

ADANI MINING PTY LTD:

Carmichael Project – Revised Subsidence Assessment

In Support of the Environmental Impact Statement

DOCUMENT REGISTER

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Report produced to:- Provide predicted revised subsidence movements and impact assessments at the proposed Carmichael Project In support of the EIS.

Associated reports:- MSEC575 (Revision A – October 2012) – Adani Mining Pty Ltd, Carmichael Project – Subsidence Prediction and Subsidence Impact Assessment Report, In Support of the Environmental Impact Statement.

Background reports available at www.minesubsidence.com:-

Introduction to Longwall Mining and Subsidence (Revision A)

General Discussion of Mine Subsidence Ground Movements (Revision A)

EXECUTIVE SUMMARY

Adani Mining Pty Ltd (Adani, the Proponent) proposes to commence a greenfield underground coal mine in Central Queensland in the Galilee Basin.

Adani commenced an Environmental Impact Statement (EIS) process for the Carmichael Coal Mine and Rail Project (the Project) in 2010. On 26 November 2010, the Queensland (Qld) Office of the Coordinator General declared the Project a 'significant project' and the Project was referred to the Commonwealth Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) (referral No. 2010/5736). The Project was assessed to be a controlled action on the 6 January 2011 under section 75 and section 87 of the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The controlling provisions for the Project include:

- World Heritage properties (sections 12 & 15A)
- National Heritage places (sections 15B & 15C)
- Wetlands (Ramsar) (sections 16 & 17B)
- Listed threatened species and communities (sections 18 & 18A)
- Listed migratory species (sections 20 & 20A)
- The Great Barrier Reef Marine Park (GBRMP) (sections 24B & 24C).

The Qld Government's EIS process has been accredited for the assessment under Part 8 of the EPBC Act in accordance with the bilateral agreement between the Commonwealth of Australia and the State of Queensland.

The Proponent prepared an EIS in accordance with the Terms of Reference (ToR) issued by the Qld Coordinator-General in May 2011 (Qld Government, 2011). The EIS process is managed under section 26(1) (a) of the *State Development and Public Works Act 1971* (SDPWO Act), which is administered by the Qld Government's Department of State Development, Infrastructure and Planning (DSDIP).

The EIS, submitted in December 2012, assessed the environmental, social and economic impacts associated with developing a 60 million tonne (product) per annum (Mtpa) thermal coal mine in the northern Galilee Basin, approximately 160 kilometres (km) north-west of Clermont, Central Queensland, Australia. Coal from the Project will be transported by rail to the existing Goonyella and Newlands rail systems, operated by Aurizon Operations Limited (Aurizon). The coal will be exported via the Port of Hay Point and the Point of Abbot Point over the 60 year (90 years in the EIS) mine life.

Project components are as follows:

- The Project (Mine): a greenfield coal mine over EPC 1690 and the eastern portion of EPC 1080, which includes both open cut and underground mining, on mine infrastructure and associated mine processing facilities (the Mine) and the Mine (offsite) infrastructure including a workers accommodation village and associated facilities, a permanent airport site, an industrial area and water supply infrastructure
- The Project (Rail): a greenfield rail line connecting the mine to the existing Goonyella and Newlands rail systems to provide for the export of coal via the Port of Hay Point (Dudgeon Point expansion) and the Port of Abbot Point, respectively including
 - Rail (west): a 120 kilometre (km) dual gauge portion running west from the Mine site east to Diamond Creek
 - Rail (east): a 69 km narrow gauge portion running east from Diamond Creek connecting to the Goonyella rail system south of Moranbah.
 - Quarries: The use of five (5) local quarries to extract quarry materials for construction and operational purposes.

The underground component of the mine will extract coal using longwall mining methods in two seams over an approximate extent of 45 kilometres north to south with conceptual longwall lengths up to approximately 6 kilometres. Cutting heights are approximately 2.75 metres in the upper seam and 3.25 metres in the lower seam. Proposed longwall panel void widths are approximately 310 metres. The proposed multi-seam panel offsets and mains are proposed to be in a staggered arrangement.

The proposed 110 longwall panels, are located within the mining lease and are shown in Drawings Nos MSEC627-01, MSEC627-02 and MSEC627-03. These drawings also show the project Study Area, which is defined as the surface area that is likely to be affected by the conventional subsidence movements resulting from the proposed extraction of the Proposed Longwalls.

The target seams for the proposed longwalls are the AB1 Seam and D1 Seam. The AB1 seam floor contours, seam thickness contours and depth of cover contours are shown in Drawings Nos MSEC627-05,

MSEC627-07 and MSEC627-09, respectively in Appendix D. The D1 seam floor contours, seam thickness contours and depth of cover contours are shown in Drawings Nos MSEC627-06, MSEC627-08 and MSEC627-10, respectively in Appendix D. The seams dip towards the west within the proposed mining area at approximately 2 to 4 degrees, as shown in Drawings Nos. MSEC627-05 and MSEC627-06.

The depth of cover to the AB1 seam varies within the proposed mining area from approximately 120 metres above Longwalls ABLW101S and ABLW501S to 440 metres above Longwalls ABLW107S and ABLW207, as shown in Drawing No. MSEC627-09. The thickness of the AB1 and D1 seams varies from approximately 4 metres to 11.5 metres as shown in Drawings Nos MSEC627-07 and MSEC627-08. There is limited data available on the D1 seam in the south of Mine Area 5. The proposed extraction height for all longwalls is 2.75 metres in the AB1 Seam and 3.25 metres in the D1 Seam.

The majority of the land above the proposed mining area is undeveloped, with sparse vegetation. The land is understood to be used for grazing. As can be noted from the surface level contours, shown in Drawing No. MSEC627-04, the surface areas above the proposed longwalls are relatively flat. The features near the Study Area include Carmichael River that flows towards the east, small tributaries that flow to the Carmichael River, two unsealed roads, and various boundary fences.

The maximum predicted total subsidence for the proposed longwalls after extraction in the AB1 seam is 2625 mm and the maximum predicted total subsidence for the proposed longwalls after extraction in the AB1 and D1 seams is 5550 mm. The predicted subsidence parameters are summarised in Table 4.1 and Table 4.2 and the predicted subsidence contours are shown in Drawings Nos MSEC627-13 and MSEC627-14.

The assessments in this report indicate that the levels of impact that have been assessed on the natural features and items of surface infrastructure can all be managed by the preparation and implementation of management strategies. It is expected that where sufficient depth of cover and thickness of Triassic and and/or Tertiary deposits are present, there will be a low risk of direct hydraulic connection from the surface to the seam. It should also be noted, however, that more detailed assessments of some natural features and items of surface infrastructure have been undertaken by other consultants, and the findings in this report should be read in conjunction with the findings in all other relevant reports.

Monitoring of ground movements is recommended, as subsidence occurs, so that the observed ground movements can be compared with those predicted, to allow the prediction method to be continually improved and to allow regular reviews of the impact assessments in the light of new data.

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1.1. Background

Mine Subsidence Engineering Consultants was commissioned by Adani Mining Pty Ltd (Adani, the Proponent) to complete a Revised Subsidence Prediction and an Impact Assessment for the Carmichael Project (the 'project') as part of the Environmental Impact Statement (EIS).

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 - Rail (east): a 69 km narrow gauge portion running east from Diamond Creek connecting to the Goonyella rail system south of Moranbah.
 - Quarries: The use of five (5) local quarries to extract quarry materials for construction and operational purposes.

The underground component of the mine will extract coal using longwall mining methods in two seams immediately adjacent to the open cut pits and will be mined over an approximate extent of 45 kilometres north west to south east with conceptual longwall lengths up to approximately 6 kilometres. Two seams are proposed to be extracted. The upper seam is named AB1 seam and has a proposed cutting height of 2.75 metres. The lower seam is named D1 seam and has a proposed cutting height of 3.25 metres. Proposed longwall panel void widths are approximately 310 metres. The proposed multi-seam panel offsets and mains are proposed to be a staggered arrangement.

MSEC previously prepared a subsidence prediction and impact assessment report (MSEC525) in October 2012 for a longwall layout that included a total of 98 proposed longwall panels. The proposed longwall layout has since been revised to a total of 110 longwall panels, referred to in this report as the Proposed Longwalls, in a revised configuration and a south easterly extension.

The proposed longwalls are arranged in five mining areas within the mining lease and are shown in Drawings Nos. MSEC627-01, MSEC627-02 and MSEC627-03. These drawings also show the project Study Area, which is defined as the surface area that is likely to be affected by the conventional subsidence movements resulting from the proposed extraction of the Proposed Longwalls.

Chapter 1 of this report provides a general introduction to the study, which also includes a description of the mining geometry and geological details of the proposed mining area.

Chapter 2 defines the Study Area and provides a summary of the natural features and items of surface infrastructure within the Study Area.

Chapter 3 includes overviews of longwall mining, the development of mine subsidence and the methods used to predict mine subsidence movements. Descriptions of conventional and non-conventional mine subsidence parameters and the uncertainties in subsidence predictions are also provided in this chapter.

Chapter 4 provides the maximum predicted subsidence parameters resulting from the extraction of the Proposed Longwalls.

Chapter 5 provides the subsidence impact assessments on surface and sub-surface cracking. Discussions on the likely height of the fractured zone and hydraulic connectivity and the Great Artesian Basin are also provided in this chapter.

Chapter 6 provides mine subsidence impact assessment on the other natural features, items of infrastructure and built developments.

1.2. Mining Geometry

The layout of the Proposed Longwalls is shown in Drawing Nos. MSEC627-01, MSEC627-02 and MSEC627-03 in Appendix D.

The widths of the longwalls are approximately 310 metres, rib to rib. The majority of the chain pillars between the longwall panels are approximately 35 metres solid. Some pillar widths for longwalls in the D1 Seam with shallow cover are approximately 25 metres solid and longwalls greater than approximately 5km in length have two solid pillars of approximately 35 metres with three headings. A summary of the approximate longwall dimensions is provided in Table 1.1

The schedule of extraction for each 5 years of mine operation (rounded up to each fully extracted longwall panel) is presented in Drawings Nos. MSEC627-16 to MSEC627-25.

Table 1.1 Geometry of the Proposed Longwalls

Longwalls in AB1 Seam	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)	Longwalls in D1 Seam	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
Mine 1 North							
				DLW101N	2246	311	-
				DLW102N	2566	311	24
				DLW103N	2886	311	24
ABLW101N	3336	311	-	DLW104N	3220	311	24
ABLW102N	3663	311	34	DLW105N	3531	311	34
ABLW103N	3996	311	34	DLW106N	3860	311	34
ABLW104N	4328	311	34	DLW107N	4190	311	34
ABLW105N	4660	311	34	DLW108N	4519	311	34
ABLW106N	4992	311	34	DLW109N	4849	311	34
ABLW107N	5325	311	74	DLW110N	5179	311	74
Mine 1 South							
				DLW101S	1927	311	-
				DLW102S	1912	311	24
				DLW103S	1904	311	24
ABLW101S	1911	311	-	DLW104S	1939	311	24
ABLW102S	1851	311	34	DLW105S	1878	311	34
ABLW103S	1791	311	34	DLW106S	1815	311	34
ABLW104S	1728	311	34	DLW107S	1749	311	34
ABLW105S	1719	311	74	DLW108S	1740	311	74
ABLW106S	5790	311	74	DLW109S	5795	311	74
ABLW107S	5782	311	74	DLW110S	5788	311	74

Longwalls in AB1 Seam	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)	Longwalls in D1 Seam	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
Mine 2							
ABLW201	5139	311	-	DLW201	5155	311	-
ABLW202	5105	311	34	DLW202	5120	311	34
ABLW203	5070	311	34	DLW203	5084	311	34
ABLW204	4845	311	34	DLW204	4875	311	34
ABLW205	4464	311	34	DLW205	4574	311	34
ABLW206	4083	311	34	DLW206	4189	311	34
ABLW207	3702	311	34	DLW207	3774	311	34
Mine 3 North							
ABLW301N	3839	311	-	DLW301N	3839	311	-
ABLW302N	3781	311	34	DLW302N	3781	311	34
ABLW303N	3723	311	34	DLW303N	3723	311	34
ABLW304N	3668	311	34	DLW304N	3669	311	34
ABLW305N	1645	311	34	DLW305N	1713	311	34
Mine 3 South							
ABLW301S	3044	311	-	DLW301S	3046	311	-
ABLW302S	2560	311	34	DLW302S	2562	311	34
ABLW303S	2351	311	34	DLW303S	2352	311	34
ABLW304S	2262	311	34	DLW304S	2263	311	34
ABLW305S	2149	311	34	DLW305S	2150	311	34
ABLW306S	1110	311	34	DLW306S	1110	311	34
Mine 4							
ABLW401	4821	311	-	DLW401	4848	311	-
ABLW402	4839	311	34	DLW402	4865	311	34
ABLW403	4858	311	34	DLW403	4881	311	34
ABLW404	4876	311	34	DLW404	4898	311	34
ABLW405	4894	311	34	DLW405	4915	311	34
ABLW406	4912	311	34	DLW406	4931	311	34
ABLW407	4930	311	34	DLW407	4948	311	34
Mine 5 North							
ABLW501N	4205	311	-	DLW501N	4166	311	-
ABLW502N	4233	311	34	DLW502N	4190	311	34
ABLW503N	4261	311	34	DLW503N	4214	311	34
Mine 5 South							
				DLW501S	3571	311	-
				DLW502S	3411	311	24
				DLW503S	3251	311	24
				DLW504S	3090	311	24
ABLW501S	2250	311	-	DLW505S	2925	311	24
ABLW502S	2957	311	24	DLW506S	2760	311	34
ABLW503S	2783	311	34	DLW507S	2595	311	34
ABLW504S	2609	311	34	DLW508S	2430	311	34
ABLW505S	2435	311	34	DLW509S	2265	311	34
ABLW506S	2261	311	34	DLW510S	2099	311	34
ABLW507S	2087	311	34	DLW511S	1936	311	34
ABLW508S	1913	311	34	DLW512S	1752	311	34

1.3. Surface Topography

The surface level contours in the vicinity of the proposed longwalls are shown in Drawing No. MSEC627-04.

The surface topography within the Project Area consists of low-lying gently sloping plains of generally less than 2% gradient. The Carmichael River is the regional drainage line in the area, which flows towards the east in the southern part of the mining lease area. The proposed longwalls have been set back from the Carmichael River and the closest longwall is approximately 655 metres from the river.

As shown in Drawing No. MSEC627-04, the lowest elevation above the footprint of the Proposed Longwalls is approximately 228 metres AHD, near the Carmichael River. The highest point is at approximately 346 metres AHD above the proposed Longwall ABLW104N.

1.4. Seam Level Information

The principal coal-bearing formations at the project are the Bandanna Formation and Colinlea Sandstone. Within the Bandanna Formation and Colinlea Sandstone there are seven significant coal seam groups (AB, B, C, D1, D2/D3, E, and F).

The target seams for the proposed longwalls are the AB1 Seam and D1 Seam.

The seam floor contours, seam thickness contours and depth of cover contours for the AB1 Seam are shown in Drawings Nos. MSEC627-05, MSEC627-07 and MSEC627-09, respectively, in Appendix D. The seam floor contours, seam thickness contours and depth of cover contours for the D1 Seam are shown in Drawings Nos. MSEC627-06, MSEC627-08 and MSEC627-10, respectively, in Appendix D.

The seams dip towards the west within the proposed mining area at approximately 2 to 4 degrees, as is shown on Drawings Nos. MSEC627-05 and MSEC627-06.

The depth of cover to the AB1 seam varies within the proposed mining area from approximately 120 metres above Longwalls ABLW101S and ABLW501S to 440 metres above Longwalls ABLW107S and ABLW207, as is shown on Drawings No. MSEC627-09.

The thickness of the AB1 and D1 seams varies from approximately 4 metres to 11.5 metres as is shown in Drawings Nos. MSEC627-07 and MSEC627-08. There is limited data available on the D1 seam in the south of Mine Area 5. The proposed extraction height for all longwalls is 2.75 metres in the AB1 Seam and 3.25 metres in the D1 Seam.

The interburden thickness between the AB1 and D1 seams varies from approximately 70 metres to 130 metres.

1.5. Overburden Geology

The surface lithology within the Project Area can be seen in Fig. 1.1, which shows the proposed longwalls, the Project Area, the Study Area and the exploration bore collar locations overlaid on the 1:250,000 Surface geology map published by Geosciences Australia.

A typical stratigraphic section is provided in Fig. 1.2.

The regional and local geology are described in a coal resource estimate report by Xenith Consulting Pty Ltd (Xenith, 2009) and provide the following descriptions:

“The Galilee Basin is an intracratonic basin that covers approximately 247,000 km² in central Queensland. The maximum stratigraphic thickness is 2800 m and ranges from Late Carboniferous to Middle Triassic in age. The basin fill accumulated in alluvial plain environments and contains thick, widespread coal seams of Permian Age. Permo-Triassic rocks are only exposed along the eastern margin of the basin with the remainder covered by fill of the Jurassic-Cretaceous Eromanga Basin. (Leblang, 2005).”

“The majority of the lease area is mantled by a sequence of sediments of Tertiary age. The Tertiary ranges in thickness from 45m to 100m, comprising red and yellow, clayey mudstone and soft sandstone.

The formation overlies the Permo-Triassic sequence unconformably.”

“The Triassic sequence in this area consists of the Dunda Beds and underlying Rewan Formation with thicknesses of up to 200m of Triassic sediments penetrated in the deepest drill holes in the West of the lease. The Dunda Beds consist of yellow to red-brown, medium-grained, quartz sandstones with minor mudstone interbeds. The Rewan Formation comprises interbedded grey-green, fine to medium-grained, lithic sandstone and grey-green mudstone.”

Data provided by Adani Mining indicate the depth of Tertiary sediments above the proposed longwalls varies up to approximately 70 metres maximum depth. Contours of the depth of Tertiary sediments are provided in Drawing No. MSEC627-11. The depth of weathering above the proposed longwalls varies from approximately 20 metres to 100 metres. Contours of the depth of weathering are provided in Drawing No. MSEC627-12.

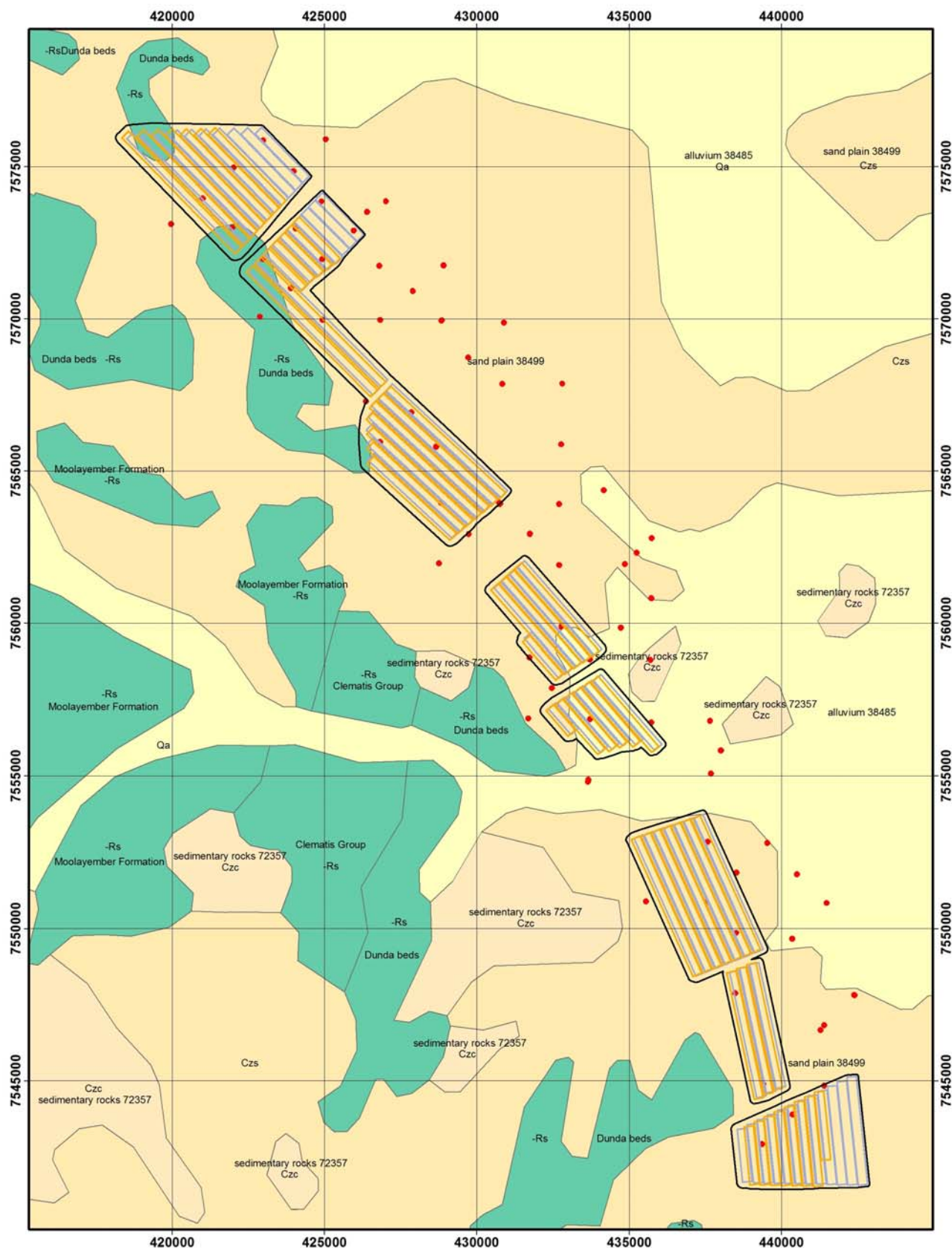


Fig. 1.1 1:250,000 Surface geology (Published by Geosciences Australia)
 (Legend: (Rs) Triassic sandstone siltstone mudstone conglomerate, (Czc) Cenozoic consolidated siliclastic rocks, (Czs) Cenozoic sand plain, (Qa) Quaternary channel and flood plan alluvium gravel sand silt clay)

Age		Lithology	Stratigraphy	Thickness
Tertiary		Clays / Mudstones		40 - 100m
Triassic		Mudstone / Siltstone	Rewan Formation	
Late Permian		Sandstone	Bandanna Formation	
		COAL - AB Seam		12 - 18m Resource Seam
		Sandstone / Siltstone		10m
		COAL - B splits		1 - 2m
		Siltstone / Mudstone		60 - 70m
		COAL - C Seam (carbonaceous)		3 - 4m
		Siltstone / Sandstone	Colinlea Sandstone	2 - 20m
		COAL - D1 Seam		4 - 6m Resource Seam
		Sandstone		5 - 30m
		COAL D2/D3 Seam		8 - 10m Resource Seam
		Siltstone / Mudstone		10 - 20m
		COAL - E Seam		1 - 3m Resource Seam
		Sandstone / Siltstone		5 - 10m
		COAL - F Seam		1 - 5m Resource Seam
Early Permian		Sandstone		

Fig. 1.2 Stratigraphic Column of the project lease area
(source: Linc Energy Ltd, Galilee Project – MDLa 372, Insitu Coal Resource Estimate, Nov 2009, provided by Adani Mining)

2.1. Definition of the Study Area

The Study Area is defined as the surface area that is likely to be affected by the conventional subsidence movements resulting from the proposed extraction of the Proposed Longwalls. The extent of the Study Area has been determined by a 26.5 degree angle of draw around the extent of the proposed longwalls. The 26.5 degree angle of draw provides an approximate position of the limit of subsidence, which is taken as 20 mm of vertical subsidence. Drawing No. MSEC627-01 shows the project Study Area.

The areas that lie outside the Study Area are expected to experience far-field movements. These movements are small and unlikely to result in impacts on the great majority of surface and sub-surface features. Some features, such as a large bridge, may be sensitive to differential far-field movements and these are discussed later in this report.

2.2. Overview of the Natural Features and Items of Surface Infrastructure within the Study Area

The major natural features and items of surface infrastructure within the Study Area can be seen in the Drawing No. MSEC627-13. The proposed longwalls have been overlaid on the 1:250,000 Topographic Map of the area, published by Geosciences Australia, which is presented in Fig. 2.1.

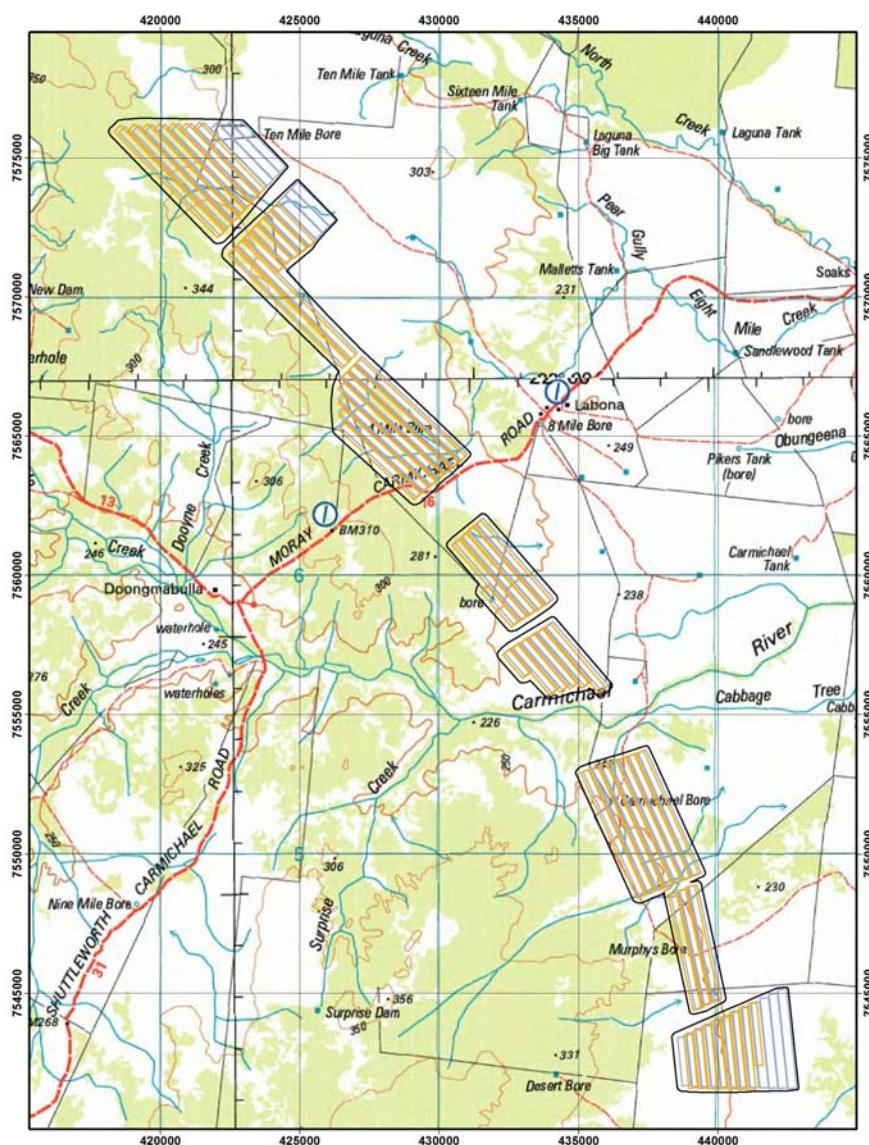


Fig. 2.1 1:250,000 Topographic Map (Published by Geosciences Australia)

The majority of the land above the proposed mining area is undeveloped, with sparse vegetation. The land is understood to be used for grazing. As can be noted from the surface level contours, shown in Drawing No. MSEC627-04, the surface areas above the proposed longwalls are relatively flat with varying surface level contours ranging from 228 metres AHD to 346 metres AHD. The features near the Study Area include Carmichael River that flows towards the east, small tributaries that flow to the Carmichael River, two unsealed roads, and various boundary fences.

3.1. Introduction

This chapter provides a brief overview of longwall mining, the development of mine subsidence and the methods that have been used to predict the mine subsidence movements resulting from the extraction of the proposed longwalls. Further details on longwall mining, the development of subsidence and the methods used to predict mine subsidence movements are provided in the background reports entitled *Introduction to Longwall Mining and Subsidence* and *General Discussion on Mine Subsidence Ground Movements* which can be obtained from www.minesubsidence.com.

3.2. Overview of Coal Mining Methods

3.2.1. Bord and Pillar First Workings

Bord and pillar first workings comprise a series of self supporting roadways (or bords) within the coal seam leaving a grid of pillars which are designed to be long term stable. These first workings are extracted using continuous miners which are remote-controlled, track-mounted, electrically powered coal cutting and loading machines that can be used to form mine roadways and extract coal pillars. This method of extraction is commonly undertaken to form main headings within underground coal mines and to form the development headings around proposed longwall panels. This method of extraction is sometimes undertaken as the primary extraction method for a coal mine where the depths of cover are very shallow, or where the surface subsidence has to be limited so as to minimise the potential impacts on surface features.

The widths of the roadways are typically limited to around 5.5 metres to 6.0 metres, which reduces the likelihood of roof falls and minimises the load on the pillars. In order for the roadways to remain stable for the life of the mine, the roof and often the sides of the roadways have to be supported using mesh and anchors. The widths of pillars which are designed to be long term stable are typically a minimum of the depth of cover divided by 10 (i.e. $H/10$) or three times the pillar height (i.e. $3T$), whichever is greater. Wider pillars may be required where the roof or floor is weak.

As the depth of cover increases, the widths of the pillars also increase in order to carry the extra weight of the overburden, resulting in less coal resource being recovered. Because of these issues, it is generally uneconomic to use bord and pillar first workings as the primary production method at depths of cover in the order of 200 metres or greater. Bord and pillar first workings, however, are used successfully at shallower depths of cover, or where the surface subsidence has to be limited so as to protect the surface features.

The proposed first workings for this project have typical roadway widths of 5 metres and typical pillar widths of 35 metres. The depth of cover above the proposed first workings varies between 120 metres and 440 metres.

The subsidence observed at the surface above bord and pillar first workings mostly results from the compression of the coal pillars and the strata above and below the seam due to the weight of overburden. Where the pillars have been designed to be long term stable, the vertical subsidence observed at the surface is typically less than 20 mm. As natural or seasonal variations in the surface levels, due to the wetting and drying of the surface soils, have been measured in the order of 20 mm, or even greater, vertical subsidence of less than 20 mm is usually defined as negligible.

3.2.2. Longwall Mining

Longwall mining is a method used to extract large rectangular panels (i.e. blocks) of coal, typically 150 metres to 400 metres wide and 1 kilometre to 5 kilometres long. The coal is progressively mined by a shearer that shaves off slices of coal up to 1 metre thick along the longwall face, under the protection of hydraulic supports, until all the panel is fully extracted. While the technology has changed considerably over the years, the basic idea of longwall mining is to maintain a safe working space for the miners along a wide coal face whilst removing all of the coal and allowing the roof and overlying rock to collapse into the void behind. The Carmichael Project proposes to extract all underground panels using longwall mining techniques.

Firstly a large rectangular panel or pillar is initially formed using continuous miners or road headers. Gate roads are first driven all around the large rectangular pillar before longwall mining begins. The gate road along one long side of the panel is called the maingate where fresh air and mine workers are carried to the face and the extracted coal is conveyed along conveyors. The gate road on the other side of the panel is called the tailgate where air is carried away from the face and also provides a secondary means of egress.

A number of hydraulic jacks, called powered roof supports, chocks or shields, provide support to the roof along the coalface at one end of the longwall panel. Each chock or shield is typically 1.75 metres wide and the supports are placed in a long line, side by side, for the full width of the coal face. An individual support can weigh 30 tonnes to 40 tonnes, can extend to a maximum cutting height of up to 6 metres and can support 1,000 tonnes to 1,250 tonnes of

the overlying strata weight. Each chock can hydraulically advance itself around 1 metre forward after each slice of coal is extracted.

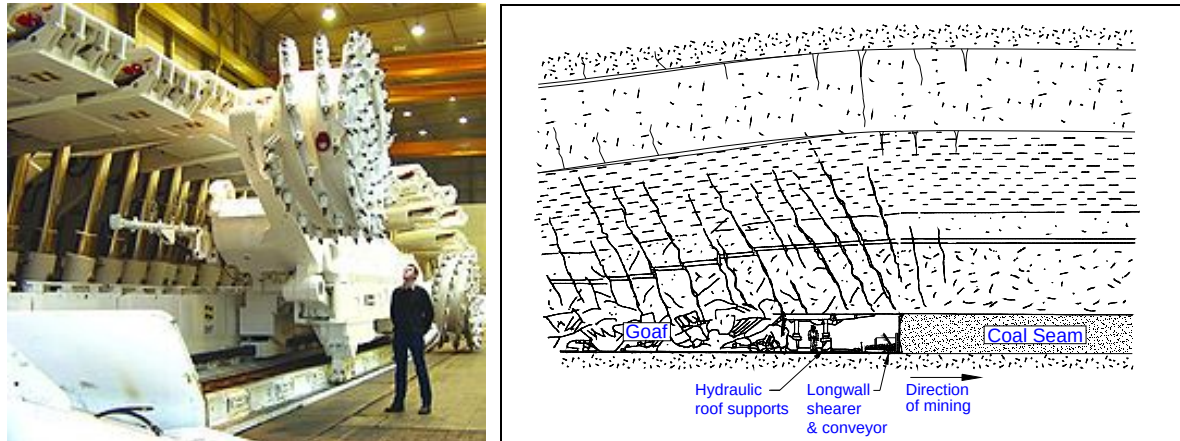


Fig. 3.1 Cross-section along the Length of a Typical Longwall at the Coal Face and a photograph of a typical Shearer, Conveyor and Hydraulic Support Chocks



Fig. 3.2 An Operating Longwall Face

Note: The following features can be seen: coal seam under extraction, the coal shearer, the face conveyor and system of self-advancing hydraulic roof supports ('chocks' or 'shields').

The coal is cut in slices from the coalface by a shearer and the coal falls onto an armoured face conveyor (AFC), which is placed in front of the powered roof supports, and carries the coal from the longwall face to the maingate. From here it is loaded onto a network of conveyor belts for transport to the surface. At the maingate, the coal is often reduced in size in a crusher and loaded onto the first conveyor belt by the beam stage loader (BSL). As the shearer removes the coal, the AFC is snaked over behind the shearer and the powered roof supports move forward into the newly created cavity.

As the longwall face progresses through the seam, the overlying roof strata falls into the mined void (goaf) and the subsidence process of the overburden strata commences. The collapsed roof strata comprises loose blocks and can contain large voids depending on the loading and compaction that follows. Immediately above the mined void and the collapsed zone, the strata can remain relatively intact and bends into the void, resulting in new vertical fractures, opening up of existing vertical fractures and bed separation. The strata layers above that bend and shear with the amount of strata sagging, fracturing and bed separation reducing towards the surface.

The basic idea behind longwall mining was developed many years ago, but it has only been in the last thirty years that mining equipment has become powerful and reliable enough to successfully and safely extract large longwall blocks. Safety, productivity and cost considerations dictate that longwall mining is now the major, viable, high production method of coal mining adopted in the majority of Australian underground coal mines that operate at depths greater than about 300 metres.

Longwall mining has a better level of resource recovery when compared to the bord and pillar extraction method, has less need for roof support consumables, has higher volume coal clearance systems and has minimal manual handling. In addition, the safety of the miners is enhanced by the fact that they are always under the hydraulic roof supports when they are extracting coal.

It takes two longwall development heading panels to delineate the first longwall block. Thereafter, only one set of longwall gateroads needs to be driven for each new adjacent longwall panel because the new panel also makes use of one of the gateroads left over from the previous panel. The interpanel pillars that separate each gateroad are known as chain pillars.

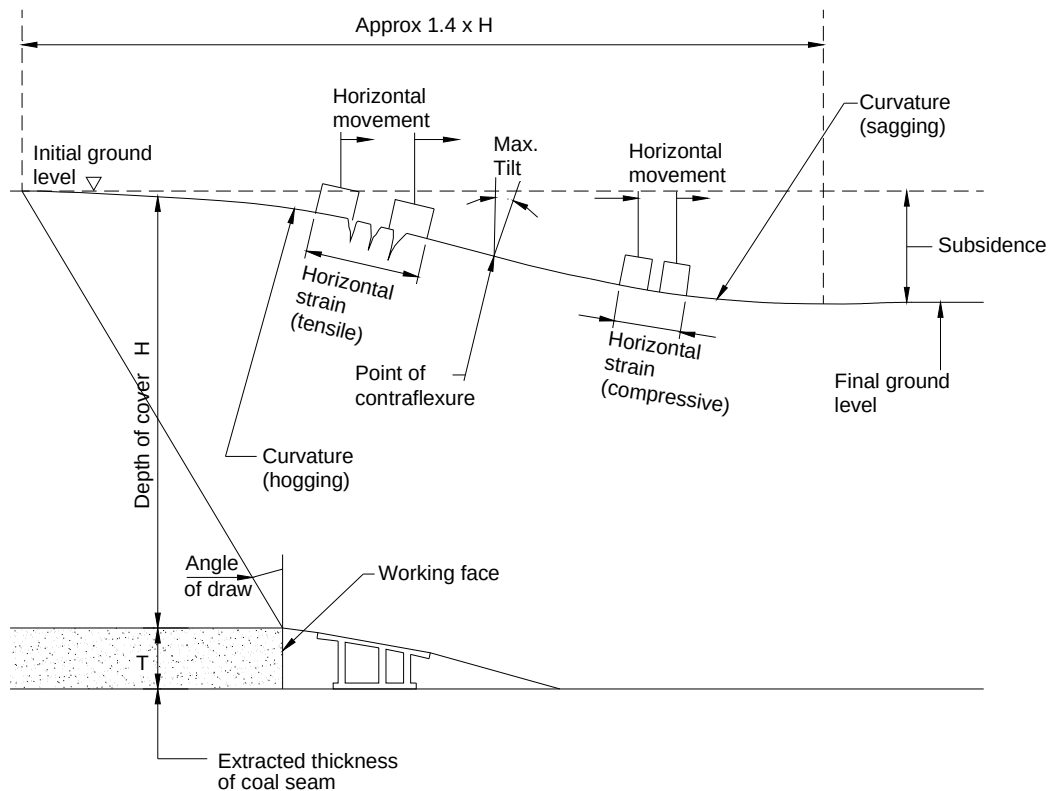
Longwall extraction operations effectively result in the formation of very wide and very long excavations separated by a single or double row of relatively narrow chain pillars. Longwall mining therefore involves both first workings and second workings. The mains development and gateroads are first workings, which result in no measurable subsidence at the surface, and the longwall panels are a type of second workings. As with pillar extraction, significant subsidence and resulting disturbance of the subsurface and surface may occur, depending on the mining layout.

3.3. Overview of Conventional Subsidence Parameters

The normal ground movements resulting from the extraction of pillars or longwalls are referred to as conventional or systematic subsidence movements. These movements are described by the following parameters:-

- **Subsidence** usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements in some cases, where the subsidence is small beyond the longwall goaf edges, can be greater than the vertical subsidence. Subsidence is usually expressed in units of *millimetres (mm)*.
The magnitude of the maximum vertical subsidence at the surface will vary depending on a number of factors including the longwall panel and pillar widths, the chain pillar stability, the presence of nearby previously extracted mined panels, the depth of cover, the extracted seam thickness, the geology of the strata layers between the surface and coal seam and on the geology of the strata layers in the floor below the seam.
- **Tilt** is the change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.
- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/kilometres (km⁻¹)*, but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*.
When the surface subsides in the shape of a trough over a mined panel, it curves inwards towards the centre of the trough and outwards near the perimeter of the trough. This behaviour is referred to as curvature. Curvature in an outwards direction results in the ground 'stretching' or 'hogging' and is referred to as convex curvature. Curvature in an inwards direction over the centre of a mined panel causes the ground to sag and move closer together and is referred to as concave curvature.
Hence curvature results in points on the surface moving in both a vertical direction and a horizontal direction as they subside into a subsidence trough. Curvature is calculated at a point from three pegs and hence has a direction.
Curvature is convex or 'hogging' over the goaf edges and concave or 'sagging' toward the bottom of the subsidence trough. The convention usually adopted is for convex curvature to be positive and concave

curvature to be negative.



- **Strain** is the relative differential horizontal movements of the ground. **Normal strain** is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them. Strain is typically expressed in units of *millimetres per metre (mm/m)*. **Tensile Strains** occur where the distance between two points increases and **Compressive Strains** occur when the distance between two points decreases. So that ground strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20.

Whilst mining induced normal strains are measured along monitoring lines, ground shearing can also occur both vertically and horizontally across the directions of monitoring lines. Most of the published mine subsidence literature discusses the differential ground movements that are measured along subsidence monitoring lines, however, differential ground movements can also be measured across monitoring lines using 3D survey monitoring techniques.

- **Horizontal Displacement**, or the horizontal component of subsidence, is often greatest near the point of maximum tilt and declines to zero at the limit of subsidence and at the point of maximum subsidence. Horizontal displacement is usually expressed in millimetres. Early researchers and mine subsidence surveyors did not measure or predict the horizontal displacements as they were far more difficult to measure or predict accurately. Modern survey methods measure the easting, northing and reduced level of pegs at each epoch from which the actual mining induced horizontal movements and directions can be determined. Horizontal displacements include remote or regional or far field horizontal displacements and they are caused by several mechanisms, as discussed later,
- **Horizontal shear deformation** across monitoring lines can be described by various parameters including horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index. It is not possible, however, to determine the horizontal shear strain across a monitoring line using 2D or 3D monitoring techniques. High deformations along monitoring lines (i.e. normal strains) are generally measured where high deformations have also been measured across the monitoring line (i.e. shear deformations) and vice versa.
- **Angle of draw** is a term used to describe the extent of the spread of subsidence beyond the mined panel edges. Most of the observed subsidence occurs over the mined panels with lower subsidence values being observed tapering to zero at some point beyond the edges of the mined panels, i.e. over the solid unmined coal areas. The observed angle of draw is the inclination or angle in degrees from the vertical of the line connecting the goaf edge of the workings to a point on the surface beyond the edge of the panel where 20mm subsidence has been observed at the surface. Observed angles of draw in NSW generally range from 10 to 30 degrees, however, wide variations are recorded due to many factors. This limit or cut off of measuring to 20mm was chosen to determine the observed angle of draw because natural ground movements of more

than 20mm are commonly observed due to changing moisture and climatic conditions and it is generally accepted that vertical subsidence movements of less than 20 mm will have negligible impact on surface infrastructure.

For designing mine layouts to protect surface features, the predicted angle of draw can be assumed to be $26\frac{1}{2}$ degrees from the edge of the extraction, i.e. a point on the surface at a distance of half the depth of cover from the longwall goaf edges, where local data is not available. Where local data exists and it can be shown that the local angle of draw is generally less than $26\frac{1}{2}$ degrees, then, the lower angle of draw can usually be used.

The actual observed angles of draw seem to be dependent on many factors including, the magnitude of the maximum subsidence, the depth of cover, the geology of the overburden, the magnitude of in-situ horizontal stress, the presence and proximity of nearby previously extracted panels, the dip of the strata, and the presence and proximity of faults, dykes and other geological structures.

- **Residual** subsidence is defined as the additional, time-dependent subsidence that develops after mining is completed or moved sufficiently far enough away from the affected area. As a general guide, active subsidence forms 90 to 95 % of the total subsidence in most cases, and this occurs when mining is within the area of influence of the point.

There is limited information to determine residual subsidence precisely because observations of long term residual subsidence require dedication on the part of the observers to continue monitoring very small changes in subsidence over a long period of time. Long term subsidence monitoring at Metropolitan Colliery in NSW has measured average rates of subsidence of 3 to 7 mm per year. As the rate of subsidence development reduces asymptotically to miniscule levels, survey accuracy and the shrinking and swelling of the soil due to changes in moisture content form a large proportion of the measured changes.

The **incremental** subsidence, tilts, curvatures and strains are the additional parameters which result from the extraction of each longwall. Since observed incremental movements were derived or extracted by subtracting increments from the total, transient or cumulative profiles, then, it is valid to add predicted incremental profiles to obtain the cumulative, transient, total or final profiles. The **total** subsidence, tilts, curvatures and strains are the final parameters at the completion of a series of longwalls (i.e. Longwalls 101 to 411). The **travelling** tilts, curvatures and strains are the transient movements as the longwall extraction face mines directly beneath a given point. It is important to realise that the travelling tilts, curvatures and strains can be larger than the final tilts, curvatures and strains. Often the direction of the travelling tilts, curvatures and strains are different from the final tilts, curvatures and strains.

A cross-section through a typical single longwall panel showing typical profiles of systematic subsidence, tilt, curvature and strain is provided in Fig. 3.3.

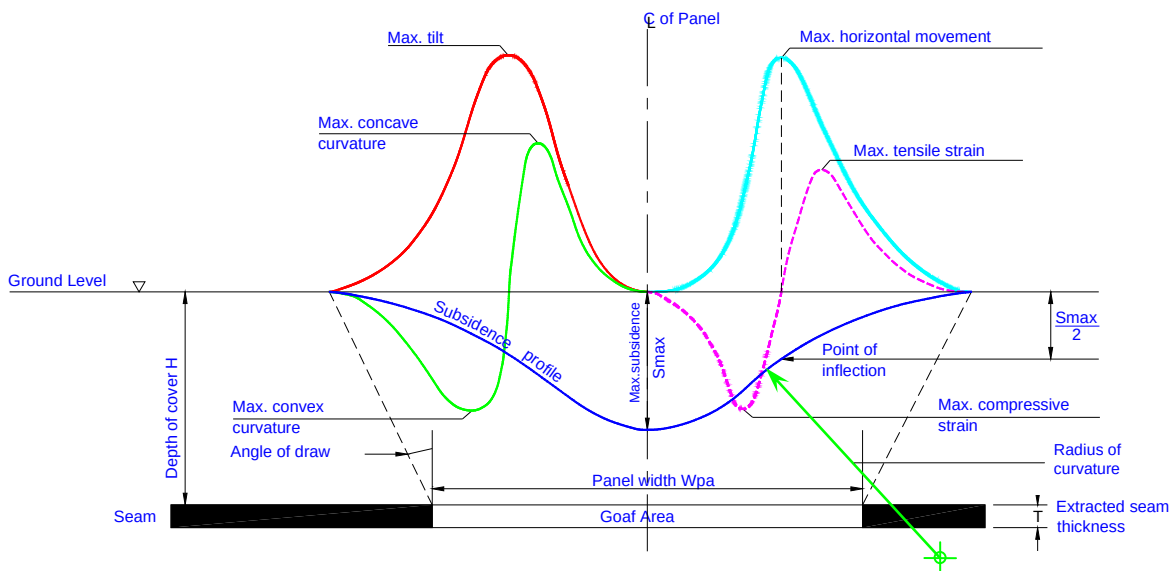


Fig. 3.3 Typical Profiles of Conventional Subsidence Parameter for a Single Longwall Panel

Conventional and Non-Conventional Subsidence Parameters, Effects, Impacts and Consequences

Some new subsidence terms and definitions were first published in an Independent Inquiry report entitled “*Strategic Review of Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield*”, (Southern Coalfields Inquiry Report), which was published in July 2008. “*Impacts of Potential Underground Coal Mining in the Wyong Local Government Area Strategic Review*”, which was also published in July 2008. This terminology was expanded by the same authors in the “*The Metropolitan Coal Project PAC Inquiry Report*”, 2009. The new terms and definitions draw a distinction between subsidence effects, subsidence impacts, environmental consequences,

consequences, secondary consequences, conventional effects and non-conventional effects. These new terms are detailed and referenced below;

- **“Conventional** or general model of surface subsidence is based on the presence of straightforward and uniform site conditions, including:
 - the surface topography is relatively flat and the seam is level,
 - the surrounding rock mass is relatively uniform and free of major geological disturbances or dissimilarities,
 - the mine workings are laid out on a regular pattern.” [Section 4.1.3 - Southern Coalfields Inquiry Report].**“Conventional** surface subsidence effects and their impacts are well understood and are readily and reasonably predictable by a variety of established method.” [Section 6 - Southern Coalfields Inquiry Report].
“The various subsidence parameters associated with this conventional, or general, model of subsidence behaviour are sometimes referred to as the systematic components of subsidence, whilst those associated with site-specific behaviours are referred to as non-systematic. This distinction in subsidence behaviour can be misleading since most site specific features also respond to undermining in a systematic manner. This Inquiry has maintained the convention of treating subsidence outcomes based on the conventional model of subsidence behaviour as being the standard or norm, and then adapting these to take account of variations created by the effects of the presence of specific natural features”. [Section 4.1.2 - Southern Coalfields Inquiry Report].
“Conventional behaviour refers to the manner in which the surface responds to subsidence effects when the topography is flat, the coal seam is level and the geology is uniform and free of structural disturbances.” [Section 2.8 - Wyong Inquiry Report].
“In conventional subsidence circumstances, a number of empirical, analytical and numerical subsidence prediction techniques are capable of producing reasonably accurate predictions of vertical displacement, typically within ± 150 mm. The more noteworthy of these are the incremental subsidence prediction technique, the influence function technique and a number of numerical modelling codes. However, the accuracy of any subsidence prediction technique should never be taken for granted. All depend to some extent on input parameters being representative of the specific site conditions.” [Section 2.8.6.1 - Wyong Inquiry Report].
“Particular care has to be taken when predicting subsidence for a greenfields site due to a lack of site specific data. A number of panels need to be extracted before subsidence prediction models can be properly calibrated and validated.” [Section 2.8.6.1 - Wyong Inquiry Report].
- **“Where conventional conditions are not met, surface subsidence effects may vary from those that would be predicted using the conventional model. Such subsidence effects are generally known as ‘non-conventional’,”** [Section 4.1.3 - Southern Coalfields Inquiry Report]
“Prediction of some of the subsidence effects on specific features, such as valley closure, uplift and upsidence and far-field horizontal displacements, is being carried out by a number of specialist consultants and research institutions in NSW, although the science of such prediction, and hence its reliability, is at a far earlier stage than the prediction of conventional subsidence effects.” [Section 4.3.2 - Southern Coalfields Inquiry Report]
“A number of the site conditions which are associated with non-conventional subsidence effects are present in the Southern Coalfield, in particular, valleys and gorges, locally-steep topography and geological features including faults and dykes” [Section 6 - Southern Coalfields Inquiry Report].
“The understanding of non-conventional surface subsidence effects (especially far-field horizontal movements, valley closure, upsidence and other topographical effects) is not as advanced. Both valley closure and upsidence are difficult to predict. Upsidence is a highly variable factor, particularly at the local scale, and is less predictable than valley closure. However, there is a rapidly developing database of non-conventional surface subsidence impacts in the Southern Coalfield which is being used to develop improved prediction. It is the Panel’s view that these techniques are less advanced, and less reliable than those used for conventional subsidence.” [Section 6 - Southern Coalfields Inquiry Report]
“Since unpredicted impacts of subsidence on rivers and significant streams in the Southern Coalfield first came to public attention, the coal mining industry has made significant advances in its understanding of and ability to predict non-conventional subsidence effects. The level of understanding which has resulted from this work leads this field internationally.” [Section 6 - Southern Coalfields Inquiry Report].
“Coal mining companies should place more emphasis on identifying local major geological disturbances or discontinuities (especially faults and dykes) which may lead to non-conventional subsidence effects, and on accurately predicting the resultant so-called ‘anomalous’ subsidence impacts” .” [Section 6 - Southern Coalfields Inquiry Report]
Non-Conventional Surface Subsidence Effects; The more common site specific variations to the conventional model of surface subsidence encountered in New South Wales that can affect surface subsidence relate to;
 - steep topography;
 - valleys and gorges;
 - far-field horizontal movements;
 - massive overburden strata; and
 - pillar foundation settlement or failure. [Section 2.8.3 - Wyong Inquiry Report].

