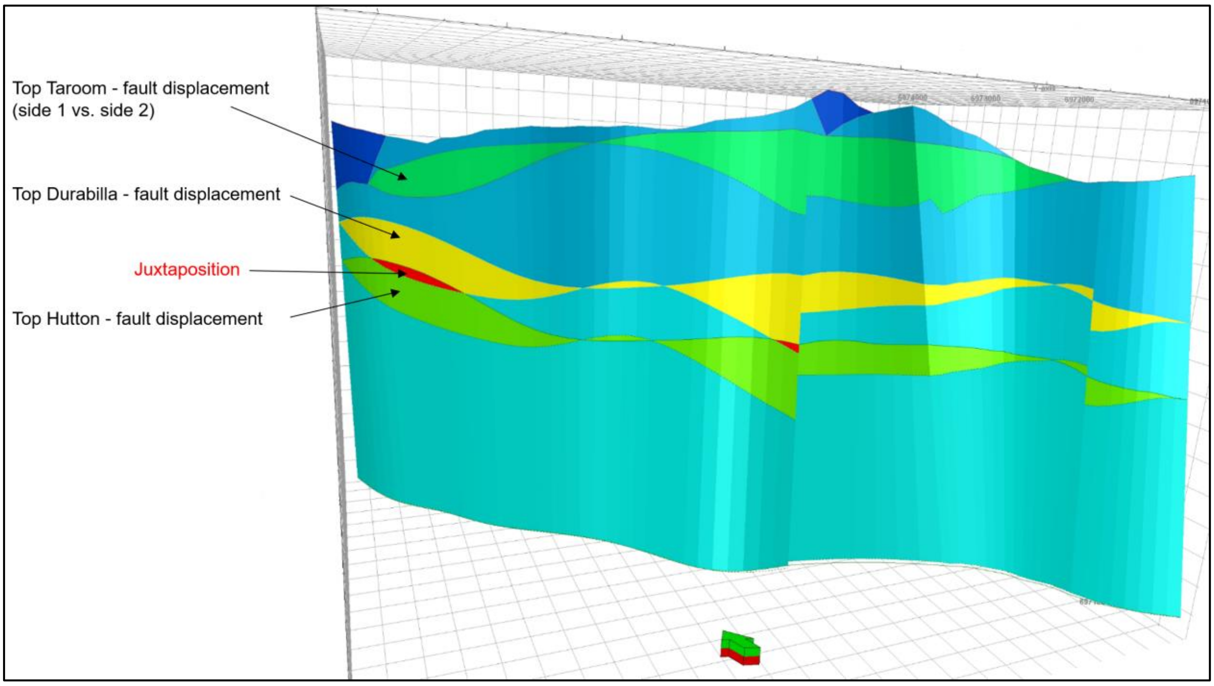

Figure 5-9: Juxtaposition mapping for Fault 1 (New Acland OGIA geomodel 2020)

5.8 Horrane Fault geological model

5.8.1 Key features and objectives

The UWIR 2019 identified the Horrane Fault as having sufficient displacement to bring the coal seams at the base of the Walloon Coal Measures in contact with the Hutton Sandstone. To further understand groundwater flow near connectivity features, OGIA undertook a review of available 2D seismic surveys in the vicinity of the Horrane Fault to refine faults mapping. The depth converted 2D seismic and fault interpretations (Gonzalez & Hayes 2020) were used to better characterise and delineate the different stratigraphic units around the Horrane Fault.

The following key features were represented in this geological model:

- Surat units relevant to CSG impacts – reservoir, overlying and underlying aquifers

- complex fault modelling from new seismic depth converted interpretation
- erosional contact between the Cenozoic and the Surat units
- Walloon Coal Measures subdivisions
- Identification of potentially juxtaposed area between reservoir and aquifer from fault displacement

5.8.2 Modelling approach

The model is capped by the 1" DEM ground elevation. The uppermost layer is the Cenozoic alluvium – mostly the Condamine Alluvium. Within the model extent, the base of the Cenozoic surface was kept consistent with the surface created for the regional geological model, as no new information was available within the model domain. It was developed by first developing thickness map (from water bores) of the unit and then subtracted from the DEM to generate the erosional base of Cenozoic surface.

The Condamine Alluvium is present over most of the model extent. The shallower Surat units are outcropping or subcropping underneath the Condamine Alluvium toward the eastern model boundary. For the Surat units, the model includes the overburden (Gubberamunda Sandstone and Westbourne Formation were lumped into a single unit), the Springbok Sandstone (upper and lower), the subdivided Walloon Coal Measures, the Durabilla Formation, and the Hutton Sandstone (upper and lower).

The depth converted faults and seismic horizon interpretations, along with stratigraphic markers, were used as primary datasets (Figure 5-10). The same modelling workflow used for the regional geological model (section 5.3) was applied to the construction of the Horrane Fault geological model, with the difference of using angular faults as pillars of the model using the Pillar Gridding process. A series of stratigraphic depth surfaces (mAHD) were created for each formation boundary using stratigraphic markers and seismic horizon depths converted and integrated into the model via the Make Horizons process (Petrel). Due to the limited data control, the Springbok and Hutton sandstones subdivisions were modelled based on isochore (or thickness) maps in the Make Zones process. These modelling steps bring all input data together, adjusting them to accommodate each other, accounting for thickness and spacing accommodation. Table 5-6 summarises the data and processes used in the generation of the Horrane Fault geological model.