- **“Subsidence effects:** the deformation of the ground mass surrounding a mine due to the mining activity. The term is a broad one, and includes all mining-induced ground movements, including both vertical and horizontal displacement, tilt, strain and curvature.” [Glossary Section - Southern Coalfields Inquiry Report].
“The term ‘**subsidence effects**’ is used to describe subsidence itself – i.e. deformation of the ground mass caused by mining, including all mining-induced ground movements such as vertical and horizontal displacements and curvature as measured by tilts and strains.” [Section 2.8 - Wyong Inquiry Report].
- **“Subsidence impacts:** the physical changes to the ground and its surface caused by **subsidence effects**. These impacts are principally tensile and shear cracking of the rock mass and localised buckling of strata caused by valley closure and upsidence but also include subsidence depressions or troughs.” [Glossary Section - Southern Coalfields Inquiry Report].
“The term ‘**subsidence impacts**’ is used to describe the physical changes to the ground and its surface that may be caused by these subsidence effects. These impacts are principally surface depressions, tensile and shear cracking of the rock mass and localised buckling of strata caused by valley closure and upsidence.” [Section 2.8 - Wyong Inquiry Report].
- **“Environmental consequences:** the environmental consequences of **subsidence impacts**, including loss of surface flows to the subsurface, loss of standing pools, adverse water quality impacts, development of iron bacterial mats, cliff falls, rock falls, damage to Aboriginal heritage sites, impacts on aquatic ecology, ponding, etc.” [Glossary Section - Southern Coalfields Inquiry Report].
“The **environmental consequences** of these impacts may include ponding, loss of groundwater, loss of surface flows to the subsurface, adverse water quality impacts, impacts on aquatic ecology, cliff falls, rock falls etc.” [Section 2.8 - Wyong Inquiry Report]
“The Southern Coalfield Inquiry defined the terms **subsidence impact**, **subsidence effect** and **environmental consequence** in respect of subsidence and natural features. The Panel has extended the use of these terms to also include man-made structures and surface modifications. The term **effect** describes subsidence itself. Any physical change to the fabric or structure of the ground, its surface, or man-made features is described as an **impact**. The term **consequence** is used to describe any change in the amenity or function of a feature that arises from an **impact**. In turn, some **consequences** may give rise to secondary **consequences**.” [Section 3.2.1 - The Metropolitan Coal Project PAC Inquiry Report, 2009].
- **“Consequences related to natural features are referred to as **environmental consequences**. By way of example, tensile strain due to the ground surface being ‘stretched’ as a result of undermining is an **effect**, a crack resulting from the tensile strain is an **impact**, loss of water down the crack is a **consequence**, and the drying of a water dependent ecosystem as a result of this loss of water is a **secondary consequence**. The latter two are included under **environmental consequences** in some contexts.”** [Section 3.2.1 - The Metropolitan Coal Project PAC Inquiry Report, 2009].

3.4. Vertical Subsidence Movements

The magnitude of the maximum vertical subsidence at the surface will vary depending on a number of factors including the longwall panel and pillar widths, the chain pillar stability, the presence of nearby previously extracted mined panels, the depth of cover, the extracted seam thickness, the geology of the strata layers between the surface and coal seam and on the geology of the strata layers in the floor below the seam.

The maximum subsidence observed normally where there are strong and massive conglomerate and sandstone strata units present, is typically between 55 % and 60 % of the extracted seam thickness, for single seam extractions, which is lower than the 65% of the extracted seam thickness for overburdens where there are fewer massive strong units. These maximum subsidence percentages would be observed where ever the widths of the panels are supercritical, i.e. greater than 1.4 times the depths of cover. Lower levels of subsidence would be observed where the panels are sub-critical and unmined coal left in chain pillars reduces the levels of the observed subsidence.

Techniques for predicting surface subsidence effects can be classified under three categories, namely empirical, analytical/numerical and hybrid methods. Empirical techniques are based on the back analysis of previous field outcomes. Reliability of outcomes is dependent, therefore, on the overall size and representativeness of the database and considerable care is required if the techniques are applied to conditions that are outside of this database. The more common empirical prediction methods are:

- **Graphical**, which involves plotting suites of curves showing relationships between various parameters and subsidence outcomes;
- **Upper Bound**, which involves constructing an envelope over measured maximum or worse case outcomes and predicting on the basis of that envelope;
- **Profile Function**, which attempts to define the shape of the vertical displacement curve by a mathematical equation and is confined in general to single (isolated) excavations; and
- **Incremental Profile Method**, which involves constructing the overall vertical displacement profile by summing the incremental vertical displacement that occurs each time a panel is extracted.

Analytical techniques are based on applying mathematical solutions derived from first principles to calculate how the rock mass will behave when an excavation is made within it. Most of the mathematical formulae have been known for decades; however, until the advent of computers, they could only be solved for very simple, two dimensional mining layouts. Advances in computational power now enables more complex mathematical equations to be solved, thereby enabling more detailed mining layouts, geological and geotechnical conditions and ground behaviour mechanisms to be analysed. Such analysis has now come to be known as mathematical modelling, numerical analysis or computer modelling. No one mathematical model is currently capable of fully describing rock behaviour and so numerical models still require a database for calibration purposes. Modelled outcomes need to be accepted with caution, especially at greenfield sites.

A number of techniques are capable of producing reasonably accurate predictions of vertical displacement, typically within ± 150 mm. The accuracy of any subsidence prediction technique depends to a large extent on input parameters being representative of the specific site conditions. Particular care has to be taken when predicting subsidence for a greenfields site due to a lack of site specific data. A number of panels need to be extracted before subsidence prediction models can be properly calibrated and validated.

3.5. Horizontal Subsidence Movements

The predictions of mining induced horizontal movements are not as accurate as the predictions of vertical movements. Studies have shown that the magnitudes of the absolute horizontal displacements can be estimated in the Newcastle Coalfields, from the predicted tilt profiles, by applying a tilt-to-horizontal displacement factor of 10, and it is generally assumed that these movements are generally directed towards the centre of the mined longwall panel, as shown in Fig. 3.4.

Considering the relationship between mining induced bending curvature of a surface strata layer and horizontal strain on the surface, it can be deduced that a tilt-to-horizontal displacement factor of 10, equates to the bending in a surface strata beam of 30 metres depth bending about its centre line. This general rule is considered approximate only since the observed mining-induced horizontal movements showed considerable scatter in magnitude from these estimates and, the observed movements are not always directed towards the centre of the mined panel. It was recognised that applying this factor was more accurate for predicting the maximum value of horizontal movements over a panel than in predicting the lower values of mining-induced horizontal movements and it was accepted that many other variables had also been found to influence mining induced horizontal movements.

The understanding of mining induced horizontal ground movements is improving with improvements in the monitoring techniques to measure the magnitude, direction, and lateral extent of mining induced horizontal ground movements. The early subsidence monitoring involved the two dimensional measurement of vertical displacement and differential horizontal movements in one direction. Improvements in three dimensional monitoring, stress change monitoring, high resolution surveying techniques, GPS technology and satellite based differential interferometry using synthetic aperture radar (DinSAR) are providing a much better basis for understanding the extent and the mechanics of the mining induced horizontal ground movements.

With the development of accurate three dimensional surveying techniques, horizontal mining induced movements are now routinely observed to extend well beyond measureable vertical subsidence movements and the distances defined by the 26.5 degree angle of draw. It has now been found that the magnitude of mining-induced horizontal movements and the direction of these horizontal movements are controlled by a complex interaction of multiple factors, including the magnitude of the vertical subsidence, the presence of previously extracted panels, the depth of cover, the location of the peg relative to the extracted voids, the surface topography, the strata thicknesses and geology and the magnitude and direction of the in-situ horizontal stresses.

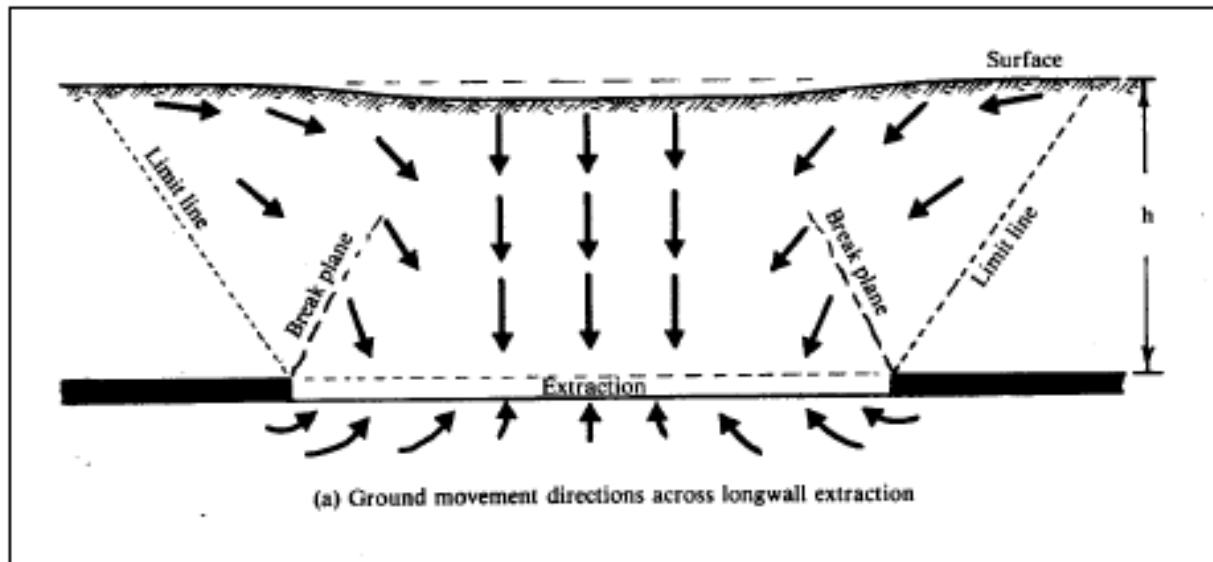


Fig. 3.4 Normal Mining Induced Movements above an Extracted Area (after Whittaker, Reddish and Fitzpatrick, 1985)

Before year 2000, it was not common to have survey control for mine subsidence monitoring only extending about one depth of cover or a few hundred metres from the edges of the approaching longwall goaf because of the challenges associated with maintaining survey accuracy over large distances. Now an array of bench marks is established around the area being subsided with far more accurate equipment and surveying techniques. Anderson et al (2007) describe the current use of concentric networks of survey control remote from mining and located on all sides of the mining areas. While it took some years before GPS technology became readily available and was able to be routinely used for subsidence monitoring at a high enough resolution, the effect has been profound. After survey control was established all around a mining area it became apparent that there was a need for reconciliation of small horizontal movements at either end of these early subsidence lines.

In flat terrain the vertical subsidence movements that are observed directly over extracted longwall panels are generally greater than the horizontal ground movements. The magnitude of the observed horizontal movements over the extracted panels represent about 30% of the vertical movements and the pegs are observed to move in changing directions with time as a longwall face first approaches, passes underneath and then moves beyond a point.

Mining induced horizontal movements have been recorded in all directions but typically they occur in the direction toward the active mining activity and, in non-conventional conditions of steep terrain, additional down slope movements are common. Outside the longwall panel boundaries though the mining induced horizontal ground movements are often found to be greater than the vertical ground movements at those points. Near the edge of the panel, the mining induced horizontal ground movements are typically observed to be about twice the magnitude of the observed vertical movements at that peg. In areas further away and beyond the boundaries of the project area, the horizontal ground movements tend to be many times the magnitude of the observed vertical subsidence movements. Small uniform horizontal movements have been measured kilometres from the edges of some panels in certain conditions. These small mining induced horizontal ground movements are called far field movements and these regional, remote or far field movements tend to be small, uniform and have low associated tilts and strains.

The three main mechanisms have been recognised to contribute to the observed magnitude and direction of the mining induced horizontal ground movements and the measured movements are a combination of all three of these mechanisms in greater or lesser proportions depending on the site conditions:

- Conventional horizontal movement that occurs generally toward the subsidence trough associated with the bending curvature of the overburden strata beams directly over an extracted longwall panel, typically, estimated with tilt-horizontal movement factors of 10 to 15 depending on geological conditions,
- Stress relief of the overburden strata toward the extracted panel, which are very dependent on the levels of in-situ horizontal stress that are locked in the various overburden layers, the goaf height relative to the depth of cover and extent of interlocking or friction resistance between these layers, and
- Horizontal movements toward topographic low points in a downslope direction, (i.e. steep slope and valley closure movements, which include vertical and horizontal components), caused by in-situ stress relief and re-distribution, by strata dilation along vertical joints/fractures and by block rotation mechanism within the overburden.

Although the prediction of vertical subsidence can be undertaken with reasonable accuracy the prediction of mining-induced horizontal ground movements is far less accurate when based on tilt-horizontal movement factors only. Previous studies have shown that this horizontal ground displacement prediction method is only approximate and,

whilst it tends to be conservative where the tilts are high, it tends to underestimate the horizontal movements where the tilts are low. When comparing the predicted and observed horizontal movements over many longwalls, it becomes apparent that these approximate horizontal movement predictions are most accurate in conventional conditions, i.e. above simple mine layouts with consistent geological conditions and uniform extracted coal seam thicknesses under flat surface terrains.

Increased magnitudes of horizontal movements are generally observed when non-conventional conditions occur, i.e. where steep slopes or surface incisions exist, as these natural topographic features influence both the magnitude and the direction of horizontal ground movement patterns. Similarly, increased levels of observed horizontal movements are often measured around sudden changes in geology, or where blocks of coal are left between longwalls or near other previously extracted series of longwalls.

The observed far-field horizontal movements beyond the normal vertical subsidence limits of the extracted panels also tend to be higher than the predicted horizontal movements using the above approximate horizontal ground displacement prediction method because these far field horizontal movements are generated by the stress relief mechanism rather than the bending curvature of the overburden strata beams.

With ongoing monitoring, analysis and research of subsidence induced ground movements, an improved understanding of the influence of the various mechanisms that affect the observed mining induced horizontal displacements is continually being developed and more accurate horizontal movements may be predicted in the future by combining the predicted horizontal displacements from the varying components from each of these mechanisms.

As described previously, normal strains are the differential horizontal movements of the ground. Conventional ground strains can, therefore, be estimated by multiplying the ground curvature by the same factor used to determine absolute horizontal movement from tilt. That is, for the proposed longwalls the maximum conventional ground strains can be estimated by applying a factor of 10 to the maximum conventional curvatures. However, like the prediction of horizontal movement, it should be noted that these horizontal strain predictions are not as accurate as the vertical predictions of subsidence and tilt.

To allow for the variability in the predicted horizontal movements and strains, a statistical approach has been used to provide the distributions of strain, rather than providing a single predicted conventional strain. The range of potential strains resulting from the extraction of the proposed longwalls are provided with the probabilities of exceedance of the various strain ranges, based on monitoring data from previously extracted longwalls in the Newcastle Coalfield, as discussed in Section 4.3.

It is generally accepted that vertical subsidence of less than 20 mm will have negligible effect on surface infrastructure and this is generally adopted as the cut-off point for determination of the angle of draw. In many locations, ground movements of more than 20 mm have been observed due to moisture and climatic conditions. In the Newcastle Coalfield, if local data is not available, the cut-off-point or the limit of vertical subsidence is taken as a point on the surface defined by an angle of draw of 26.5 degrees from the edge of the extraction, i.e. a point on the surface at a distance of half the depth of cover from the longwall goaf edges. Where local data exists and it can be shown that the angle is generally less than 26.5 degrees, then, the lower angle of draw can be used.

3.6. Far-field Movements

As discussed above, far field movements are the measured horizontal movements at pegs located beyond the longwall panel edges and over solid unmined coal areas that were generated by the release of in-situ horizontal stress.

Far-field horizontal movements tend to be small bodily movements towards the extracted goaf area. The measured far field movements at pegs that are located beyond the longwall panel edges and over solid unmined coal areas are often much greater than the observed vertical movements at those pegs. An empirical database of observed horizontal movements has been developed which confirms this.

For example, at the location beyond the panel edges, where the predicted conventional vertical subsidence value is 20 mm, i.e. at a distance of about half of the depth of cover from the panel edges, horizontal movements of up to 100 mm have been observed, with an average observed horizontal movement of approximately 40 mm.

These far field horizontal movements are higher than the vertical movements beyond the longwall panel edges and over solid unmined coal since these movements are derived from two components. First there is the mining induced horizontal movement component caused by the mining induced bending curvature of the strata beds into the goaf areas plus, there is an additional component caused by a relief of the in situ horizontal compressive stresses in the strata around the longwalls. Further away from the longwalls, the observed far field horizontal movements are believed to be predominantly a result of the in-situ stress relief mechanism. Before mining these in situ stresses, which are generally compressive in all directions, are in equilibrium or balance. When mining occurs, the equilibrium is disturbed and the stresses achieve a new balance by shearing through the weaker strata units allowing the strata to move or expand towards the goaf areas, where the confining stresses have been relieved.

When large horizontal displacements are measured outside a longwall extraction area, they are more likely to be a result of far-field movements than a result of the mining induced curvature mechanism. Far-field horizontal

movements have been observed at considerable distances from extracted longwalls. Such stress relief movements are becoming more predictable and also occur whenever significant excavations occur at the surface or underground. The methods used to predict far-field horizontal movements have continued to develop in recent years using the current and available 3D monitoring data and the confidence levels in these predictions continue to improve.

Far-field horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain. As such, these movements generally do not result in impacts on natural features or built environments, except where they are experienced by large structures which are very sensitive to differential horizontal movements.

In some cases increased higher levels of far-field horizontal movements are observed where steep slopes or surface incisions exist nearby, as these features influence both the magnitude and the direction of ground movement patterns. Similarly, increased observed horizontal movements are often observed around sudden changes in geology or where blocks of coal are left between longwalls or near other previously extracted series of longwalls.

Far-field horizontal movements and the method used to predict such movements are described further in Section 4.4.

3.7. Overview of Non-Conventional Subsidence Movements

Conventional subsidence profiles are typically smooth in shape and can be explained by the expected caving mechanisms associated with overlying strata spanning the extracted void. Normal conventional subsidence movements due to longwall extraction are easy to identify where longwalls are regular in shape, the extracted coal seams are relatively uniform in thickness, the geological conditions are consistent and surface topography is relatively flat.

As a general rule, the smoothness of the profile is governed by the depth of cover and lithology of the overburden, particularly the near surface strata layers. Where the depth of cover is greater than 400 metres, the observed subsidence profiles along monitoring survey lines are generally smooth. Where the depth of cover is less than 100 metres, the observed subsidence profiles along monitoring lines are generally irregular with much higher tilts, curvatures and strains and at these shallow depths of cover the collapsed zone above the extracted longwalls can extend up to or near to the surface.

Irregular subsidence movements are occasionally observed at the deeper depths of cover along an otherwise smooth subsidence profile. The cause of these irregular subsidence movements can be associated with:-

- sudden or abrupt changes in geological conditions,
- steep topography, and
- valley related mechanisms.

Non-conventional movements due to shallow depths of cover, geological conditions, steep topography and valley related movements are discussed in the following sections.

3.7.1. Non-Conventional Subsidence Movements due to Shallow Depth of Cover

Irregular ground movements are commonly observed in shallow mining situations where the collapsed zone that develops above the extracted longwalls extends up to or near the surface. These types of irregular movements are generally only observed where the depths of cover are less than 100 metres and where the longwalls are supercritical.

The minimum depth of cover directly above the proposed longwalls is 80 metres, which occurs at the north western end of the proposed Longwall 201. The longwalls with depths of cover less than approximately 220 metres are supercritical and, therefore, blocky subsidence movements could occur resulting in larger cracking and stepping at the surface.

3.7.2. Non-conventional Subsidence Movements due to Changes in Geological Conditions

It is believed that most non-conventional ground movements are a result of the reaction of near surface strata to increased horizontal compressive stresses due to mining operations. Some of the geological conditions that are believed to influence these irregular subsidence movements are the blocky nature of near surface sedimentary strata layers and the possible presence of unknown faults, dykes or other geological structures, cross bedded strata, thin and brittle near surface strata layers and pre-existing natural joints. The presence of these geological features near the surface can result in a bump in an otherwise smooth subsidence profile and these bumps are usually accompanied by locally increased tilts, curvatures and strains.

Even though it may be possible to attribute a reason behind most observed non-conventional ground movements, there remain some observed irregular ground movements that still cannot be explained with the available geological

information. The term “anomaly” is therefore reserved for those non-conventional ground movement cases that were not expected to occur and cannot be explained by any of the above possible causes.

It is not possible to predict the locations and magnitudes of non-conventional anomalous movements. In some cases, approximate predictions for the non-conventional ground movements can be made where the underlying geological or topographic conditions are known in advance. It is expected that these methods will improve as further knowledge is gained through ongoing research and investigation.

In this report, non-conventional ground movements have been included statistically in the predictions and impact assessments, by basing these on the frequency of past occurrence of both the conventional and non-conventional ground movements and impacts. The analysis of strains provided in Section 4.3 includes those resulting from both conventional and non-conventional anomalous movements.

3.7.3. Non-conventional Subsidence Movements due to Steep Topography

Non-conventional movements can also result from down slope movements where longwalls are extracted beneath steep slopes. In these cases, elevated tensile strains develop near the tops of the steep slopes and elevated compressive strains develop near the bases of the steep slopes. The potential impacts resulting from down slope movements include tension cracks at the tops and sides of the steep slopes and compression ridges at the bottoms of the steep slopes.

3.7.4. Valley Related Movements

The streams within the Study Area may be subjected to valley related movements which are commonly observed as a result of longwall mining at deep mines in NSW. Valley bulging movements are a natural phenomenon, resulting from the formation and ongoing development of the valley, as illustrated in Fig. 3.5. The potential for these natural movements are influenced by the geomorphology of the valley.

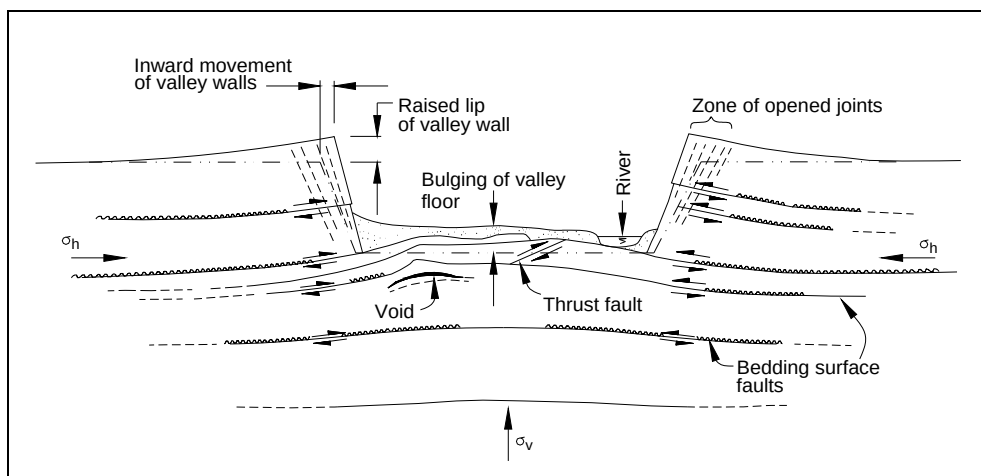


Fig. 3.5 Valley Formation in Flat-Lying Sedimentary Rocks (after Patton and Hendren 1972)

Valley related movements can also be caused by or accelerated by mine subsidence as the result of a number of factors, including the redistribution of horizontal in-situ stresses and downslope movements. Mining induced valley related movements are normally described by the following parameters:-

- **Upsidence** is the reduced subsidence within a valley which results from the dilation or buckling of near surface strata at or near the base of the valley. The term **uplift** is used only for the cases where the ground level is raised above the pre-mining level, i.e. when the upsidence is greater than the subsidence. The magnitude of upsidence, which is typically expressed in the units of *millimetres (mm)*, is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.
- **Closure** is the reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in the units of *millimetres (mm)*, is the greatest reduction in distance between any two points on the opposing valley sides.
- **Compressive Strains** occur within the bases of valleys as a result of valley closure and upsidence movements. **Tensile Strains** also occur in the sides and near the tops of the valleys as a result of valley closure movements. The magnitudes of these strains, which are typically expressed in the units of *millimetres per metre (mm/m)*, are calculated as the changes in horizontal distance over a standard bay length, divided by the original bay length.

Predicted valley related movements resulting from longwall extraction are made using the empirical method outlined in ACARP Research Project No. C9067 (Waddington and Kay, 2002). Further details can be obtained from the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at www.minesubsidence.com.

Valley related movements have not been reported in the available mine subsidence observed data from the Bowen Basin coal fields. The reasons for this are varied and include the following:

- Longwall mining in the Bowen Basin has typically occurred at relatively shallow depths of cover, where the large conventional subsidence movements can mask any valley related movements that may occur.
- The ground surface in the Bowen Basin typically includes Quaternary and Tertiary sedimentary deposits, which can mask any valley related movements that may have occurred in the bedrock beneath.
- The terrain in many parts of the Bowen Basin is relatively flat. The magnitude of mining-induced valley related movements is influenced by the depth of the valley. In the case of the proposed Carmichael Project, the valley depths are relatively shallow and appear to be incised within the alluvial deposits, whilst, the valley sites where substantial valley related movements have been observed in NSW are much deeper and wider and are incised in sandstone valleys and gorges.
- There has been limited monitoring for valley related movements in the Bowen Basin as it is difficult to install fixed survey pegs in alluvial river beds.

Predictions of valley related movements have not been provided for the project for the reasons above. While the depth of cover to some areas of the proposed mining area are similar to those in deep mines in NSW, it is considered likely that any valley related movements at the surface will be small because of the generally flat terrain, and presence of Tertiary sedimentary deposits at the proposed project.

3.8. The Incremental Profile Method

The predicted conventional subsidence parameters for the proposed longwalls were determined using the Incremental Profile Method, which was developed by MSEC, formerly known as Waddington Kay and Associates. The method is an empirical model based on a large database of observed monitoring data that essentially involves two steps; first the prediction of incremental subsidence profiles over each longwall based on the local seam thicknesses, the incremental panel and pillar widths, the presence of adjacent previously mined panels and the local depths of cover. The second step is the addition of all the incremental subsidence profiles to form the total subsidence profiles over the series of longwalls.

It has been shown, by predicting the subsidence movements using this two step process, that more accurate and more site specific subsidence parameters can be derived than otherwise obtained using methods that attempt to predict the total subsidence profiles in one step.

The empirical database that has been used to develop and calibrate the Incremental Profile Method includes mine subsidence ground monitoring data from mines and collieries gathered by MSEC from the Southern, Western, Newcastle and Hunter Coalfields of New South Wales and from the Bowen Basin in Queensland, including: Angus Place, Appin, Awaba, Austar, Baal Bone, Bellambi, Beltana, Blakefield South, Bulga, Bulli, Burwood, Carborough Downs, Chain Valley, Central, Clarence, Coalcliff, Cook, Cooranbong, Cordeaux, Corrimal, Cumnock, Dartbrook, Delta, Dendrobium, Donaldson, Eastern Main, Ellalong, Elouera, Fernbrook, Glennies Creek, Grasstree, Gretley, Invincible, John Darling, Kemira, Kestrel, Lambton, Liddell, Mandalong, Metropolitan, Moranbah North, Mt. Kembla, Munmorah, Nardell, Newpac, Newstan, Newvale, Newvale 2, NRE Wongawilli, Oaky Creek, Ravensworth, South Bulga, South Bulli, Southern, Springvale, Stockton Borehole, Teralba, Tahmoor, Tower, Wambo, Wallarah, Western Main, Ulan, United, West Cliff, West Wallsend, and Wyee.

Further details on the Incremental Profile Method are provided in the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained from the MSEC website at www.minesubsidence.com.

3.9. Testing and Calibration of the Incremental Profile Method

3.9.1. Available Subsidence Monitoring Data

The proposed Carmichael Project is a Greenfield site. There is therefore no monitoring data available from this site or from nearby collieries for calibration of the Incremental Profile Method model.

Cook Colliery is located in Queensland within the Bowen Basin and is approximately 330 kilometres to the south east of the proposed Carmichael Project. The Castor seam was extracted at Cook Colliery and the Castor Seam is an upper seam within the Rangal Coal Measures, which are directly correlative to the Bandanna Formation. The AB1 seam is the upper coal seam within the Bandanna Formation. Both formations are overlain by the Rewan Formation Triassic sequence.

It is therefore anticipated that the goafing characteristics of the overburden materials of the Rewan Formation at the Carmichael Project will be similar to those of the overburden materials of the Rewan Formation at Cook Colliery. Therefore the subsidence monitoring data from Cook Colliery can provide a sound basis to calibrate the IPM model for the Carmichael Project. Extensive data from the monitoring of subsidence movements over panels in the Castor Seam at Cook Colliery has been obtained and Caledon Coal Pty Ltd has kindly granted permission to use this data for calibration of our Incremental Profile Method Model.

At Cook Colliery the Castor Seam panels were mined using varying partial extraction systems and longwall panels with varying panel widths. Few of the partially extracted panels in the Castor Seam were supercritical in width. In some cases the partially extracted panels at Cook Colliery only included wide stable pillars whilst, at other panels, the partial extraction system mined up to 85% of the panel area leaving stooks and thin remnant pillars that would readily fail when undermined by the proposed Argo Seam longwalls. Whilst most of the Castor Seam panels were extracted using partial extractions systems with continuous miners, six of the Castor Seam panels were extracted by longwalls.

The longwall panel widths in the Castor Seam were not supercritical as their widths, (172 to 205 metres), represented between 0.73 to 1.32 times the depths of cover, (i.e. sub-critical width range). The extracted seam thickness in the Castor Seam workings ranged from 2.8 to 3 metres.

The initial mine subsidence monitoring and prediction advice for Cook Colliery was published by Bill Kapp (1980). Kapp advised;

“Subsidence movements at Cook Colliery, as well as geological sections at Cook and Leichhardt Collieries, suggest that subsidence behaviour at Blackwater would approach that of United Kingdom strata rather than the Newcastle and Southern Coalfields of N.S.W.

The crowding of the subsidence contours along the western edge of extraction is noteworthy. At this depth a geological anomaly might be suspected, but with no such evidence, the initial large deformation of the main strata is the likely cause. Such steep profiles over the start of an area of extraction have been observed in the Southern Coalfield, N.S.W.

The limit angle at Cook Colliery ranges from 15.3° to 21.5° and the mean is 19.6°.

Although present data is used as a guide in forecasting, further subsidence monitoring work over extraction areas is needed to improve the confidence of forecasting subsidence, slope changes, curvatures and strains. In further work, strains should be measured directly.”

The following Figs. 3.5 and 3.6 show the monitoring layouts and the observed subsidence results over the One West Panel, Castor Seam at Cook Colliery.

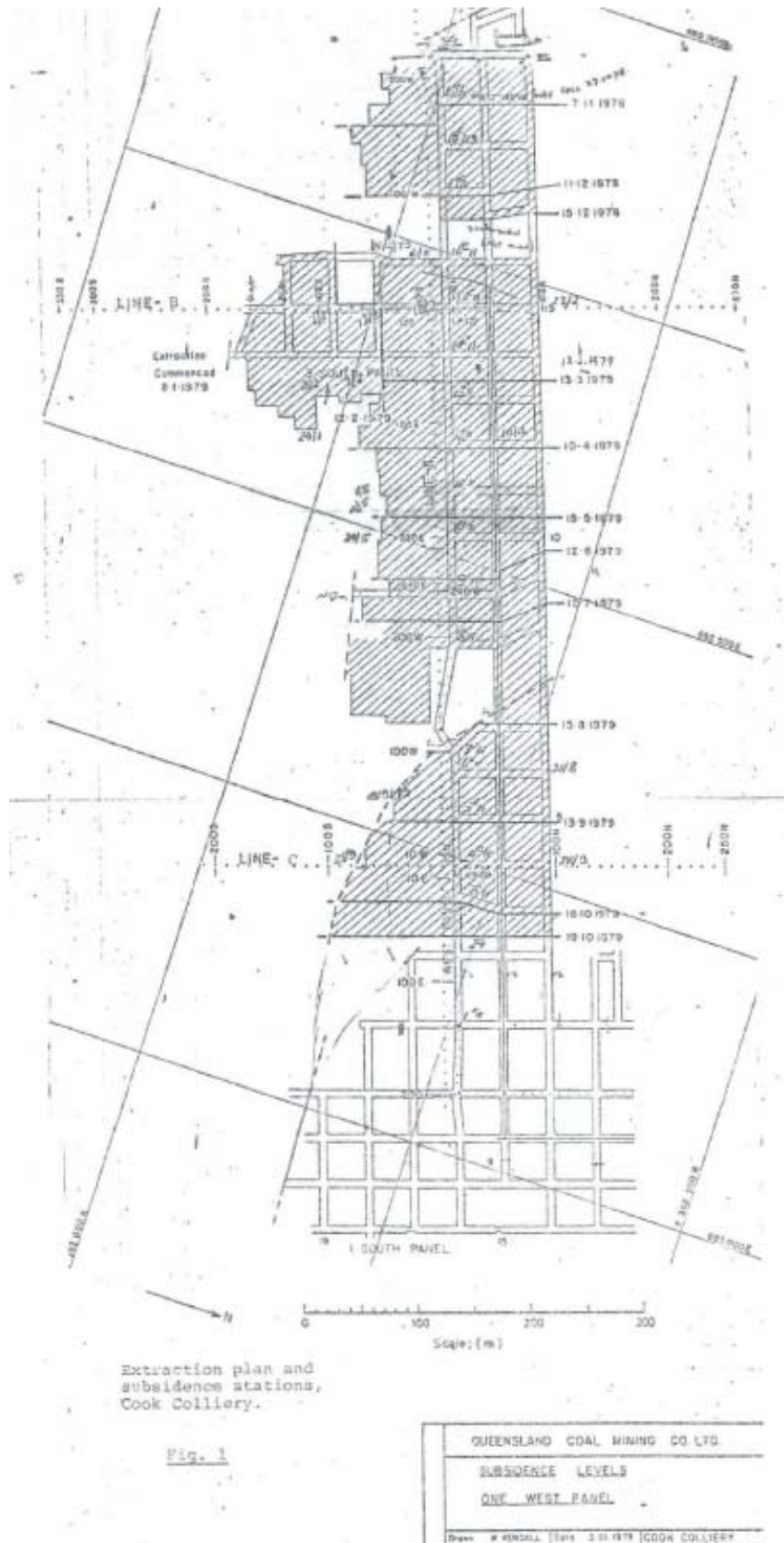


Fig. 3.6 Initial Subsidence Monitoring Details (Kapp, 1980)

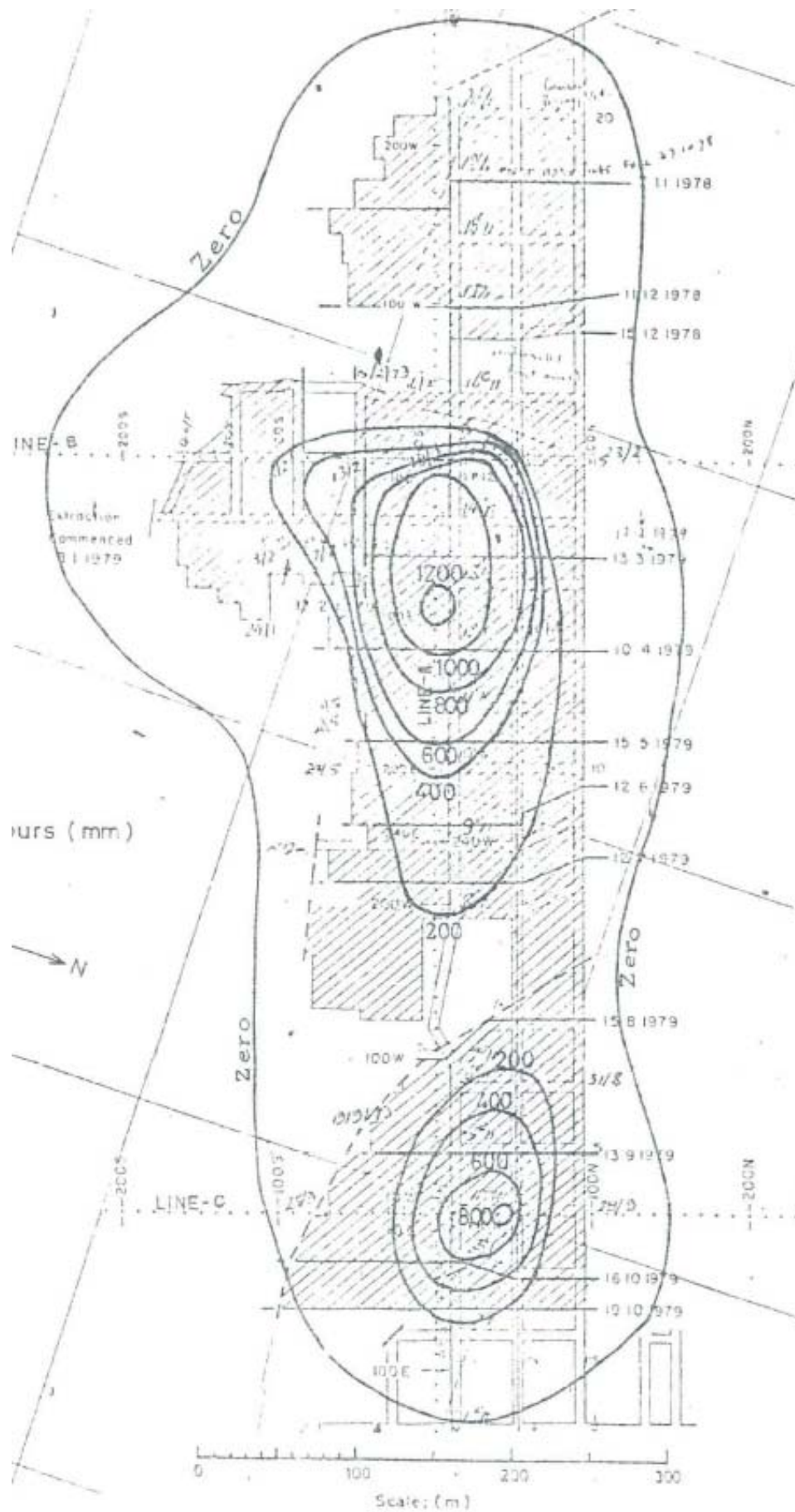


Fig. 3.7 Initial Subsidence Monitoring Results (Kapp, 1980)

Further details of subsidence monitoring over Cook Colliery were published in June 1993 by ACIRL following a NERRDP funded research project title “Improved Methods of Subsidence Engineering” that was prepared by Peter Willey, Peter Hornby, Steve Ditton, Giles Pucket and Greg McNally. This project followed detailed subsidence monitoring that was undertaken by the Colliery over Longwalls 1 to 4 as a result of extraction of the Castor Longwalls 1 to 4.

Willey, et al, (1993) advised;

“A subsidence monitoring program was established over Longwall 4 at Cook Colliery. The monitoring consisted of measurements of mining induced movements both on the surface and between the seam and the surface. Cook Colliery was chosen as the site for the program for a number of reasons:

- * The overburden is composed of a sequence of laminates and thin sandstone layers with one massive sandstone layer overlying the Aries Seam “(Fig. 3.8 below). “This is in contrast to the large amount of massive sandstones and conglomerates found in the Newcastle and Southern Coalfields of New South Wales.
- * There were no previous workings above the extraction panel.
- * The surface terrain is relatively flat virtually eliminating topographic effect on subsidence. Also, surveying is quicker and therefore cheaper over flat ground.
- * Management and staff at CRQ Ltd gave a large amount of assistance particularly with the drilling of boreholes and the initial survey layout.”

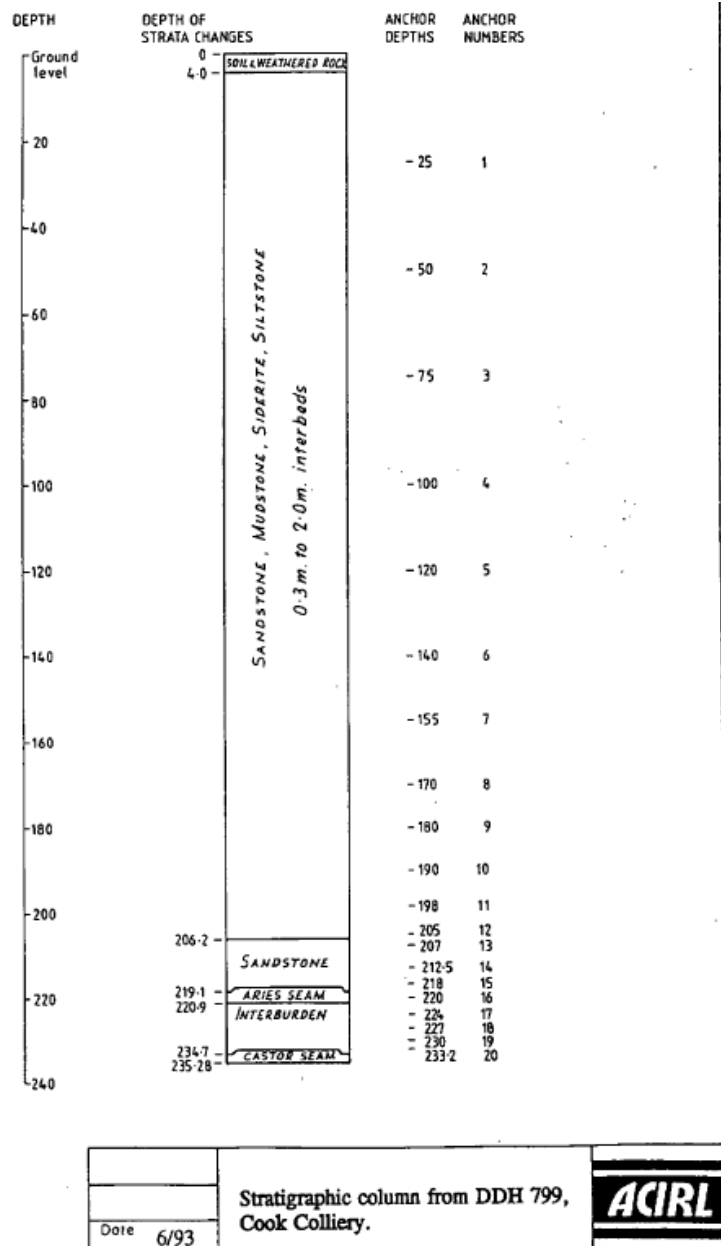


Fig. 3.8 Stratigraphic Column near Castor Seam Longwall 4 (Willey, et al, 1993)

"Longwall 4 is 168m wide and extracted an average of 2.9m of the Castor Seam at a depth of about 235m below the surface. Vertical subsidence above Longwalls 1 and 2, each 168m wide, was about 1.6 to 1.9m. Subsidence above Longwall 3 was in order of 1.7 to 2.0 but this panel was 200m wide. Surface strains had not been measured over any of the first three longwalls. Maximum subsidence over Longwall 4 was 1.7m as shown in the figures below and Table below summarises the mining details for Longwall 4."

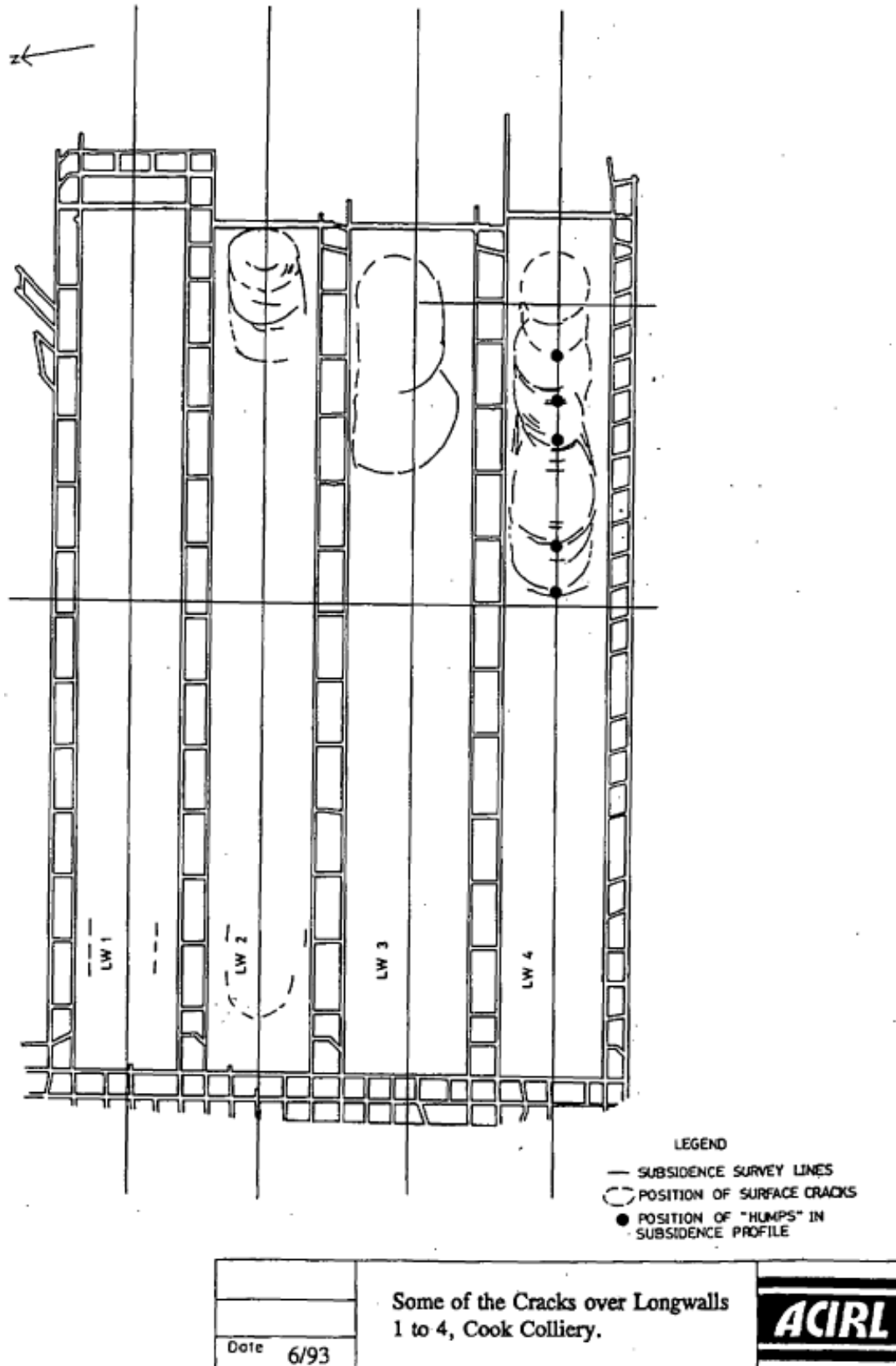


Fig. 3.9 Observed Subsidence Cracks after extraction of Longwalls 1 to 4 in the Castor Seam at Cook Colliery (ACIRL)

Summary of the Mining Details for Longwall 4, Cook Colliery

SEAM	Castor	
EXTRACTION THICKNESS	2.9m	
PANEL WIDTH	168m	
CHAIN PILLAR WIDTH	25 to 38m	
PANEL LENGTH	1320m	
DEPTH OF COVER	235m	
PREVIOUS WORKINGS	Nil	
GEOLOGY (From DDH 799)	0 to 206m	Interbedded sandstones, mudstones, siderite and siltstone.
	206 to 219m	Massive Sandstone
	219 to 221m	Aries Seam
	221 to 235m	Interburden
	235 to 238m	Castor Seam

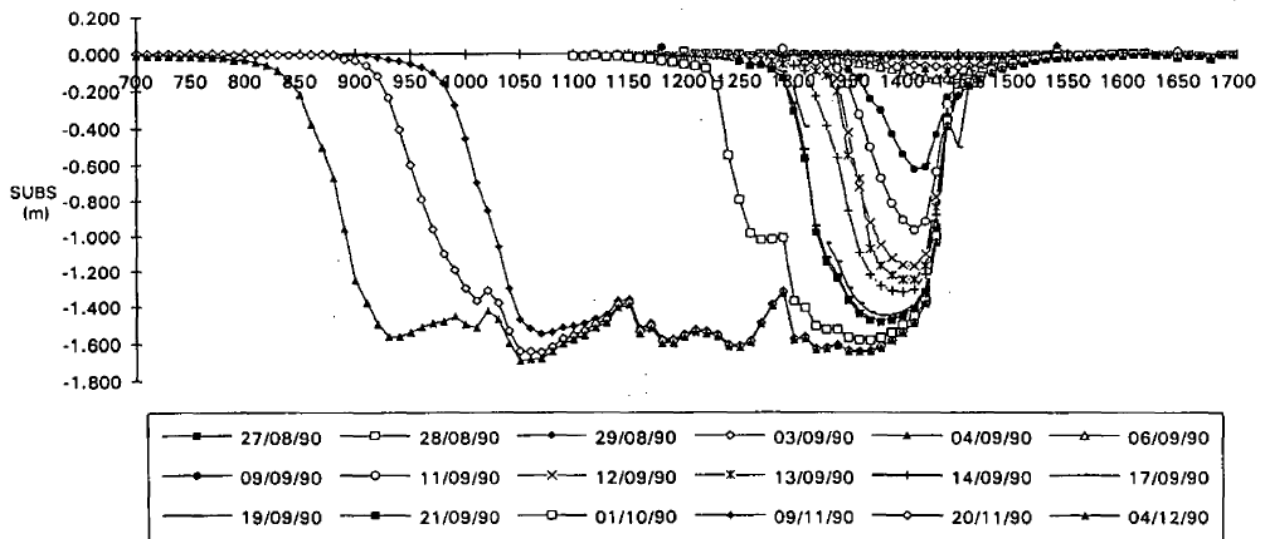


Fig. 3.10 Centreline Subsidence Profile, Castor Seam Longwall 4 (Willey, et al, 1993)

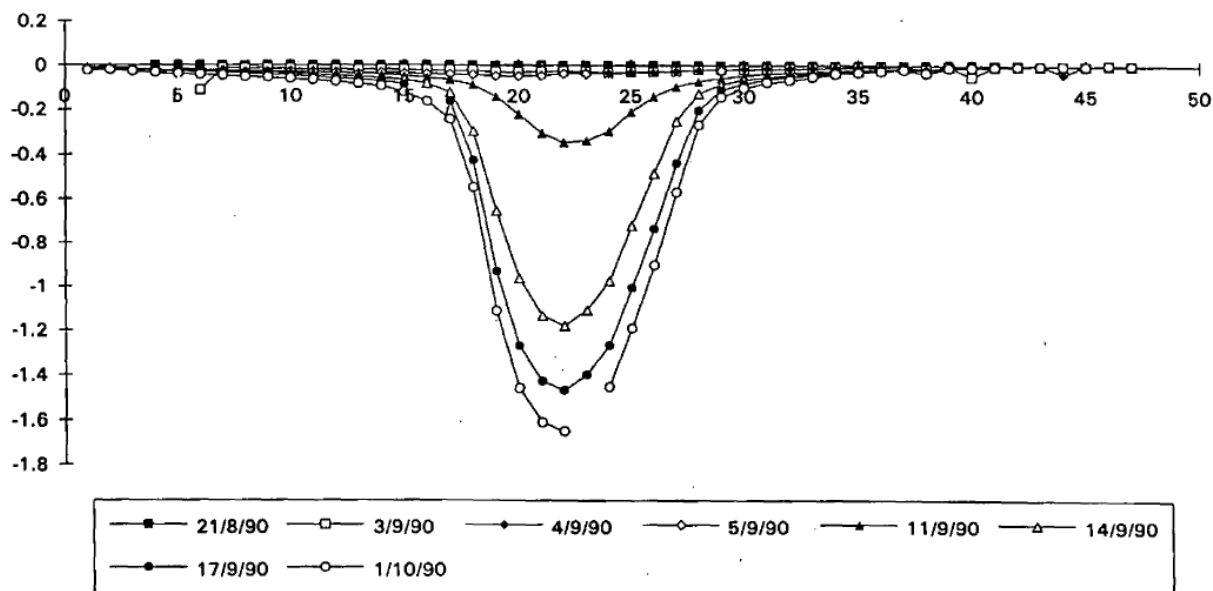


Fig. 3.11 Crossline Subsidence Profile, Castor Seam Longwall 4 (Willey et al 1993)

"The Figure below is a map of the surface cracks over Longwall 4. High points on the longwall centreline coincide with these cracks and, of course, high tensile strains. The maximum tensile strain measured over 10m baylengths was 20mm/m but generally they were less than 10mm/m. These were associated with surface cracks up to 200mm across. Compressive strains reached 12mm/m and were more consistent with values of 7 to 10mm/m being common."

The maximum tilt was 65mm/m although most tilts were below 20mm/m.

Curvatures were quite tight getting up to 2.5km^{-1} (radius = 0.4km) regularly and as tight as 4.78km^{-1} (radius=0.209km) near the start of the longwall.

The most striking feature of the centreline subsidence plot over LW4 is the way in which the subsidence fluctuates between about 1.35m and 1.7m over a relatively short distance. This fluctuation produces the tight curvatures.

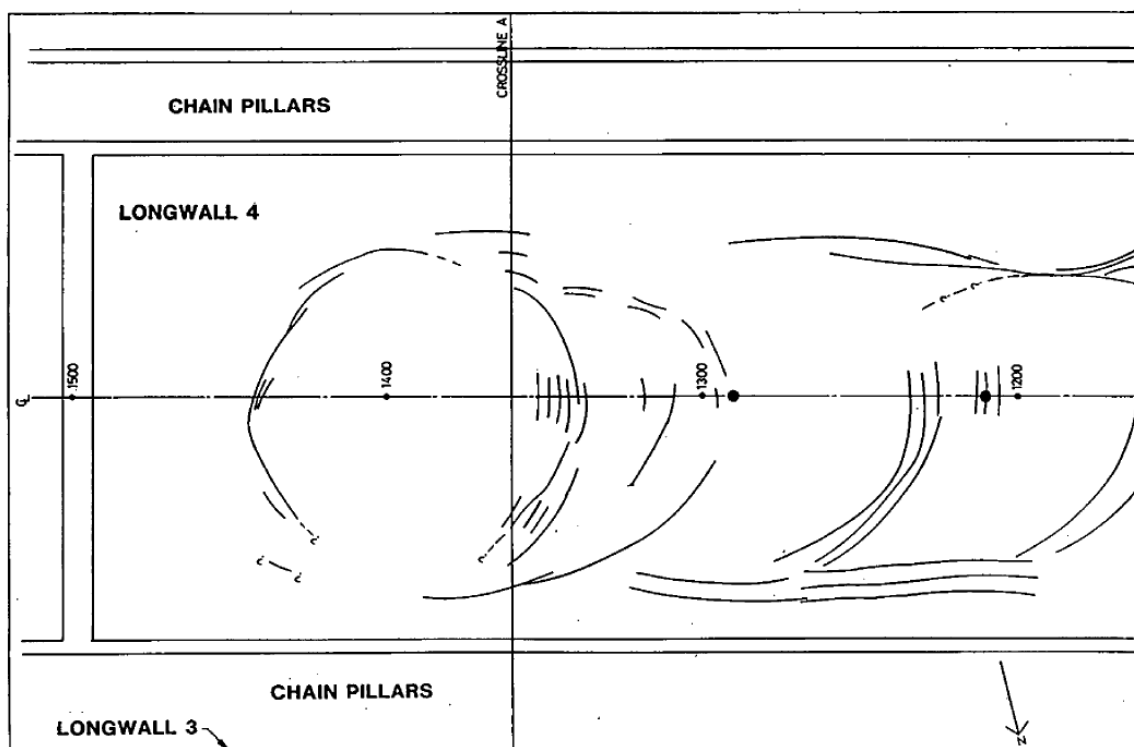


Fig. 3.12 Survey Pegs and Surface Cracks over Castor Seam Longwall 4 (Willey et al 1993)

"The surface crack pattern first developed in a circle of about 40m diameter centred near peg 1380. These cracks first appeared when the longwall face was under pegs 1250 to 1300 and coincided with major goaf falls underground. Major cracks continued to appear as the longwall retreated producing the arcuate pattern shown in the above Figures." (Figs. 3.8 and 3.11 above).

"The spacing between major crack groups was generally between 50 and 100m. A feasible explanation for this phenomenon was that the massive sandstone layer above the Aries Seam was driven to failure at regular intervals by the retreating longwall. Monitoring of chock loadings during this period supports this view with cyclic loadings being recorded every 10 to 15m or so of face advance (Frith and Stewart, 1993, in press).

Results from the borehole extensometer " (Fig. 3.12 below)," were somewhat ambiguous. When the longwall face was about 20m before the borehole the cables attached to Anchors 16 to 20 broke. This was probably due to shearing along the interface between the Aries Seam and the overlying massive sandstone at a depth of 219m. Anchors 4, 9 and 10 also broke at about this time and it is thought that their cables were caught on the broken cables from Anchors 16 to 20. Other cables broke later leaving only 8 working. This Figure shows the movements of the surviving anchors as the longwall face retreated."

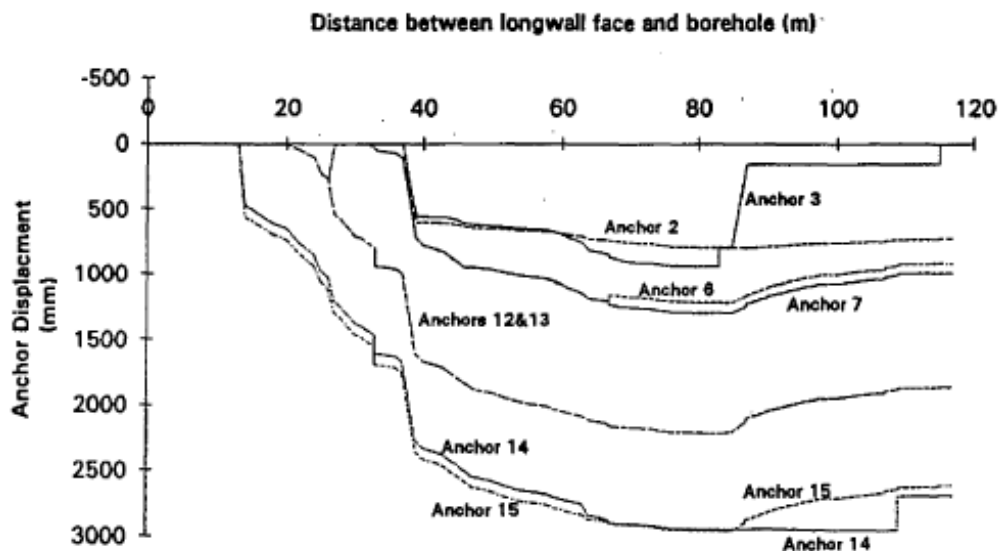


Fig. 3.13 Crossline Subsidence Profile, Castor Seam Longwall 4 (Willey et al 1993)

Further details of the observed levels of monitored subsidence over Cook Colliery were published in December 2005 by Galvin & Associates in a report titled "Longwall Mining Considerations at Cook Colliery." Galvin advised;

"Surface cracking and surface subsidence measurements confirmed that the area had subsided regionally. It was reported that surface subsidence almost equated to the amount of coal extracted. That is, surface subsidence approximated mining height x areal extraction. Typically, in Australian conditions, maximum surface subsidence approximates 60% of the extracted volume of coal and somewhat less in partially extracted panels. Two reasons that could account for the high level of recorded subsidence over 502 panel are:

1. The area extracted was greater than that shown on the plan,
2. The superincumbent strata have very good caving properties.

Investigations that I have previously undertaken at the adjacent and now closed Laleham Colliery confirmed that significantly higher levels of subsidence occur in this mining region than experienced in other Australian mining regions. The caving angle is also steeper, resulting in a lower angle of draw. Both of these factors contribute to lower abutment stress and a smaller abutment stress zone around the perimeter of caved workings."

Based on the above published papers on subsidence monitoring at Cook Colliery, high levels of subsidence can be observed at Cook Colliery because the overburden is composed of a sequence of laminates and thin sandstone layers. This can be compared and contrasted against the large amount of massive sandstones and conglomerates found in the Newcastle and Southern Coalfields of New South Wales. It is noteworthy that Bill Kapp advised that; "Subsidence movements at Cook Colliery, as well as geological sections at Cook and Leichhardt Collieries, suggest that subsidence behaviour at Blackwater would approach that of United Kingdom strata rather than the Newcastle and Southern Coalfields of N.S.W."

Detailed mine subsidence monitoring was undertaken along and across each of the Castor Longwalls 1 to 6, and hard copies of these monitoring results were provided by Caledon. Figs 3.13 to 3.15 show some of this monitoring and Figs. 3.9 and 3.10 show the monitoring data published by ACIRL along and across Castor Seam Longwall 4. All this subsidence monitoring data has now been entered into the MSEC mine subsidence survey data base.

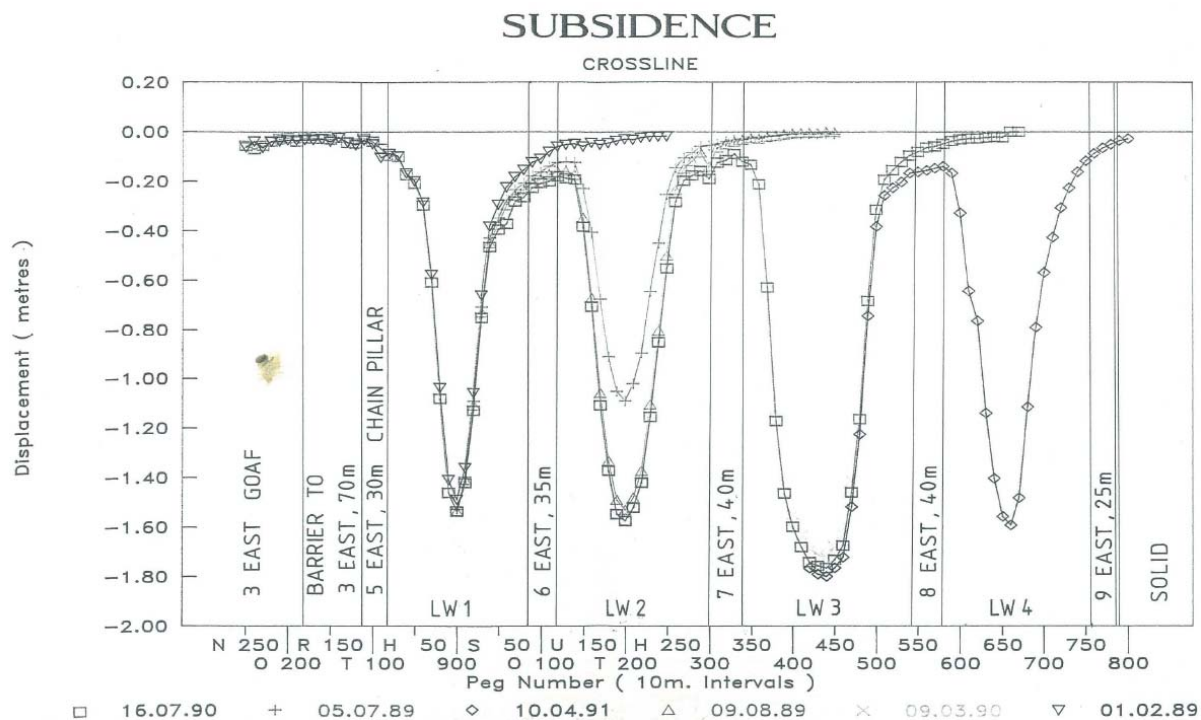


Fig. 3.14 Crossline Subsidence Profile, Castor Seam Longwalls 1 to 4 (Cook)

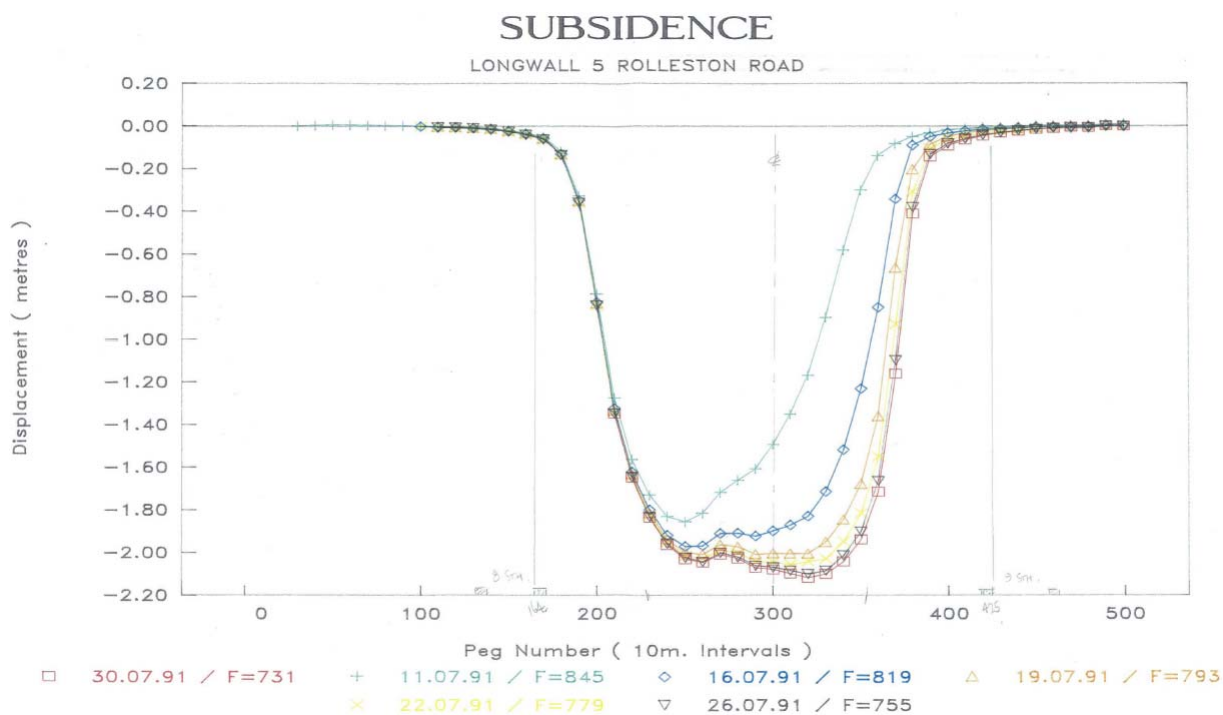


Fig. 3.15 Rolleston Road Subsidence Profile, Castor Seam Longwall 5 (Cook)

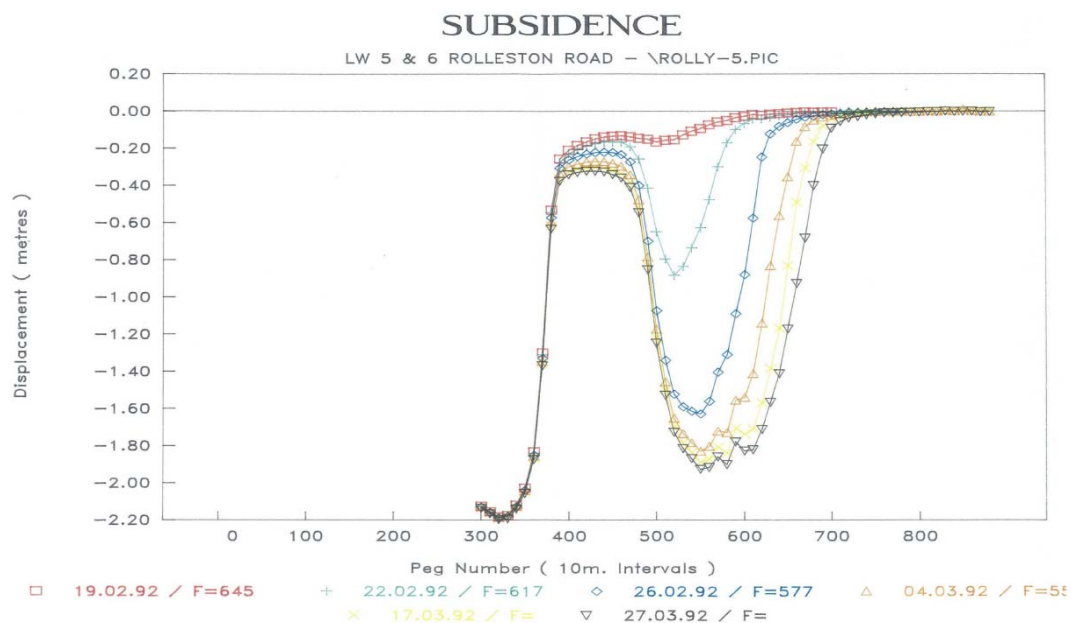


Fig. 3.16 Rolleston Road Subsidence Profile, Castor Seam Longwalls 5 and 6 (Cook)

3.9.2. Calibration for Local Single-seam Mining Conditions

The MSEC Standard Incremental Profile Method (IPM) model was initially used to predict mine subsidence movements for the single-seam conditions over the Castor Seam panels at Cook Colliery along the available subsidence monitoring lines. Comparisons were then undertaken between the observed and predicted subsidence movements using single-seam conditions over the Castor Seam Longwalls 1 to 4.

The following figures, Fig. 3.16 to 3.19, show the observed subsidence profiles, the initial standard IPM predictions and the new calibrated predictions over the Castor Seam Longwalls 1 to 4.

These comparisons indicated that the standard IPM prediction model provides subsidence predictions that were lower in magnitude and the shape of the subsidence profiles resulted in tilts and curvatures that were also less than those that were observed after the survey monitoring, see particularly Fig. 3.19.

This initial review/comparison confirmed the previous advice from Kapp (1980), Willey (1995) and Galvin (2005) that the lack of any massive strata units and the presence of thinly bedded claystone and siltstone laminates at Cook Colliery results in very steep caving angles, high compaction or low bulking of the goafed material and much higher than expected levels of subsidence compared to other Australian mining regions.

Based on these initial predictions and comparisons against the observed subsidence monitoring results, a calibrated IPM model was developed to better predict the single-seam subsidence at Cook Colliery for panels of similar panel widths and depths of cover at Castor Seam Longwalls 1 to 4.

In essence the adjusted model uses the Standard MSEC IPM prediction curves, but, the panel width-to-depth-of-cover (W/H) ratio used in the model is twice the actual panel W/H ratios at Cook Colliery – in order to get the shape of the profiles to match the actual steep observed subsidence profiles and, then, the predicted subsidence profiles values are increased to obtain a reasonable match between observed and predicted subsidence magnitudes.

It can be seen from the above figures, that the observed profiles of subsidence, tilt and curvature along these monitoring lines at Cook Colliery, (i.e. the blue coloured lines on Figs 3.16 to 3.19), reasonably match those predicted using the standard Incremental Profile Method (i.e. the solid red coloured lines on Figs 3.16 to 3.19). In some locations, there are small lateral shifts between the observed and predicted profiles, which could be the result of surface dip, seam dip, or variations in the overburden geology.

It should be recognised that this geological calibration is based on panel widths of 172 metres to 200 metres and depths of cover between 215 metres and 235 metres. The depths of cover above the proposed longwalls at the Carmichael Project vary from less than 100 metres to more than 500 metres and the proposed void widths are 310 metres.

The calibration of the IPM model for the Cook Colliery data has resulted in a significant increase in the maximum predicted subsidence over the uncalibrated model.

While this provides a level of conservatism when compared to monitoring data from other collieries, it will be necessary to review predicted subsidence parameters at the commencement of mining at the Carmichael Project to consider the need for additional further modification to the prediction model.

Cook Colliery - Castor Seam Workings **Predicted Profiles of Total Conventional Subsidence, Tilt and Curvature** **along a Longitudinal Line down LW1 due to the Extraction of LW1**

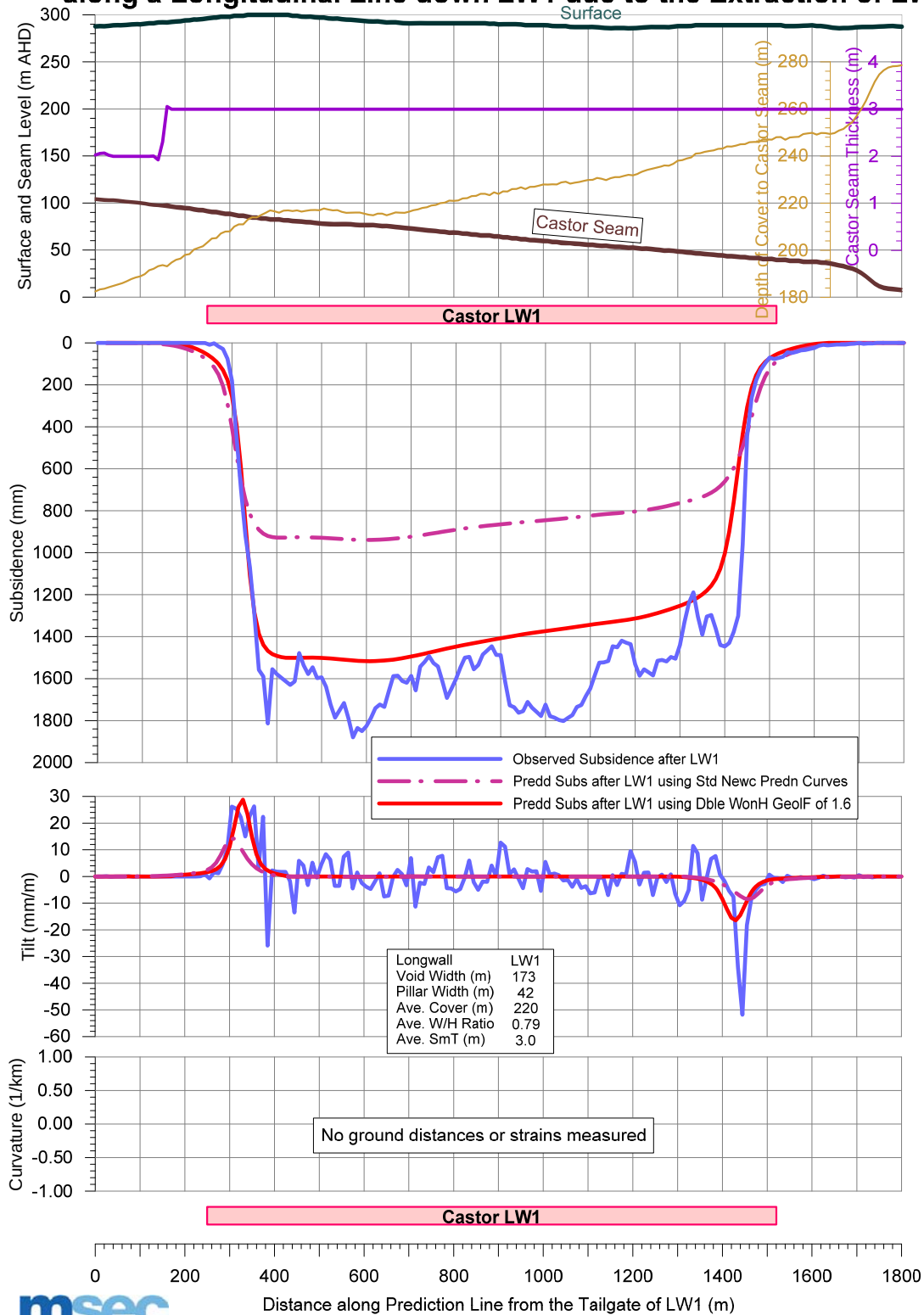


Fig. 3.17 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along Castor LW1 Longitudinal Line

Cook Colliery - Castor Seam Workings **Predicted Profiles of Total Conventional Subsidence, Tilt and Curvature** **along a Longitudinal Line down LW2 due to the Extraction of LW1 to LW2**

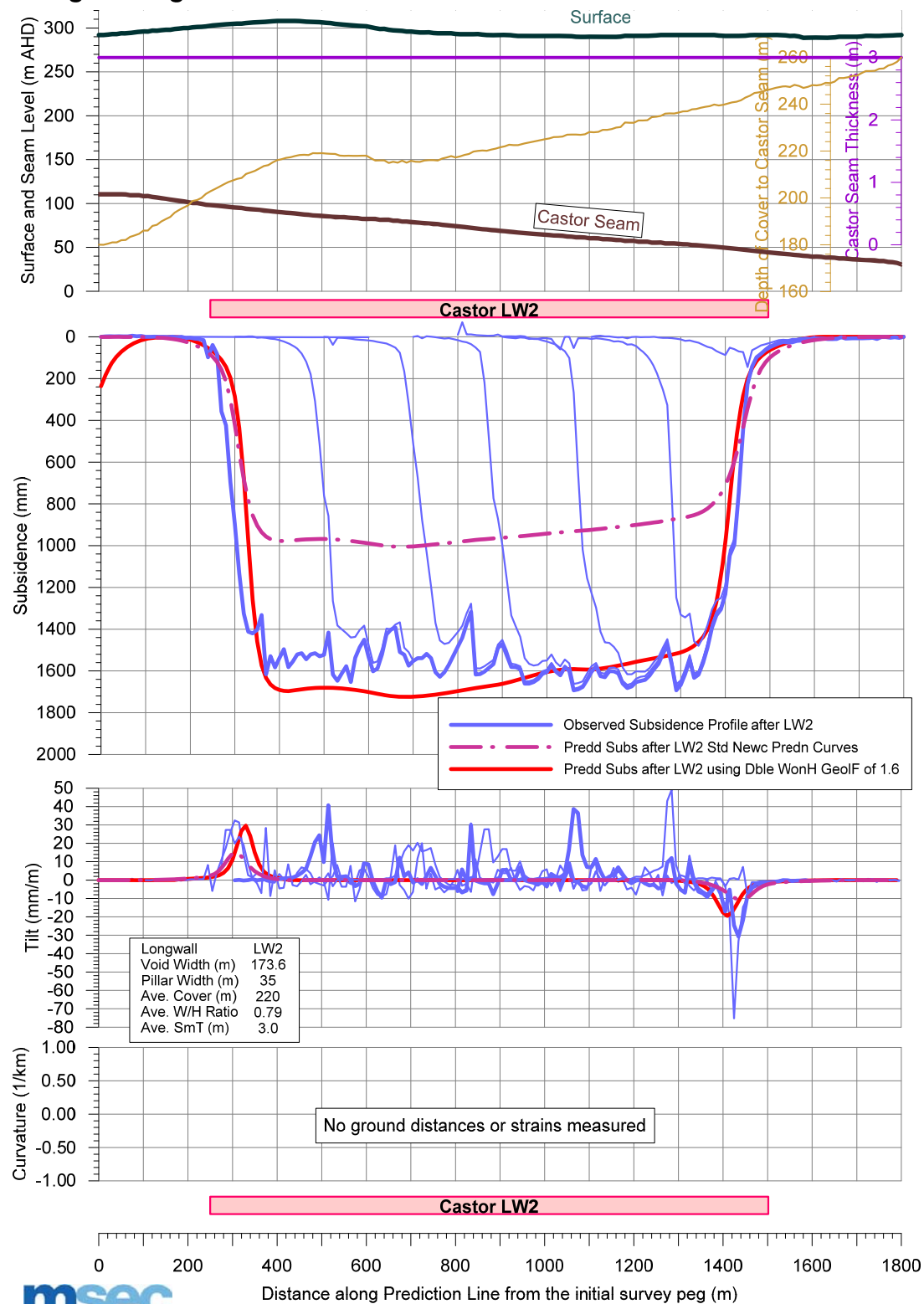


Fig. 3.18 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along Castor LW2 Longitudinal Line

Cook Colliery - Castor Seam Workings **Predicted Profiles of Total Conventional Subsidence, Tilt and Curvature** **along a Longitudinal Line down LW3 due to the Extraction of LW1 to LW3**

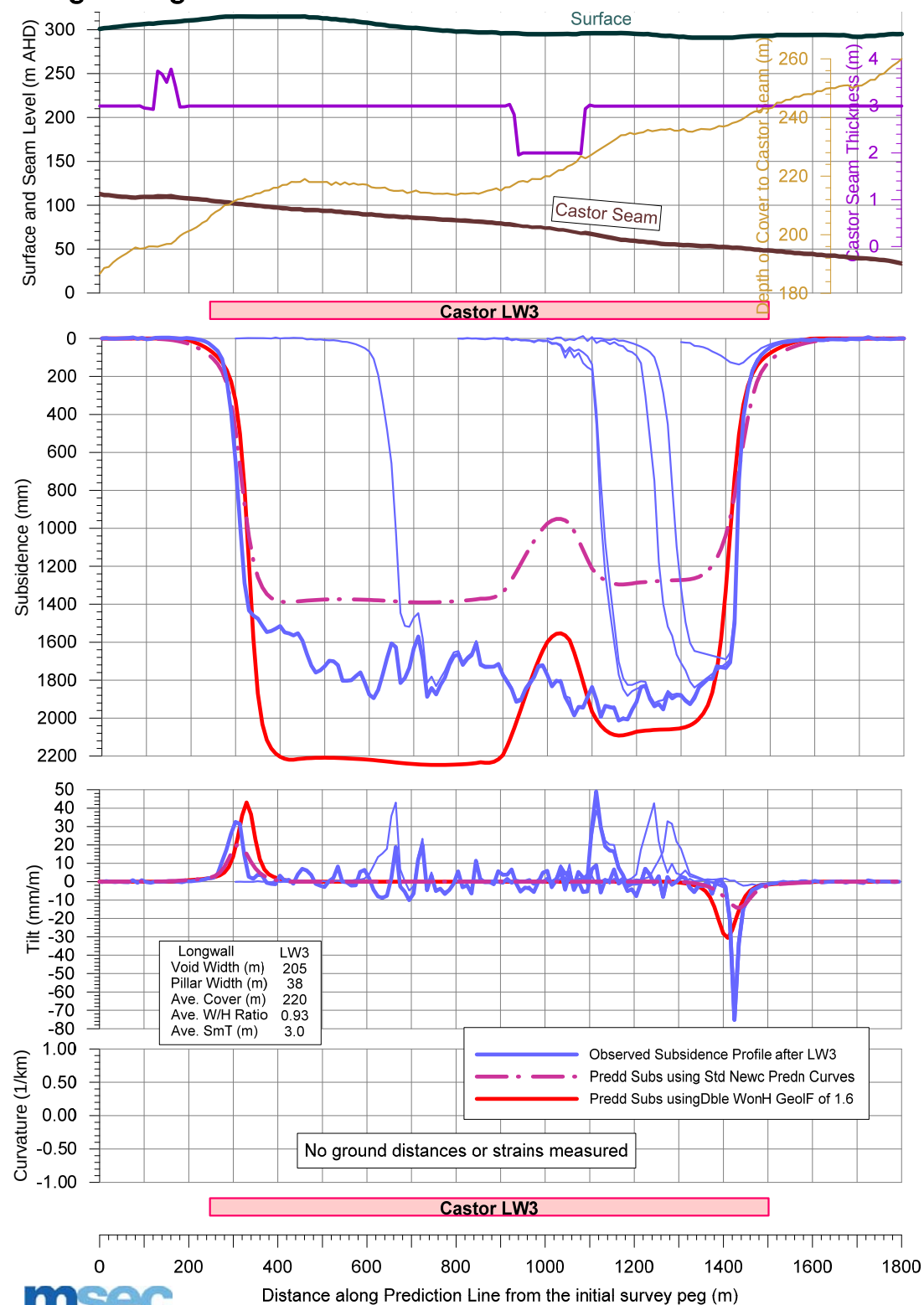


Fig. 3.19 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along Castor LW3 Longitudinal Line

Cook Colliery - Castor Seam Workings **Predicted Profiles of Total Conventional Subsidence, Tilt and Curvature** **across Cross Line over Longwalls 1 to 4**

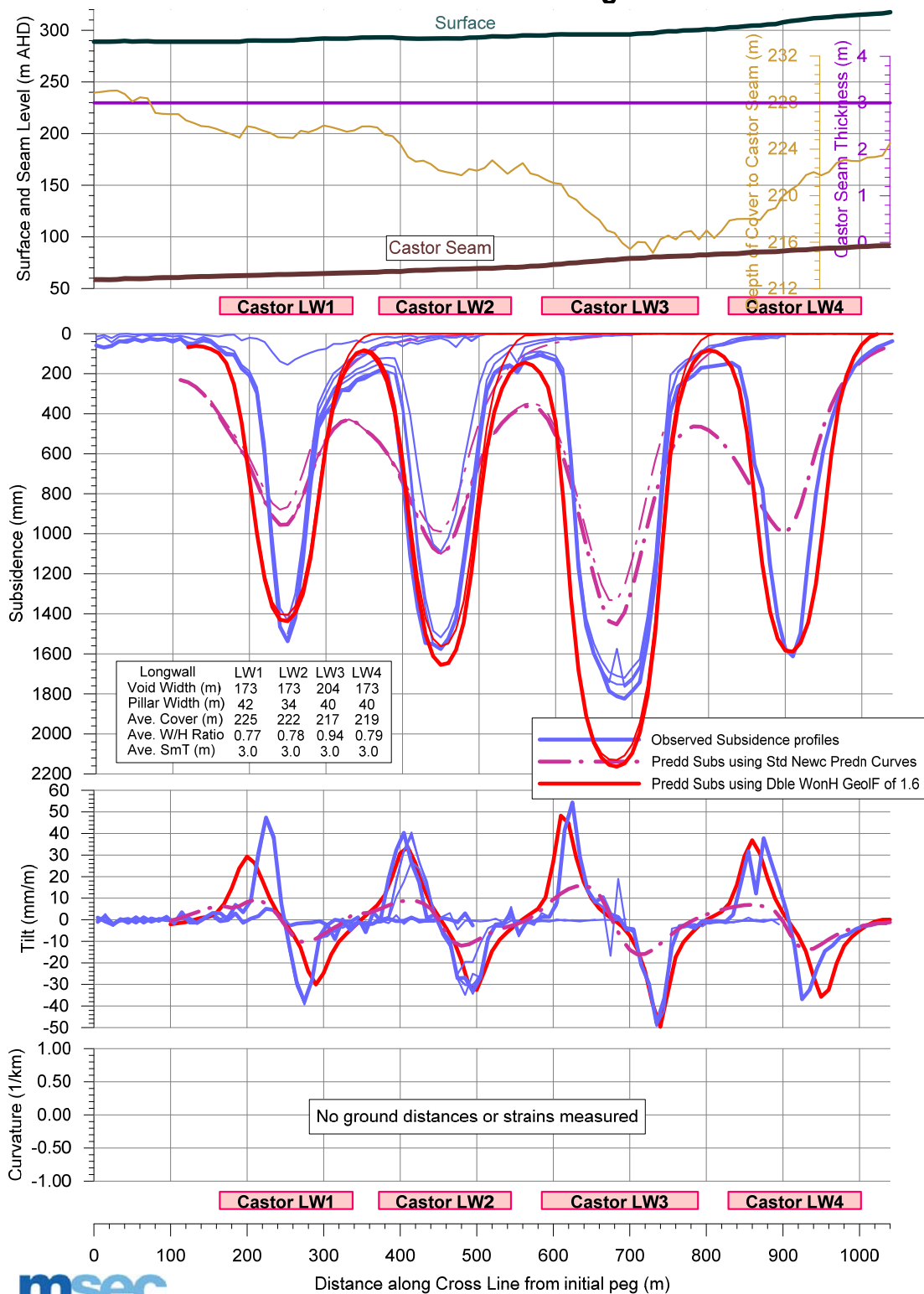


Fig. 3.20 Comparison of Observed and Predicted Subsidence, Tilt and Curvature along Castor LW1 to LW4 cross lines

3.9.3. Calibration for Multi-Seam Mining Conditions

The magnitudes of the available observed multi-seam subsidence cases are higher than equivalent single-seam cases and the observed shapes of these multi-seam subsidence profiles are much more complicated, because of the additional mining and complex geological factors involved in multi-seam cases, including;

- the extent and magnitude of the subsidence experienced after the previously mined panels, i.e. the extent of mining induced voids within the seam and the overlying strata that occurred when the previous workings were extracted,
- the likelihood of re-working and settlement of the mining induced voids within the previously mined workings.
- the local geological conditions in both seams,
- whether the interburden thickness is small resulting in high interaction with the overlying goafs and pillars, or, so large that little interaction occurs,
- the stability of the stooks, remnant pillars and chain pillars in the previously mined seam,
- the ratio between the extracted seam thickness of the previously mined panels compared to the extracted seam thickness in the panels of the currently mined seam, plus,
- the proximity of the previously extracted workings and longwalls within the lower seam.

Based on the observed monitoring data after the extraction of longwalls under or above longwalls at Sigma, Liddell and Cumnock Collieries, as well as observed monitoring data at a number of other Collieries in the NSW Coalfields and in the UK, it was recommended in the paper by Li et al (2007 & 2010) that the additional maximum subsidence resulting from multi-seam mining can be estimated from the following equation:-

$$S_2 = a_2 T_2 \quad (\text{Li et al, 2010})$$

where $a_2 = (a_m - a_1)(T_1 / T_2) + a_m$

a_1 = Maximum subsidence resulting from the extraction of the upper seam (single-seam conditions) as a proportion of the extracted seam thickness

a_m = Maximum total subsidence resulting from the extraction of the upper seam (single-seam conditions) plus the extraction of the lower seam (multi-seam conditions) as a proportion of total extracted seam thickness of both seams

T_1 = Extracted seam thickness in upper seam

T_2 = Extracted seam thickness in lower seam

Guidance was provided in these papers by Li et al (2007 & 2010) on an upper bound " a_m " value for cases involving longwalls under longwalls, but it appears that these recommendations are only relevant for a limited range of panel widths, depths of cover, interburden thicknesses and seam thicknesses.

The IPM model of predicting mine subsidence has been used successfully to back predict and to predict the subsidence ground movements for various longwall panels in multi-seam conditions for both longwall under longwall cases as well as for longwall under bord and pillar and partial extraction cases. The IPM model for multi-seam subsidence prediction is based on calibrating the predicted single-seam predictions by various multi-seam factors.

The multi-seam factors vary depending on the predicted subsidence as proportions of the extracted seam thicknesses of the overlying and underlying seams, the actual seam thicknesses of the overlying and underlying seams and the interburden thickness between the overlying and underlying seams. The multi-seam factors are the greatest for the cases where the interburden thicknesses are the lowest and where the proportions of subsidence to the extracted seam thicknesses in the overlying and underlying seams were the lowest.

The multi-seam factor for the proposed longwalls at the Carmichael Project in the D1 Seam, based on an interburden thickness between 70 and 130 metres resulted in an incremental subsidence of 95% of extracted seam thickness for a single longwall based on multi-seam conditions.

Shapes of the Multi-seam Subsidence Profiles

It has been found from past longwall mining experience that the shapes of multi-seam subsidence profiles depend on, amongst other factors, the depths of cover, interburden thickness, extraction heights and the relative locations between the longwalls within each seam.

In the cases where the chain pillars within the lower seam are located directly beneath the chain pillars, or stable remnant pillars, within the overlying seam, which are referred to as *Stacked Cases*, the observed subsidence profiles are steeper and more localised above the longwalls when compared with those for similar single-seam conditions. In the cases where the chain pillars, or stable remnant pillars, within the lower seam are offset from the chain pillars within the overlying seam, which are referred to as *Staggered Cases*, as is the case at the Carmichael

Project, the subsidence profiles are flatter and extend further when compared with those for similar single-seam conditions.

The observed subsidence profiles for multi-seam cases are typically wider than those observed for single-seam cases, as shown in Fig. 3.21, which result from the reactivation of the goafs and chain pillars in the overlying seam. In this figure, the observed multi-seam profiles are shown in black and the observed single-seam profiles are shown in cyan and red. It should be noted, that the observed multi-seam profiles shown in this figure are based primarily on cases where the longwalls extracted in the underlying seam were offset, or staggered to the previously extracted longwalls in the overlying seam.

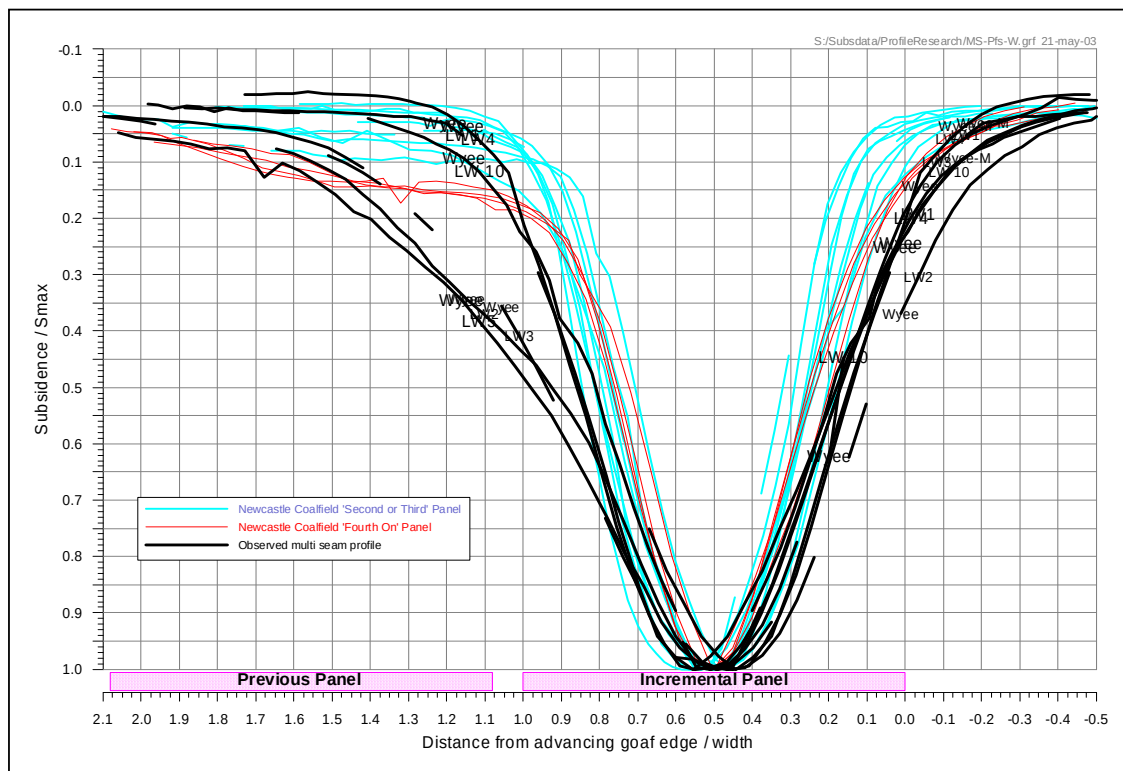


Fig. 3.21 Comparison between Single and Multi-Seam Incremental Subsidence Profiles

3.10. Reliability of the Predicted Conventional Subsidence Parameters

The Incremental Profile Method has been tested and calibrated against observed monitoring data at Cook Colliery. It has been found that there is a reasonable correlation between observed and predicted subsidence, where the prediction model generally produces conservative results.

The Incremental Profile Method is based upon a large database of observed subsidence movements and has been found, in most cases, to give reasonable, if not, conservative predictions of maximum subsidence, tilt and curvature. The following quotations from the NSW government inquiry report titled “*The Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield - Strategic Review*”, State of New South Wales through the NSW Department of Planning (DOP, 2008) provides an overview of the available mine subsidence prediction techniques, including the Incremental Profile Method, and have concluded;

“Techniques for predicting surface subsidence effects can be classified under three categories, namely empirical, analytical/numerical and hybrid methods. Empirical techniques are based on the back analysis of previous field outcomes. Reliability of outcomes is dependent, therefore, on the overall size and representativeness of the database and considerable care is required if the techniques are applied to conditions that are outside of this database. The more common empirical prediction methods are:”

- “1. **Graphical**, which involves plotting suites of curves showing relationships between various parameters and subsidence outcomes;”*
- “2. **Upper Bound**, which involves constructing an envelope over measured maximum or worse case outcomes and predicting on the basis of that envelope;”*
- “3. **Profile Function**, which attempts to define the shape of the vertical displacement curve by a mathematical equation and is confined in general to single (isolated) excavations; and”*
- “4. **Incremental Profile Method**, which involves constructing the overall vertical displacement profile by summing the incremental vertical displacement that occurs each time a panel is extracted”*

...

"A number of techniques are capable of producing reasonably accurate predictions of vertical displacement, typically within ± 150 mm. The more noteworthy of these are the incremental subsidence prediction technique, the influence function technique and a number of numerical modelling codes. However, the accuracy of any subsidence prediction technique should never be taken for granted. All depend to some extent on input parameters being representative of the specific site conditions. Particular care has to be taken when predicting subsidence for a greenfields site due to a lack of site specific data. A number of panels need to be extracted before subsidence prediction models can be properly calibrated and validated."