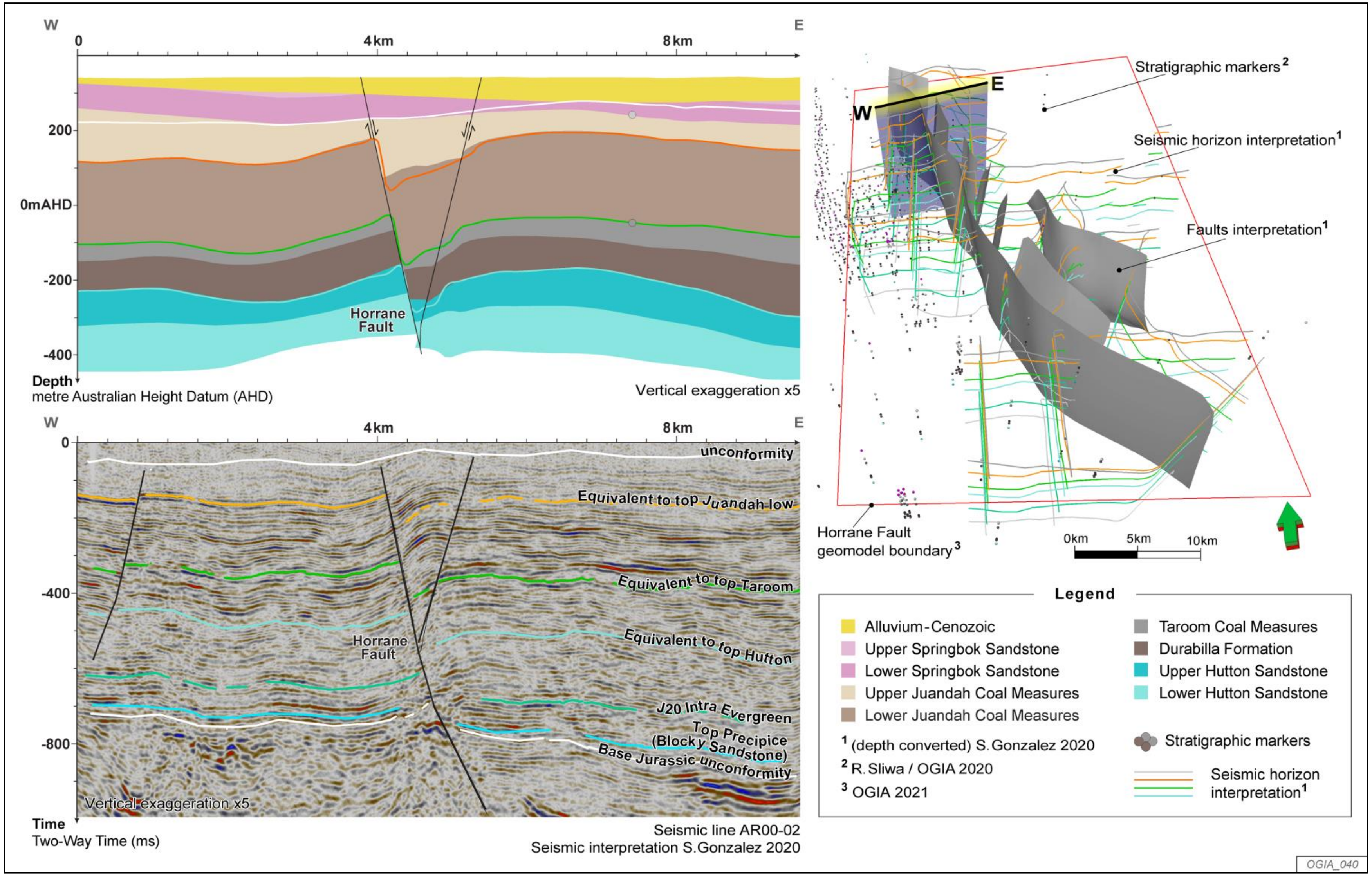

Figure 5-10: Horrane Fault geological model and 2D seismic interpretations

Table 5-6: Data and processes summary for the Horrane Fault geological model

Age	Basin	Stratigraphic surface	OGIA's reference name	Stratigraphic markers count	Formation extent	Primary input	Comment	Surface type	Petrel modelling process
		Ground elevation	00_DEM_ 1sec	NA	NA	1" DEM		Erosional	Make Horizons
		Base Cenozoic	Base_ Alluvium	381[a] + 356[b]	Same as 2018 geomodel	Water bores	Based on 2018 regional model output (no new data available)	Erosional	
Jurassic	Surat Basin	Top upper Springbok Sandstone	W330_ SPRINGBOK	None in the model extent	Same as 2018 geomodel	Petroleum wells and seismic interpretation	New surface from new compiled 2020 markers (outside model) and a trend surface (UNCDepthOG1) – from seismic	Conformable	
		Top lower Springbok Sandstone	W240_ SPBOKBAS	1		Petroleum wells	Isochore map from new compiled 2020 markers	Conformable	Make Zones
		Top Walloon Coal Measures	W410_ SPUNCON	128	Same as 2018 geomodel	Petroleum wells and seismic interpretation	New surface from new compiled 2020 markers and depth converted seismic interpretation (UNCDepthOG1)	Erosional	Make Horizons
		Top Lower Juandah Coal Measures	W420_ JUANLOW	180	Same as 2018 geomodel	Petroleum wells and seismic interpretation	New surface from new compiled 2020 markers and depth converted seismic interpretation (W420Depth_OG_WT)	Conformable	
		Top Taroom Coal Measures	W470_ TAROOM	106	Same as 2018 geomodel	Petroleum wells and seismic interpretation	New surface from new compiled 2020 markers and depth converted seismic interpretation (W470Depth_OG_WT)	Conformable	
		Top Durabilla Formation	W480_ DURABILLA	104	Same as 2018 geomodel	Petroleum wells	New surface from new compiled 2020 markers and a trend surface (W470_Taroom)	Conformable	
		Top upper Hutton Sandstone	W510_ HUTUP	7	Same as 2018 geomodel	Petroleum wells and seismic interpretation	New surface from new compiled 2020 markers, depth converted seismic interpretation (W510Depth_OG_WT) and a trend surface (W480_Durabilla)	Conformable	
		Top lower Hutton Sandstone	W520_ HUTLOW	15		Petroleum wells	Isochore map from newly compiled 2020 markers	Conformable	Make Zones
		Top Upper Evergreen Formation	W540_ EVERUP	6	Same as 2018 geomodel	Petroleum wells and seismic interpretation	New surface from new compiled 2020 markers and a trend surface (J20Depth_OG_WT)	Conformable	Make Horizons

Notes:

a. Cenozoic confident dataset (OGIA 2017) within extent
b. Cenozoic reference dataset (OGIA 2017) within extent

5.8.3 Model results

This geological model focuses on the Surat units that are affected by the Horrane Fault, with a particular interest in the Walloon Coal Measures reservoir and adjacent aquifers – Springbok and Hutton sandstones, and Condamine Alluvium. The Horrane Fault geological model covers 1,000 km^2. The model represents ten layers and eight faults with a 100 m grid resolution.