....

"Incremental Profile Method: *It has been known for decades that, in theory, the vertical surface displacement profile over mine workings at any point in time can be constructed by summing the increments of vertical displacement arising from the mining of each panel making up those workings. The Australian coal mining industry has provided considerable research funding over the last decade to effectively 'reverse engineer' the subsidence prediction process by utilising the large databases of subsidence information relating to the Southern Coalfield and the Newcastle Coalfield in NSW to define the characteristic shape for each increment of vertical displacement resulting from a mining operation. Once the vertical displacement profile has been created, it can be used to calculate tilt, curvature and strain in the same manner as that described for the profile function technique. This prediction technique offers a number of benefits over other empirical techniques because variations in depth, seam thickness and seam dip can be taken into account, as well as the influence of multiple mining panels - and subsidence predictions can be produced at any nominated point on the surface."*

The prediction of the conventional subsidence parameters at a specific point is more difficult than providing the prediction of the maximum likely subsidence movements. The predicted subsidence profiles obtained using the Incremental Profile Method reflect the way in which each parameter varies over the mined area and indicate the movements that are likely to occur at any point on the surface. However, variations between predicted and observed parameters at a point can occur where there is a lateral shift between the predicted and observed subsidence profiles, which can result from seam dip or variations in topography. In these situations, the lateral shift can result in the observed parameters being greater than those predicted in some locations, with the observed parameters being less than those predicted in other locations.

The prediction of multi-seam subsidence at a point is more difficult to achieve accurately than single-seam cases and is subject to more complex and variable factors.

The prediction of strain at a point is even more difficult as there tends to be a large scatter in observed strain profiles. It has been found that measured strains can vary considerably from those predicted at a point, not only in magnitude, but also in sign, that is, tensile strains have been observed where compressive strains were predicted, and vice versa.

The following reasons contribute to why ground strain predictions cannot be provided with the same degree of confidence as subsidence and tilt predictions:-

- Variations in local geology can affect the way in which the near surface rocks are displaced as subsidence occurs. In the compression zone, the surface strata can buckle upwards or can fail by shearing and sliding over their neighbours. If the surface strata layers are thinly bedded or if localised cross bedding exists within the top strata layer, then shearing can occur at relatively low values of stress. These variations in local geology can result in fluctuations in the local strains, which can range from tensile to compressive. In the tensile zones around mined voids, existing joints can be opened up at relatively low strain values and new fractures can be formed at random, leading to localised concentrations of tensile strain.
- Current conventional horizontal movement prediction methods are principally based on factors being applied to the predicted ground curvature movements and do not account for the release of insitu horizontal stress, the far-field movement mechanisms or valley related movements. Where the mining induced curvatures are low and the ground movements due to the release of insitu stress, i.e. far field, slope and valley related movements, are high, then the ratio of horizontal movement to tilt or the ratio of strain to curvature can be much higher than those predicted using a strain to curvature ratio of 10 or 15.
- Where a thick surface layer of soil, clay or rock exists, the underlying movements in the bedrock are often transferred to the surface at reduced levels and the measured strains are, therefore, more evenly distributed and hence more systematic in nature than they would be if they were measured at rockhead.
- Strain measurements can sometimes give a false impression of the state of stress in the ground. For example:-
 - buckling of the near-surface strata can result in localised cracking and apparent tensile strain in areas where overall, the ground is in fact being compressed, because the actual values of the measured strains are dependent on the locations of the survey pegs.
 - where existing natural joints open up or new cracks develop in the tensile phase, it may be difficult for these joints to close up during the compressive phase, if the joints fill with soil or if shearing occurs during the movements. In these cases, the ground can appear to be in tension when, in reality, it is actually in compression.

- Sometimes, survey limitations or errors can also affect the measured strain values and these can result from movement in the benchmarks, inaccurate instrument readings, or disturbed survey pegs. In these circumstances it is not surprising that the predicted conventional strain at a point does not match the measured strain. For example, it is difficult to measure variations in bay lengths more accurately than ± 5 mm, especially where tripods have to be set over sunken survey marks. Over a typical bay length of 20 metres, surveying error variations of ± 0.25 mm/m are commonly seen in the observed strain data.
- In sandstone dominated environments, much of the earlier tensile ground movements can be concentrated at existing natural joints. These concentrations of strain at these pre-existing joints results in higher strain values being observed at the natural joints accompanied by lower values between the joints.
- It is also recognised that the ground movements above a longwall panel can be affected by the gradient of the coal seam, the direction of mining and the presence of faults and dykes above the panel, which can result in a lateral shift in the subsidence profile.

It is also likely that some localised irregularities will occur in the subsidence profiles due to near surface geological features. The irregular movements are accompanied by elevated tilts, curvatures and strains, which often exceed the conventional predictions. In most cases, it is not possible to predict the locations or magnitudes of these irregular movements. Further discussions on irregular movements are provided in Section 4.5.

For the above reasons, rather than adopting one relationship between mining induced curvature and strain for the predictions of strain, the strain predictions provided in this report are based on a statistical analysis of measured strains, including both conventional and non-conventional anomalous strains, which is discussed in Section 4.3.

The Incremental Profile Method approach therefore allows site specific appropriate predictions of subsidence, tilt and strains for each natural feature or item of infrastructure and provides a more realistic assessment of the mining induced impacts than by predicting the maximum predicted parameters at every point, which would be overly conservative and would yield an excessively overstated assessment of the potential subsidence impacts.

4.0 PREDICTED SUBSIDENCE PARAMETERS FOR THE PROPOSED LONGWALLS

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of the Proposed Longwalls in the AB1 and D1 Seams.

The predicted maximum subsidence, tilt and curvature have been determined using the Incremental Profile Method, with prediction curves that have been calibrated based on observed subsidence data from Cook Colliery as discussed in Section 3.9.

The maximum predicted subsidence parameters and the predicted subsidence contours provided in this report describe and show the conventional movements and do not include valley related upsidence and closure movements, nor the effects of faults and other geological structures.

4.2. Maximum Predicted Conventional Subsidence, Tilt and Curvature

A summary of the maximum predicted values of incremental conventional subsidence, tilt and curvature, due to the extraction of each of the proposed longwalls, is provided in Table 4.1.

Table 4.1 Maximum Predicted Incremental Conventional Subsidence, Tilt and Curvature Resulting from the Extraction of Each of the Proposed Longwalls

Maximum Predicted Incremental Conventional Parameters in AB1 Seam					Maximum Predicted Incremental Conventional Parameters in D1 Seam				
Longwall	Subsidence	Tilt	Hogging Curvature	Sagging Curvature	Longwall	Subsidence	Tilt	Hogging Curvature	Sagging Curvature
-	-	-	-	-	DLW101N	2925	95	>5.00	>5.00
-	-	-	-	-	DLW102N	2925	70	3.28	3.25
-	-	-	-	-	DLW103N	2925	55	1.62	1.66
ABLW101N	2475	60	2.38	2.61	DLW104N	3025	45	1.02	1.05
ABLW102N	2475	45	1.41	1.49	DLW105N	2875	35	0.67	0.68
ABLW103N	2425	35	0.85	0.86	DLW106N	2625	25	0.42	0.58
ABLW104N	2325	25	0.54	0.54	DLW107N	2275	20	0.26	0.55
ABLW105N	2175	20	0.36	0.49	DLW108N	1975	15	0.16	0.45
ABLW106N	2050	20	0.42	0.53	DLW109N	1800	15	0.11	0.31
ABLW107N	1850	15	0.32	0.47	DLW110N	1375	10	0.07	0.19
-	-	-	-	-	DLW101S	2925	>100	>5.00	>5.00
-	-	-	-	-	DLW102S	2925	>100	>5.00	>5.00
-	-	-	-	-	DLW103S	2925	75	3.18	3.65
ABLW101S	2475	90	>5.00	>5.00	DLW104S	3075	55	1.74	1.82
ABLW102S	2475	60	2.58	2.85	DLW105S	3025	45	1.02	1.04
ABLW103S	2475	45	1.29	1.38	DLW106S	2825	35	0.63	0.65
ABLW104S	2400	35	0.75	0.79	DLW107S	2525	25	0.38	0.58
ABLW105S	2200	25	0.45	0.48	DLW108S	2075	20	0.22	0.51
ABLW106S	2350	30	0.61	0.65	DLW109S	2275	20	0.31	0.54
ABLW107S	2200	25	0.42	0.51	DLW110S	2025	15	0.20	0.49
ABLW201	2475	55	2.12	2.32	DLW201	3050	45	1.20	1.23
ABLW202	2475	45	1.33	1.39	DLW202	2975	40	0.94	0.99
ABLW203	2450	35	0.89	0.95	DLW203	2875	35	0.68	0.70
ABLW204	2350	30	0.64	0.66	DLW204	2675	30	0.50	0.58
ABLW205	2225	25	0.47	0.49	DLW205	2400	20	0.33	0.57
ABLW206	2050	20	0.40	0.49	DLW206	2100	15	0.22	0.51
ABLW207	1825	15	0.25	0.46	DLW207	1875	15	0.15	0.36
ABLW301N	2425	35	0.86	0.89	DLW301N	2675	30	0.51	0.58
ABLW302N	2375	30	0.64	0.67	DLW302N	2575	25	0.40	0.59
ABLW303N	2300	25	0.52	0.53	DLW303N	2425	20	0.32	0.57
ABLW304N	2225	25	0.46	0.49	DLW304N	2275	20	0.26	0.56
ABLW305N	2125	20	0.37	0.48	DLW305N	2150	20	0.22	0.53
ABLW301S	2475	45	1.31	1.37	DLW301S	2900	35	0.77	0.81
ABLW302S	2425	35	0.83	0.86	DLW302S	2725	30	0.53	0.59
ABLW303S	2350	30	0.64	0.65	DLW303S	2500	25	0.38	0.58
ABLW304S	2300	25	0.54	0.55	DLW304S	2350	20	0.30	0.57
ABLW305S	2225	25	0.46	0.49	DLW305S	2200	20	0.24	0.54
ABLW306S	2050	20	0.39	0.49	DLW306S	1975	15	0.18	0.45
ABLW401	2475	45	1.61	1.61	DLW401	2925	35	0.76	0.81
ABLW402	2475	40	1.26	1.25	DLW402	2875	35	0.65	0.66
ABLW403	2475	40	0.98	1.03	DLW403	2800	30	0.56	0.62
ABLW404	2425	35	0.80	0.84	DLW404	2675	30	0.49	0.59

Maximum Predicted Incremental Conventional Parameters in AB1 Seam					Maximum Predicted Incremental Conventional Parameters in D1 Seam				
Longwall	Subsidence	Tilt	Hogging Curvature	Sagging Curvature	Longwall	Subsidence	Tilt	Hogging Curvature	Sagging Curvature
ABLW405	2375	30	0.62	0.67	DLW405	2525	25	0.37	0.58
ABLW406	2325	25	0.54	0.55	DLW406	2375	20	0.27	0.57
ABLW407	2250	25	0.46	0.49	DLW407	2225	20	0.23	0.55
ABLW501N	2475	40	1.20	1.24	DLW501N	2725	30	0.56	0.60
ABLW502N	2450	35	0.91	0.94	DLW502N	2650	25	0.47	0.58
ABLW503N	2400	30	0.72	0.75	DLW503N	2525	25	0.38	0.58
-	-	-	-	-	DLW501S	2925	>100	>5.00	>5.00
-	-	-	-	-	DLW502S	2925	80	3.71	4.48
-	-	-	-	-	DLW503S	2925	70	2.82	3.07
ABLW501S	2475	>100	>5.00	>5.00	DLW504S	3075	60	1.94	2.14
ABLW502S	2475	85	4.65	>5.00	DLW505S	3075	55	1.56	1.59
ABLW503S	2475	65	2.91	3.45	DLW506S	3075	45	1.16	1.24
ABLW504S	2475	55	2.02	2.24	DLW507S	3000	40	0.90	0.95
ABLW505S	2475	45	1.42	1.54	DLW508S	2900	35	0.72	0.75
ABLW506S	2475	40	1.11	1.11	DLW509S	2800	30	0.59	0.63
ABLW507S	2425	35	0.82	0.87	DLW510S	2675	30	0.49	0.59
ABLW508S	2375	30	0.67	0.68	DLW511S	2525	25	0.37	0.58
-	-	-	-	-	DLW512S	2300	20	0.29	0.56

The predicted total conventional subsidence contours, resulting from the extraction of the Proposed Longwalls, in the AB1 seam and D1 seam are shown in Drawings Nos MSEC627-14 and MSEC627-15 respectively, in Appendix D. The predicted total conventional subsidence contours for the Proposed Longwalls after each 5 years of scheduled mine operation (rounded up to the nearest fully extracted longwall panel) are presented in Drawings Nos. MSEC627-26 to and MSEC627-34, in Appendix D. A summary of the maximum predicted values of total conventional subsidence, tilt and curvature, after the extraction of each of the Proposed Longwalls, is provided in Table 4.2.

Table 4.2 Maximum Predicted Total Conventional Subsidence, Tilt and Curvature after the Extraction of the Proposed Longwalls

Maximum Predicted Total Conventional Parameters in AB1 Seam					Maximum Predicted Total Conventional Parameters in D1 Seam				
Longwall	Subsidence	Tilt	Hogging Curvature	Sagging Curvature	Longwall	Subsidence	Tilt	Hogging Curvature	Sagging Curvature
ABLW101N to ABLW107N	2575	55	2.28	2.52	DLW101N to DLW110N	5225	95	>5.00	>5.00
ABLW101s to ABLW107S	2625	95	3.93	3.26	DLW101S to DLW110S	5550	>100	>5.00	>5.00
ABLW201 to ABLW207	2575	55	2.13	2.22	DLW201 to DLW207	5175	95	3.06	3.02
ABLW301N to ABLW305N	2425	35	0.86	0.89	DLW301N to DLW305N	4100	50	1.15	1.07
ABLW301S to ABLW306S	2600	45	1.38	1.42	DLW301S to DLW306S	4650	70	1.66	1.82
ABLW401 to ABLW407	2575	45	1.60	1.62	DLW401 to DLW407	5000	70	1.84	1.92
ABLW501N to ABLW503N	2575	40	1.16	1.21	DLW501N to DLW503N	4650	50	1.26	1.28
ABLW501S to ABLW508S	2625	>100	>5.00	>5.00	DLW501S to DLW512S	5450	>100	>5.00	>5.00

The predicted total tilts provided in the above table are the maxima after the completion of the proposed longwalls. The predicted curvatures provided in the above table are the maxima during or after the extraction of the proposed longwalls.

The maximum predicted conventional tilt is greater than 100 mm/m (i.e. 10 %), which represents a change in grade of greater than 1 in 10. The maximum predicted conventional curvatures are both greater than 5.0 km⁻¹, which represent a minimum radius of curvature of less than 200 metres.

The predicted conventional subsidence parameters vary across the Study Area as a result of, amongst other factors, variations in the longwall geometry, depths of cover and extraction height. To illustrate this variation, the predicted profiles of conventional subsidence, tilt and curvature have been determined along Prediction Lines 1 to 9, the locations of which are shown in Drawings Nos MSEC627-14 and MSEC627-15.

The predicted profiles of conventional subsidence, tilt and curvature along the Prediction Lines 1 to 9, resulting from the extraction of the proposed longwalls, are shown in Fig. C01 to Fig. C09, respectively, in Appendix C. The predicted total profiles along the prediction lines, after the extraction of each of the proposed longwalls, are shown as solid red lines. The range of predicted curvatures, in any direction to the prediction lines, at any time during or after the extraction of the proposed longwalls, are shown by the grey shading. The predicted profiles of subsidence, tilt and curvature presented in Fig. C01 to Fig. C09, in Appendix C include profiles after each 5 years of scheduled mine operation (rounded up to the nearest fully extracted longwall panel).

4.3. Predicted Strains

The prediction of strain is more difficult than the predictions of subsidence, tilt and curvature. The reason for this is that strain is affected by many factors, including ground curvature and horizontal movement, as well as local variations in the near surface geology, the locations of pre-existing natural joints at bedrock, the depth of bedrock and, in this case, multi-seam mining conditions. The profiles of observed strain, therefore, can be irregular even when the profiles of observed subsidence, tilt and curvature are relatively smooth.

It has been found that, for single-seam mining conditions, applying a constant factor to the predicted maximum curvatures provides an approximate prediction for the predicted maximum normal or conventional strains, even though it is recognised that this prediction method does not account for horizontal movements due to the release of insitu horizontal stress, the far-field movement mechanisms or valley related movements. The locations that are predicted to experience hogging or convex curvature are expected to be net tensile strain zones and locations that are predicted to experience sagging or concave curvature are expected to be net compressive strain zones. In the Hunter Coalfield of NSW, it has been found that a factor of 10 provides a reasonable relationship between the predicted maximum curvatures and the predicted maximum conventional strains for single-seam conditions. At a point, however, there can be considerable variation from the linear relationship, resulting from non-conventional movements or from the normal scatters which are observed in strain profiles. When expressed as a percentage, observed strains can be many times greater than the predicted conventional strain for low magnitudes of curvature.

It is not simple to provide a similar relationship between curvature and strain for multi-seam mining conditions, since there is very limited empirical data to establish this relationship and such a relationship would not account for horizontal movements due to the release of insitu horizontal stress, the far-field movement mechanisms or valley related movements. In addition to this, localised strains also develop in multi-seam mining conditions, as the result of remobilising the existing goaf and chain pillars in the overlying seam, which are also not directly related to curvature.

The observed data from Cook Colliery which was used for calibration of the prediction model did not include strain measurements. The expected magnitudes of strain for multi-seam mining conditions have therefore been based on the observed strains for multi-seam mining in the Hunter Coalfield of NSW. The maximum observed tensile and compressive strains along eight monitoring lines for a longwall mined directly beneath existing longwalls are provided in Table 4.3.

Table 4.3 Maximum Observed Strains for the Monitoring Lines above Multi-seam mining in the Hunter Coalfield

Monitoring Line	Depth of Cover (m)	Extraction Height (m)	Interburden Thickness between Seams (m)	Maximum Observed Tensile Strain (mm/m)	Maximum Observed Compressive Strain (mm/m)
1	190 ~ 220	2.8	75 ~ 80	13	10
2	170 ~ 180	2.5	70 ~ 75	18	14
3	190 ~ 220	2.8	75 ~ 80	6	2
4	165 ~ 175	2.7	75 ~ 80	7	8
5	150 ~ 220	2.5 ~ 3.2	70 ~ 90	3	4
6	170 ~ 210	2.3 ~ 2.9	70 ~ 80	11	19
7	180 ~ 210	2.1 ~ 2.9	75	5	19
8	190 ~ 210	2.9	75	23	11

It can be seen from the above table, that the maximum observed tensile strain was 23 mm/m and the maximum observed compressive strain was 19 mm/m. It is noted, that lines 3 and 5 were located outside the extents of the longwall and, therefore, the strains measured along these lines were less than those measured along the other lines.

4.3.1. Analysis of Strains in Survey Bays

For features that are in discrete locations it is appropriate to assess the frequency of the observed maximum strains for individual survey bays.

The monitoring lines discussed above have been analysed to determine the maximum observed tensile and compressive strains in the survey bays located directly above multi-seam longwall extraction, at any time during the extraction of the longwall. A number of probability distribution functions were fitted to the empirical data. It was found that a *Generalised Pareto Distribution (GPD)* provided a reasonable fit to the raw strain data.

The histograms of the maximum observed tensile and compressive strains for the monitoring lines measured during multi-seam longwall mining, is provided in Fig. 4.1. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

The averages of the maximum strains that the individual survey bays experienced at any time during mining were 1.7 mm/m tensile and 2.6 mm/m compressive. The maximum strains that any survey bay experience at any time during mining were 23 mm/m tensile and 19 mm/m compressive.

Confidence levels have been determined from the empirical strain data using the fitted GPDs. In the cases where survey bays were measured multiple times during the longwall extraction, the maximum tensile strain and the maximum compressive strain were used in the analysis (i.e. single tensile strain and single compressive strain measurement per survey bay).

The 95 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining were 7 mm/m tensile and 9 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays experienced at any time during mining were 14 mm/m tensile and 13 mm/m compressive.

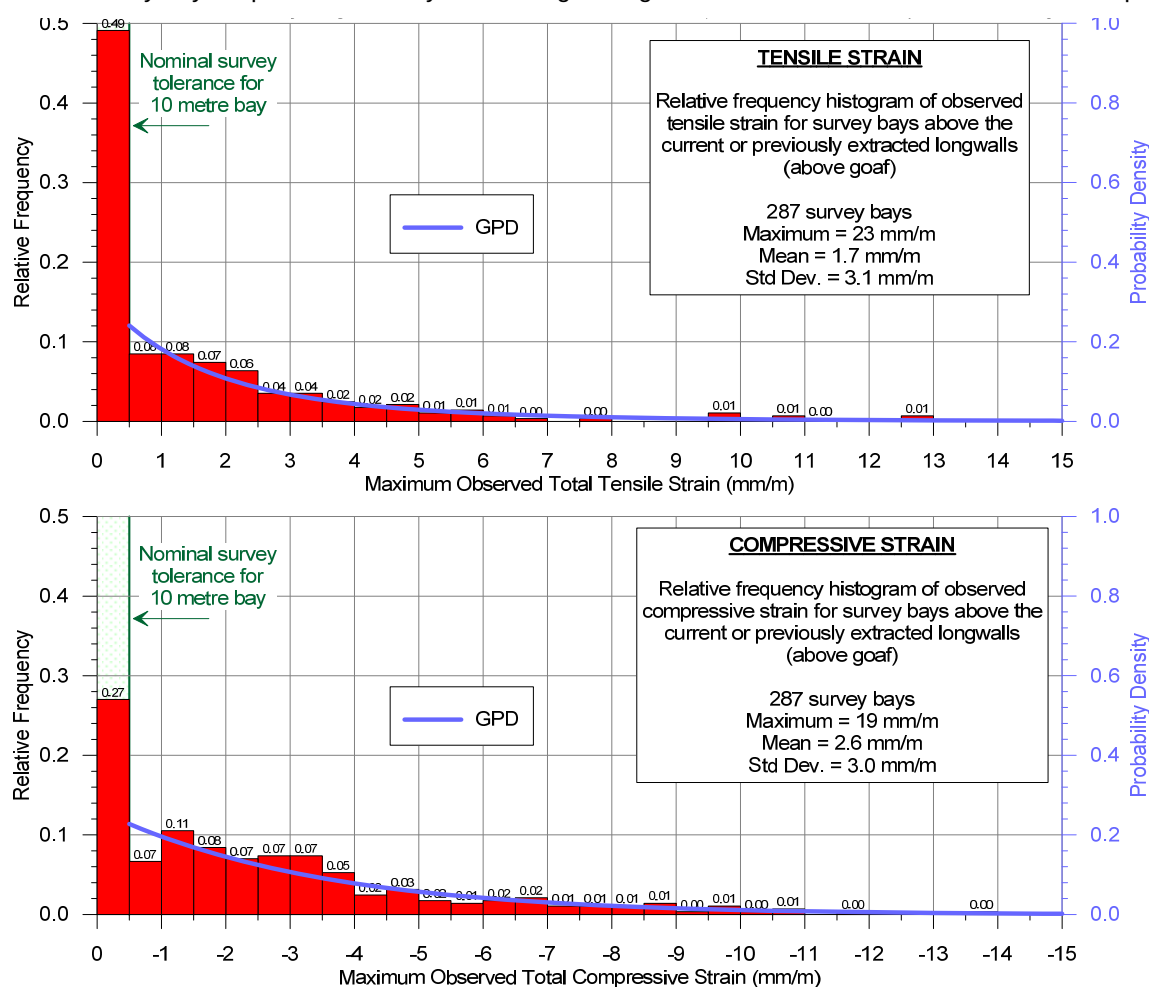


Fig. 4.1 Distributions of the Measured Maximum Tensile and Compressive Strains for Survey Bays Located Directly Above Multi-seam Longwall Mining

4.3.2. Analysis of Strains along Whole Monitoring Lines

For linear features such as roads and pipelines, it is more appropriate to assess the frequency of observed maximum strains along whole monitoring lines, rather than for individual survey bays. That is, an analysis of the maximum strains anywhere along the monitoring lines, regardless of where the strain actually occurs.

Four of the eight monitoring lines (i.e. 50 %) had recorded maximum total tensile strains greater than 10 mm/m, two of the eight monitoring lines (i.e. 25 %) had recorded maximum total tensile strains greater than 15 mm/m and one of the eight monitoring lines (13 %) had recorded maximum total tensile strain greater than 20 mm/m.

Also, four of the eight monitoring lines (i.e. 50 %) had recorded maximum total compressive strains greater than 10 mm/m, two of the eight monitoring lines (i.e. 25 %) had recorded maximum compressive strains greater than 15 mm/m and none of the monitoring lines (i.e. 0 %) had recorded maximum total compressive strain greater than 20 mm/m.

4.4. Predicted Far-field Horizontal Movements

As discussed in Section 3.6, in addition to the conventional subsidence movements that have been predicted above and adjacent to the proposed longwalls, it is also likely that far-field horizontal movements will be experienced during the extraction of the proposed longwalls.

An empirical database of observed incremental far-field horizontal movements has been compiled using monitoring data primarily from the NSW Coalfields. The far-field horizontal movements resulting from longwall mining were generally observed to be orientated towards the extracted longwall. At very low levels of far-field horizontal movements, however, there was a high scatter in the orientation of the observed movements.

The observed incremental far-field horizontal movements, resulting from the extraction of a single longwall, are provided in Fig. 4.2. The confidence levels, based on fitted GPD's, have also been shown in this figure to illustrate the spread of the data.

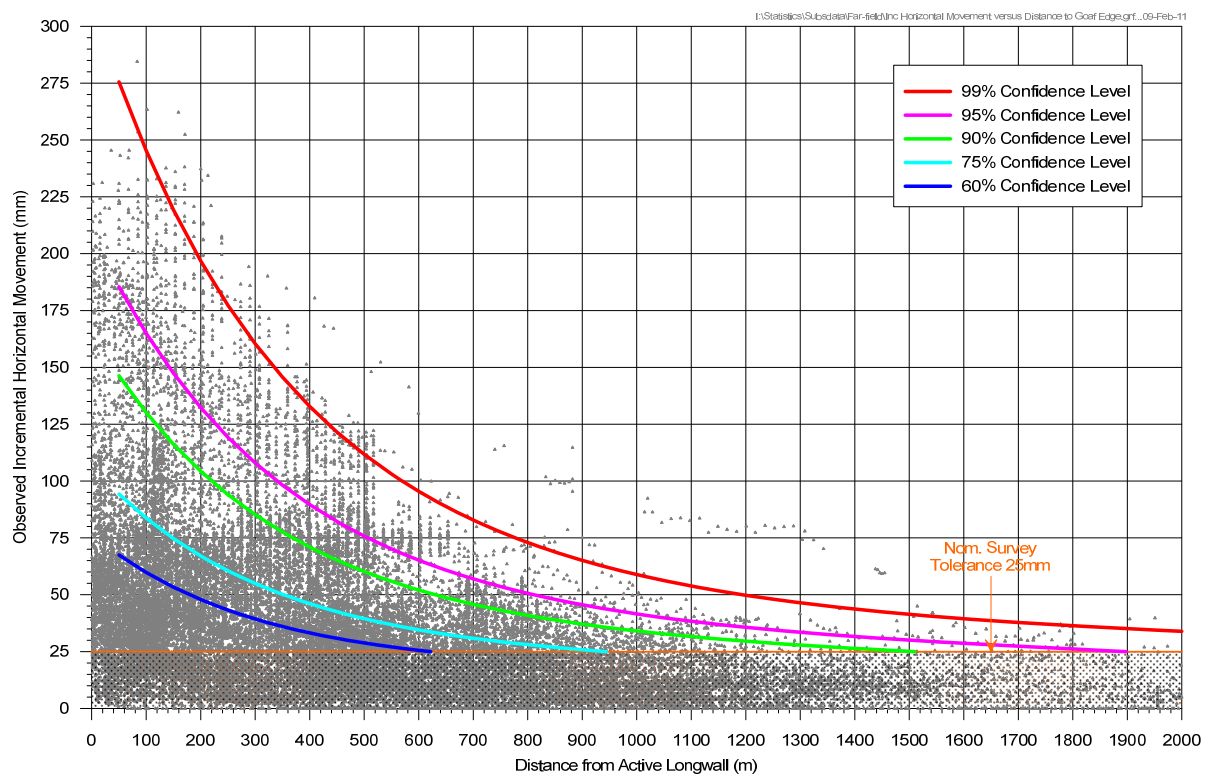


Fig. 4.2 Observed Incremental Far-Field Horizontal Movements

As successive longwalls within a series of longwalls are mined, the magnitudes of the incremental far-field horizontal movements decrease. This is possibly due to the fact that once the in-situ stresses within the strata have been redistributed around the collapsed zones above the first few extracted longwalls, the potential for further movement is reduced. The total far-field horizontal movement is not, therefore, the sum of the incremental far-field horizontal movements for the individual longwalls.

The predicted far-field horizontal movements resulting from the extraction of the proposed longwalls are very small and could only be detected by precise surveys. Such movements tend to be bodily movements towards the extracted goaf area, and are accompanied by very low levels of strain, which are generally less than the order of survey tolerance (i.e. less than 0.3 mm/m). The impacts of far-field horizontal movements on the natural features and items of surface infrastructure within the proposed longwalls is not expected to be significant, except where they occur at large structures which are sensitive to small differential movements.

We are not aware of far-field horizontal movement data in Queensland and cannot therefore include this information in the data set. It is anticipated that the magnitude of far field horizontal movements will be less than those in NSW at equivalent depths of cover because of the presence of the Quaternary and Tertiary deposits at the surface.

4.5. Non-Conventional Ground Movements

It is likely non-conventional ground movements will occur within the Study Area, due to near surface geological conditions, which were discussed in Section 3.7. These non-conventional movements are often accompanied by elevated tilts, curvatures and strains which are likely to exceed the conventional predictions.

In most cases, it is not possible to predict the exact locations or magnitudes of the non-conventional anomalous movements due to near surface geological conditions. For this reason, the strain predictions provided in this report are based on a statistical analysis of measured strains from previous longwall mining, including both conventional and non-conventional anomalous strains, which is discussed in Section 4.3.

5.1. Mining Induced Surface Deformation

Longwall mining can result in surface cracking, heaving, buckling, humping and stepping at the surface. The prediction of surface cracking widths, depths and spacings is more difficult than the predictions of subsidence, tilt and curvature. This is because the sizes and extents of surface deformations are influenced by many factors, including mine subsidence movements, which are dependent on:

- mine geometry;
- depth of cover;
- extracted seam thickness;
- the presence of valleys and steep surface topography and the location relative to the extracted longwall goaf edges;
- local variations in the near surface geology;
- the locations of pre-existing natural joints at bedrock;
- the presence and plasticity of any soils that overlie the bedrock; and
- the depth of the surface bedrock unit.

The surface crack widths and frequencies of the cracks are also dependent upon the pre-existing jointing patterns in the bedrock. Large natural joint spacing can lead to concentrations of strain and possibly the development of fissures at rockhead, which are not necessarily coincident with the joints.

Fractures and joints in sedimentary strata occur naturally during the formation of the strata and from subsequent erosion and weathering processes. Longwall mining can result in additional fracturing in the bedrock, which initially tends to occur in the tensile zones, but fractures can also occur due to buckling of the surface beds in the compressive zones. Because of the difficulties in predicting surface cracking, instead of providing site specific crack width predictions, areas of cracking and severity of cracking can be assessed based on the general geological profiles and zones of the predicted subsidence parameters.

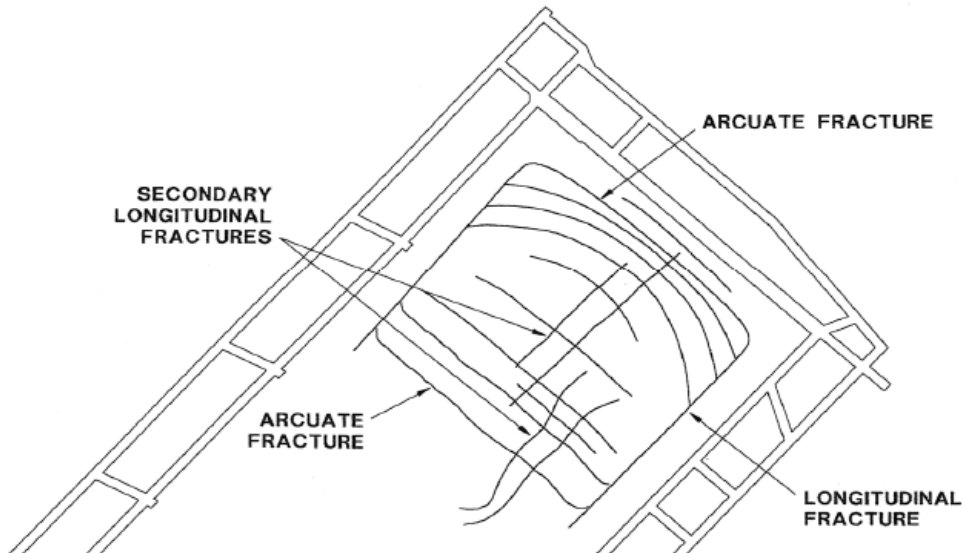
As subsidence occurs, surface cracks will generally appear in the tensile zone, i.e. within 0.1 to 0.4 times the depth of cover from the longwall perimeters. Most of the cracks will occur within a radius of approximately 0.1 times the depth of cover from the longwall perimeters. The cracks will generally be parallel to the longitudinal edges of the longwalls (except at the ends where they follow the contours of subsidence).

At shallow depths of cover, it is also likely that transient surface cracks will occur above and parallel to the moving extraction face, i.e. at right angles to the longitudinal edges of the longwall, as the subsidence trough develops. This cracking, however, tends to be transient, since the tensile phase of the travelling wave, which causes the cracks to open up, is generally followed by a compressive phase, which partially recloses them. It has been observed in the past, however, that shearing also occurs and the surface cracks which are opened during the tensile phase of the travelling wave cannot fully close during the compressive phase, and can result in formation of compressive ridges at the surface.

The incidence of surface cracking is dependent on the location relative to the extracted longwall goaf edges, the depth of cover, the extracted seam thickness and the thickness and inherent plasticity of the soils that overlie the bedrock. The widths and frequencies of the cracks are also dependent upon the pre-existing jointing patterns in the bedrock. Large joint spacing can lead to concentrations of strain and possibly the development of fissures at rockhead, which are not necessarily coincident with the joints.

The main factors contributing to surface cracking would be the depth of cover to the extracted seam, the thickness and characteristics of the surface strata layer, the magnitude of the mining induced subsidence, the presence of pre-existing joints or faults and surface topography changes. Shearing cracks are usually observed at very shallow depths and localised shearing cracks through thin surface strata layers are commonly observed in the beds of valley floors. Many of the observed mining induced surface cracks are located within the areas of highest mining induced tensile stress which indicates that the mining induced bending curvature is a principal cause. Hence it is concluded that the observed surface cracks are formed through a combination of several mechanisms and factors, with the depth of cover determining which mechanism predominates. The largest surface crack widths and step heights are expected to occur where the predicted ground strains are the greatest, in the locations of the shallowest depths of cover as well as in the locations of the natural joints.

At shallow depths of cover, i.e. approximately 200 metres or less, such as those which are present above the north eastern end side of Mine 1 and the eastern side of Mine 5, surface cracking and heaving can potentially occur in any location above the extracted longwalls. The larger and more permanent cracks, however, are usually located in the final tensile zones around the perimeters of the longwalls. Open fractures and heaving, however, can also occur due to the buckling of surface beds that are subject to compressive strains. An example of crack patterns that develop in shallow depths of cover is shown in Fig. 5.1 below.



**Fig. 5.1 Survey of Major Fracture Pattern at Approx. 110m Cover
(Source: Klenowski, ACARP C5016, 2000)**

Over previously mined longwalls, typical surface crack widths up to the order of 100 mm and step heights in the order of 100 mm have been commonly observed at shallow depths of cover, say less than 200 metres. Larger crack widths have been observed with shallow depths of cover where thicker seams are extracted, near steep terrain or where thick massive strata beams are present. These larger tensile cracks tend to be isolated and located around the perimeters of the longwalls and along the tops of steep slopes, due to down slope movements resulting from the extraction of the proposed longwalls. The typical surface cracks and these larger isolated cracks can normally be easily identified and remediated to prevent loss of surface water – Klenowski (ACARP C5016, 2000).

5.1.1. Observed Cracking

The following photographic records that were obtained from Longwall operations in the Bowen Basin provide guidelines to the nature and extent of cracking that might occur above the proposed longwalls at the Carmichael Project.



**Fig. 5.2 Very large crack above longwall commencing at approx. 180 m cover,
where the surface crack has been eroded by water**



Fig. 5.3 Step in ground across longwall centreline at approx. 180 m cover



Fig. 5.4 Large crack and possible step across longwall centreline (crack appears to have been eroded)



Fig. 5.5 **Series of long cracks along longwall tailgate at approx. 250m cover**



Fig. 5.6 Typical crack along longwall commencing at approx. 300m cover



Fig. 5.7 Typical crack along Longwall commencing end at approx. 300m cover

5.1.2. Observations of Surface Cracking in NSW at higher depths of cover and within multi-seam mining

Experience in NSW and Queensland has found that the severity and frequency of surface cracking reduces as the depth of cover to the extraction increases.

Most of the mining-induced surface cracking that is observed in NSW occurs where the depths of cover are less than 200 metres. Mining at depths of cover greater than about 400 metres in NSW results in few surface cracks being observed, and in plateau areas away from valleys, easily repaired surface cracking can occur in isolated locations only, as shown in Fig. 5.8.

Localised cracking is often observed in exposed bedrock areas within valley floor areas in NSW. At the Carmichael Project, however, the beds of the creeks and rivers above the proposed longwalls consist of deep alluvial beds and the type of cracks that are observed in bedrock in NSW are not expected.

Cracking is expected to occur within the banks and beds of the undermined watercourses at Carmichael Project and these cracks are prone to erosion if they are not repaired. Please refer to other reports in the EIS for the project on mitigation and remediation plans for mining beneath the major watercourses.



Fig. 5.8 Photographs of Surface Cracking on sides of steep sloping areas in the NSW Southern Coalfield with greater than 400 metres cover



Fig. 5.9 Photographs of Surface Cracking above multi-seam longwall extraction in the Hunter Coalfield around 200m cover

5.1.3. Potential surface cracking at Carmichael Project

It has been observed that the severity and frequency of cracking is generally greater where the depth of cover is shallow and when panel widths are increased.

The surface cracking observations obtained from other collieries were used to correlate observed cracking with mining induced hogging curvature. The predicted final mining-induced hogging curvature after the mining of all previously extracted longwalls was chosen for the correlation as it shows how the ground bends into the centre of the longwall panel. Curvature is a good indicator for surface cracking as zones of tensile strains are commonly found where hogging curvature occurs.

Predicted final hogging curvatures after the mining of the proposed longwalls in the AB1 seam at the Carmichael Project are shown in Fig. 5.10 and predicted additional final hogging curvatures after the mining of the proposed longwalls in the D1 seam are shown in Fig. 5.11. The colour scale demonstrates the variation in the magnitude of predicted curvature above the panels due to varying depths of cover and panel width. The same colour scale has been used in both figures to allow a direct comparison to be made. The variations in predicted hogging curvature are due to the changing depths of cover. In addition to the plotted final curvature contours, it should be noted that as the longwall face travels along each panel, a travelling transient curvature wave is applied along the panel that subjects the central areas of the panel to travelling curvatures that are of similar magnitudes as the plotted final curvatures. For reasons of clarity, predicted travelling or transient tensile strains that develop as each longwall travels from one end to the other have not been shown. Predicted sagging curvatures, where compressive buckling may occur, have also not been shown.

There is limited data available on the depth of surface tensile cracking. It is believed that the depth of cracking is a function of the mechanisms that are causing the tensile and shearing stresses, i.e. whether the surface cracking is being caused by the shearing stresses in shallow depths of cover, local variations of geology – particularly the presence of natural jointing, faulting and dykes, mining induced curvatures, release of in-situ horizontal stresses, downslope movements or valley related movements.

In many cases researchers have excavated downwards at observed surface cracks to assess how deep the cracks extend. From the surface most of the observed cracks generally are thicker on the surface and taper down to thinner widths with depth. This may suggest that these cracks were formed by mining induced bending curvature rather than shearing which usually results in a uniform crack thickness. Where bending is the main mechanism, the surface cracks will extend down to approximately the depth of the neutral axis of the surface strata layer. That is the depths of these surface cracks will vary from place to place depending on the thickness of the top surface strata layer.

Available literature suggests surface cracking depths in areas of hogging curvature can extend to depths in the order of 5 to 10 metres but greater depths may occur depending on the geological setting, the depths of cover and the mine subsidence parameters.

It is recommended that visual monitoring be carried out during the mining period to assess the degree of surface cracking and to coordinate remediation works as needed. Please refer to advice in the EIS for the surface cracking rehabilitation plan.

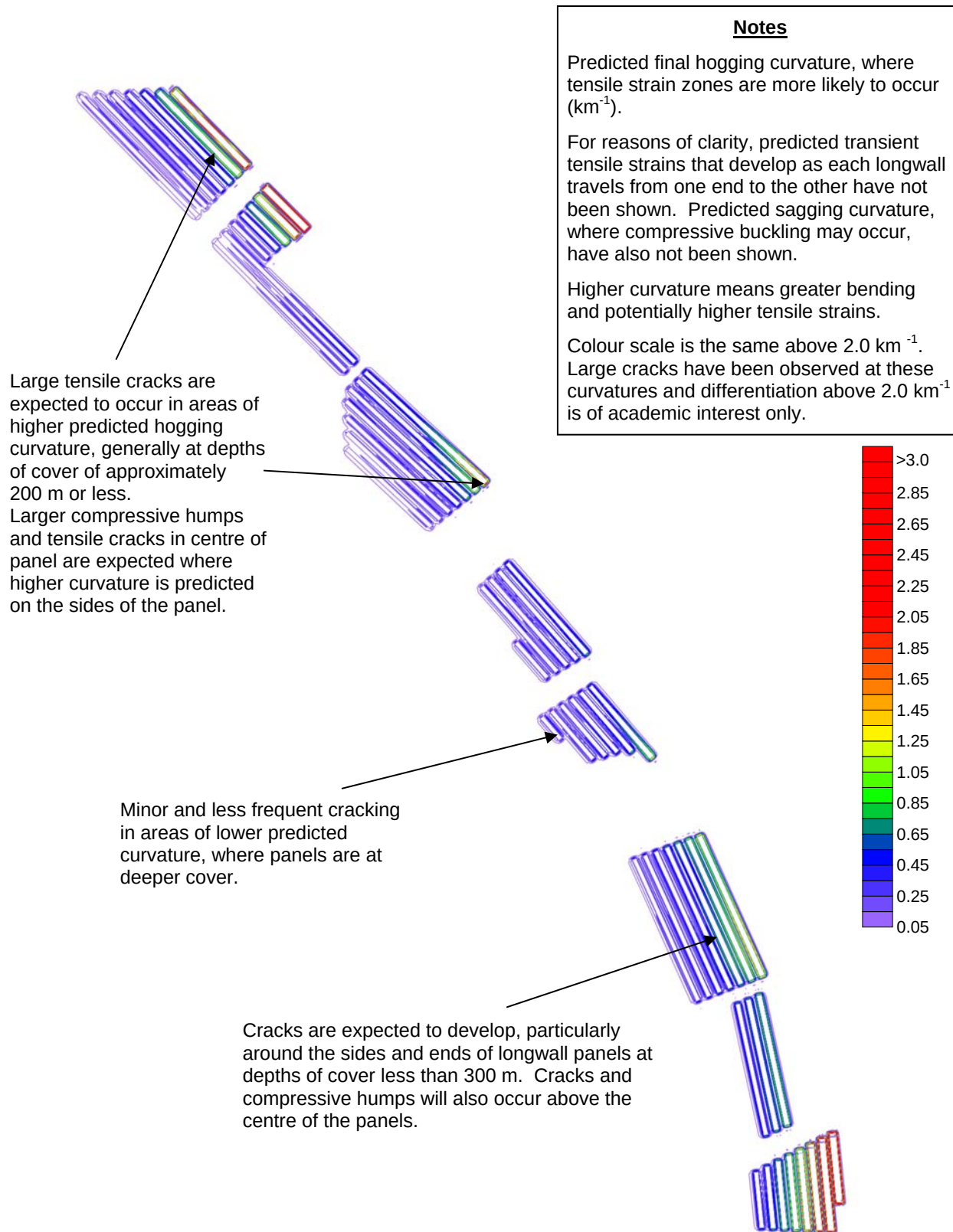


Fig. 5.10 Predicted final hogging curvatures (km^{-1}) due to the mining of all longwalls in the AB1 seam, accompanied by comments on potential for surface cracks

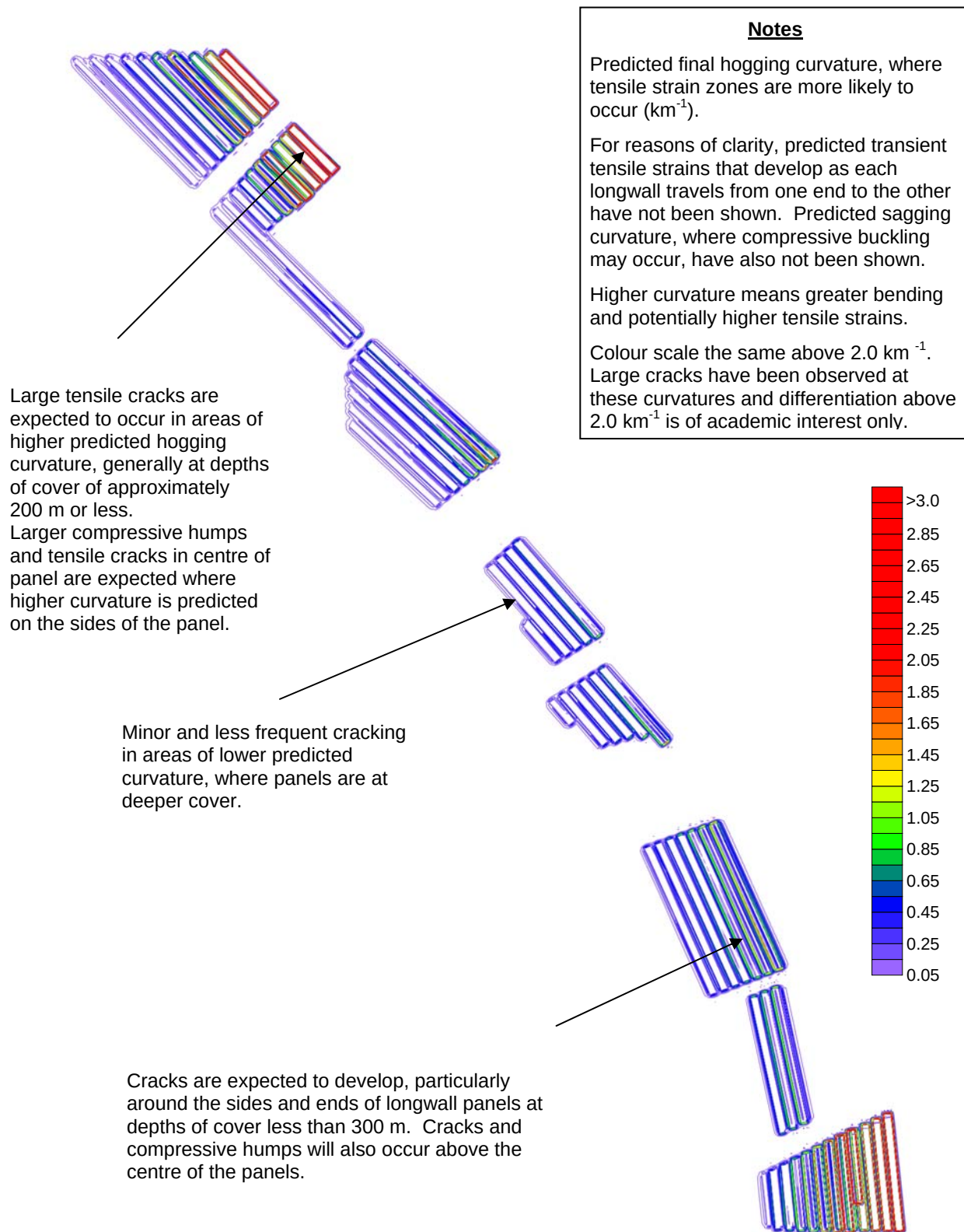


Fig. 5.11 Predicted additional final hogging curvatures (km^{-1}) due to the mining of all longwalls in the AB1 and D1 seams, accompanied by comments on potential for surface cracks

5.2. Mining Induced Sub-Surface Cracking and Effects of Cracking

5.2.1. General Background to Sub-Surface Cracking

The underground extraction of coal panels can induce vertical and horizontal mine subsidence ground movements, bedding plane separation, vertical shearing, fractures and breakages of the overlying strata, which can potentially impact on surface water and groundwater resources that are present before the coal is extracted. The extent of the mining induced strata deformation, the associated fracturing and the geology of the strata layers will dictate the effect of mining on the surface water bodies and on the aquifers.

The proposed longwall mining at the project will result in mine subsidence, bedding plane separation, shearing and additional surface cracking both at the surface and within the sub surface strata units. The extent and severity of these mining induced ground deformations will vary across the project area depending on a number of factors, including:

- depths of cover;
- widths of the longwall panels and pillars;
- extracted seam thicknesses;
- the presence of previously extracted panels;
- strata layer thicknesses;
- geology of the strata layers;
- presence of near surface geological structures;
- locations of natural jointing within the units; and
- the presence of valleys and steep surface topography.

There have been cases where mine subsidence ground movements have caused extensive cracking within watercourses at depths of cover of less than 200 metres, resulting in surface water being captured and flowing into mine workings. If the flows into the mine are small and the mine pumps can cope, then, this additional water may only be an operational problem for the mine, but, the loss of this water can seriously impact on the surface environment and the flora and fauna that are dependent on the surface and groundwater resource. There have also been instances where water from the overlying surface waters or from sub surface aquifers have drained into mines where the depths of cover above the coal seams were more than 200 metres causing closure of these mines. In contrast there are also many documented reports of successful mining under oceans, seas, lakes, dams, ponds, rivers and creeks with less than 100 metres depth of cover without any water draining into the mine.

Hence mining impacts on surface and ground water bodies are variable and, rather than assuming the best or the worst conditions, it is important to appreciate the circumstances applying to each of these cases and to understand when surface water and groundwater may connect with the mine.

The extent, severity and manner of impacts of mining on surface water resources vary between different coal mines because every situation is different. Each stream is unique in terms of its characteristics, which include flow conditions, water quality, gradients, valley depths and degree of incision, sediment and nutrient load, ecosystems, bedrock mineralogy and geomorphology.

The nature and extent of mining beneath or near these streams also varies considerably in terms of the proximity of the extraction to the stream, the size and thickness of the extraction and the depth of cover. The specific geology of each case should be closely considered as the presence or absence of strong channels or impermeable layers completely changes generalisations based on panel width or seam thickness. The complexity of factors involved requires impact assessments for mining applications near streams to be undertaken on a case by case basis by geologists, subsidence engineers, surface and ground water hydrologists.

5.2.2. Review of Literature on Mining Induced Sub-Surface Cracking and Cracking Zones

A considerable amount of mining, including longwall mining, has been undertaken over the last two centuries beneath the oceans, seas, lakes, dams, rivers, creeks and streams in Australia. The issue of hydraulic connections between the surface water bodies and the mine workings has been the subject of several inquiries and strategic reviews commissioned by State Governments (including; Wardell 1975, Reynolds 1977, Southern Coalfield NSW DoP July 2008 and Wyong NSW DoP July 2008).

Engineers, surveyors, geologists and groundwater hydrologists have published many papers on the effects of mine subsidence on surface water and groundwater resources. Varying opinions have been published regarding which subsidence parameter most influences the observed impacts, how best to determine the likely impacts of mining on water resources, and the choice of which computer programmes should be utilised in these studies. Despite these varying opinions, some basic understandings have been developing in this field and a summary of what is felt to be the important points is presented below.

The following sketch shown in Fig. 5.12, which was provided to the Wyong Strategic Review Inquiry by Wallarah Coal, illustrates the nature of cracking and the possible influence of mining for a single longwall panel. In this sketch

it is shown that mining can cause cracking from the seam level up to the surface, however, above a fractured, highly connected and depressurised zone, there can be, depending on various factors, a constrained zone in which there can be disconnected cracking, increased horizontal permeability and bedding plane shear, but with negligible changes to the vertical permeability of the strata.

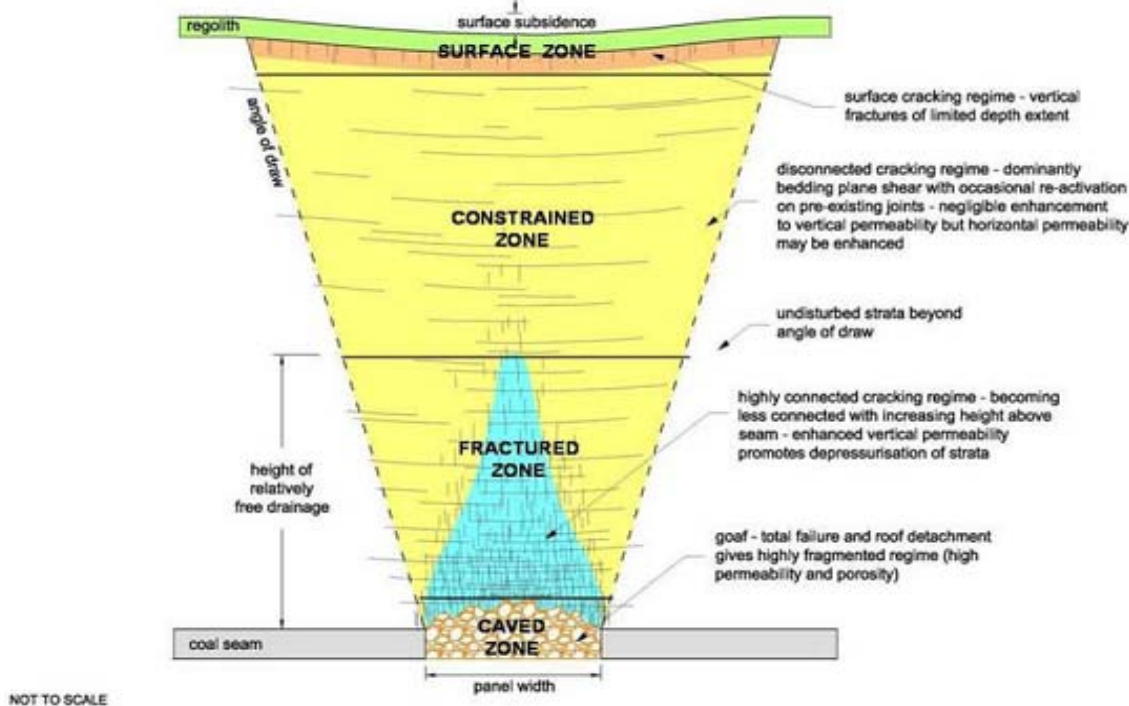


Fig. 5.12 Conceptual Model of Caving and the Nature of Fracturing above a Mine Excavation (Source: Adapted from Wyong Areas Coal Joint Venture)

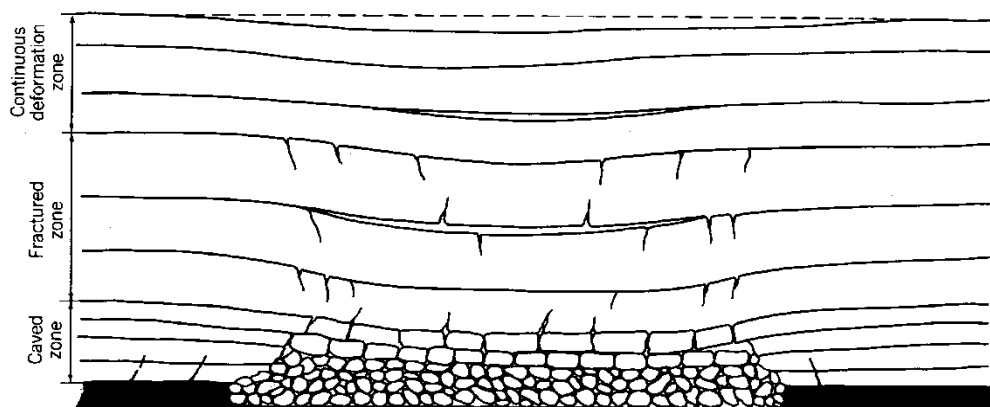


Fig. 5.13 Zones in the Overburden According to Peng and Chiang (1984)

Many researchers have investigated and reported on the influence of underground mining on water bodies and on aquifers that are affected by mining. A common approach in these studies is to divide the strata above the longwall into a number of zones, as shown in Fig. 5.13, with different deformation characteristics, in order to explain the various observed findings. This approach is good, but, the difficulty comes when one tries to assign “typical” extents of the various zones, as this is dependent on many variables.

5.2.3. Review of Literature on Height of Fracturing versus Height of Hydraulically Connected Fractures

The height of the free draining fractured zone is not equal to the height to the top of the highest observed mining induced fracture alone as some of the fractures higher up in the sequence may not be connected or do not drain to the mined void.

The height above the seam of the relatively free draining fractured zone is an important issue and it appears to be dependent on many factors, most notably including; the longwall panel width, the seam thickness extracted, the

thicknesses and geomechanical properties of the overlying strata units, the presence of faults and natural jointing, the presence of layers of clay, claystone, shale, siltstone, mudstone, tuff and tuffaceous horizons that can restrict the vertical flow of groundwater, and, where very wide supercritical panels are being extracted, the bulking and compaction factors of the goafed material.

The height of free draining fractured zone cannot be definitively measured using borehole extensometers alone as significant bed separation, vertical dilation and increased horizontal permeability can occur above certain strata layers even though there has been no change to the vertical permeability below these layers towards the mine void.

The height of fracturing cannot be definitively determined after comparing borehole piezometers and permeability testing at selected horizons before and after mining alone either as significant bed separation, vertical dilation and increased horizontal permeability can occur above certain strata layers even though there is no change to the vertical permeability below these layers towards the mine void.

Instead of just having a borehole extensometer or just having borehole piezometers and permeability testing, it appears that it is best to have pre-mining groundwater condition information over a long period, a borehole sub-surface strata extensometer, and post mining permeability and piezometric level measurements when assessing the mining induced heights of fracturing. Usually researchers find cases where either a sub-surface strata extensometer was used or cases where piezometric level measurements or cases where pre-mining and post mining permeability testing was undertaken. There are few cases in the published literature where all this data is available for a site.

Seedsman & Dawkins (ACARP C13009, 2006) advise that an early empirical hydrogeological model for strata above longwalls was developed by Kendorski et al (1979) and the zones were defined by ratios of height to extraction thickness as shown in Table 5.1. Earlier work on heights of fracturing and effects on surface and groundwater was also published by Orchard and Wardell in terms of the seam thickness extracted. Holla reported on various sub-surface strata extensometer investigations including some permeability testing and Holla reported all his results in terms of the extracted seam height.

Table 5.1 Definition of Hydrogeological Zones

	Height above seam (normalized to extraction thickness)	Definition
Constrained zone	> 60 t	No change in hydrogeological conditions
Dilated zone	60 t	Sagging of beds, no failure, opening of bedding surface leading to increased storativity.
Fractured zone	24t - 30t	Strata crack and settle. Fractures through individual beds, opening of bedding planes, shearing and dislocation of beds.
Caved zone	6t - 10 t	Strata fall and detach, complete disruption, broken and rubble-sized strata

Seedsman & Dawkins (ACARP C13009, 2006) advised that the Kendorski model was compatible with the inflow history from the German Creek and Oak Creek Mines as published by Klenowski (ACARP C5016, 2000) and the Kendorski model has also been applied to the NSW Newcastle coal measures, where the overburden geologies are dominated by the presence of massive conglomerates, by Forster and Enever (1992).

An extensive groundwater testing program was conducted by Forster and Enever (1992) in the Lake Macquarie region of NSW, i.e. just south of Newcastle, which resulted in the development of a practical hydro-geological model of subsurface behaviour zones specific to this area. Forster and Enever (1992) produced the hydro-geological model, which was based on ratios of zone heights to extraction thicknesses, for supercritical longwall panels in the Great Northern Seam which has been reproduced as Fig. 5.14.

Interestingly the original model was principally based on the results from three boreholes, two at the Wyee Mine and one at Cooranbong Colliery, where the panels were very wide with high levels of subsidence. The observed heights of fracturing at the three sites were 63 metres, 40 metres and 58 metres respectively. The determination of height of fracturing was based on various geological and geotechnical evaluations of this region together with many other local permeability and piezometric tests.

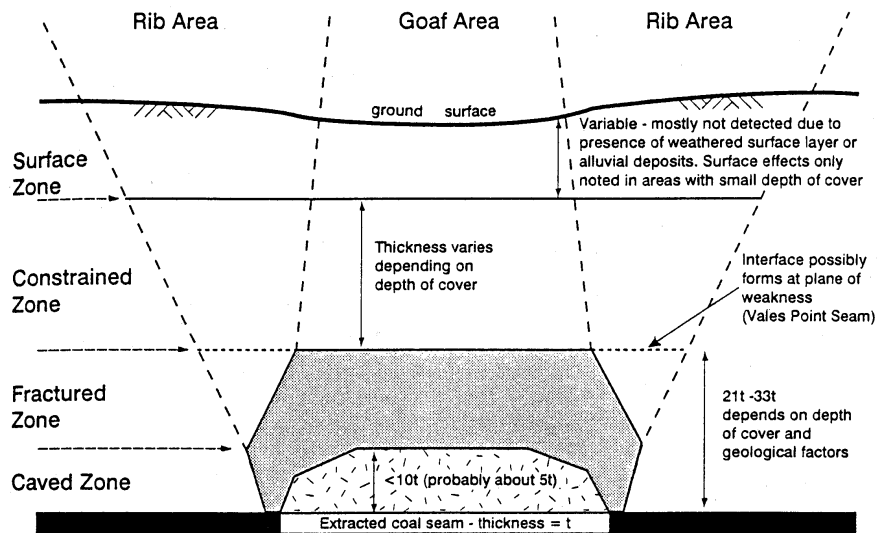


Fig. 5.14 Zones in the Overburden according to Forster (1995)

It has been subsequently deduced that the relatively low heights of fracturing in this Central Coast region of NSW, compared to other geological regions, is predominantly due to two factors, that is, the consistent presence of the strong and massive strata beams within the overburden that limit subsidence movements plus, very importantly, the presence of numerous reported layers of clay, claystone, shale, siltstone, tuff and tuffaceous horizons, between these stronger strata channels that can restrict the vertical flow of groundwater.

Forster and Enever (1992) did flag that it is not sufficient to create a constrained zone above mine workings but that this zone must also have a low natural permeability and/or contain beds of low permeable strata for it to function as a hydraulic barrier between the surface and the mine workings. The same conclusion was suggested to Mr Justice Reynolds, refer to Reynolds (1977), i.e. that the mine plans should limit panel widths to one third the depth of cover under stored waters so that the height of connective fracturing within a goaf should not go up more than one third the depth of cover and, as long as there were aquicludes or aquitards within the middle constrained zone or the surface one third of the depth of cover then loss of water from the dams should be minimal.

Exploration and instrumentation boreholes have revealed that some of the claystones and tuffs in the NSW Newcastle and Southern Coalfields have a high propensity to swell significantly and that the floor sediments of the coastal lakes can include clay rich material. The role that these materials may have played in producing successful outcomes also needs to be borne in mind.

A further extensive analysis of surface and sub-surface subsidence, cracking and groundwater data from the Newcastle region was undertaken by Ditton & Frith (ACARP C5016, 2003) and these authors developed a sub-surface fracturing model that was based predominantly on work published by Whittaker and Reddish (1989), see Fig. 5.15 below.

The Whittaker and Reddish model was developed in response to the water ingress problems associated with early longwall extraction at the Wistow Mine in Selby, UK where a longwall panel was located at 350 metres depth and experienced groundwater inflows of 121 to 136 litres/sec when sub-surface fracturing intersected a limestone aquifer that was 77 metres above the seam. This model identified the existence of two distinct zones of fracturing above super-critical width extractions (*continuous* and *discontinuous* fracturing).

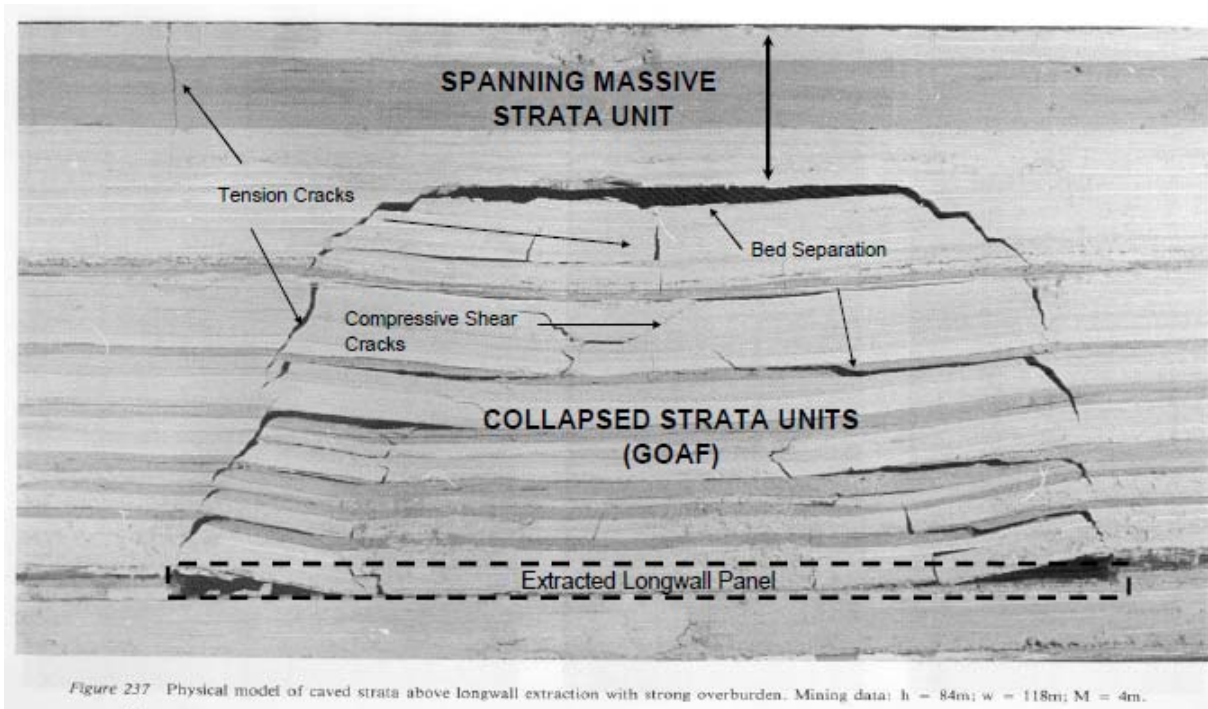


Fig. 5.15 Overburden behaviour with strong massive units Whittaker & Reddish (1989)

The definition of the extent of *continuous* fracturing that was used in the Whittaker and Reddish model refers to the height at which a direct connection of the fractures occurs within the overburden and the workings; it represents a direct hydraulic connection for groundwater inflows. The height is very different to the potential height of fracturing which can extend higher, but, within which the remote fractures and cracks are not connected.

The definition of the extent of *discontinuous* fracturing refers to the height at which the horizontal permeability increases as a result of strata de-lamination and fracturing, i.e. a slight temporary reduction in head without full water loss or direct connections to the workings.

Most of the fracturing in the Whittaker and Reddish modelling was observed to occur close to the rib-side only as the fracturing in the overburden above the middle portion of the panel tended to close and did not appear to represent an area in which groundwater inflows into the workings would be generated.

Ditton & Frith (ACARP C5016, 2003) developed their height of fracturing model based on the following data in their Table 5.2 which they advised was derived from previously published literature.

Table 5.2 Predicted Tensile Strains and Sub-Surface Fracturing Data

Mine No. (refer to Appendix D for Mine details)	W (m)	H (m)	T (m)	S_{max} (m)	Predicted Smooth Profile Strain, E_{max} (mm/m)	a^* (m)	b^* (m)	A (a/H) (m)	B (b/H) (m)	a/T	S_{max}/W^2 **
1-NSW	170	185	2.0	0.99	2.8	63	163	0.34	0.88	31.5	0.034
2-NSW	250	210	3.1	1.9	2.5	40	170	0.20	0.85	12.5	0.030
3-NSW	105	75	2.8	1.27	9.4	58	64	0.77	0.85	20.7	0.115
4-QLD	205	132	2.4	1.28	3.1	21	117	0.16	0.89	8.9	0.038
5-QLD	200	142	2.8	1.40	2.9	18	127	0.13	0.89	6.4	0.035
6-QLD	205	95	3.2	1.86	9.4	55	85	0.58	0.89	17.2	0.099
7-NSW	150	350	2.7	0.28	1.0	n/m	150	n/m	0.43	n/m	0.018

Note : * - a = Distance to total drilling fluid loss above workings.

* - b = Distance to partial drilling fluid loss above workings.

** - S_{max}/W^2 = a new robust term (i.e. Overburden Curvature Index) to plot A and B against instead of tensile strain (see below for further explanation).

n/m – not measured as drilling terminated before depth was reached.

From the table above it can be seen that the highest fracturing height used in developing this Ditton & Frith (ACARP C5016, 2003) model was 63 metres above the mined seam which is less than fracture heights advised in many other published reports. For example, as listed in Table 5.3, higher fracturing heights were noted in Klenowski (ACARP C5016, 2000) for varying inflow rates into various Queensland mines. Flows varied from 140 l/sec at

70 metres cover depth to 2 l/sec at 175 metres cover depth. There is a trend of generally regular decrease in flow rate with increasing depth of cover up to 175 metres depths of cover.

Table 5.3 Maximum Recorded Inflow Rates into Longwall Mines with Increasing Cover Depths

LOCATION	DEPTH OF COVER (m)	INFLOW RATE (l/sec)	COMMENTS
Southern Colliery	70	140	
Oaky No. 1 Underground Mine	100	83	
Southern Colliery	105	50	Flooded highwall mining entries
Southern Colliery	120	45	
Southern Colliery	140	27	
Oaky No. 1 Underground Mine	150	6	
Southern Colliery	160	30	Permian rock in creek bed
Oaky No. 1 Underground Mine	160	9	
Oaky No. 1 Underground Mine	175	2	

Inflow rates from ponded water are largely a function of the amount of subsidence induced tensile strain at the base of the pond. In the case of overlying aquifers, inflow rate is a function of the amount of subsidence induced tensile strain at the base of the aquifer and the permeability of the aquifer, as drawdown occurs.

The suggested guidelines below that were included in Klenowski (ACARP C5016, 2000) apply to geotechnical environments similar to those at the Oaky Creek and German Creek Mines, with Permian rock extending from the base of the ponded water to the mining horizon. In the case of soft, plastic Permian overburden or the presence of a pond floor layer of low permeability, cohesionless alluvium in which subsidence cracks self-heal, less conservative guidelines could possibly be adopted, but only after thorough geotechnical investigations.

Klenowski (ACARP C5016, 2000) stated that for ponded water at cover depths of greater than 160 metres, remedial works will generally not be required and standard underground pumping systems should be capable of handling minor increases in flow. This is a very useful consideration for the Carmichael Project as few areas over the proposed longwalls are shallower than 160 metres.

For ponded water at cover depths ranging from 160 metres down to 120 metres, underground pumping systems should be capable of pumping a flow rate of at least 50 l/sec. For ponded water at cover depths ranging from 120 metres to 70 metres, flow rate increases from about 45 l/sec to 140 l/sec, and pre and post-subsidence remedial works are recommended, as well as the installation of large capacity, emergency, underground pumps. If pre-subsidence remedial works are not possible, underground pumping systems, capable of handling increased flows, need to be installed.

Experience has shown that it is extremely difficult to mine longwall coal when goaf water flow rates of greater than 20 l/sec occur along the face line. In such cases, dams and transportable pumping systems need to be installed in gate roads or sumps adjacent to gate roads. Where possible, mine designs should accommodate goaf water flows away from longwall faces.

While many authors seem to use seam thickness as the preferred mining parameter that influences cracking heights and dilation, such as Kendorski (1993), Forster and Enever (1992) and Ditton and Frith (ACARP C10023, 2003), many other authors have noted the importance of depth of cover, (Klenowski ACARP C5016, 2000), and others suggested that it is more logical to normalise measured fracture heights to panel width and not extraction thickness, e.g. Mills and O'Grady (1998) and Seedsman (ACARP C13009, 2006).

More recently, however, other authors such as Gale (ACARP C13013, 2008) advise that the height of the fractured zone is dependent on many factors including panel width and seam thickness, but, Gale prefers to relate the height of connective fracturing to the mining induced tensile strains and depths of cover and not to just one factor.

It has been highlighted that a thick and strong strata layer within the overburden may significantly reduce surface subsidence movements and sites with these strong strata beams would have differing heights of connective fracturing compared to sites without any strong or massive strata beams. Sites with a high number of claystone, shales and tuffaceous layers throughout the overburden, especially where these clay or tuff layers can swell and seal any minor fractures have exhibited far lower heights of connective fracturing compared to sites with mainly sandstone layers.

Accordingly, it is recognised that it may not be appropriate to use heights of cracking or connectivity models that were developed based solely on one factor, say seam thickness or geometry of the mined panel, especially if all the monitoring data was drawn from sites within one geological area, for use at other sites with differing geological

conditions. It is generally considered preferable to first review the geological conditions at the site in question to assess which model would be appropriate.

While keeping the above general advice in mind, a theoretical height of a fractured zone (n.b. not necessarily with connective cracking and draining into the mine) can be approximated from the mining geometry alone, as being equal to the panel width (W) minus the span (w) divided by twice the tangent of the angle of break. This geometry only model is not proposed for general use, it is just proposed to show the influence of geometry, as illustrated in Fig. 5.16.

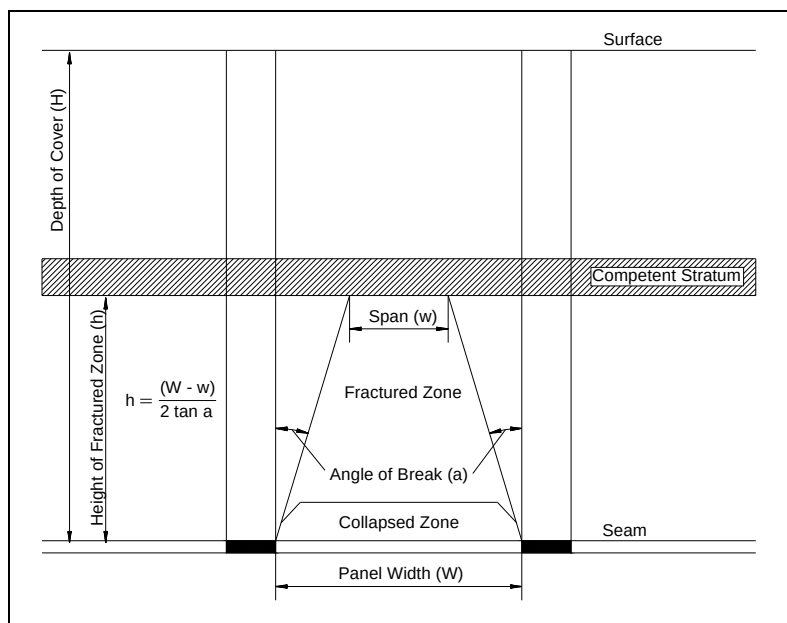


Fig. 5.16 Theoretical Model Illustrating the Development and Limit of the Fractured Zone using Geometry alone

MSEC has gathered observed borehole data on the observed fracture height of the connective draining zone sourced from a number of literature studies. The data points collected to date are shown in Fig. 5.17.

The data points are compared with the results of the theoretical geometry only model developed by MSEC, using an angle of break of 20 degrees and spanning width of 30 metres. The results are also compared with lines representing factors of 1.0 times and 1.5 times the panel width, which was suggested by Gale (ACARP C13013, 2008).

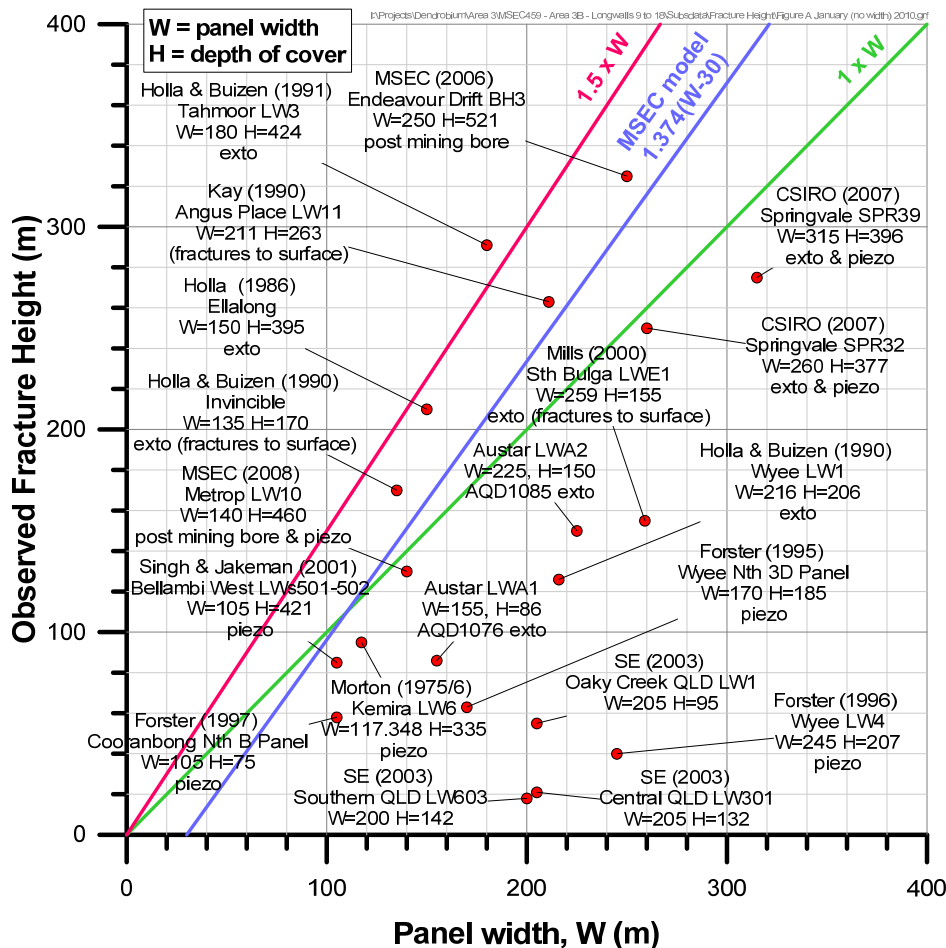


Fig. 5.17 Observed Fracture Heights versus Panel Width

It can be seen from Fig. 5.17, that the MSEC model and Gale's suggested factors of 1.0 and 1.5 provide reasonable but conservative estimates for the height of fracturing, for these available data points, but, it is accepted that both these models are generalisations and the MSEC model shown above, i.e. being based on geometry only, is not being proposed as a general model for predicting heights of fracturing or heights of hydraulically connected fracturing. It should be remembered, however, that this plot includes a wide variety of geological conditions that affect the results significantly.

It can be seen from Fig. 5.17 that the maximum panel void width is 315 metres, which is similar to the proposed panel void width of 310 metres for the Carmichael Project.

Wider panel widths of 410 metres have been extracted at Ulan Coal Mine in NSW, where the depth of cover ranges from 200 to 300 metres. The overburden strata at Ulan are predominantly sandstone with some siltstone on the top of some of the ridges and with some occasional basalt flows on some other ridges. The Environmental Assessment documents for the recently approved extension of mining at Ulan included groundwater reports that indicated that the mining induced cracking above the currently extracted 410 metre wide panels at Ulan extend up to the surface and that depressurisation of the Ulan seam, in combination with the subsidence cracking of the overlying strata from the coal seam, probably through to the surface, results in the eventual depressurisation and drainage of the saturated zone above the mine. This experience highlights the significant influence of overburden geology and panel widths on the heights of fracturing.

It is reiterated that the height of fracturing using the above MSEC model or Gale's suggested factors of 1.0 and 1.5 should not be interpreted as the height at which water loss will occur, since the heights in the database were not generally determined based on water loss, but on significant changes in vertical dilation. Gale (ACARP C13013, 2008) states that, "Longwall mining creates additional fractures and changes the conductivity of pre-existing fractures. The height that mining related fractures may form has been established from monitoring and computational studies as being 1-1.5 times the panel width. However, the creation of these fractures alone does not necessarily imply that a direct hydraulic connection exists over this zone."

From the above discussions it can also be noted that previously published estimates of the height of the fracturing zone and the height of the hydraulically connected fractured zone varies widely between different studies at different locations, not only because of the varying influence of local geology, varying mined panel widths and varying depths of cover, but, also because of the method of measurement. However, it should be remembered that in some of

these published cases this height of connective fracturing was determined based solely on measured sub-surface subsidence movements from borehole extensometer and, at other sites, the height of connective fracturing was determined solely from piezometer records and at other sites it was determined based on comparisons of permeability testing. In other words great care has to be taken when reading the available literature and in interpreting the published results. Ideally borehole extensometer measurements, permeability testing and piezometer records should be used to fully assess whether surface water and aquifer resources have been impacted by mining.

As this is a complex issue, MSEC understands that no simple equation can properly estimate the heights of the collapsed and fractured zones and a detailed thorough analysis should be undertaken.

Seam thickness was initially used as the factor in determining the height of fracturing for the early English models, which may be applicable for those conditions, but, the influence of seam thickness is minor for narrow panels where the strata bridges over strong chain pillars and for cases where there are extensive bed separations and voids within the goaf. The extracted seam thickness influences the height of fracturing for very wide total extraction panels as was observed in the Forster studies, but, wherever bridging occurs between chain pillars then seam thickness would be less relevant than the panel width. However where strong and massive channels bridge between the chain pillars then generalised rules using panel widths alone become less useful.

Gale (ACARP C13013, 2008) provides useful comments in assessing the likely impacts of longwall mining under water bodies. The following notes have been reproduced from this report as they represent a reasonable summary of the above discussions;

"In most instances, guidelines relate to inflows that would endanger underground personnel and operations. In more recent times, water inflow criteria for mines has been widened to include lesser inflows that may not impact on mine safety or operations, but have the potential to reduce water flow within streams and surface aquifers. For the purpose of this report the larger inflows relating to mining safety are defined as mine inflow and the lesser inflow relating to aquifer water loss as environmental inflow, but, guidelines can be prepared for lower values once the various government bodies specify the required environmental limits."

"Longwall mining creates additional fractures and changes the conductivity of pre-existing fractures. The height that mining related fractures may form has been established from monitoring and computational studies as being 1-1.5 times the panel width. It is noted that the creation of these fractures alone does not necessarily imply that a direct hydraulic connection exists over this zone. In order for mine inflow to occur, the fractures created must form a connected and conductive network or zone to allow significant volumes of inflow."

"....." Overall, the data suggests that mine inflow (observed inflows) can occur for theoretical strain values above approximately 6mm/m and the severity of inflow increases as the strain increases. Strains above approximately 10mm/m are likely to be associated with significant inflow."

"It was recognised that the empirical relationship"....."provides a broad qualitative overview of the likelihood for various levels of inflow. In order to obtain a better understanding of environmental inflow, quantification of the potential flow rates is necessary. This was achieved by estimating the hydraulic characteristics of the overburden above longwall panels over a wide range of subsidence values."

"This was done utilising computer modelling of the overburden caving and subsidence behaviour for a range of depths and panel geometries. Back analysis of site data was also used and provided validation for the modelling outcomes."

"Simulation of the fracture distribution and resultant hydraulic conductivity of the overburden was conducted to assess the impacts both above and adjacent to longwall panels. The impact of various levels of subsidence on the conductivity of the overburden and on the water profiles which may be maintained above the longwall panels was evaluated. Geological sections from the Hunter Valley and the Bowen Basin were modelled."

"The modelled average conductivity correlated very well with the measured values and indicated that the modelling process had simulated the fracture and flow systems in the overburden above longwall panels, and provided a good estimate of conductivity."

"Overall, the results indicate that the overburden above panels having theoretical tensile strains of 4mm/m has flow networks close to the in situ conductivity. This therefore provides a reasonable estimate for the onset of enhanced conductivity of the overburden."

"It was noted that a hydraulic profile was maintained in the upper strata where the average conductivity was less than approximately 10^{-6} m/s. This indicates that flow in strata with an average conductivity less than 10^{-6} m/s is tortuous and may support a water table under the appropriate site conditions."

"These results are summarised in Figure S1."

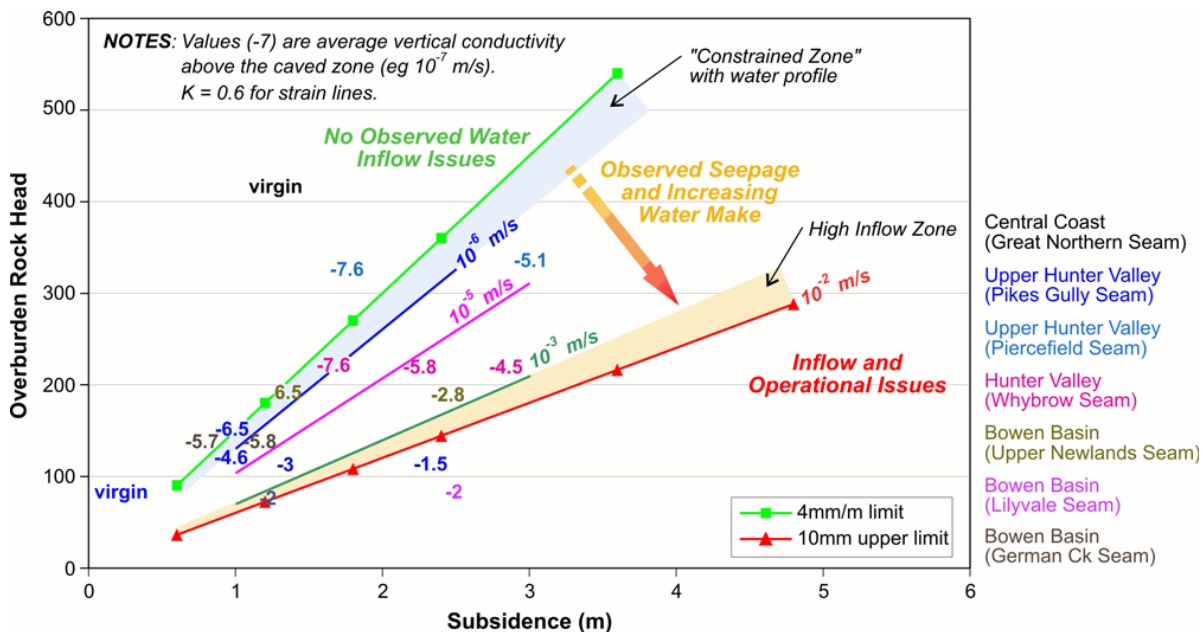


Figure S1 Average overburden conductivity characteristics relative to subsidence and depth criteria.

"In order to evaluate the potential inflow it is essential to assess the surface or aquifer conditions which would provide input into the fractured network as the nature of soils and surface topography may impact on the location and rate at which surface water may connect with the mining fractures."

"If a highly conductive fracture system above a longwall panel intersects a water saturated sand body, then the inflow rate of the system is typically controlled by the lesser conductivity of the sand and the overburden. If the fractures intersect open flowing water, then the full capacity of the fracture system will be utilised."

The complexity of the various factors requires impact assessments for mining applications near streams to be undertaken on a case by case basis. There are, however, a number of common themes that can be found in each case and these are discussed below.

Many advances in the understanding of the issue have developed and a number of criteria have evolved over the years for assessing the likelihood of a hydraulic connection between the surface and mine workings, and the four principal ones are:

- **Minimum Depths of Cover.** For a given mining width, the severity of the observed subsidence impacts decreases with increasing depth of mining. Provided that the depth of mining is sufficient to support the development of a 'constrained zone', and this zone has suitable less permeable layers, i.e. aquitards or aquicludes, then surface water or groundwater are unlikely to drain into the mining excavation. (Some drainage of surface water may still occur, but, this water is likely to remain within the rocks of the 'surface zone'.)
- **Maximum tensile strain on the surface.** Early English studies indicated that water could be prevented from entering a mine if cracking of the surface was restricted by limiting the maximum tensile strain on the surface to between 5 mm/m and 10 mm/m, depending on the nature of the strata. It is recognised today that this rule fails to include allowance for the presence of an adequate aquitard or aquiclude layer and fails to adequately consider the behaviour of the strata in the constrained zone and hence is no longer widely used.
- **Development of a constrained zone.** The recommendations of early government inquiries into mining under stored waters were based on development of a constrained zone and have been applied without incident at a number of sites. Panel widths were limited, say, to less than one third of the depth of cover so that a large constrained zone would result above the goafs in which it was believed that some less permeable materials could exist. The rule of thumb formulae may have been relevant at the sites being considered during those inquiries, however, checks need to be undertaken to ensure that adequate aquitard or aquiclude layers do exist above the fractured zone. Current mine planning still relies on this principle when mining directly beneath stored waters, but, we have moved away from adopting very narrow panels where field monitoring, field experience and advances in computer modelling show that wider panels can be utilised.

- **Presence of an aquiclude or aquitard**, being a layer of highly impermeable material, such as shale, silt, clay or tuff. Experience in Australia and around the world indicates that if the right type and thickness of less permeable materials are present, unrestricted extraction may take place beneath water bodies without surface water finding its way into the workings. However if these less permeable materials are only present in the collapsed zone and highly fractured zone then these layers do not provide a seal against downward flowing water towards the mine void. Where none of these materials are present then much higher heights of connective fracturing can occur.

More recent studies have highlighted that generalised mine design recommendations should not be applied blindly and that careful consideration must always be given to site specific geology and geological features. The specific geology of each case should be closely considered as the presence or absence of strong channels or impermeable layers completely changes generalisations based on panel width or seam thickness.

It is therefore recommended that a detailed assessment by an appropriate specialist ground water consultant be undertaken at the appropriate stage to confirm, refine and further elaborate upon this preliminary assessment. One of the most important tasks of this specialist is to confirm the presence of an appropriate aquitard or aquiclude layer within the top portions of the overburden.

5.2.4. Height of fracturing and potential for hydraulic connectivity from surface water to seam at the Carmichael Project

The discussions below on the potential for hydraulic connectivity are general in nature and based on broad facts and observations that have been provided in published literature. It is reiterated that the potential for hydraulic connectivity is best undertaken on a case by case basis and it is recommended that a detailed assessment by an appropriate specialist ground water consultant be undertaken to confirm, refine and provide further details to this preliminary assessment.

The difficulty in assessing the likely height of fracturing and height of hydraulic connectivity at this project is that the geological setting for the Carmichael project is significantly different from the geological settings in almost all the published literature on subsidence, likely height of fracturing and height of hydraulic connectivity in Australia. The models published in literature have been developed for locations with predominantly sandstone overburden or using data from cases with significant sandstone overburden. The overburden at the Carmichael project predominantly includes the Rewan formation which is described as an aquitard in the GHD Hydrogeology Report (Nov 2012) and this formation is a base unit of the Great Artesian Basin. In addition, there are significant thicknesses of clay dominated materials in the tertiary age deposits.

It must be stressed that the anticipated height of fracturing does not imply that hydraulic connectivity will extend to the same height, especially since the overburden materials at the Carmichael Project contain significant thicknesses of clay, claystone, mudstone, siltstone and kaolinitic layers which behave as aquitards. Because of this geological profile, the predicted subsidence for this project is significantly greater than for normal sandstone dominated profiles. The overburden materials are not anticipated to bulk during goafing in the manner that sandstone dominated profiles do, resulting in greater subsidence, and heights of fracturing above extracted longwall panels, which could extend up higher than usually seen in sandstone dominated environments. However, because the overburden profile has a high presence of aquitard materials in the both the Rewan formation and tertiary sediments above the proposed longwalls, there is considered to be a low risk of direct hydraulic connection between the surface aquifers and extracted seams. The best anecdotal evidence of the ability of the overburden to prevent hydraulic connection from the surface to seam is at Cook Colliery, which has continued without any operational issues and has ponds formed in the subsided surface above the longwall panels. There is no data available from Cook Colliery however, in relation to fracture height assessments or permeability changes in the overburden.

A summary of the fracture zone models discussed in Section 5.2.3 and the application to the Carmichael Project is provided in Table 5.4. The results of these models are graphically represented in Fig. 5.18. It can be seen from Fig. 5.18 that the height of fracture zones and development of constrained/dilated zones based on seam thickness vary from approximately 85 metres to 120 metres. Given the geological setting and the greater predicted subsidence for the Carmichael project, it is uncertain that the fracture networks resulting from the extraction of the proposed longwalls would conform to the zones identified in the published literature. The study by Klenowski (ACARP C5016, 2000) is based on data from Oak Creek and German Creek and suggests that remedial works are generally not required where depths of cover are greater than 160 metres.

Table 5.4 Predicted Height of Fracturing based on Published Literature

Model	Zones	Description	Height above extracted seam	Height above extracted seam at Carmichael Project (metres)
Wyong Strategic Review Inquiry (2008)	Surface Zone	Surface cracking regime – vertical fractures of limited depth extent	First 20m of the surface	20
	Constrained Zone	Disconnected cracking regime – dominantly bedding plane shear with occasional re-activation on pre-existing joints – negligible enhancement to vertical permeability but horizontal permeability may be enhanced	No information	-
	Fractured Zone	highly connected cracking regime – becoming less connected with increasing height above seam – enhanced vertical permeability promotes depressurisation of strata	No Information	-
	Caved Zone	goaf – total failure and roof detachment gives highly fragmented regime (high permeability and porosity)	3t to 10t	8 to 28
Seedsman & Dawkins (ACARP C13009, 2006) Kendorski et al (1979)	Constrained Zone	No Change in hydrogeological conditions	>60t	>165
	Dilated Zone	Sagging of beds, no failure, opening of bedding surface leading to increased storativity	60t	165
	Fractured Zone	Strata crack and settle. Fractures through individual beds, opening of bedding places, shearing and dislocation of beds	24t to 30t	66 to 83
	Caved Zone	Strata fall and detach, complete disruption, broken and rubble sized strata	6t to 10t	17 to 28
Forster (1995)	Surface Zone	Goaf Area: Horizontal compression, vertical tension, decreased vertical permeability. Rib Area: Horizontal tension, possible increased vertical permeability.	<15m thick	<15
	Constrained Zone	Goaf Area: Horizontal compression, vertical tension, no change in vertical permeability, likely increase in horizontal permeability. Rib Area: Horizontal tension, possible increased, vertical compression, some vertical permeability increase possible.	No information	
	Fractured Zone	Totally distressed, large increase in bulk permeability	21t to 33t	58 to 91
	Caved Zone	Loose caved blocks of rock	<10t	28
Guo et al (ACARP C14033, 2007)	Caving Zone	Average permeability predicted to increase by as much as 1000 to 2000 times	3t	8
	Fracture Zone	Increase of up to 50 times in vertical permeability	43t	120
	Constrained Zone	Increase of up to 2 times in vertical permeability	75t to 78t	206 to 215
	Elastic Zone	Increase of 3 to 5 times average permeability	97t to 101t	267 to 278
	Surface Zone	Increase of up to 10 times in vertical permeability		
Klenowski (ACARP C5016, 2000)		For ponded water at cover depths of greater than 160m, remedial works are generally not required and standard underground pumping systems are capable of handling minor increases in flow. For ponded water at cover depths ranging from 160m to 120m, underground pumping systems should be capable of pumping a flow rate of at least 50 l/sec. For ponded water at cover depths ranging from 120m to 70m, flow rate increases from about 45 l/sec to 140 l/sec, and pre- and post-subsidence remedial works are recommended, as well as the installation of large capacity, emergency, underground pumps.		

t = extracted seam thickness / mining height

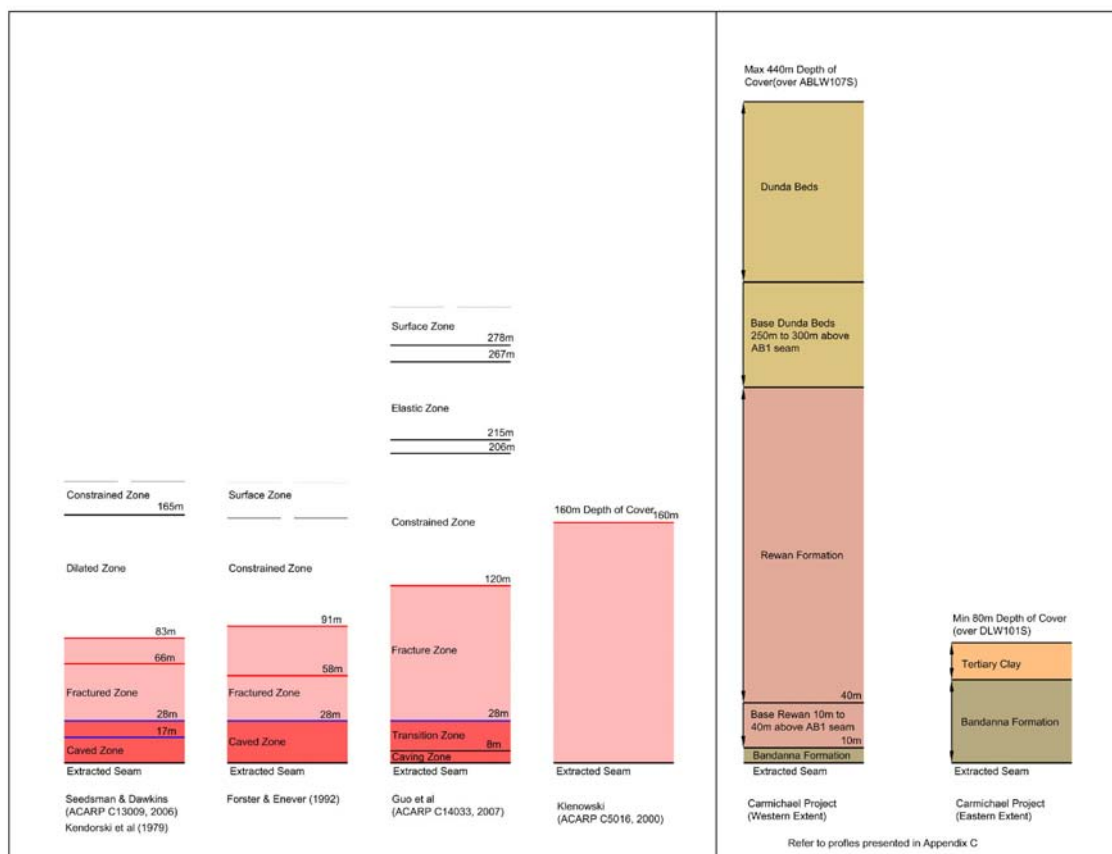


Fig. 5.18 Diagrammatic Representation of Predicted Height of Fracturing based on Published Literature

The application of the model presented by Gale (ACARP C13013, 2008) for the Carmichael Project is summarised in Table 5.5 and presented graphically in Fig. 5.18. It can be seen from Table 5.5 and Fig. 5.18 that this model predicts inflow and operational issues towards the east of the Proposed Longwalls, particularly for Mine 1 and Mine 4 and 5, where depths of cover are less than about 240 metres. It should be noted that again, this model has been developed from sandstone dominated environments and the predicted subsidence and depth of cover for the Carmichael project are generally outside the range of the data used for developing the model.