In 2020, as part of the revised interpretation and depth conversion of 2D seismic (Gonzalez & Hayes 2020), two scenarios of fault structures were interpreted: a single large fault segment and a segmented fault system. For the purpose of groundwater modelling, the Horrane Fault was defined as a single segment. Another eight faults were modelled, that in some cases, truncate the main fault, as in Figure 5-10.

The key geological features and relationships of this model are: representation of shallower Surat units subcropping underneath the Condamine Alluvium; mapping of the Horrane complex fault system; and delimitation of the Surat units. The characterisation of faults through revised interpretation and modelling, gave a greater level of confidence in the estimation of fault displacement and juxtaposition.

6 Conclusion

- In the process of preparing and updating the UWIR, the understanding of the geology and structural framework of the Surat and Bowen basins continues to evolve from the collective work undertaken by OGIA, the resource industry and research organisations.
- Geological characterisation and geological models underpin groundwater conceptualisation groundwater flow modelling.
- Geological characterisation and geomodels are based on OGIA's primarily interpretation of downhole logs from about 7,500 P&G wells in terms of six lithology types, supported by further stratigraphic marker interpretations from those wells; about 4,500 coal holes; and 24,500 water bores. 3D seismic data and more than 5,000 2D seismic lines also supported direct and indirect interpretations.
- A 21-layer, 250×250-m scale 3D regional geomodel is prepared by OGIA in the Petrel modelling platform (Schlumberger), representing all hydrostratigraphic units and regional faults in the Surat/Clarence–Moreton and southern Bowen basins and overlying Cenozoic sediments.
- Three additional subregional models are also prepared for the NCA, New Acland mining area and the Horrane Fault area.
- The seven-layer, 250×250-m scale NCA sub-regional geomodel support assessment of coal mining impacts and better understanding of surficial processes and provides a revised geology of the upper Surat Basin units and Cenozoic coverage, accounting for newly available petroleum wells and coal holes.
- The eight-layer, 100×100-m scale New Acland sub-regional geomodel supports fault characterisation and coal mining impacts in the area and captures all formations from the alluvium (and MRV) down to the Hutton Sandstone, with 10 faults.
- The 10-layer, 100×100-m scale Horrane Fault local geomodel represents the complex fault system, shallow Surat Basin units and Cenozoic relationships. It was built from revised depth-converted seismic interpretations and P&G wells to inform fault characterisation and aquifer–reservoir juxtaposition risk.
- OGIA will continue to refine and develop geomodels in specific focus areas, such as around the contact zones and Permian units, and further explore characterisation of the Springbok Sandstone – Walloon Coal Measures contact and subdivision of the Precipice Sandstone.

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Appendix 1 Model results and outputs

The model outputs comprise 22 stratigraphic surfaces defining 21 units and 32 fault segments. Figure A1-1 shows a 3D illustration of the model layering, with the cut-away exposing the main depocentre of the model.

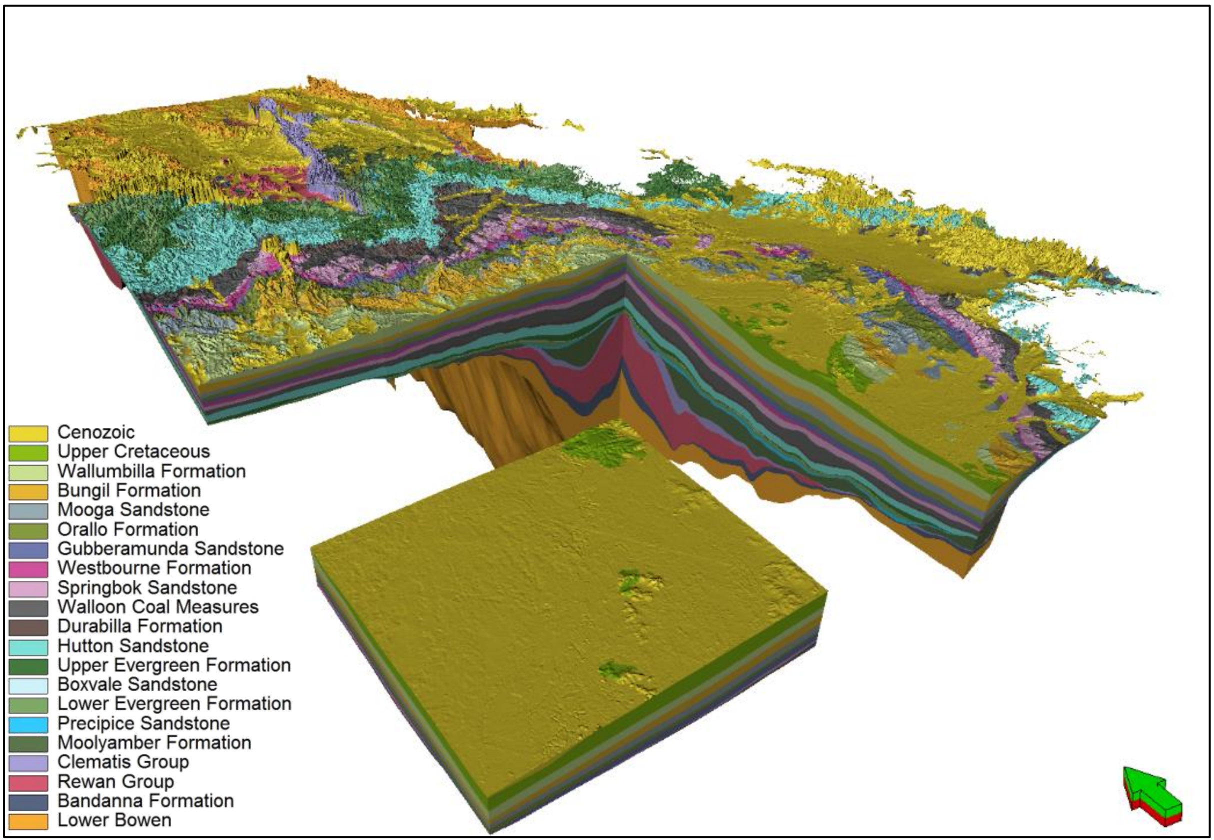

Figure A1-1: 3D view of the geological model (vertical exaggeration x25)

Figure A1-2 displays the modelled outcrop and Figure A1-3 to Figure A1-6 display cross-sections through the model and specific structural features listed above.

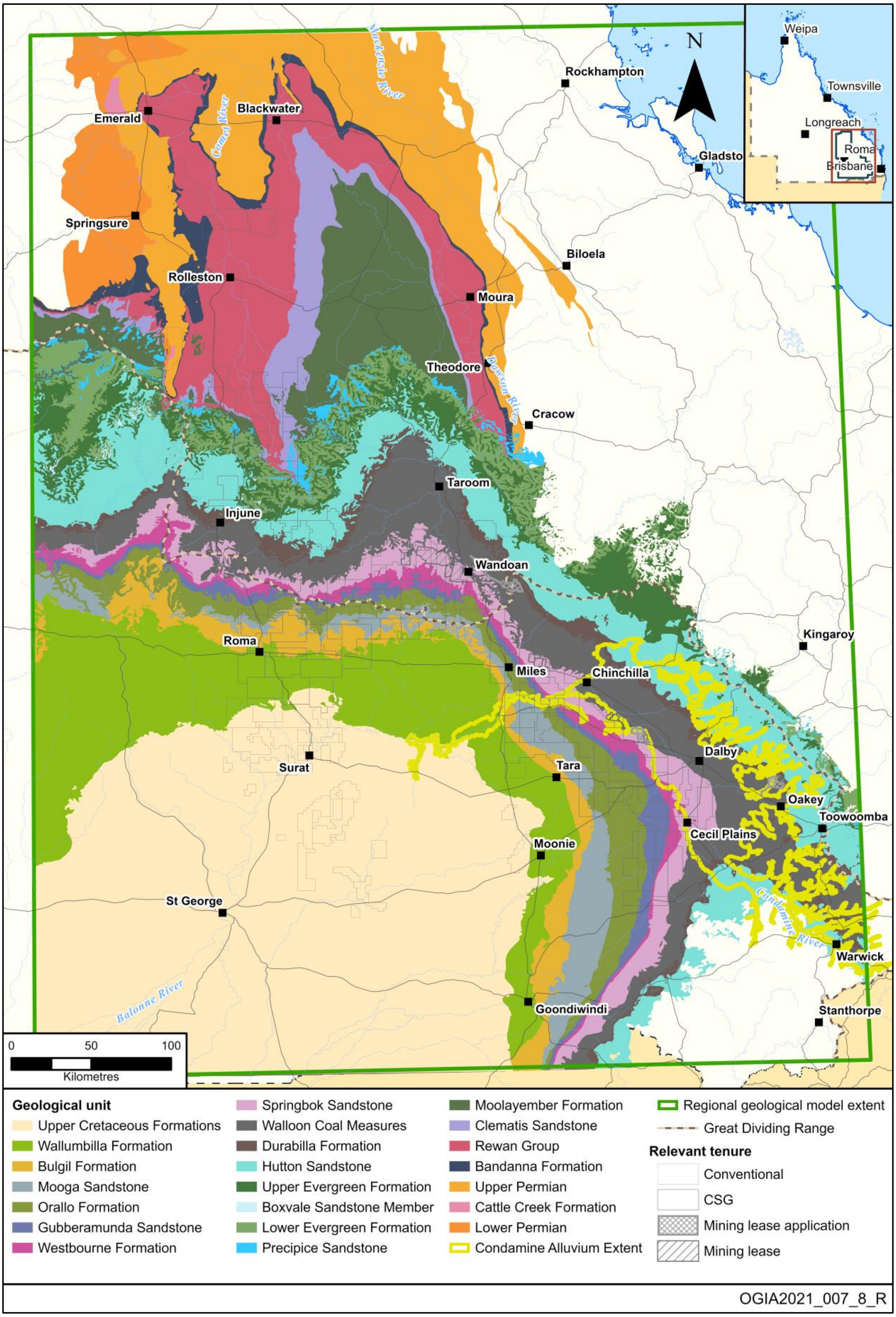

Figure A1-2: Solid geology in the model domain

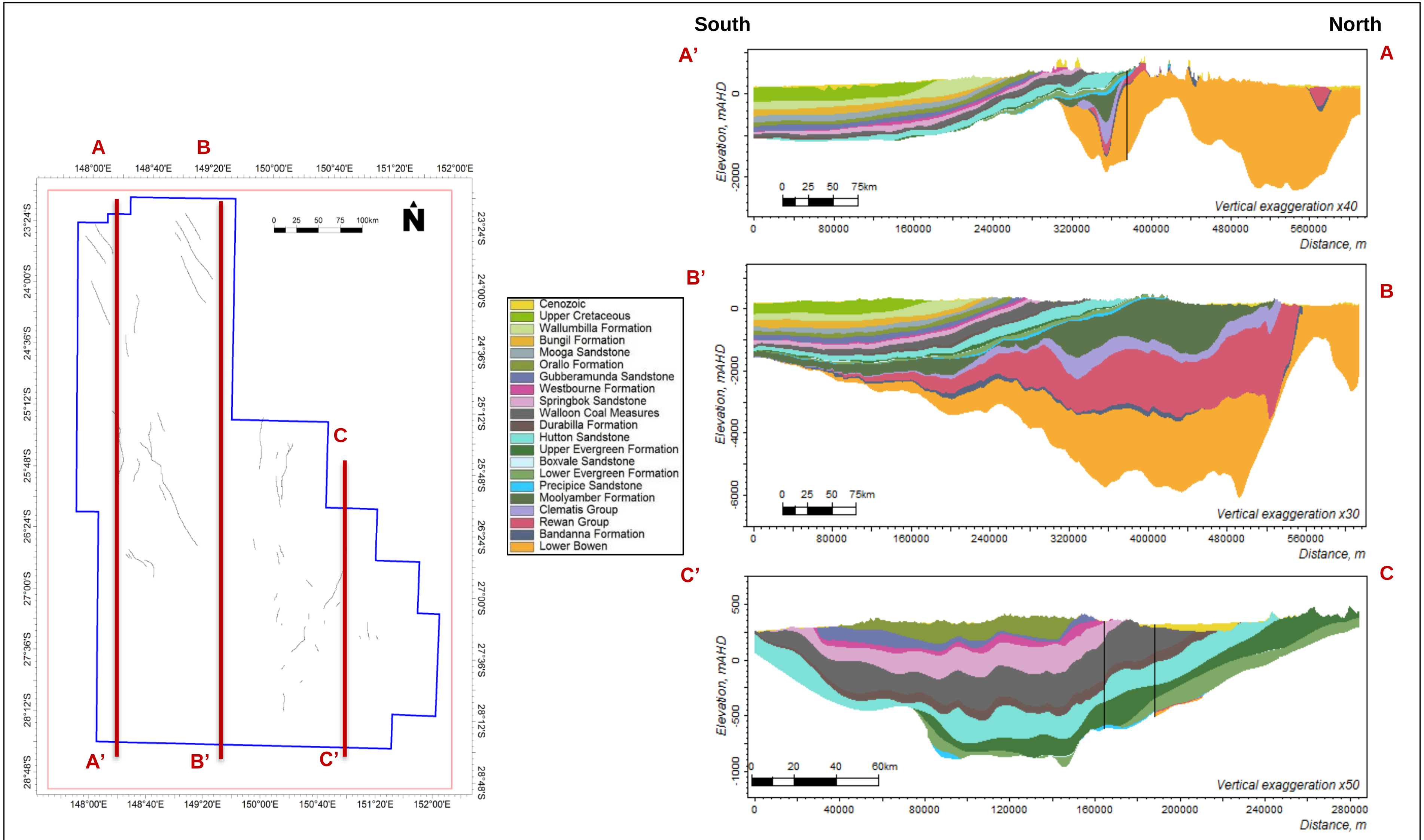

Figure A1-3: South–north cross-sections

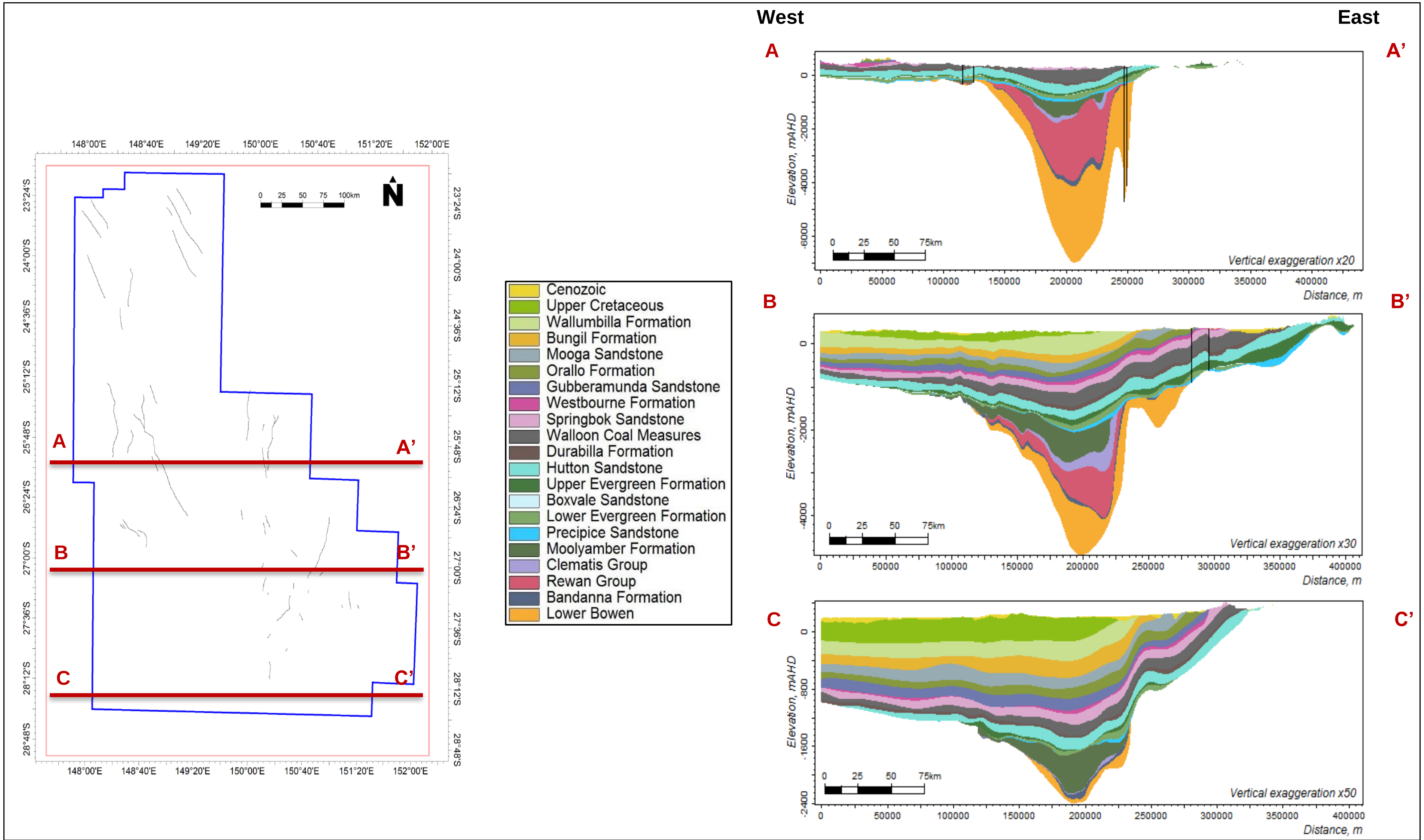

Figure A1-4: West–east cross-sections

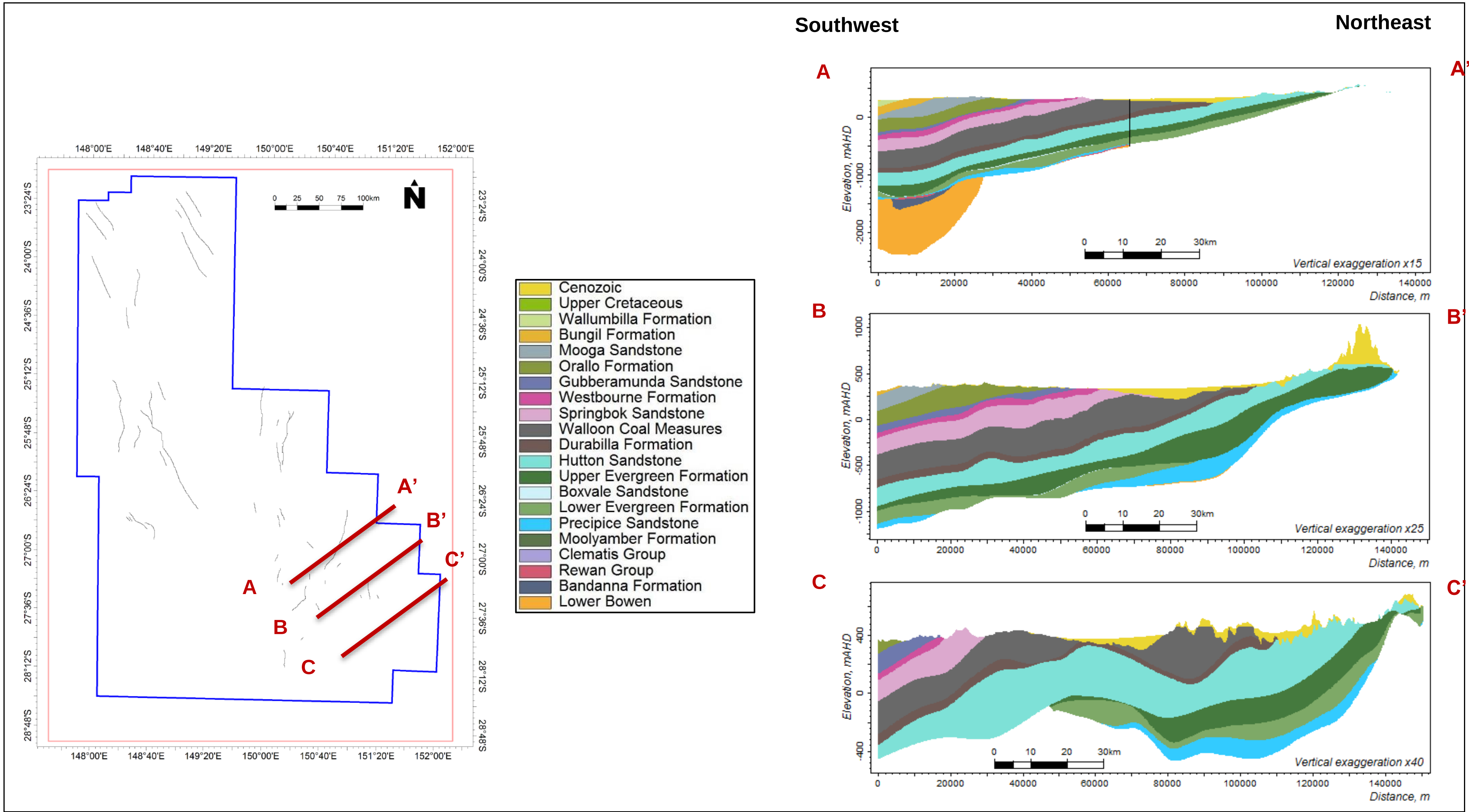

Figure A1-5: Southwest–northeast cross-sections along the Condamine Alluvium

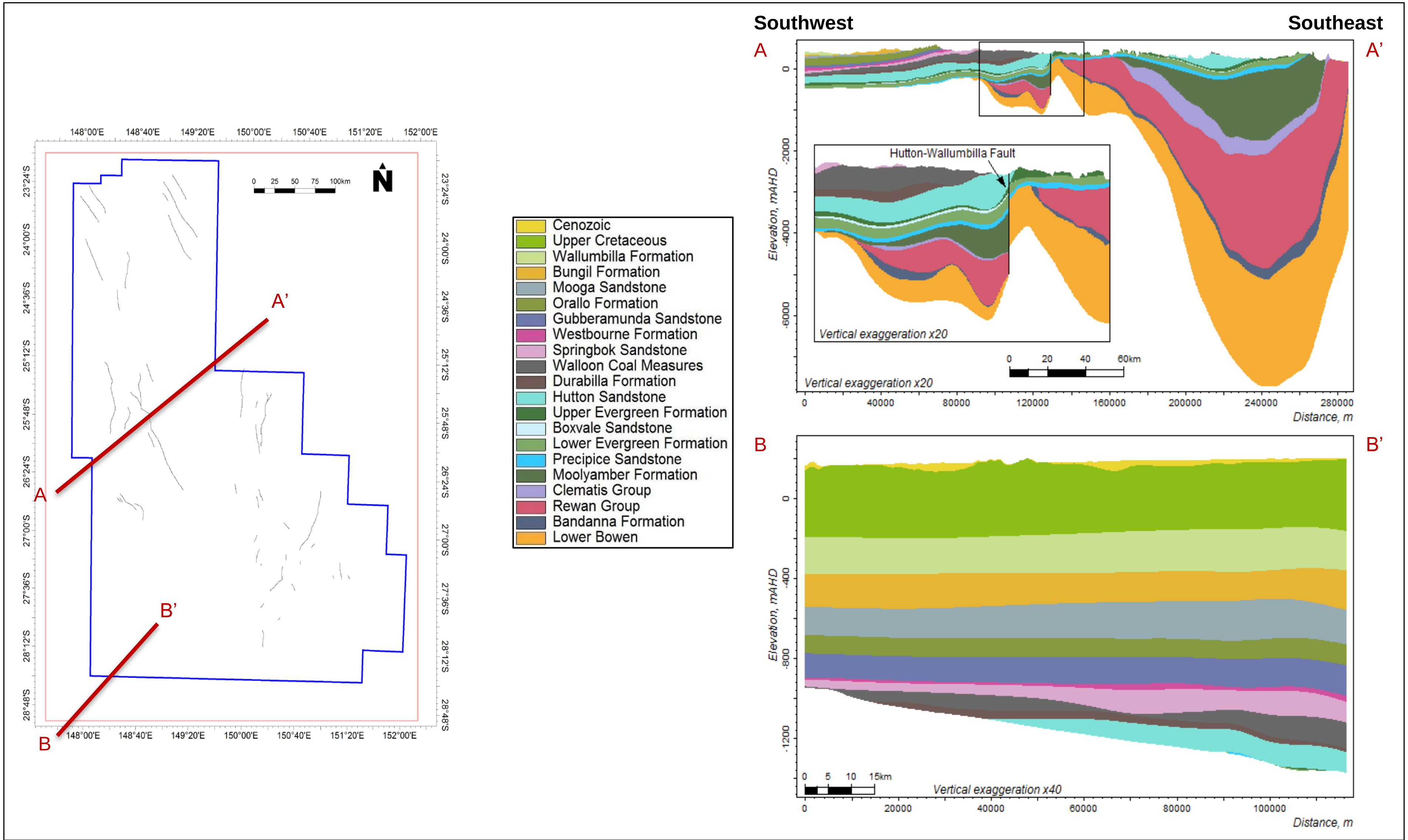

Figure A1-6: Cross-sections through the Bandanna and Surat Basin contact and the southwest basement onlap

Appendix 2 Generation of isochore maps

The isochores were created in Petrel using the *Make/edit surface* process, with the following inputs (Figure A2-1):

- isochore (true vertical thickness) points for each subdivision (Table A2-1)
- W420_JUANLOW and W470_TAROOM extents
- **Geometry tab**: selection of the surface extension (i.e. formation extent) and the grid resolution (i.e. 250 metres)
- **Algorithm tab**: for isochore/thickness surfaces, the isochore interpolation method is used – it is a specialised version of the convergent interpolation that creates better zero-lines when the input data has points with zero value or negative value
- for the Upper Juandah and Taroom coal measures isochores, which are thinner subdivisions than the Lower Juandah, the minimum value was forced to be equal to the observed value in the well dataset (under the **Algorithm tab** > **Settings** > **Z-Values**).