Table 5.5 Average Overburden Conductivity Characteristics by Gale (ACARP C13013, 2008)

Prediction Line	Mine	Longwall	Predicted Maximum Total Subsidence at prediction line	Average Depth of Cover	Gale (2008) Average overburden conductivity characteristics based on Subsidence and depth Criteria
Prediction line 1	Mine 1 North	DLW101N	3100	120	$>10^{-2}$ Inflow and Operational Issues
		DLW102N	3100	160	$>10^{-2}$ Inflow and Operational Issues
		DLW103N	3000	200	10^{-3} to 10^{-2} High Inflow Zone
		ABLW101N	5300	160	$>10^{-2}$ Inflow and Operational Issues
		ABLW102N	4800	210	$>10^{-2}$ Inflow and Operational Issues
		ABLW103N	4200	260	$>10^{-2}$ Inflow and Operational Issues
		ABLW104N	3600	300	10^{-4} Observed Seepage and Increasing Water Make
		ABLW105N	3400	330	10^{-5} Observed Seepage and Increasing Water Make
		ABLW106N	3100	370	10^{-5} to 10^{-6} Observed Seepage and Increasing Water Make
Prediction line 2	Mine 1 South	ABLW107N	2600	400	$<10^{-7}$ No observed Water Inflow Issues
		DLW101S	3100	120	$>10^{-2}$ Inflow and Operational Issues
		DLW102S	3100	160	$>10^{-2}$ Inflow and Operational Issues
		DLW103S	3000	190	10^{-3} to 10^{-2} High Inflow Zone
		ABLW101S	5400	140	$>10^{-2}$ Inflow and Operational Issues
		ABLW102S	5200	180	$>10^{-2}$ Inflow and Operational Issues
		ABLW103S	4700	220	$>10^{-2}$ Inflow and Operational Issues
		ABLW104S	4100	270	10^{-3} to 10^{-2} High Inflow Zone

Prediction Line	Mine	Longwall	Predicted Maximum Total Subsidence at prediction line	Average Depth of Cover	Gale (2008) Average overburden conductivity characteristics based on Subsidence and depth Criteria
		ABLW105S	3300	320	10 ⁻⁵ Observed Seepage and Increasing Water Make
		ABLW106S	3000	370	10 ⁻⁵ to 10 ⁻⁶ Observed Seepage and Increasing Water Make
		ABLW107S	2600	410	<10 ⁻⁷ No observed Water Inflow Issues
Prediction line 3	Mine 1 South	ABLW106S	3600	370	10 ⁻⁵ Observed Seepage and Increasing Water Make
		ABLW107S	3500	400	10 ⁻⁵ to 10 ⁻⁶ Observed Seepage and Increasing Water Make
Prediction line 4	Mine 2	ABLW201	4500	220	>10 ⁻² Inflow and Operational Issues
		ABLW202	4200	240	>10 ⁻² Inflow and Operational Issues
		ABLW203	3700	290	10 ⁻³ to 10 ⁻⁴ Observed Seepage and Increasing Water Make
		ABLW204	3300	320	10 ⁻⁴ Observed Seepage and Increasing Water Make
		ABLW205	3200	350	10 ⁻⁵ Observed Seepage and Increasing Water Make
		ABLW206	3100	380	10 ⁻⁵ to 10 ⁻⁶ Observed Seepage and Increasing Water Make
		ABLW207	2900	400	10 ⁻⁶ "Constrained Zone with water profile
Prediction line 5	Mine 3 North	ABLW301N	3900	250	10 ⁻² to 10 ⁻³ High Inflow Zone
		ABLW302N	3500	280	10 ⁻³ to 10 ⁻⁴ Observed Seepage and Increasing Water Make
		ABLW303N	3300	300	10 ⁻⁴ Observed Seepage and Increasing Water Make
		ABLW304N	3100	320	10 ⁻⁵ Observed Seepage and Increasing Water Make
		ABLW305N	3100	340	10 ⁻⁵ to 10 ⁻⁶ Observed Seepage and Increasing Water Make
Prediction line 6	Mine 3 South	ABLW301S	4100	250	10 ⁻² to 10 ⁻³ High Inflow Zone
		ABLW302S	3600	270	10 ⁻³ Observed Seepage and Increasing Water Make
		ABLW303S	3500	290	10 ⁻⁴ Observed Seepage and Increasing Water Make
		ABLW304S	3400	300	10 ⁻⁴ Observed Seepage and Increasing Water Make
		ABLW305S	3400	320	10 ⁻⁵ Observed Seepage and Increasing Water Make
Prediction line 7	Mine 4	ABLW401	4900	200	>10 ⁻² Inflow and Operational Issues
		ABLW402	4600	220	>10 ⁻² Inflow and Operational Issues
		ABLW403	4400	240	>10 ⁻² Inflow and Operational Issues
		ABLW404	4000	260	10 ⁻² to 10 ⁻³ High Inflow Zone
		ABLW405	3700	280	10 ⁻³ to 10 ⁻⁴ Observed Seepage and Increasing Water Make
		ABLW406	3500	290	10 ⁻⁴ Observed Seepage and Increasing Water Make
		ABLW407	3500	310	10 ⁻⁴ Observed Seepage and Increasing Water Make
Prediction line 8	Mine 5 North	ABLW501N	4600	220	>10 ⁻² Inflow and Operational Issues
		ABLW502N	4300	240	>10 ⁻² Inflow and Operational Issues
		ABLW503N	4100	270	10 ⁻² to 10 ⁻³ High Inflow Zone
Prediction line 9	Mine 5 South	DLW501S	3100	130	>10 ⁻² Inflow and Operational Issues
		DLW502S	3100	170	>10 ⁻² Inflow and Operational Issues
		DLW503S	3000	180	>10 ⁻² Inflow and Operational Issues
		ABLW501S	5400	120	>10 ⁻² Inflow and Operational Issues
		ABLW502S	5300	140	>10 ⁻² Inflow and Operational Issues
		ABLW503S	5100	160	>10 ⁻² Inflow and Operational Issues
		ABLW504S	4800	190	>10 ⁻² Inflow and Operational Issues
		ABLW505S	4400	210	>10 ⁻² Inflow and Operational Issues
		ABLW506S	4300	230	>10 ⁻² Inflow and Operational Issues
		ABLW507S	3800	250	10 ⁻³ Observed Seepage and Increasing Water Make
		ABLW508S	3600	270	10 ⁻³ to 10 ⁻⁴ Observed Seepage and Increasing Water Make

Prediction Line 1 - Mine 1 North

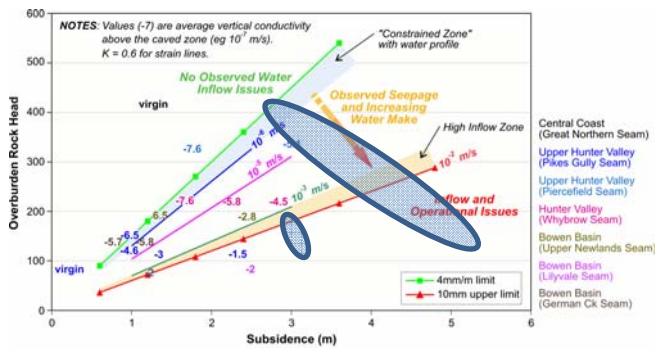


Figure S1 Average overburden conductivity characteristics relative to subsidence and depth criteria.

Prediction Line 2 - Mine 1 South

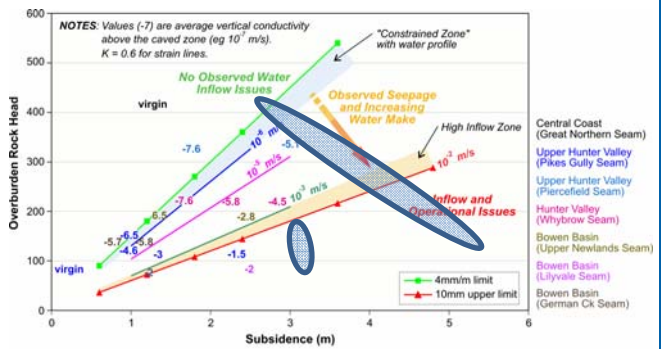


Figure S1 Average overburden conductivity characteristics relative to subsidence and depth criteria.

Prediction Line 3 - Mine 1 South

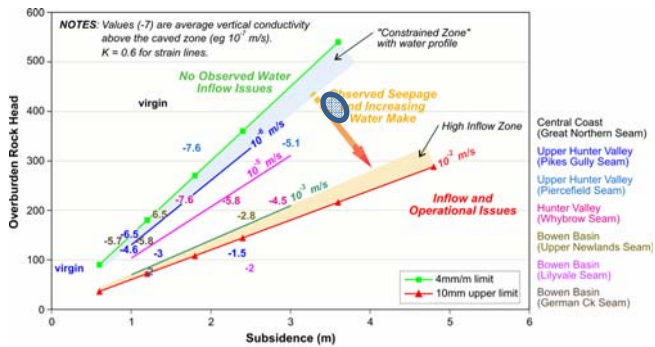


Figure S1 Average overburden conductivity characteristics relative to subsidence and depth criteria.

Prediction Line 4 - Mine 2

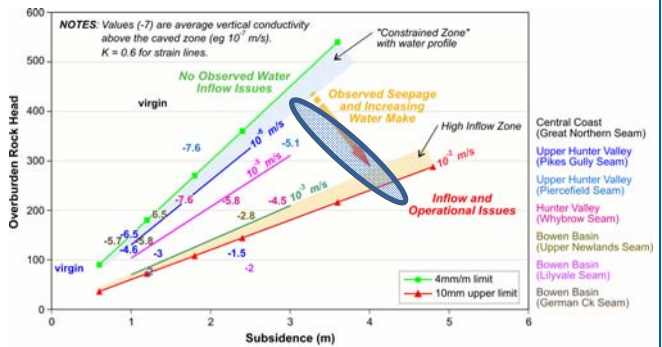


Figure S1 Average overburden conductivity characteristics relative to subsidence and depth criteria.

Prediction Line 5 - Mine 3 North

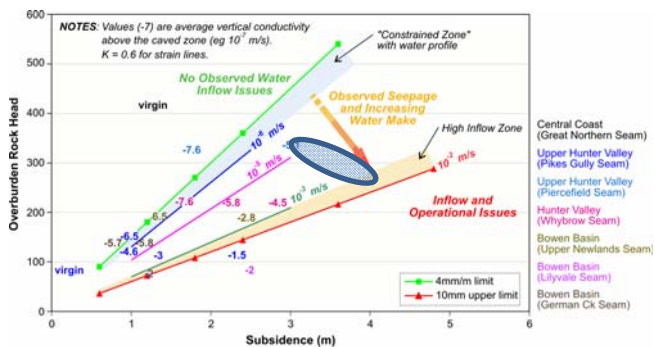


Figure S1 Average overburden conductivity characteristics relative to subsidence and depth criteria.

Prediction Line 6 - Mine 3 South

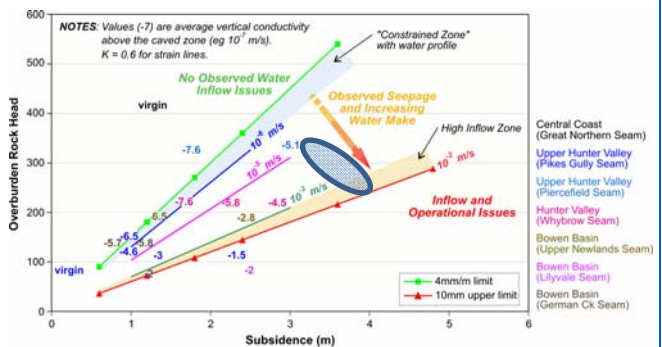


Figure S1 Average overburden conductivity characteristics relative to subsidence and depth criteria.

Fig. 5.19 Average Overburden Conductivity Characteristics by Gale (ACARP C13013, 2008)

Prediction Line 7 - Mine 4

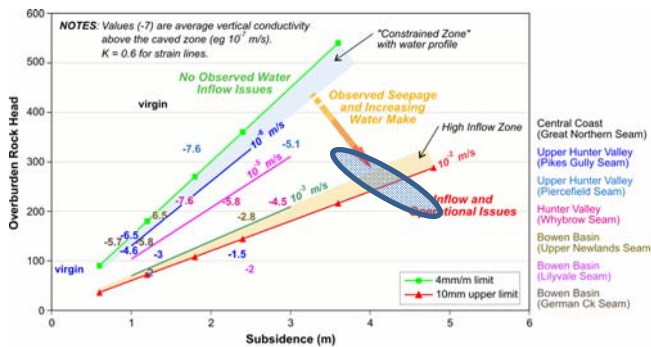


Figure S1 Average overburden conductivity characteristics relative to subsidence and depth criteria.

Prediction Line 8 - Mine 5 North

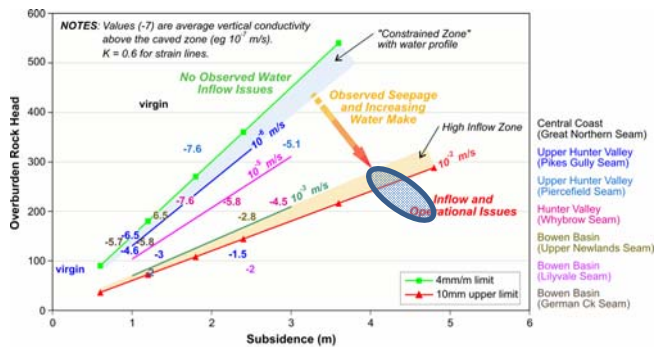


Figure S1 Average overburden conductivity characteristics relative to subsidence and depth criteria.

Prediction Line 9 - Mine 5 South

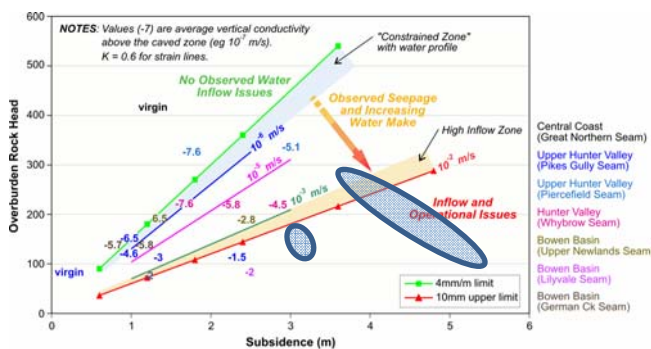


Figure S1 Average overburden conductivity characteristics relative to subsidence and depth criteria.

Fig. 5.19 Average Overburden Conductivity Characteristics by Gale (ACARP C13013, 2008) Cont.

It can be seen from Table 5.4 and Fig. 5.18 that there is considerable variation in the estimates for height of fracturing based on different published methods. The overburden above the Proposed Longwalls at the Carmichael Project include significant thickness of Tertiary and Triassic (Rewan Formation) sediments, which are generally of low strength and poor spanning capability than those found in the coalfields of NSW, upon which many of these methods are based.

The stratigraphic column shown in Fig. 1.2 identifies a sandstone layer immediately above the AB1 seam to the base of the Rewan Formation which, given the close proximity above the AB1 seam, will form part of the goaf and is not expected to span the mined void. In addition, it has been anticipated that goafing characteristics of the overburden materials will be similar to those observed at Cook Colliery, where observed subsidence was much greater than has been observed elsewhere in the Bowen Basin and NSW Coalfields. The overburden over Cook Colliery is also mostly fine grained sediments that do not include aquifers or groundwater bearing layers. Surface cracking has been observed at Cook, however the mine is still regarded by its operators as a relatively "dry" mine, as evidenced by the presence of various mining created ponds over the subsided workings.

The heights of fracturing that are summarised in Table 5.4, above, are also based on single seam extraction. With an interburden thickness of 70 metres to 130 metres between the AB1 and D1 seams, the extraction of the D1 seam will result in fracturing to the overlying AB1 seam and reworking of the fractured zone above the AB1 seam, increasing the height of the fractured zone. As a result, it is anticipated that the height of fracturing at the Carmichael Project will be at the upper end of the range of height estimates for the various published methods and potentially even higher.

Accordingly the expected height of fracturing at the Carmichael Project, is expected to extend from the AB1 seam to the surface over much of the proposed longwall footprint. It must be stressed, however, that the anticipated height of fracturing does not imply that hydraulic connectivity will extend to the same height, especially since the overburden materials at the Carmichael Project contain layers which behave as aquicludes or aquitards. Based on the geological profiles provided in the coal resource estimate report by Xenith Consulting Pty Ltd (Xenith 2009) and the borehole logs provided by Adani Mining Pty Ltd, there are significant thicknesses of clay, claystone, mudstone, tuff, siltstone and several kaolinic layers which may behave as aquitard or aquiclude layers.

The ability of the overburden to retard or prevent hydraulic connection at the Carmichael Project in the presence of aquiclude and aquitard materials in fractured strata is supported by the following information:

- The drilling investigation program for the Carmichael project encountered problems during drilling as a result of swelling clay in the boreholes.
- The mine hydrology report by GHD (GHD 2012) provides a calibrated model parameter for vertical hydraulic conductivity of $1 \times 10^{-5} \text{ m/d}$ in the Rewan Formation [Table 5-3]. The Rewan formation is a base confining unit for the Great Artesian Basin.
- The similarities between the overburden materials and extracted seams at Cook Colliery formed the basis for the calibration of the model for the Carmichael Project. Comments from Cook Colliery indicate that longwall mining had continued without any operational issues relating to surface to seam hydraulic connection. Ponded water has formed in the subsidence troughs above the extracted longwalls at Cook Colliery that were used for calibration of the model for the Carmichael Project as described in Section 3.9. This ponded water has been retained in the base of these troughs and the Rewan formation is the main overburden sequence between the extracted seam and the subsided surface.
- Longwalls have been successfully extracted beneath the Isaac River in the Bowen Basin at depths of cover from 170 metres to 250 metres, longwall widths of 314 metres and at an extracted seam thickness in the order of 4.5 metres. The longwalls were extracted below the river with no identifiable increase in mine dewatering rates. The extraction took place in a different geological setting, however this case demonstrates that the presence of aquiclude and aquitard materials in the overburden can prevent hydraulic connection between the surface and the extracted seam.

In the longwall extraction cases described above, the models for height of fracturing would suggest a height of fracturing up to or close to the surface, however extraction had continued without operational problems and without observed adverse impact to surface water.

It is expected that where sufficient depth of cover and thickness of Rewan formation and/or Tertiary clay are present, there will be a low risk of direct hydraulic connection from the surface to the seam. Conservatively adopting 160 metres based on Klenowski (ACARP C5016, 2000) would be considered a reasonable height for preliminary modelling of the height of direct hydraulic connection. Above this height, it is anticipated that there will be increase in the strata permeability due to fracturing through beds and bedding plane dilation, however the likelihood of hydraulic connectivity from the surface to the seam is anticipated to be low given the presence of aquiclude and aquitard materials in the overburden. Adopting increases in vertical permeability as suggested by Guo et al (ACARP C14033, 2007) would provide a reasonable basis for preliminary modelling. Assumptions should be conservative and should be verified by field measurement once mining commences. Development of a mathematical model for fracture networks would be the next stage for refinement of hydrogeological parameters prior to the commencement of underground operations.

The above assessment of hydraulic connectivity for the Carmichael project is based on the overburden descriptions provided in the coal resource estimate report (Xenith 2009) and the drilling data provided by Adani Mining for boreholes with spacings of the order of 1.5km or more. These descriptions of the overburden indicate the presence of materials that may act as aquicludes or aquitards and conclusions on connectivity are only applicable where these materials are consistently present. As discussed at the beginning of this section, it is recommended that a detailed assessment by an appropriate specialist ground water consultant be undertaken at the appropriate stage of the project on the potential for hydraulic connectivity from surface to seam. Please also refer to studies by the surface water consultant for further detailed information.

5.3. Great Artesian Basin

The proposed longwalls are located close to the eastern margin of the Great Artesian Basin (GAB) recharge beds. The Rewan formation forms the basement confining layer of the GAB and the base or bottom confined aquifer of the GAB is contained within the overlying Clematis sandstone. Hence the Clematis sandstone outcrops to the west of EPC1690 and forms part of the recharge beds at the eastern margin of the GAB.

The main sandstone aquifers and confining aquitards for the GAB are outlined in Fig. 5.20 (Great Artesian Basin Consultative Council, 1998) and a schematic representation of the GAB aquifers is presented in Fig. 5.21 (Geoscience Australia, 2010).

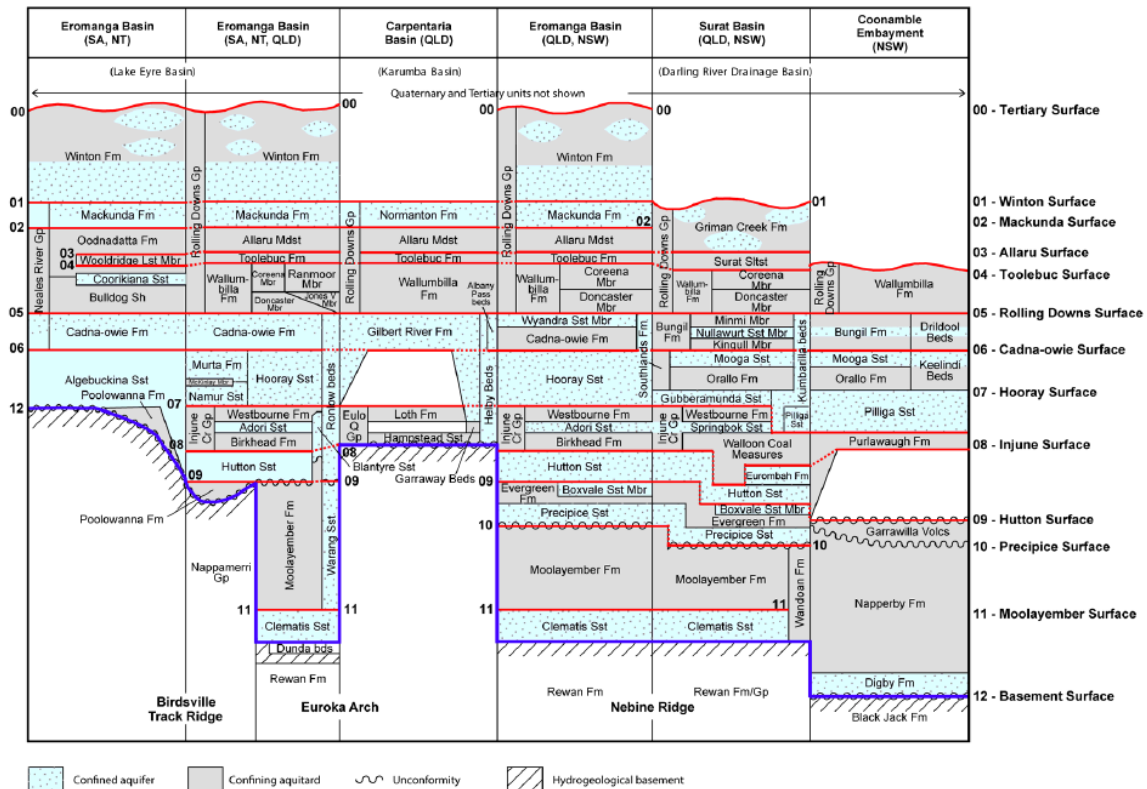


Fig. 5.20 Main Sandstone Aquifers and Confining Aquitards for the Great Artesian Basin (Source: Hydrogeochemical Baseline Mapping of the Great Artesian Basin Groundwater, Geoscience Australia, 2010)

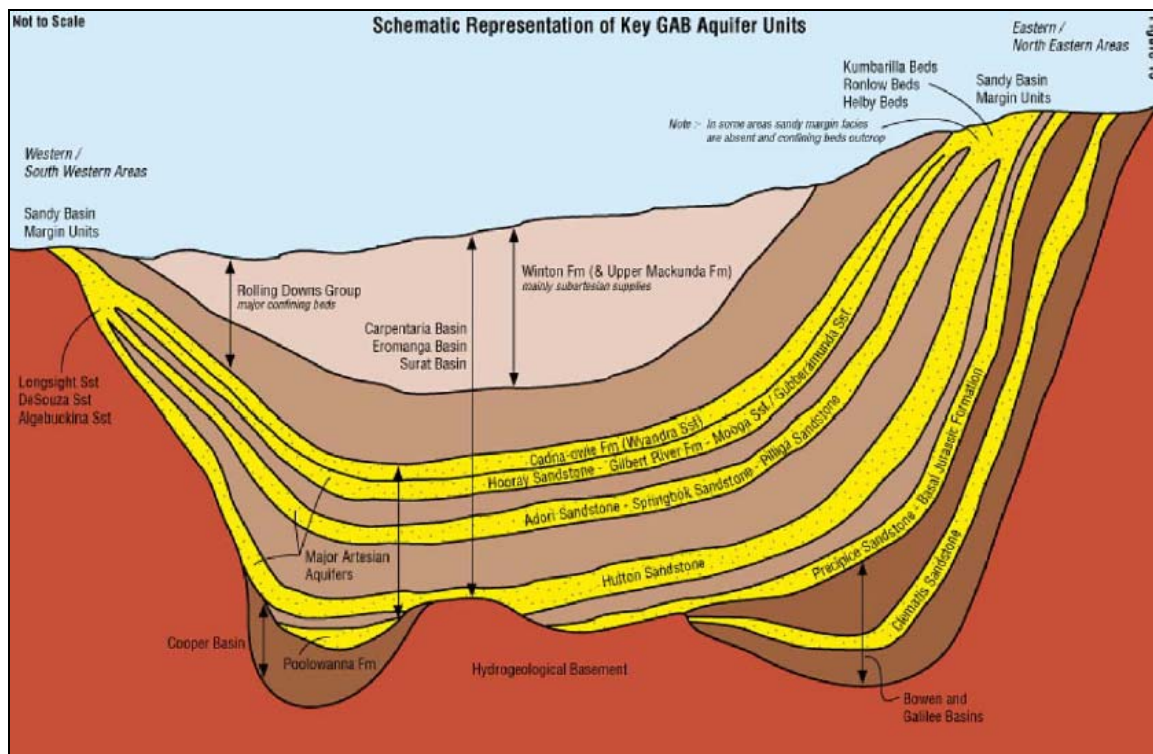


Fig. 5.21 Schematic Representation of Key GAB Aquifer Units (Source: Great Artesian Basin Resource Study, Great Artesian Basin Consultative Council, 1998)

Based on the above information and the geological information provided by Adani Mining, there are no identified GAB aquifer units outcropping within the proposed longwall footprint.

The nearest GAB aquifer unit to the proposed longwalls is the Clematis Sandstone, which is identified in the surface geological map in Fig. 1.1. The Mine Hydrology Report (GHD 2012) notes that the nearest mapped outcrop of Clematis sandstone is approximately 2 km to the west of EPC 1690. At this distance from the proposed longwalls, no measureable conventional subsidence movements and hence no impacts, are expected to result from the extraction of the proposed longwalls. It is possible, however, that the area would experience small far-field horizontal movements, which are discussed in Section 4.4.

The Mine Hydrology Report (GHD 2012) provides detailed information on the boundaries of the GAB and potential impacts on the GAB resulting from the proposed open cut and underground operations at the Carmichael Project.

6.0 POTENTIAL IMPACTS ON SURFACE INFRASTRUCTURE

A number of the major natural features and items of surface infrastructure within the Study Area can be seen in the Drawing No. MSEC627-13. The majority of the land is undeveloped, with sparse vegetation. The land is understood to be used primarily for grazing. The features within the Study Area include small tributaries that flow to the east, two unsealed roads, and boundary fences.

6.1. Streams

The locations of the watercourses in the vicinity of the proposed longwalls are shown in Drawing No. MSEC627-11, in Appendix D. There are no major creeks or streams within the Study Area.

The largest watercourse in the vicinity of the proposed longwalls is the Carmichael River, which is located outside the Study Area. The proposed longwalls have been set back from the Carmichael River and the closest longwall is approximately 655 metres from the river. A number of small tributaries are located above the proposed longwalls as shown on Drawing No. MSEC627-11. These tributaries flow generally to the north east and towards the proposed future open cut pit at the Carmichael Project.

Predicted profiles of conventional subsidence, tilt and curvature were prepared for three of the tributaries and the results are presented in Figs. C.12, C.13 and C.14 in Appendix C. In each figure, the predicted subsided surface levels along these tributaries are shown for the completion of mining in both seams.

The tributaries have shallow incisions into the surface soils. It is unlikely, therefore, that the tributaries would experience any significant valley related movements resulting from the extraction of the proposed longwalls.

The predicted subsidence and tilts are likely to be of sufficient magnitude to result in changes in the surface water flows along the drainage lines.

It can be seen from Figs. C.12, C.13 and C.14 in Appendix C that increased ponding is predicted to develop in the drainage lines directly above the proposed longwalls.

It is expected, at the magnitudes of predicted curvatures and strains, that significant fracturing and buckling would occur in the uppermost bedrock beneath the natural surface soils along the drainage lines. Surface cracking in the beds of the drainage lines would be visible at the surface where the depths of the surface soils are relatively shallow. The sizes and extents of surface cracking were discussed in Section 5.1.

It is expected, during and at the completion of mining, that earthworks would be required to manage the natural gradient along the drainage lines.

6.2. Roads

Two unsealed roads are located above the proposed longwalls, Moray Carmichael Boundary Road and Shuttleworth Carmichael Road. Predicted profiles of conventional subsidence, tilt and curvature were prepared for the two roads and the results are presented in Figs. C.10 and C.11 in Appendix C. In each figure, the predicted subsided surface levels along the roads are shown for the completion of mining in both seams.

It can be seen from Figs. C.10 and C.11 in Appendix C, that increased ponding is predicted to develop in the drainage lines directly above the proposed longwalls.

The proposed extraction will likely result in ponding, cracking, heaving, buckling and possibly steps in the pavement, which can all be repaired with minimum impact on traffic with detailed monitoring and suitable maintenance work. The potential impacts on the local road pavements can, however, be managed by the implementation of an effective subsidence management plan, with the co-operation of the relevant local or state government bodies, to ensure the safe operation of the roads during mining. Management measures will likely include proactive subsidence management of the existing pavements during mining.

6.3. Fences

Boundary fences are located across the Study Area and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence parameters within the Study Area is provided in Chapter 4.

Wire fences can be affected by tilting of the fence posts and by changes of tension in the fence wires due to strain as mining occurs. These types of fences are generally flexible in construction and can usually tolerate tilts of up to 10 mm/m and strains of up to 5 mm/m without significant impacts.

It is likely, therefore, that some of the wire fences within the Study Area would be impacted as the result of the extraction of the proposed longwalls. Any impacts on the wire fences could be remediated by re-tensioning the fencing wire, straightening the fence posts, and if necessary, replacing some sections of fencing.

APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS

Glossary of Terms and Definitions

Some of the more common mining terms used in the report are defined below:-

Angle of draw	The angle of inclination from the vertical of the line connecting the goaf edge of the workings and the limit of subsidence (which is usually taken as 20 mm of subsidence).
Chain pillar	A block of coal left unmined between the longwall extraction panels.
Cover depth (H)	The depth from the surface to the top of the seam. Cover depth is normally provided as an average over the area of the panel.
Closure	The reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in the units of <i>millimetres (mm)</i> , is the greatest reduction in distance between any two points on the opposing valley sides. It should be noted that the observed closure movement across a valley is the total movement resulting from various mechanisms, including conventional mining induced movements, valley closure movements, far-field effects, downhill movements and other possible strata mechanisms.
Critical area	The area of extraction at which the maximum possible subsidence of one point on the surface occurs.
Curvature	The change in tilt between two adjacent sections of the tilt profile divided by the average horizontal length of those sections, i.e. curvature is the second derivative of subsidence. Curvature is usually expressed as the inverse of the Radius of Curvature with the units of <i>1/kilometres (km⁻¹)</i> , but the value of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in <i>kilometres (km)</i> . Curvature can be either hogging (i.e. convex) or sagging (i.e. concave).
Extracted seam	The thickness of coal that is extracted. The extracted seam thickness is thickness normally given as an average over the area of the panel.
Effective extracted seam thickness (T)	The extracted seam thickness modified to account for the percentage of coal left as pillars within the panel.
Face length	The width of the coalface measured across the longwall panel.
Far-field movements	The measured horizontal movements at pegs that are located beyond the longwall panel edges and over solid unmined coal areas. Far-field horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain.
Goaf	The void created by the extraction of the coal into which the immediate roof layers collapse.
Goaf end factor	A factor applied to reduce the predicted incremental subsidence at points lying close to the commencing or finishing ribs of a panel.
Horizontal displacement	The horizontal movement of a point on the surface of the ground as it settles above an extracted panel.
Inflection point	The point on the subsidence profile where the profile changes from a convex curvature to a concave curvature. At this point the strain changes sign and subsidence is approximately one half of S max.
Incremental subsidence	The difference between the subsidence at a point before and after a panel is mined. It is therefore the additional subsidence at a point resulting from the excavation of a panel.
Panel	The plan area of coal extraction.
Panel length (L)	The longitudinal distance along a panel measured in the direction of (mining from the commencing rib to the finishing rib.
Panel width (Wv)	The transverse distance across a panel, usually equal to the face length plus the widths of the roadways on each side.
Panel centre line	An imaginary line drawn down the middle of the panel.
Pillar	A block of coal left unmined.
Pillar width (Wpi)	The shortest dimension of a pillar measured from the vertical edges of the coal pillar, i.e. from rib to rib.

Shear deformations	The horizontal displacements that are measured across monitoring lines and these can be described by various parameters including; horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index.
Strain	The change in the horizontal distance between two points divided by the original horizontal distance between the points, i.e. strain is the relative differential displacement of the ground along or across a subsidence monitoring line. Strain is dimensionless and can be expressed as a decimal, a percentage or in parts per notation. Tensile Strains are measured where the distance between two points or survey pegs increases and Compressive Strains where the distance between two points decreases. Whilst mining induced strains are measured along monitoring lines, ground shearing can occur both vertically, and horizontally across the directions of the monitoring lines.
Sub-critical area	An area of panel smaller than the critical area.
Subsidence	The vertical movement of a point on the surface of the ground as it settles above an extracted panel, but, 'subsidence of the ground' in some references can include both a vertical and horizontal movement component. The vertical component of subsidence is measured by determining the change in surface level of a peg that is fixed in the ground before mining commenced and this vertical subsidence is usually expressed in units of <i>millimetres (mm)</i> . Sometimes the horizontal component of a peg's movement is not measured, but in these cases, the horizontal distances between a particular peg and the adjacent pegs are measured.
Super-critical area	An area of panel greater than the critical area.
Tilt	The change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the horizontal distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of <i>millimetres per metre (mm/m)</i> . A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.
Uplift	An increase in the level of a point relative to its original position.
Upsidence	Upsidence results from the dilation or buckling of near surface strata at or near the base of the valley. The magnitude of upsidence, which is typically expressed in the units of <i>millimetres (mm)</i> , is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain

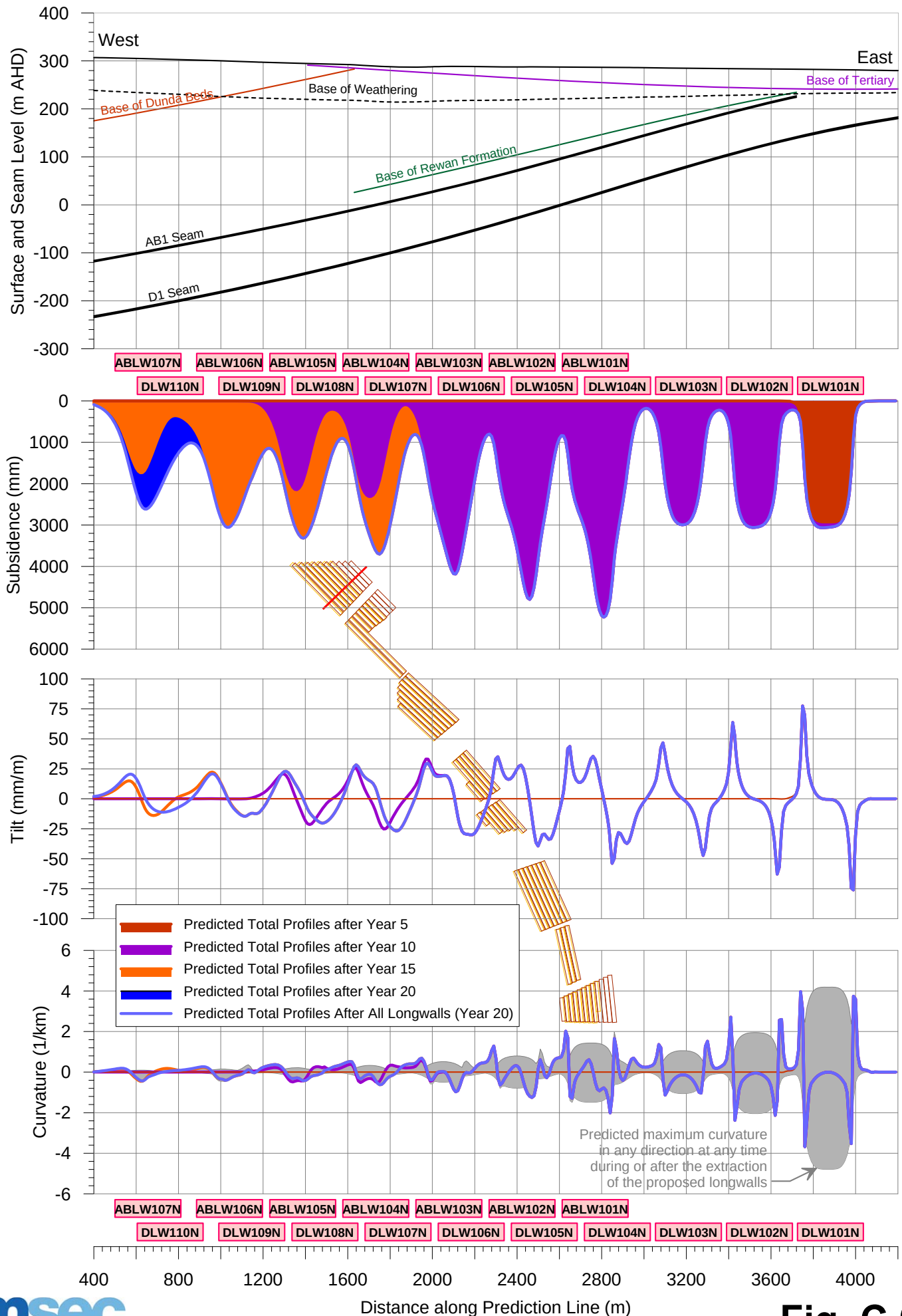
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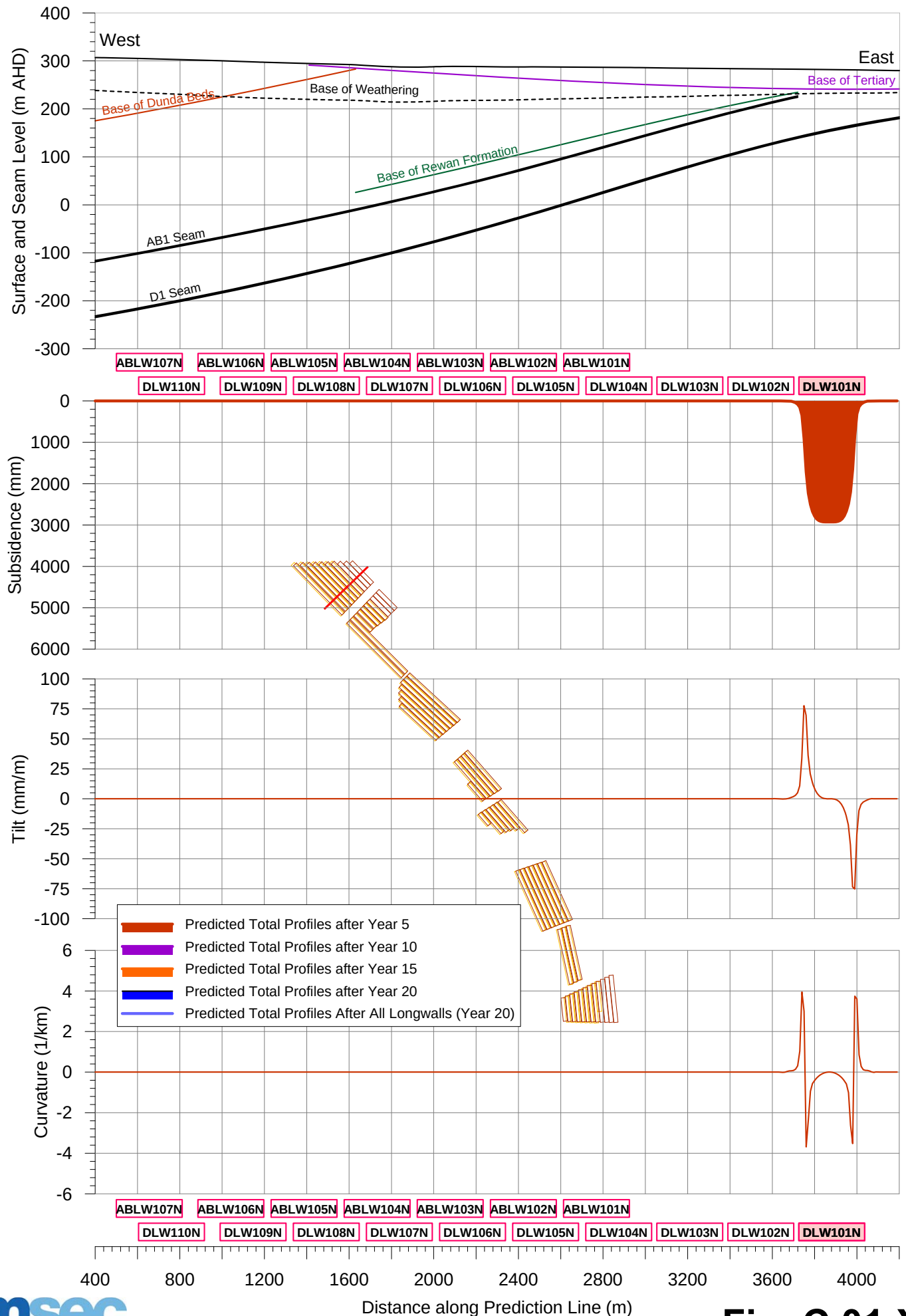
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APPENDIX C. FIGURES