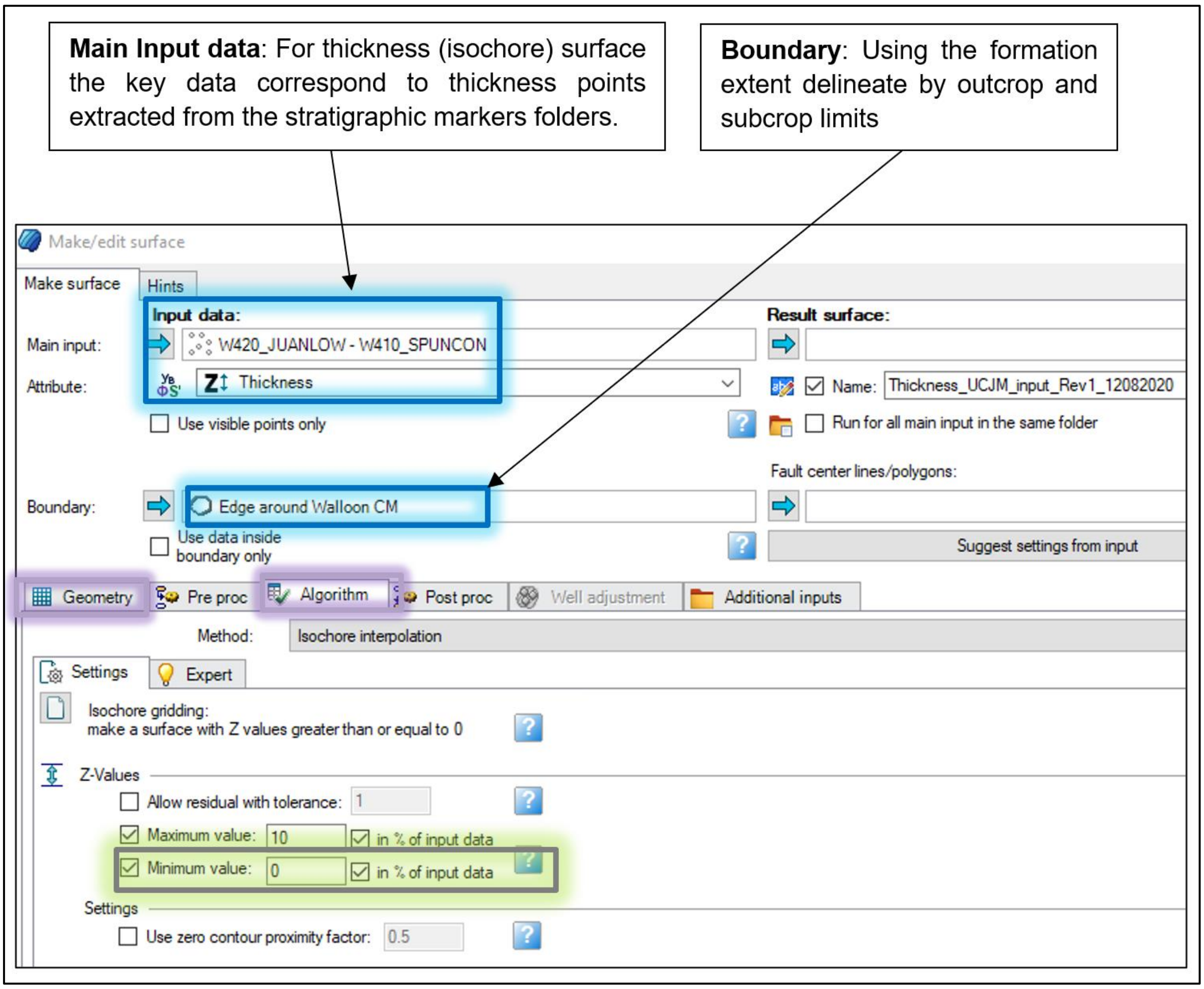

Figure A2-1: Petrel, Make/edit surface process pane to create isochore maps

Table A2-1: Thickness values for well data and maps

Subdivision	Count	Well data			Isochore map		
		Min	Mean	Max	Min	Mean	Max
Upper Juandah Coal Measures	4,479	11	97	218	11	48	220