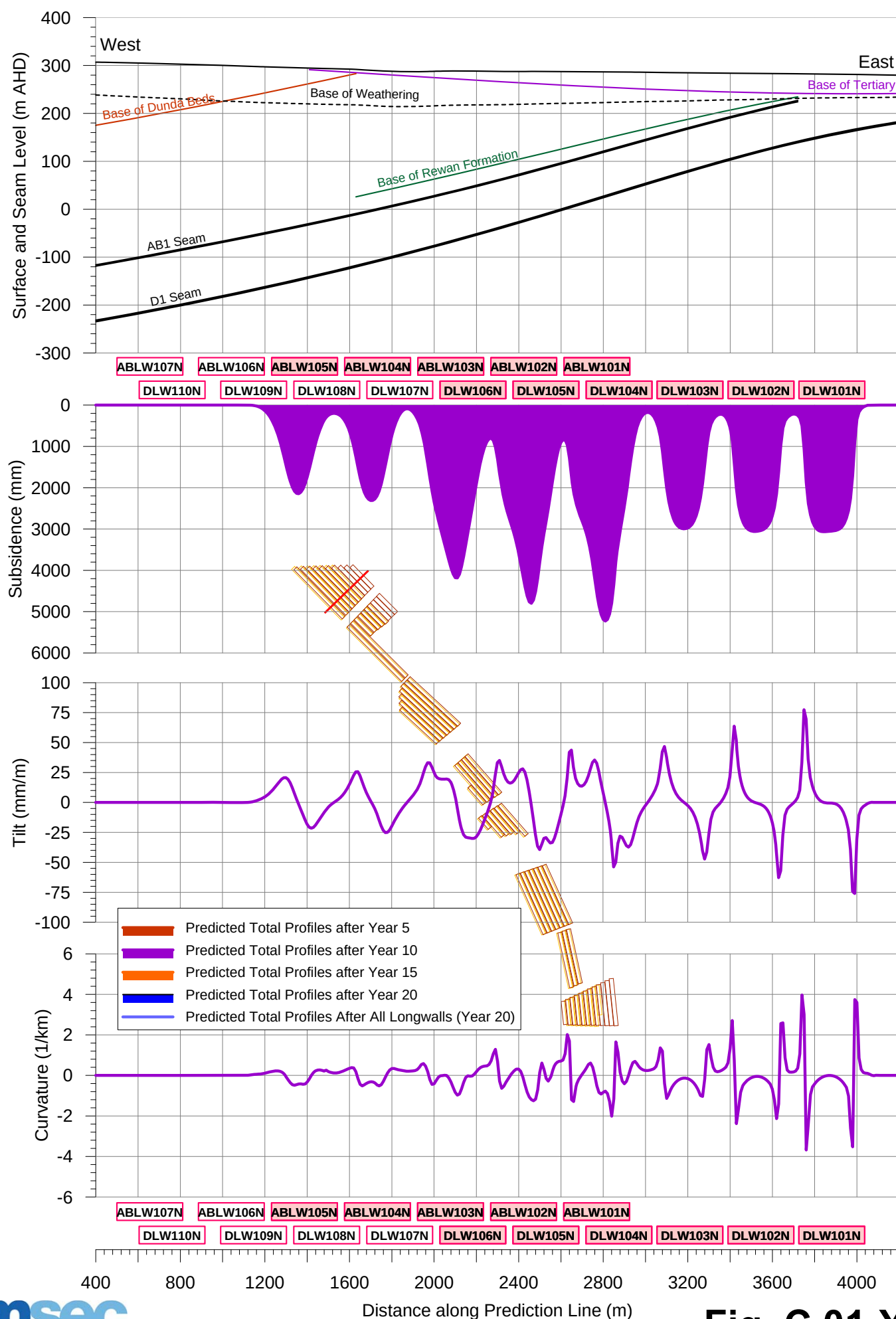
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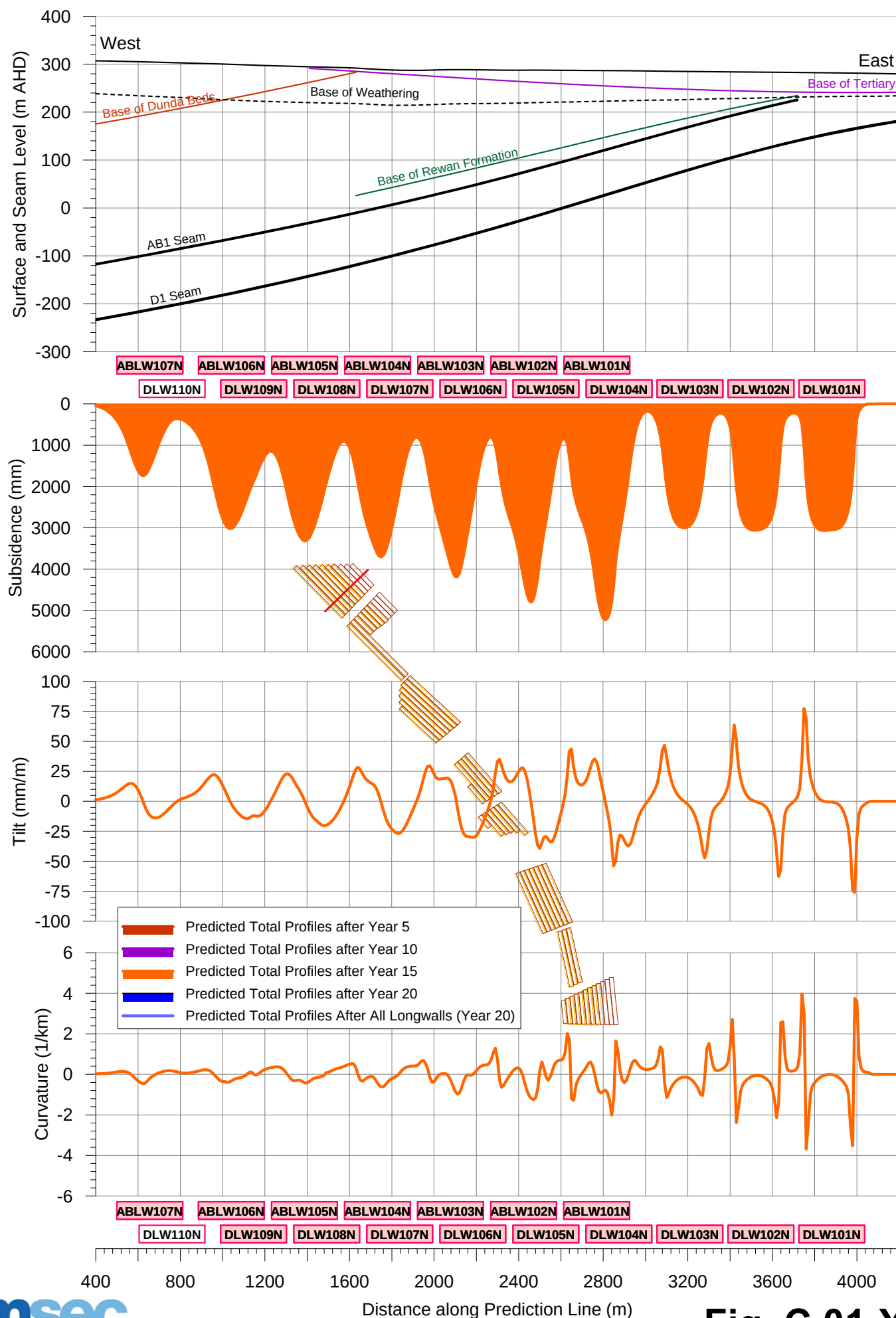
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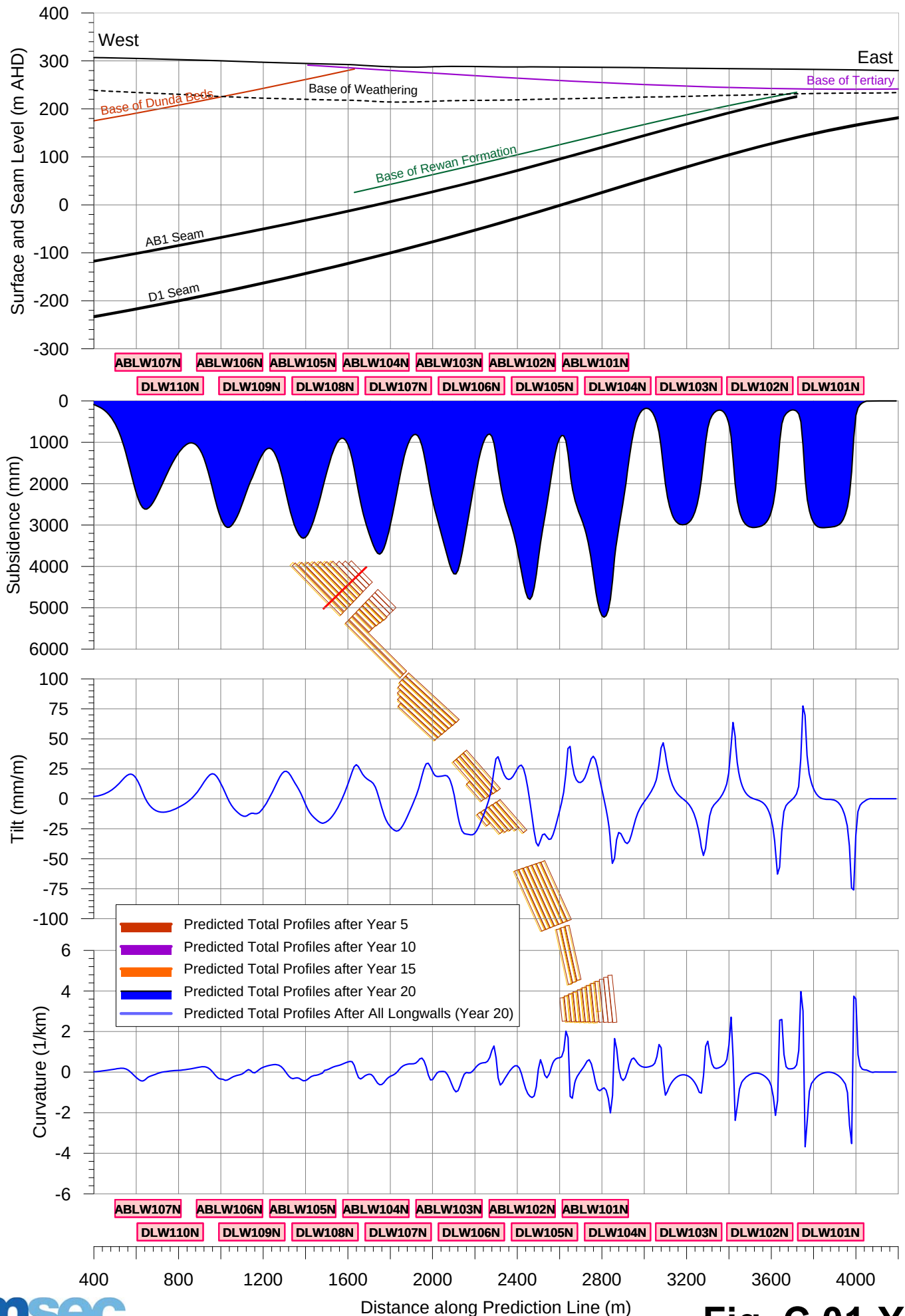
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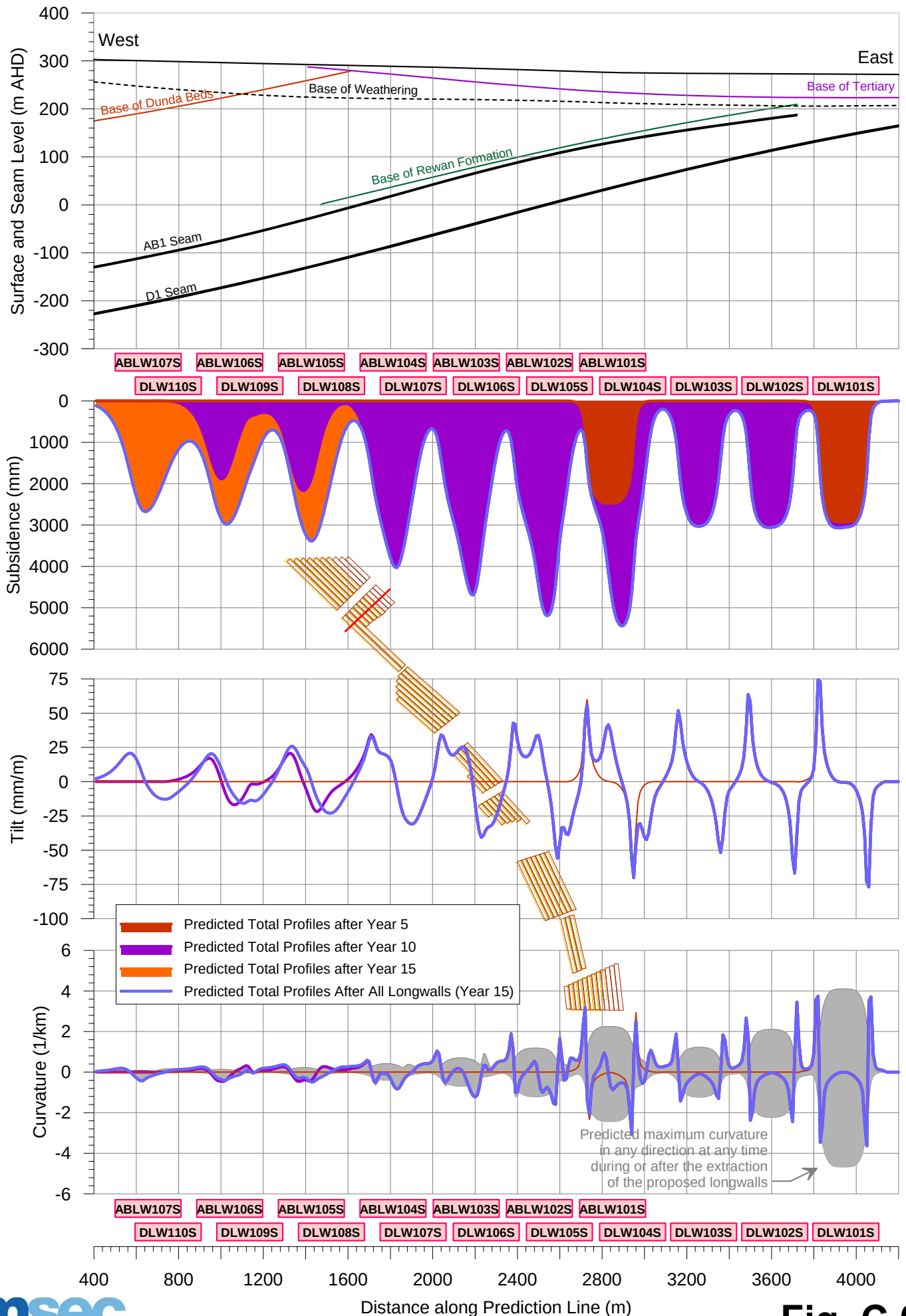
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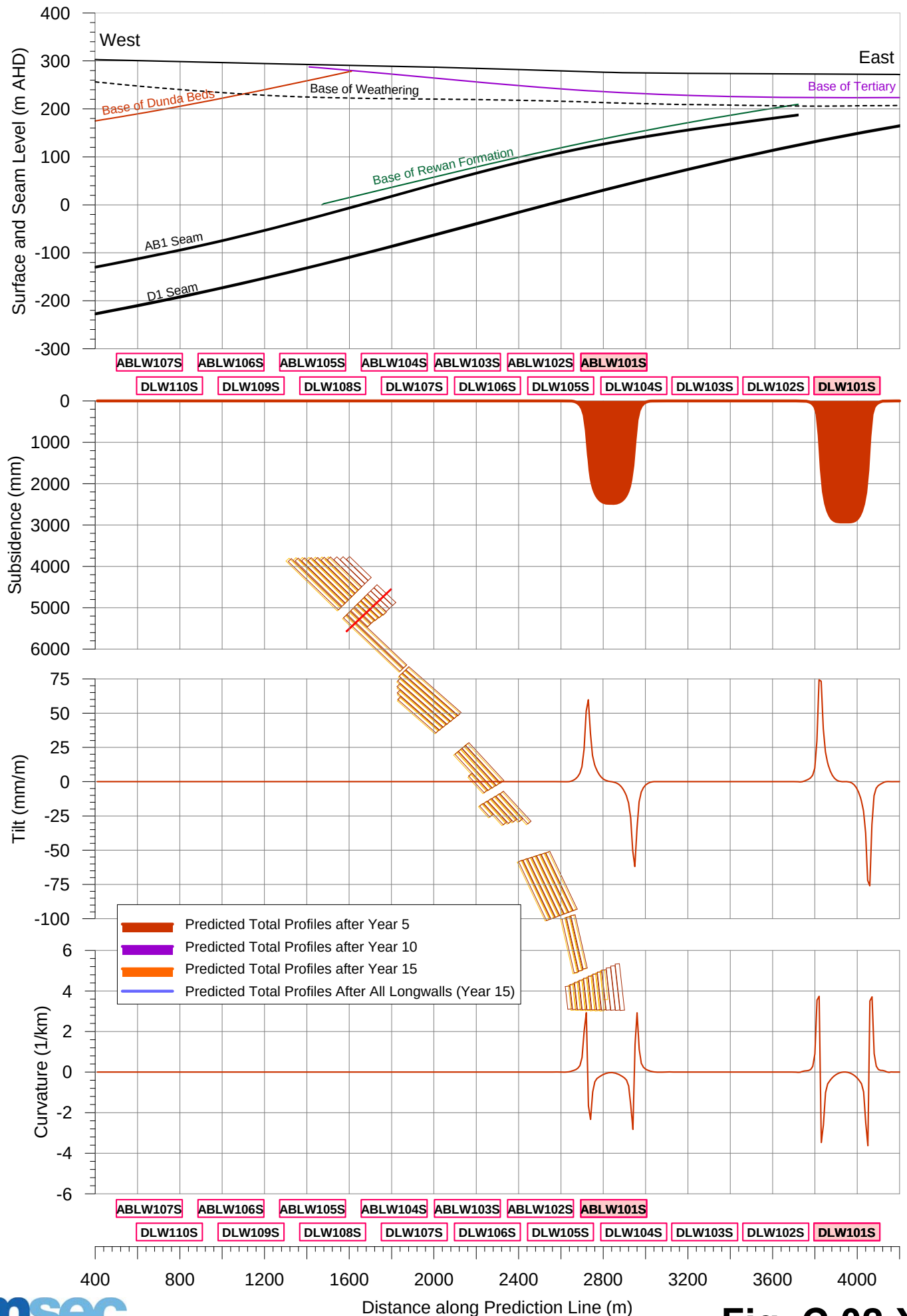
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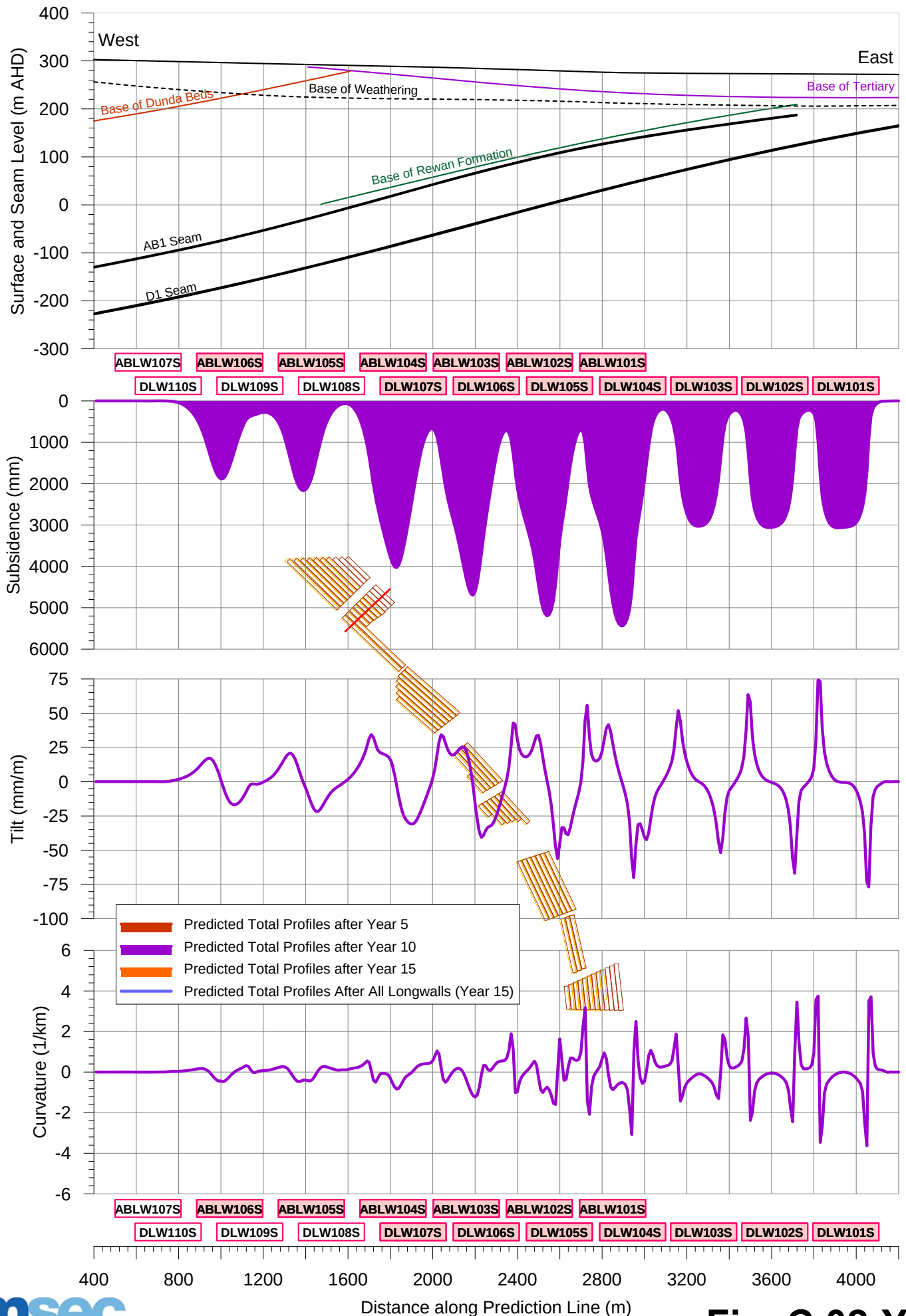
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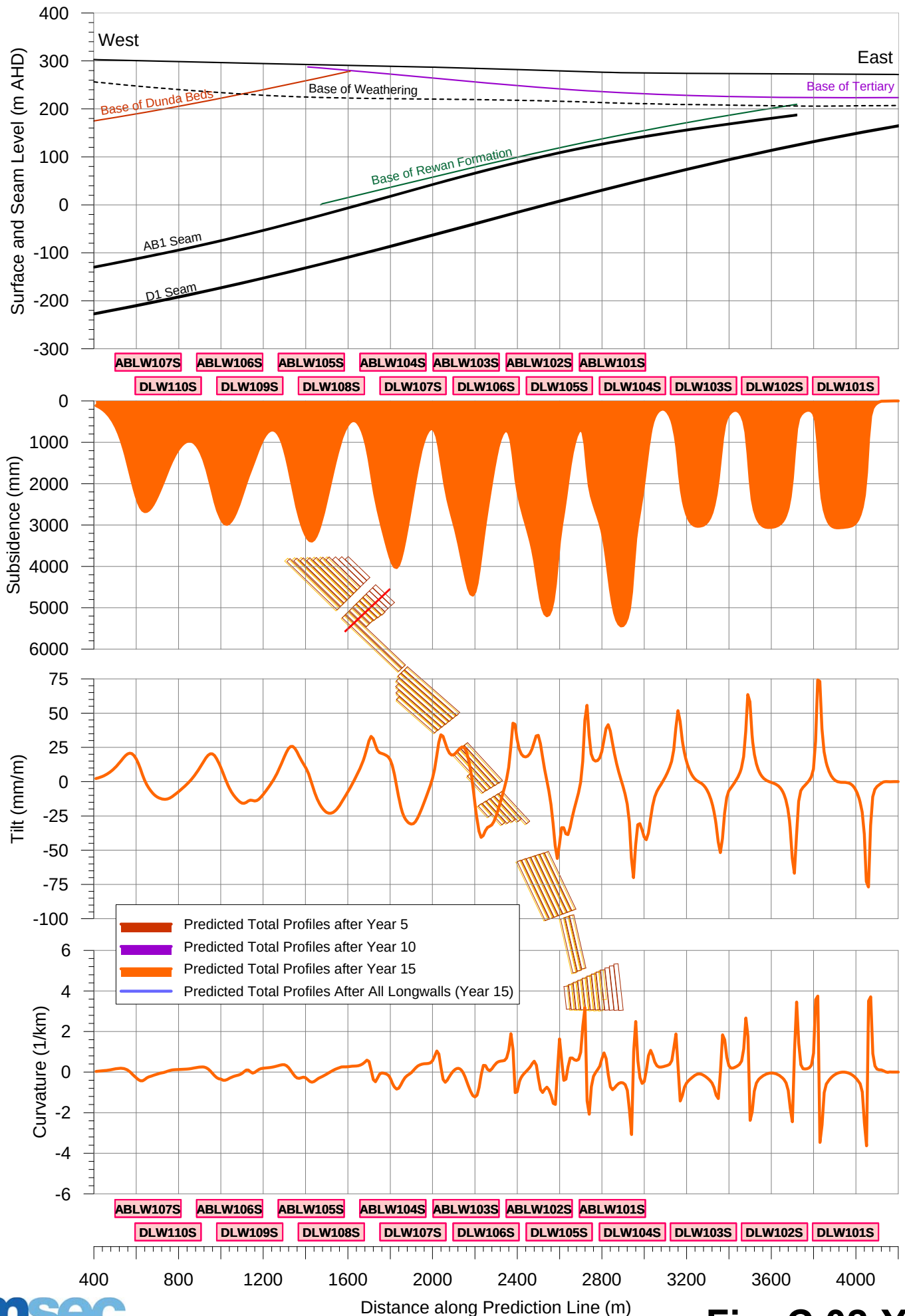
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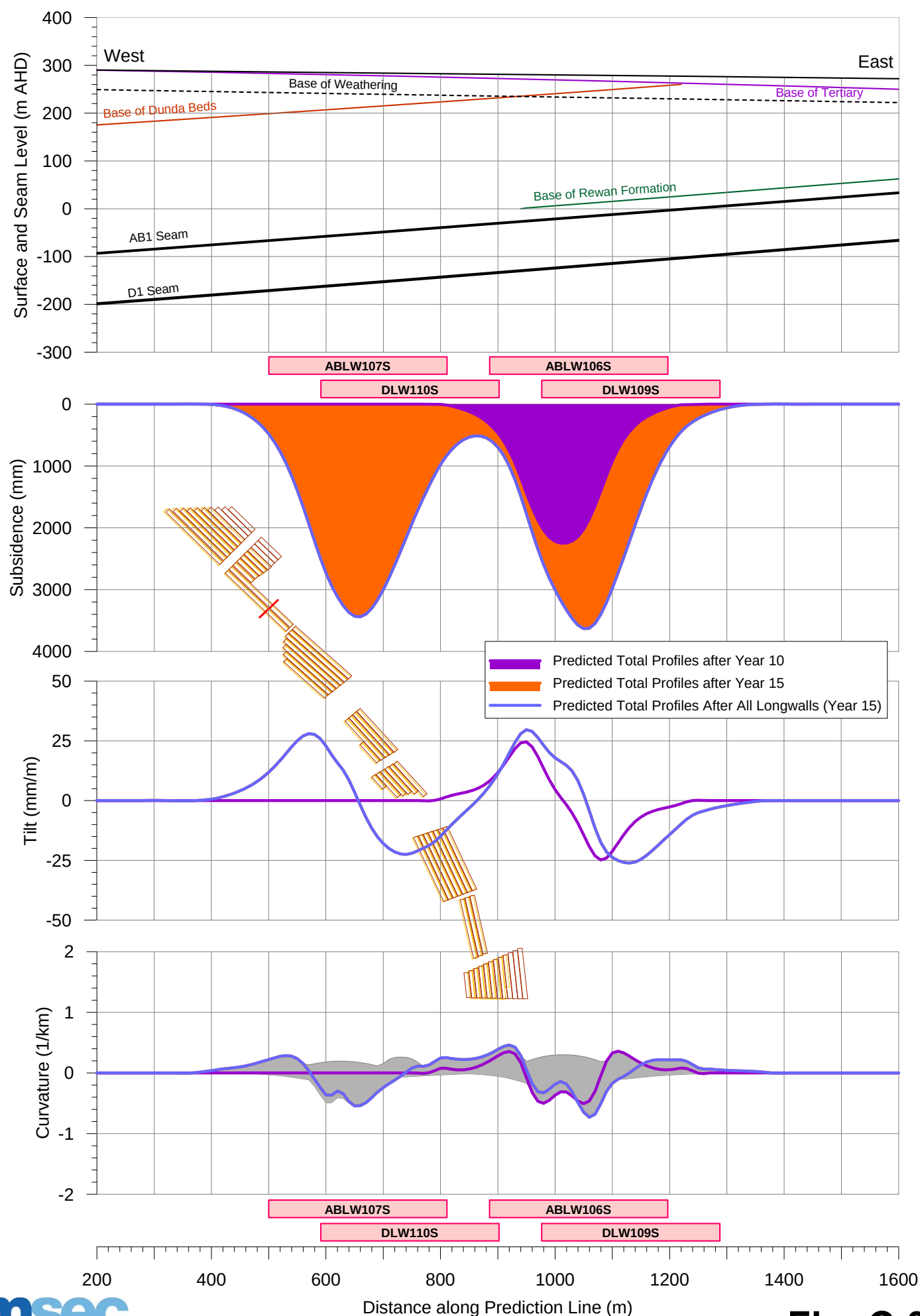
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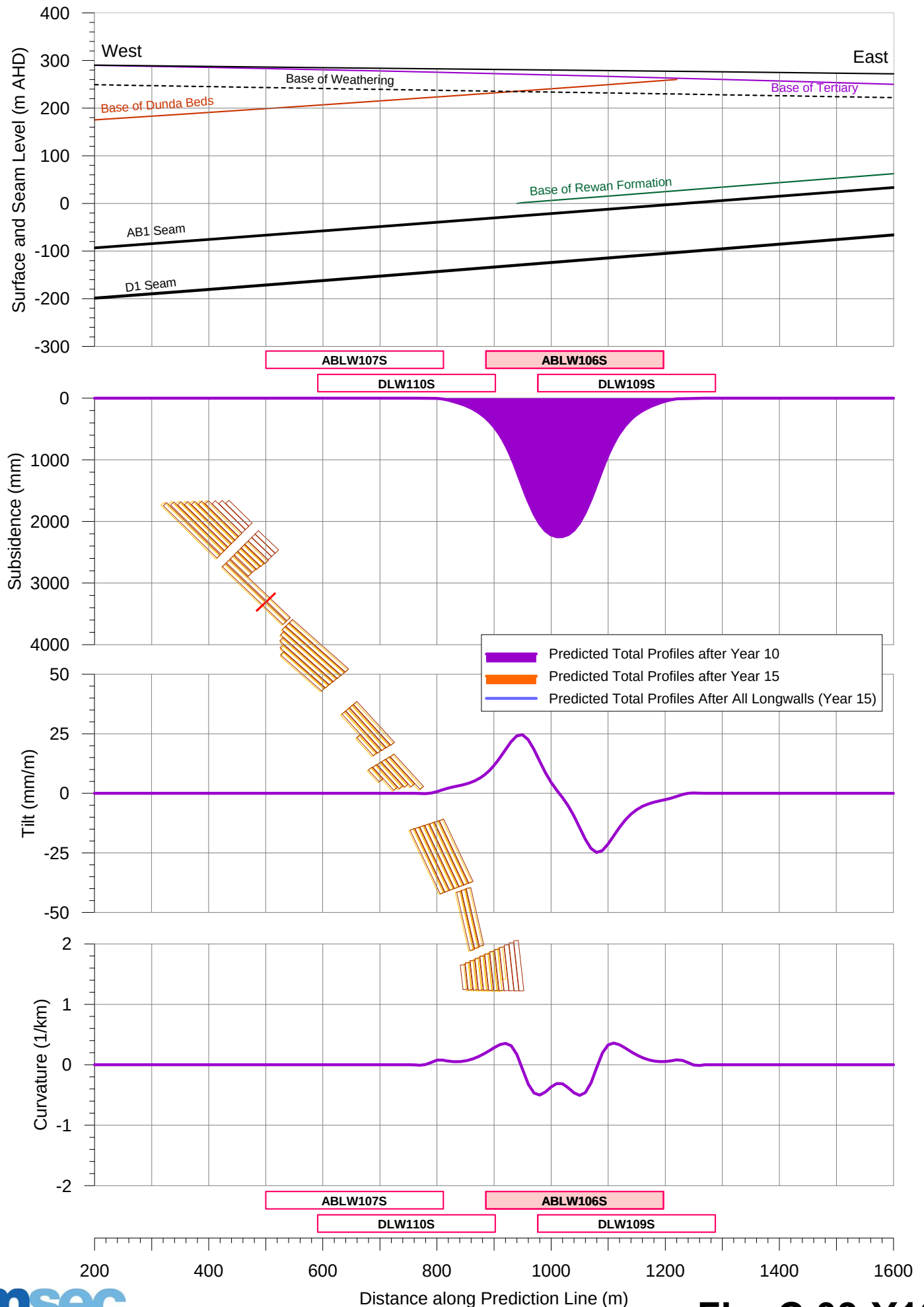
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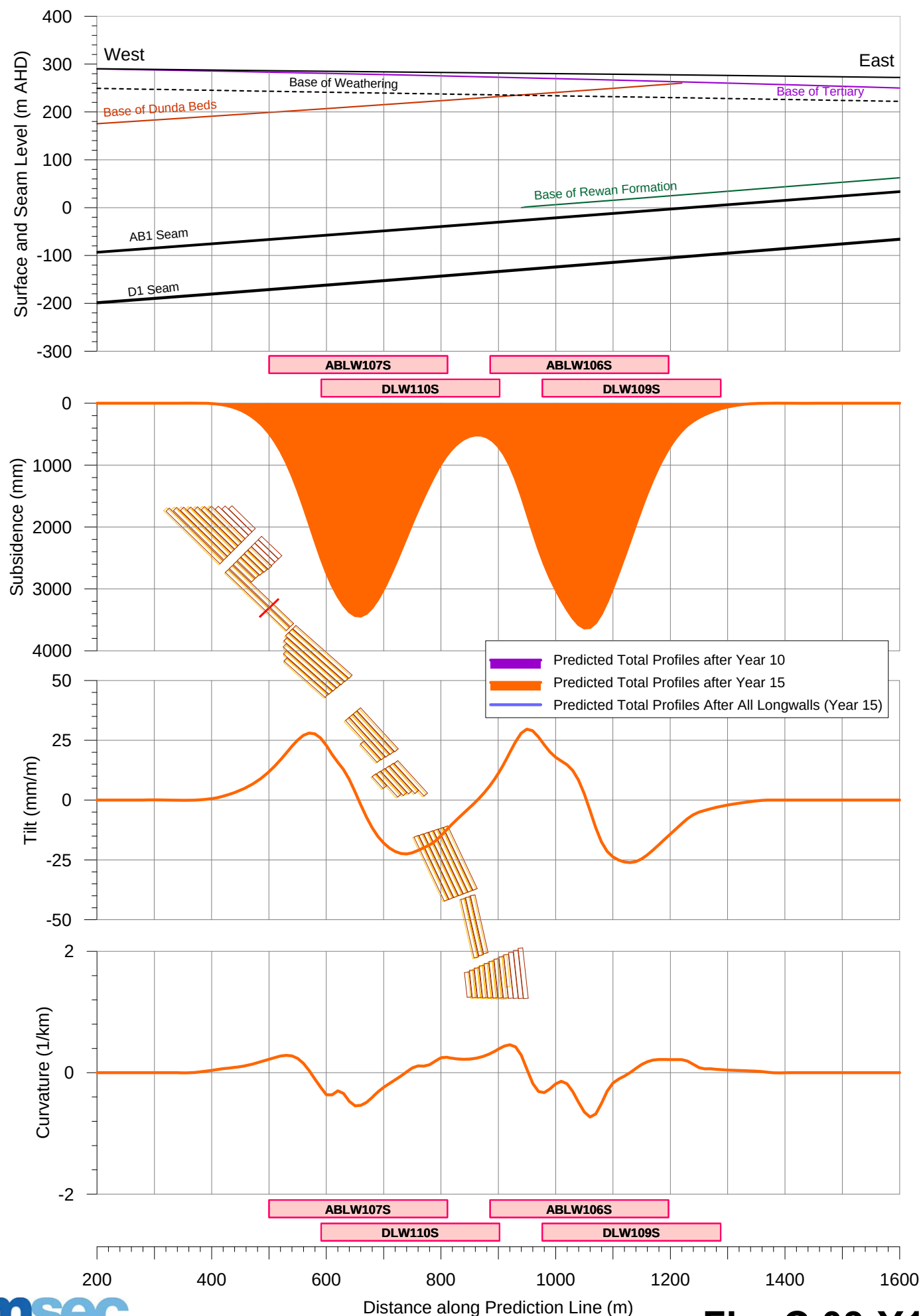
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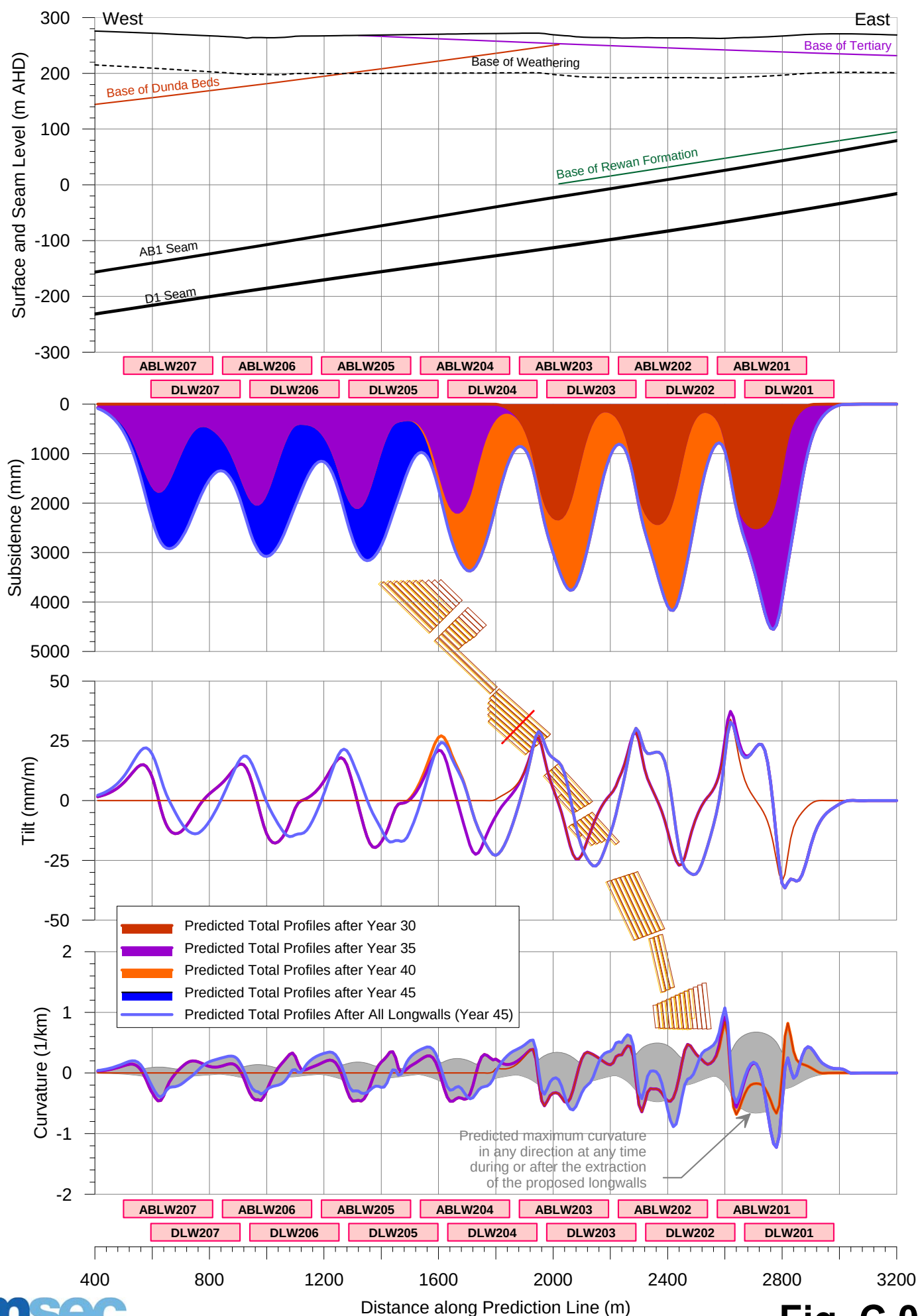
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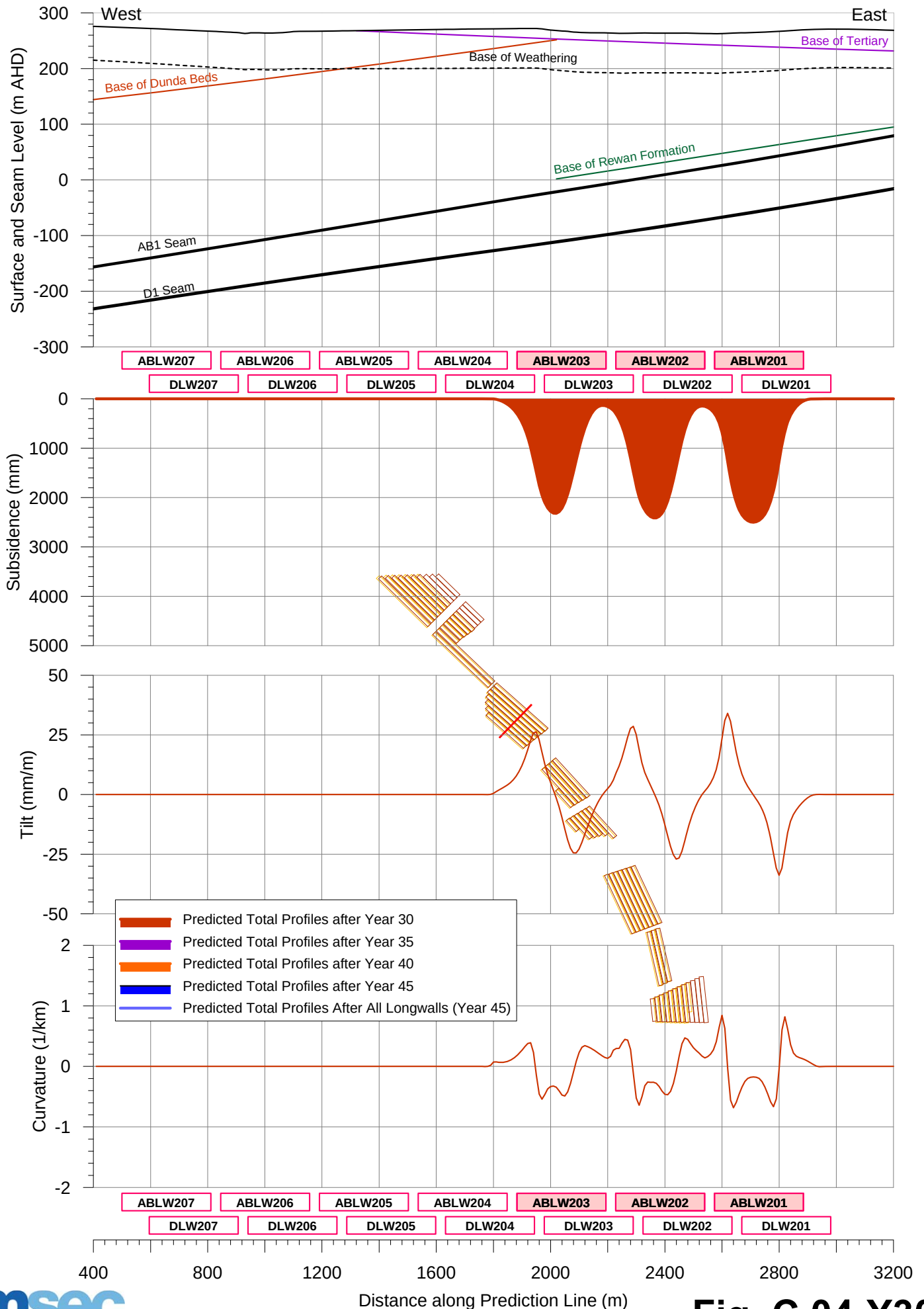
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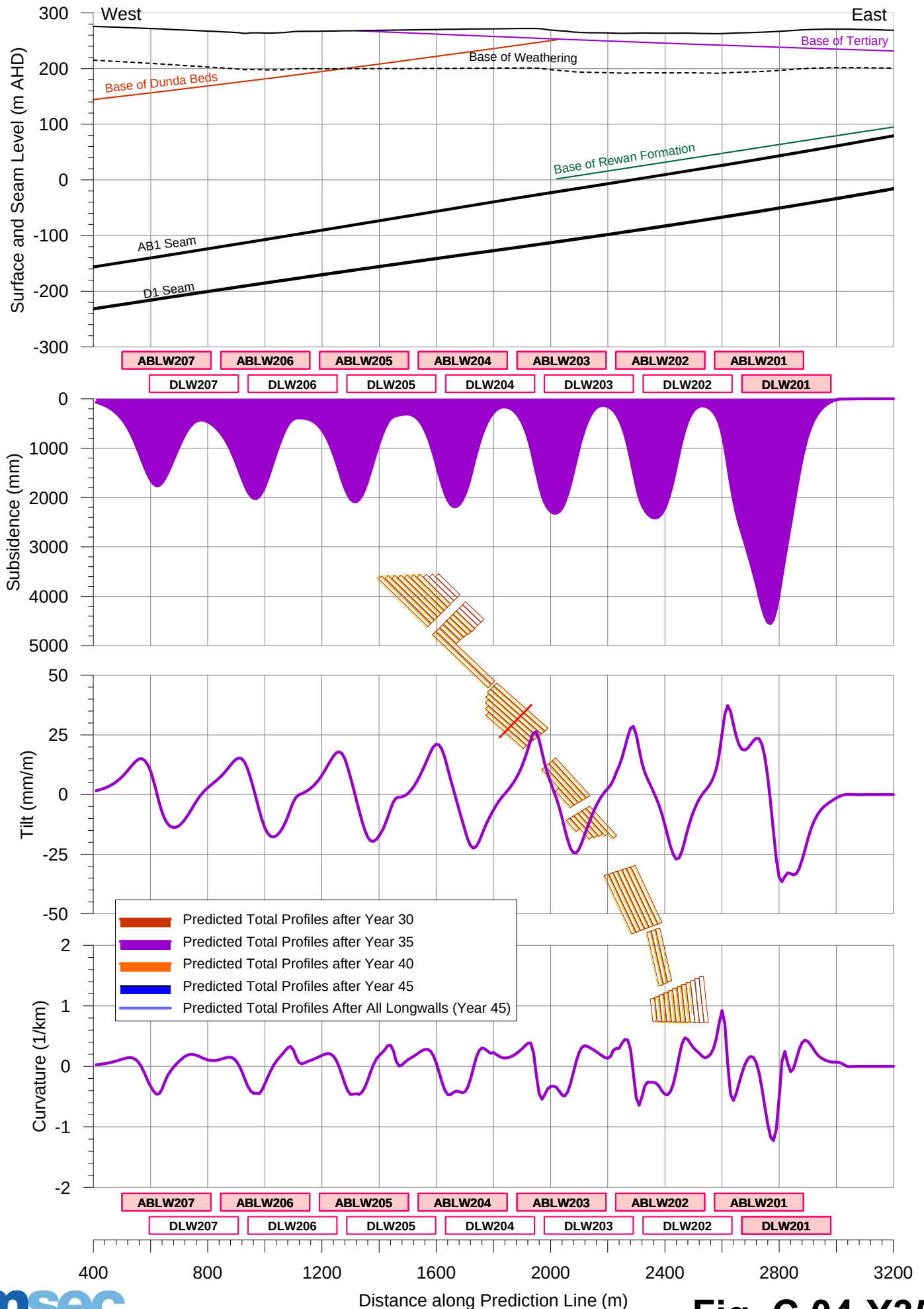
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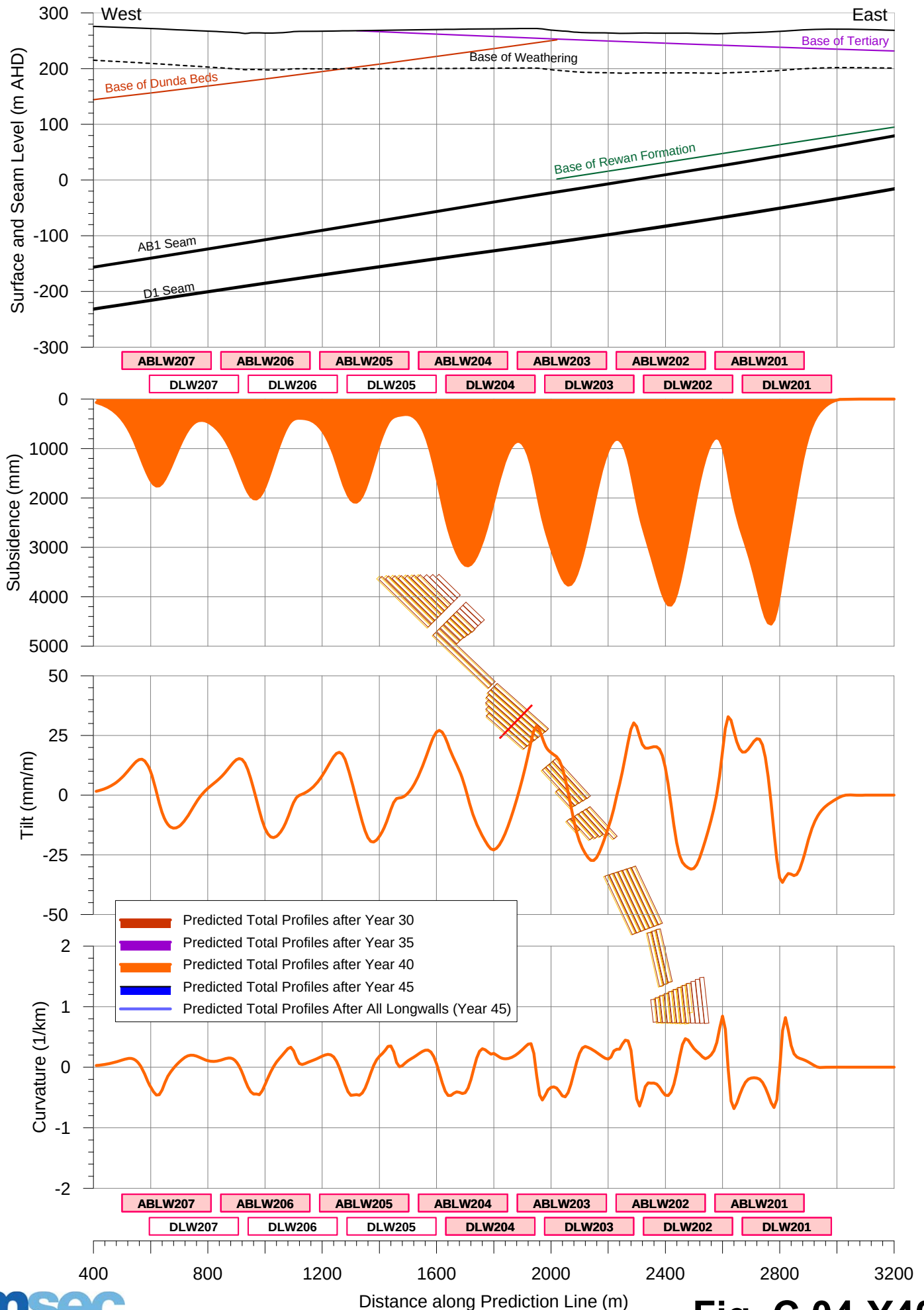
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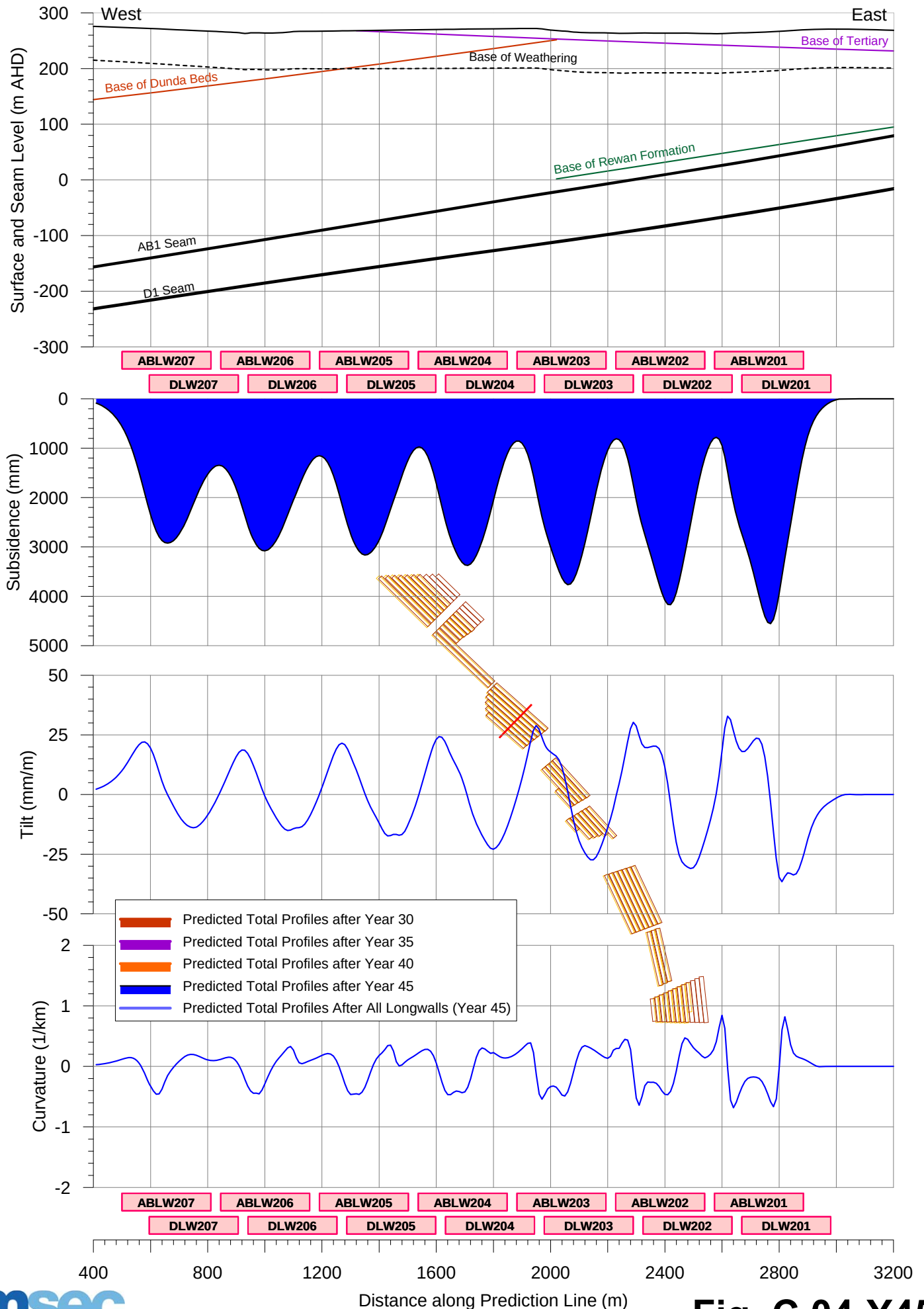