Lower Juandah Coal Measures	4,759	97	211	315	97	152	315
Taroom Coal Measures	5,705	3	44	124	3	29	136

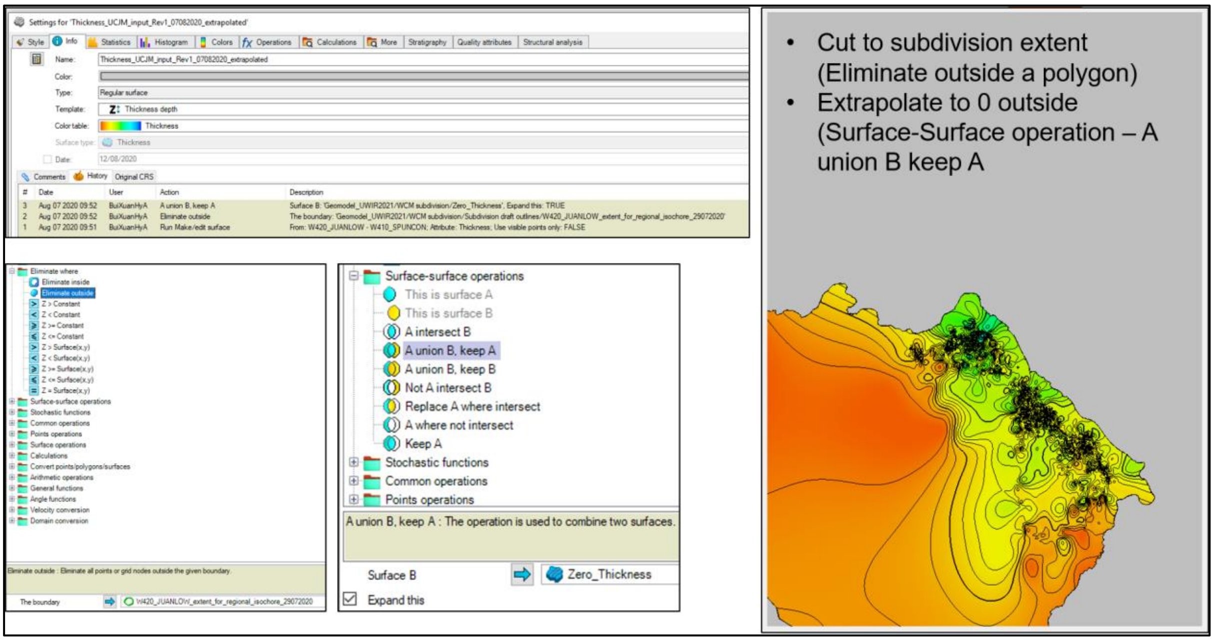

Figure A2-2: Petrel, final clipping and extrapolating maps to zero thickness outside of the steps: formation extents

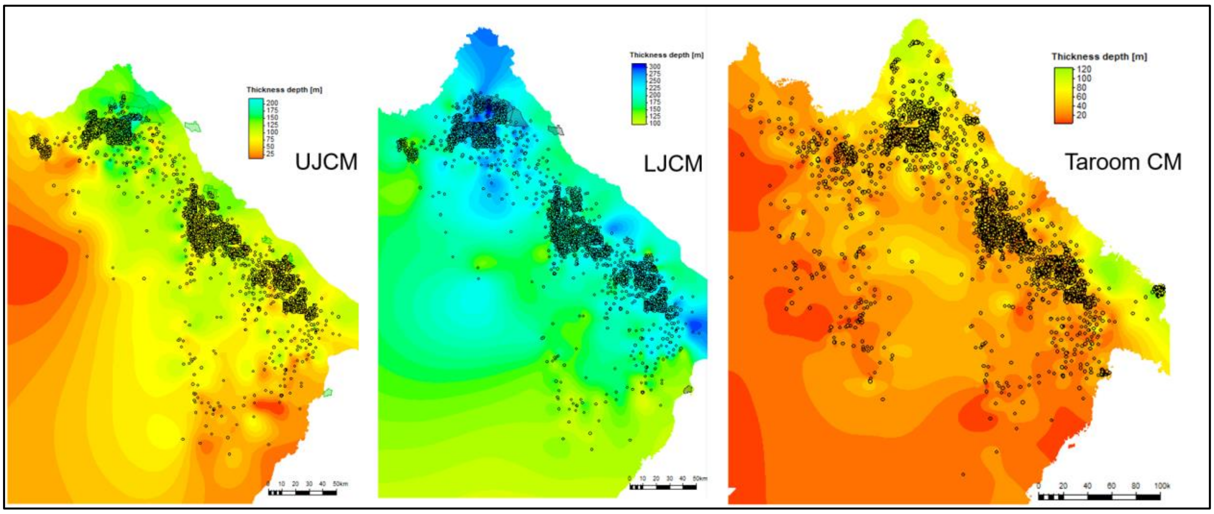

Figure A2-3: Output isochore maps