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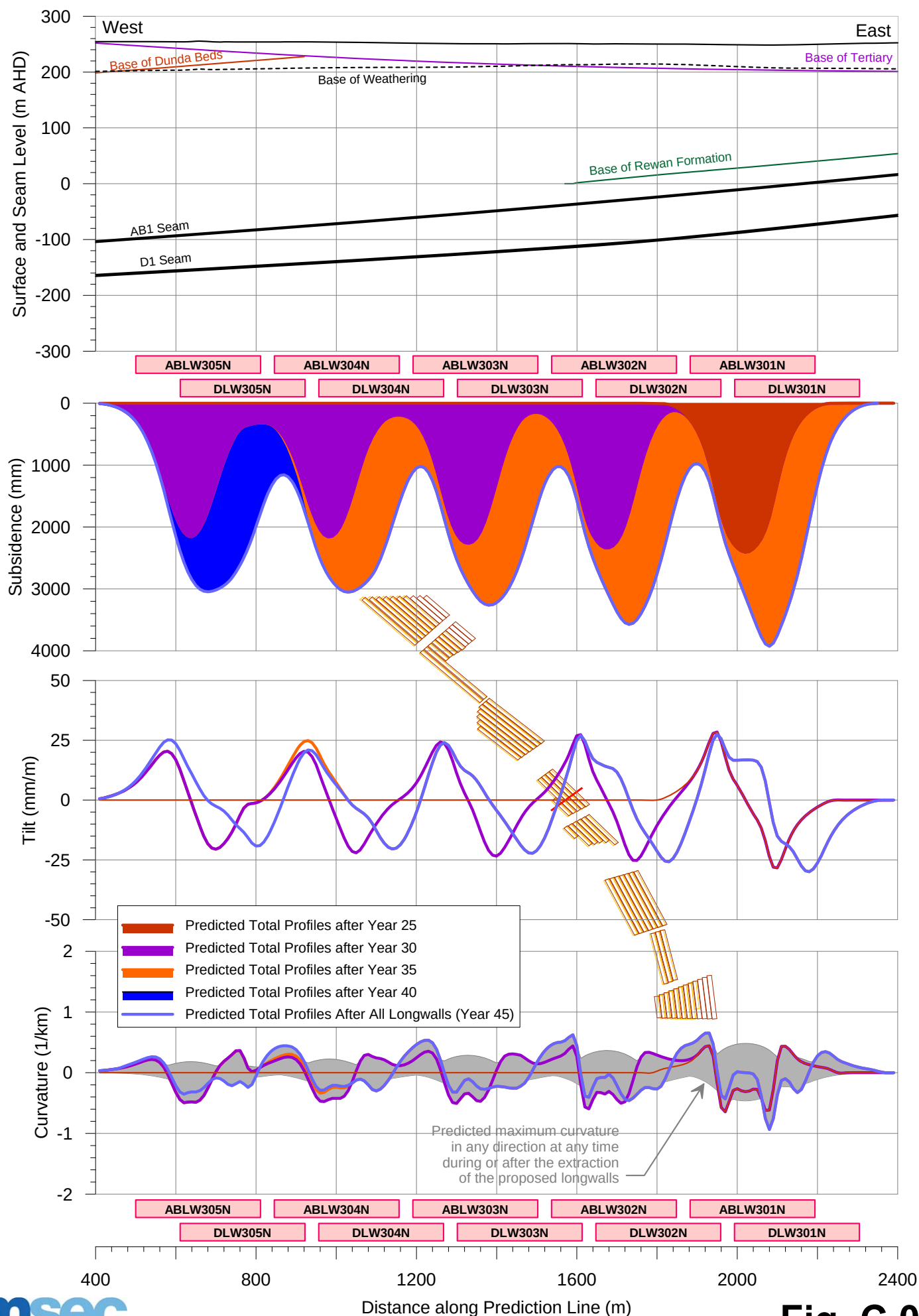
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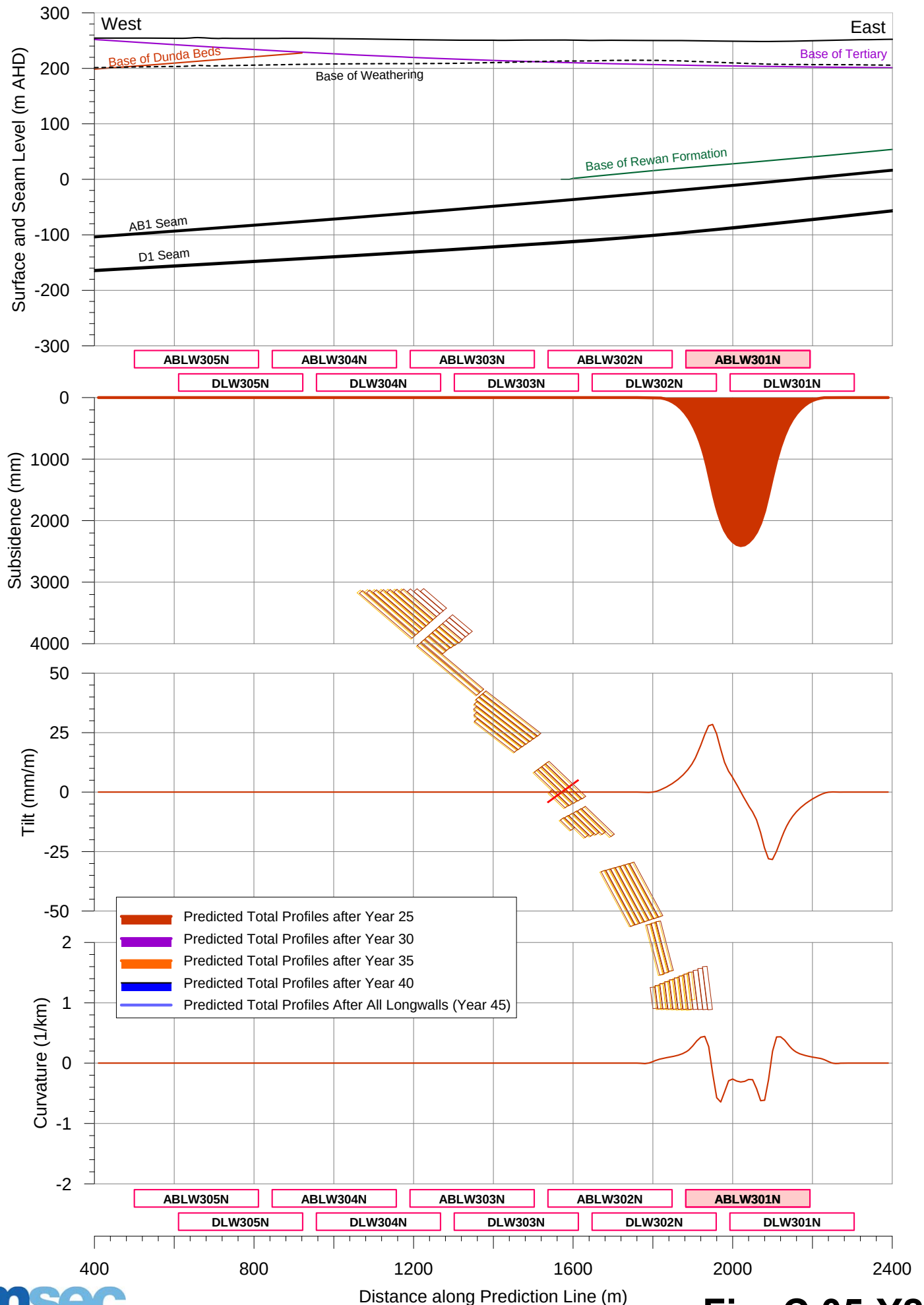
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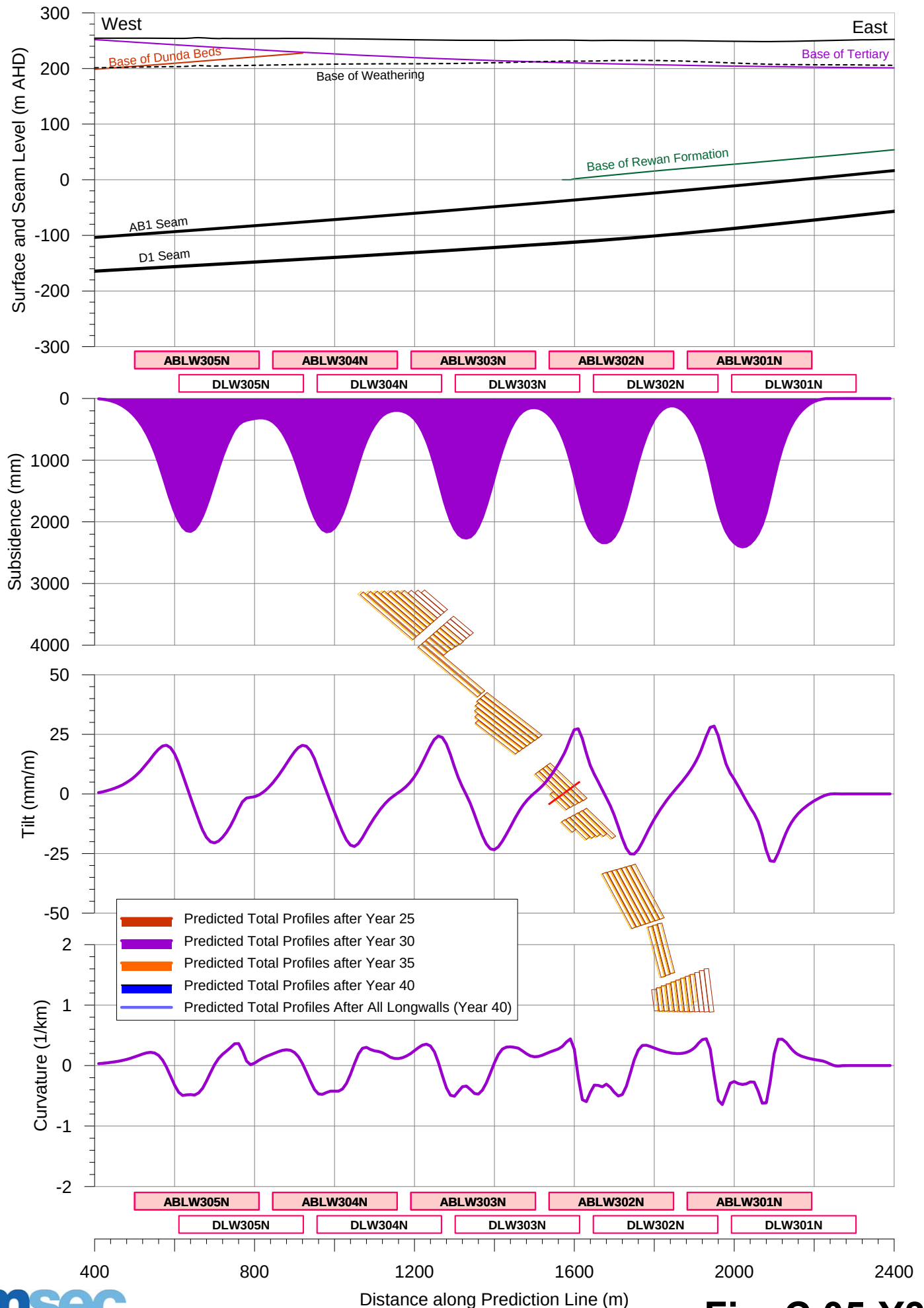
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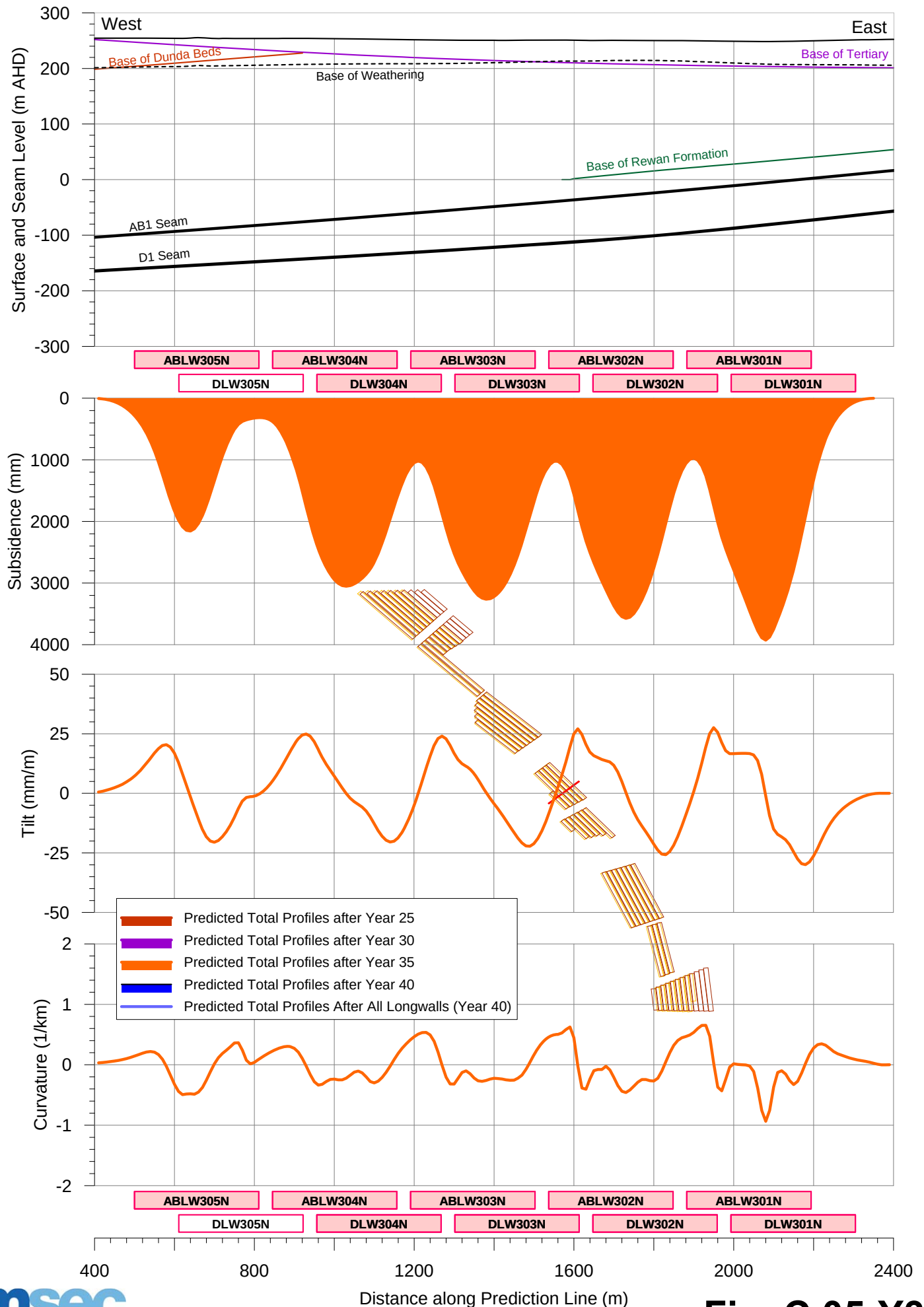
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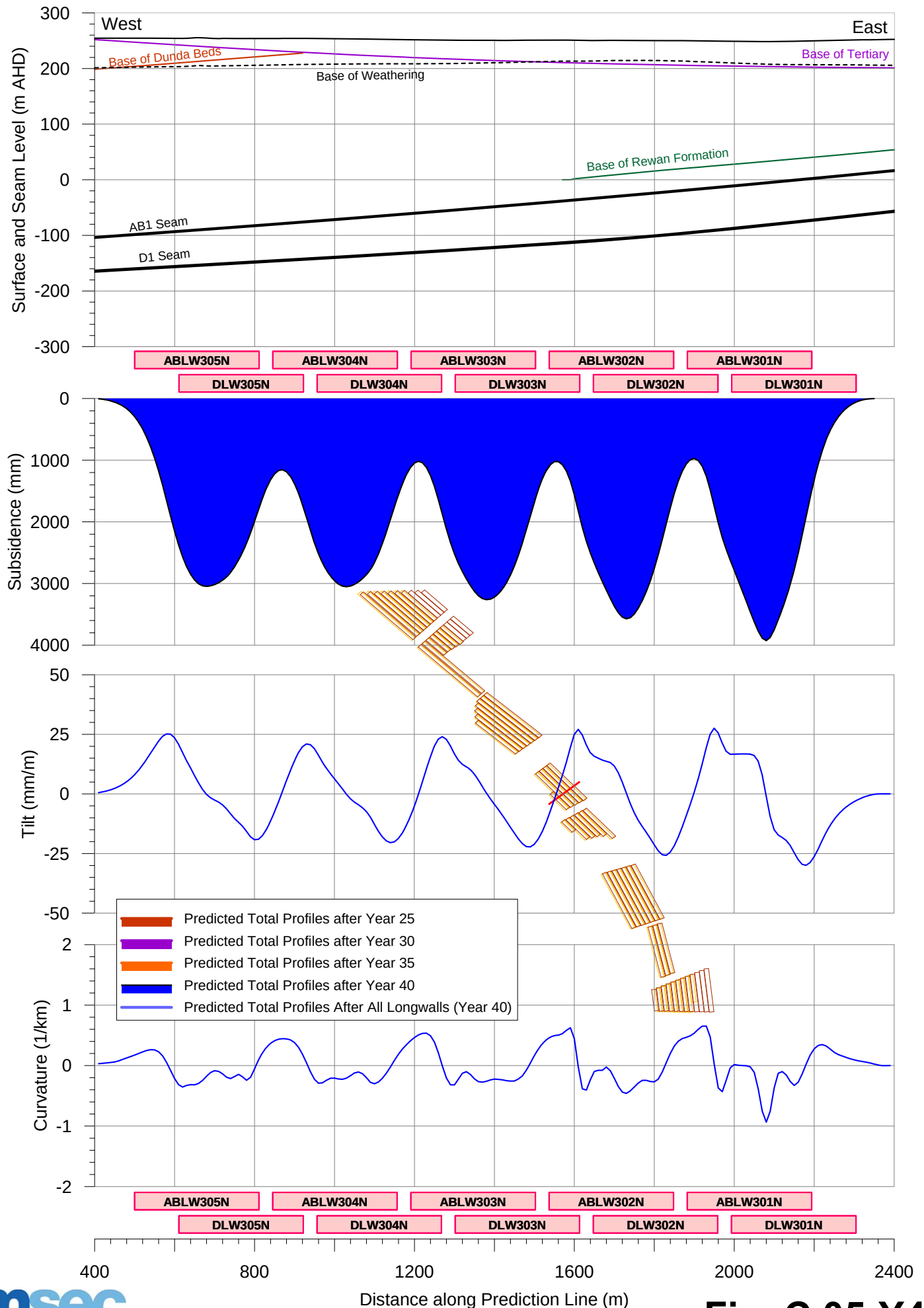
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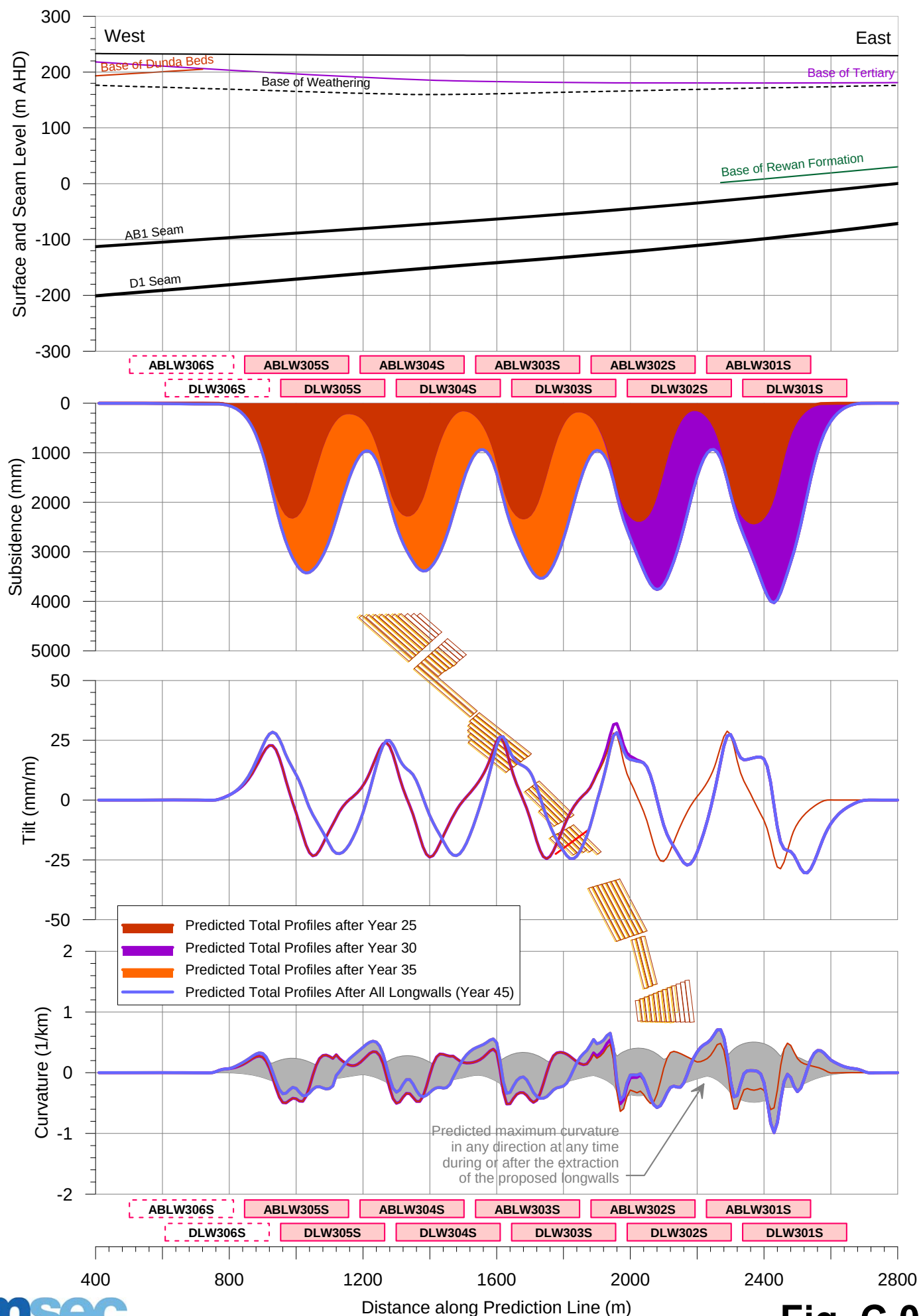
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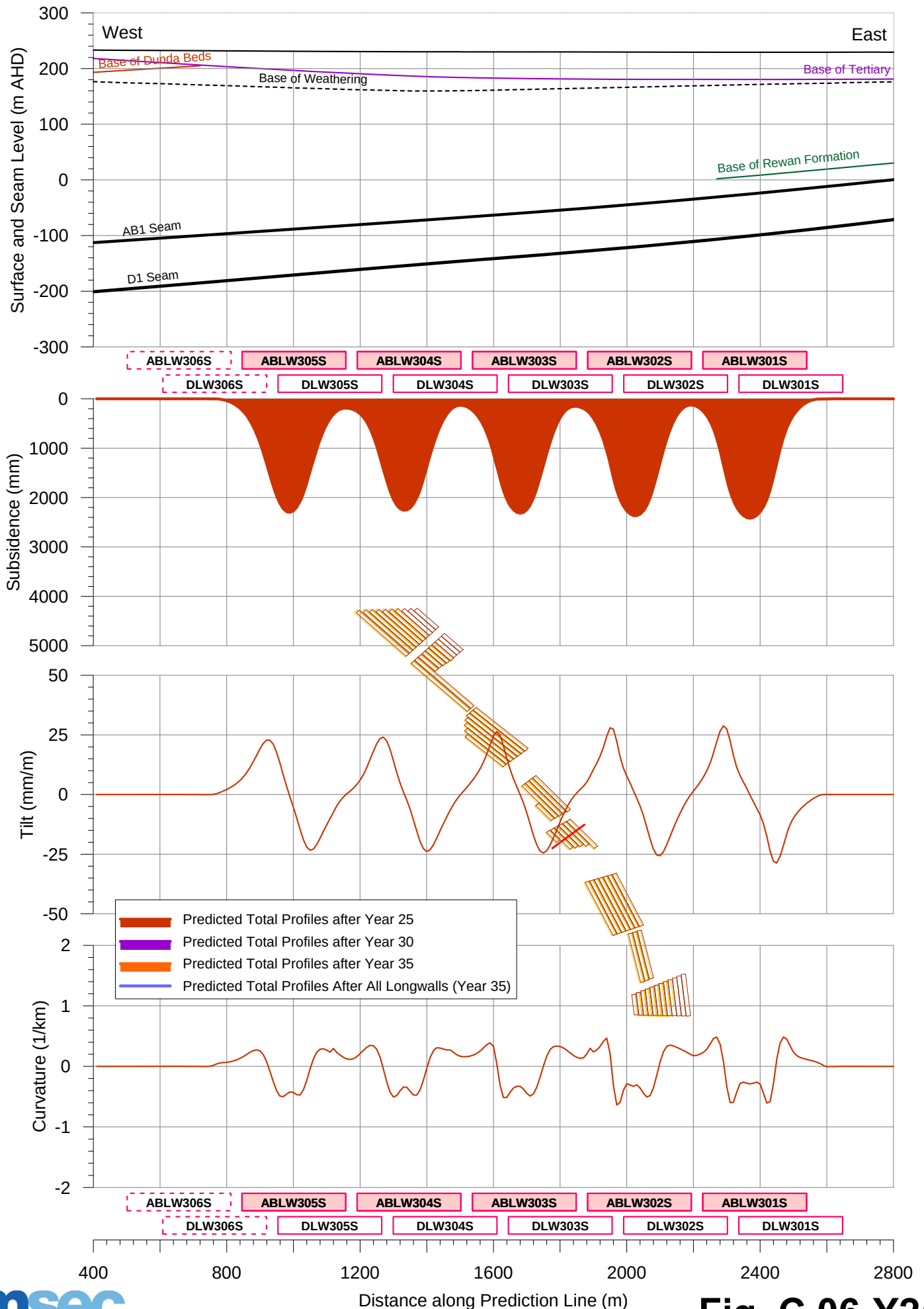
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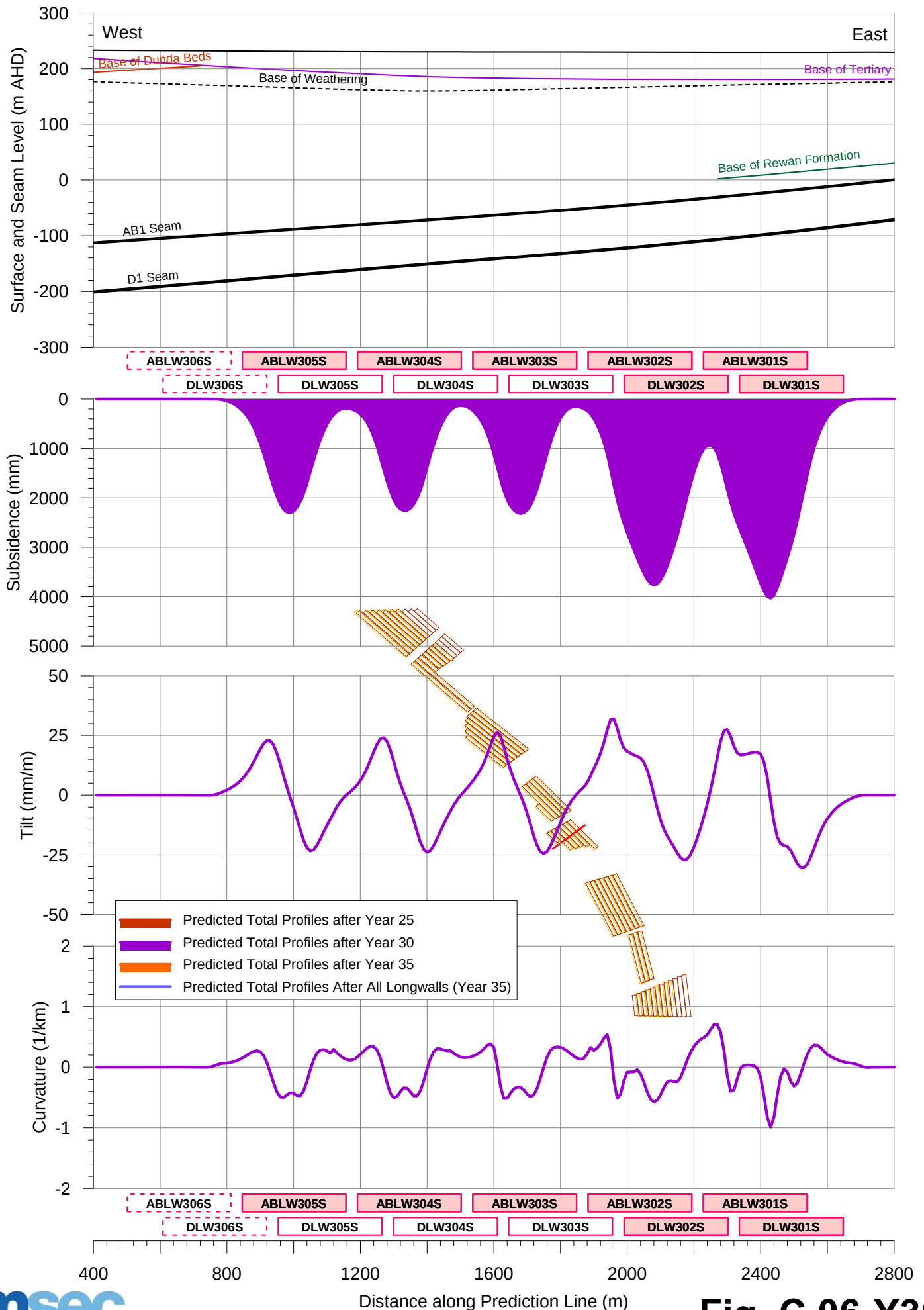
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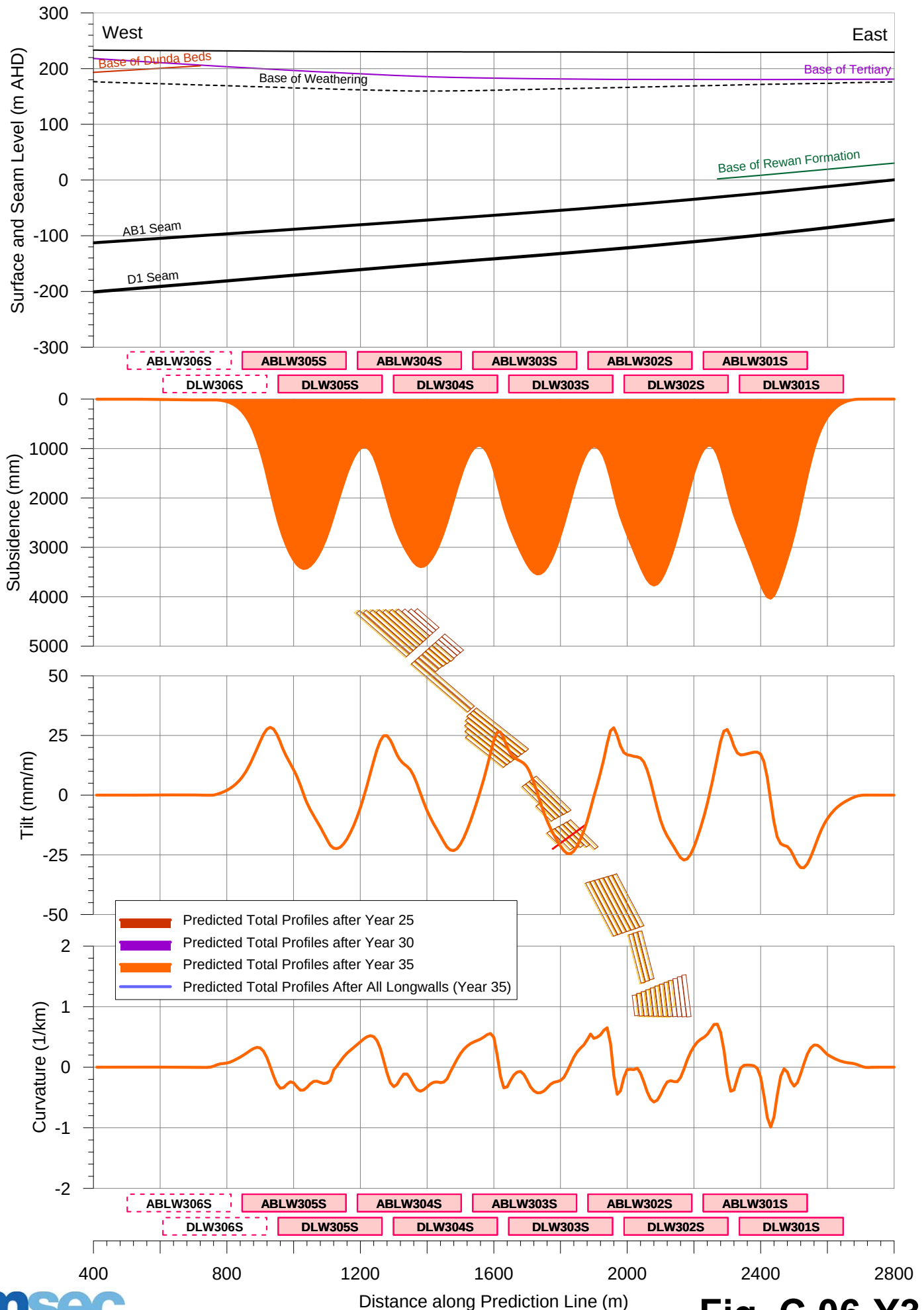
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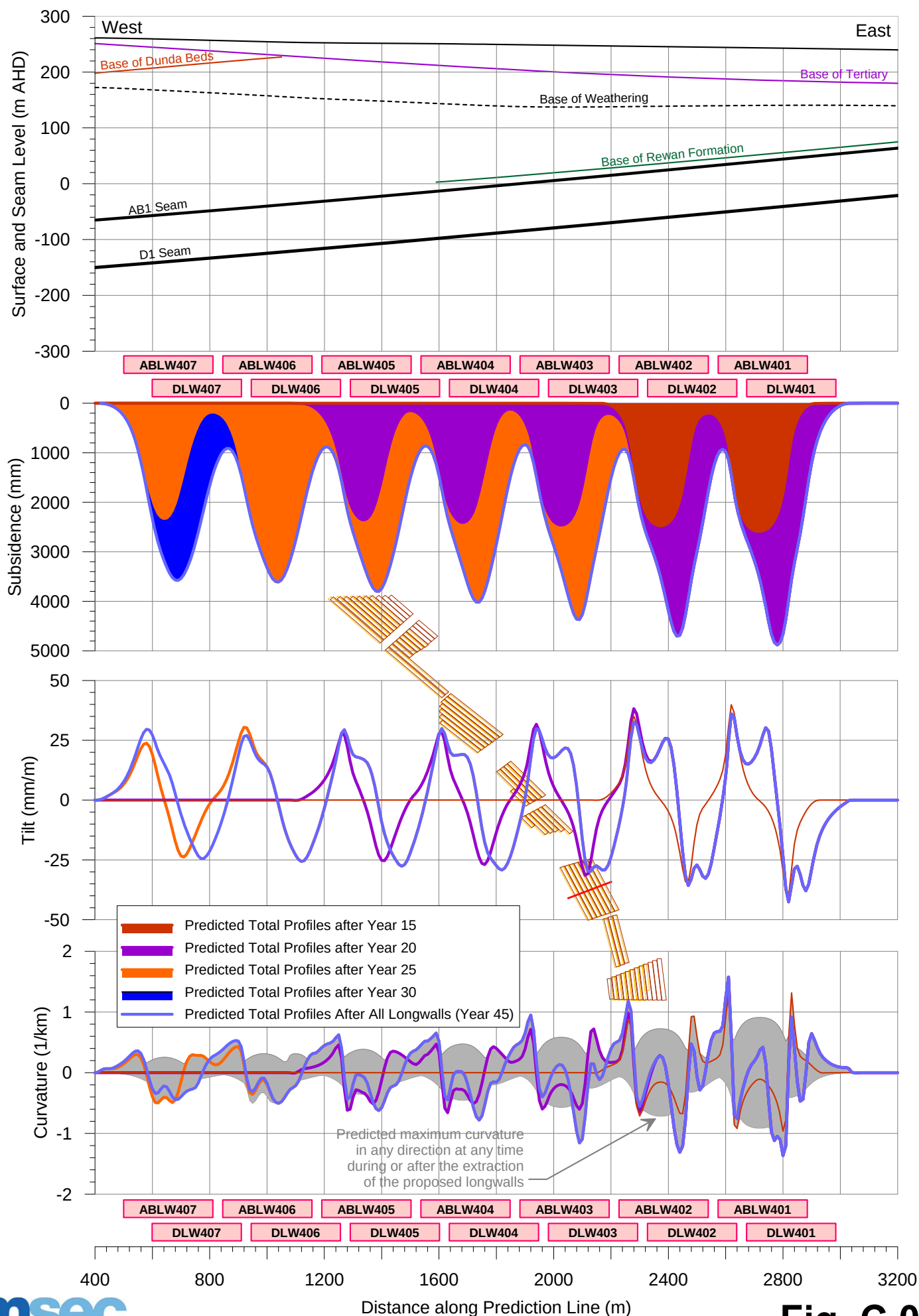
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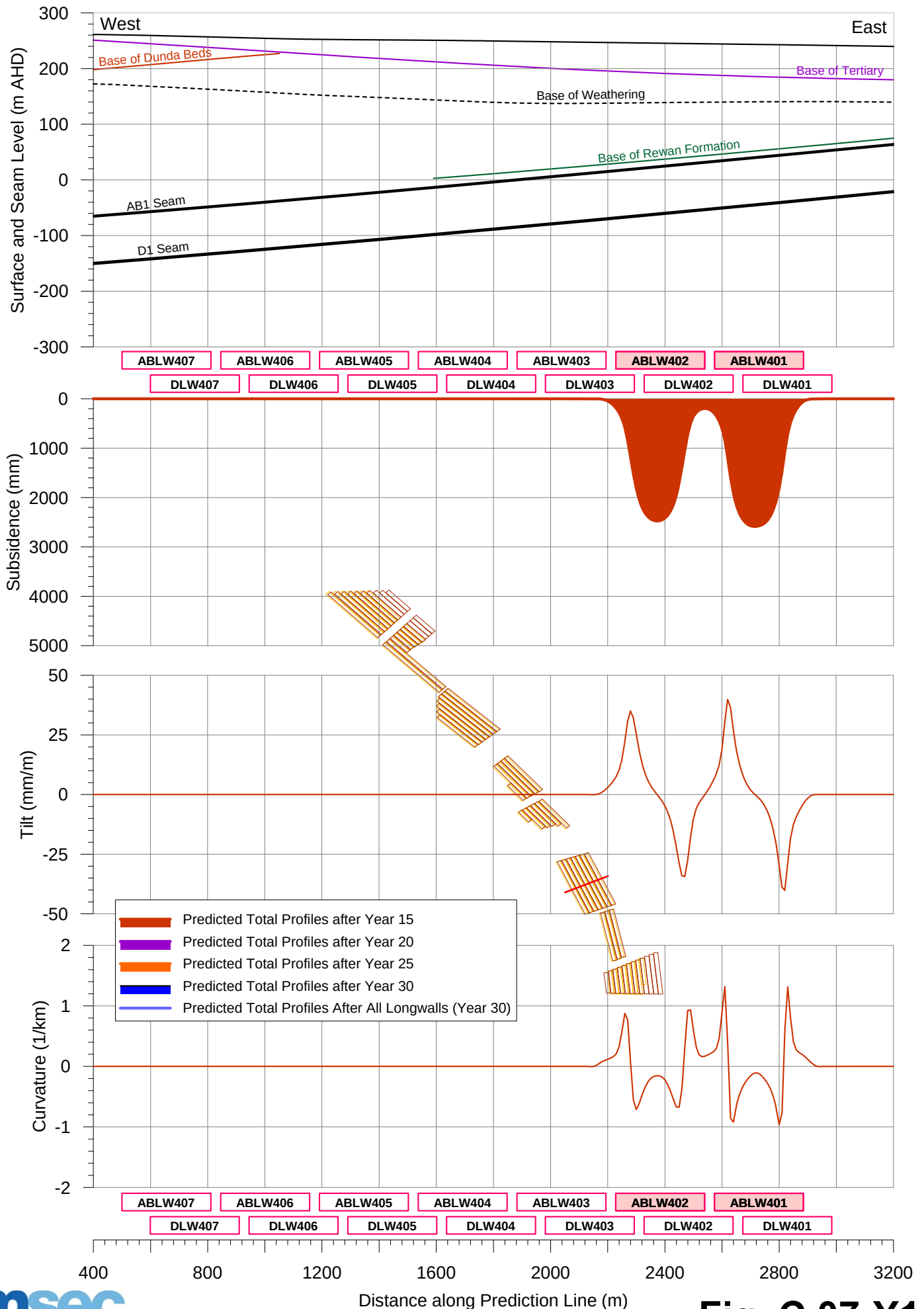
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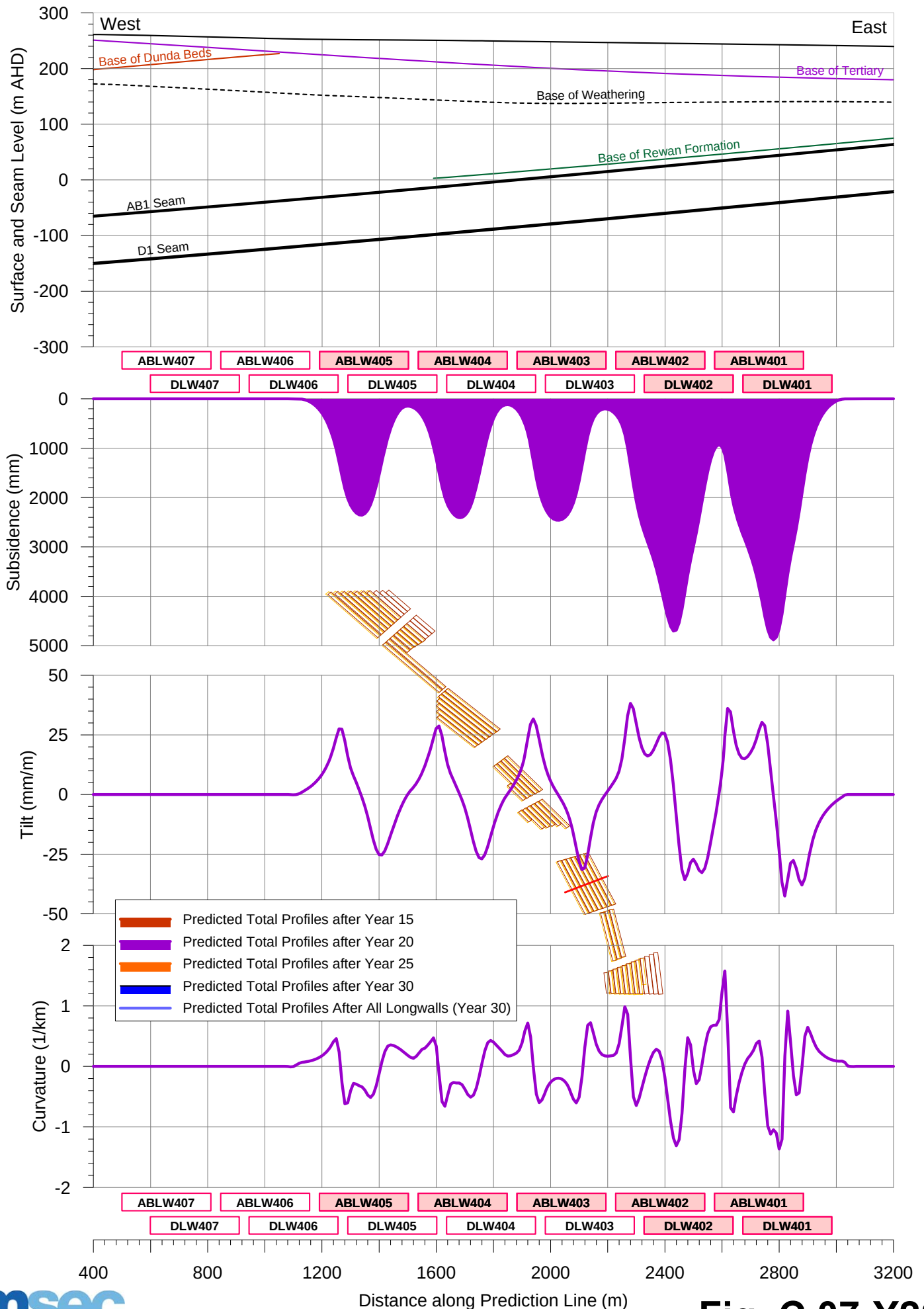
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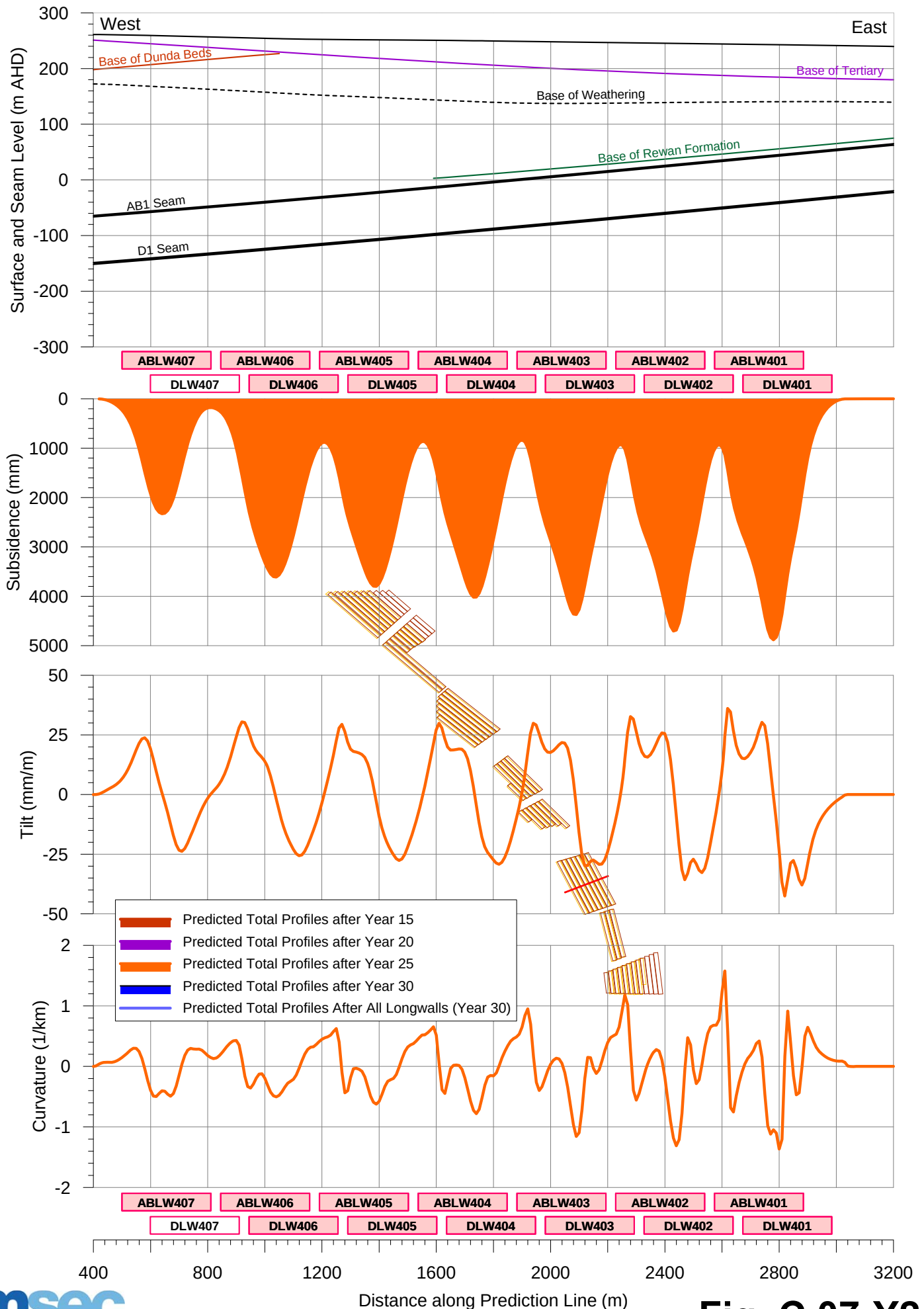
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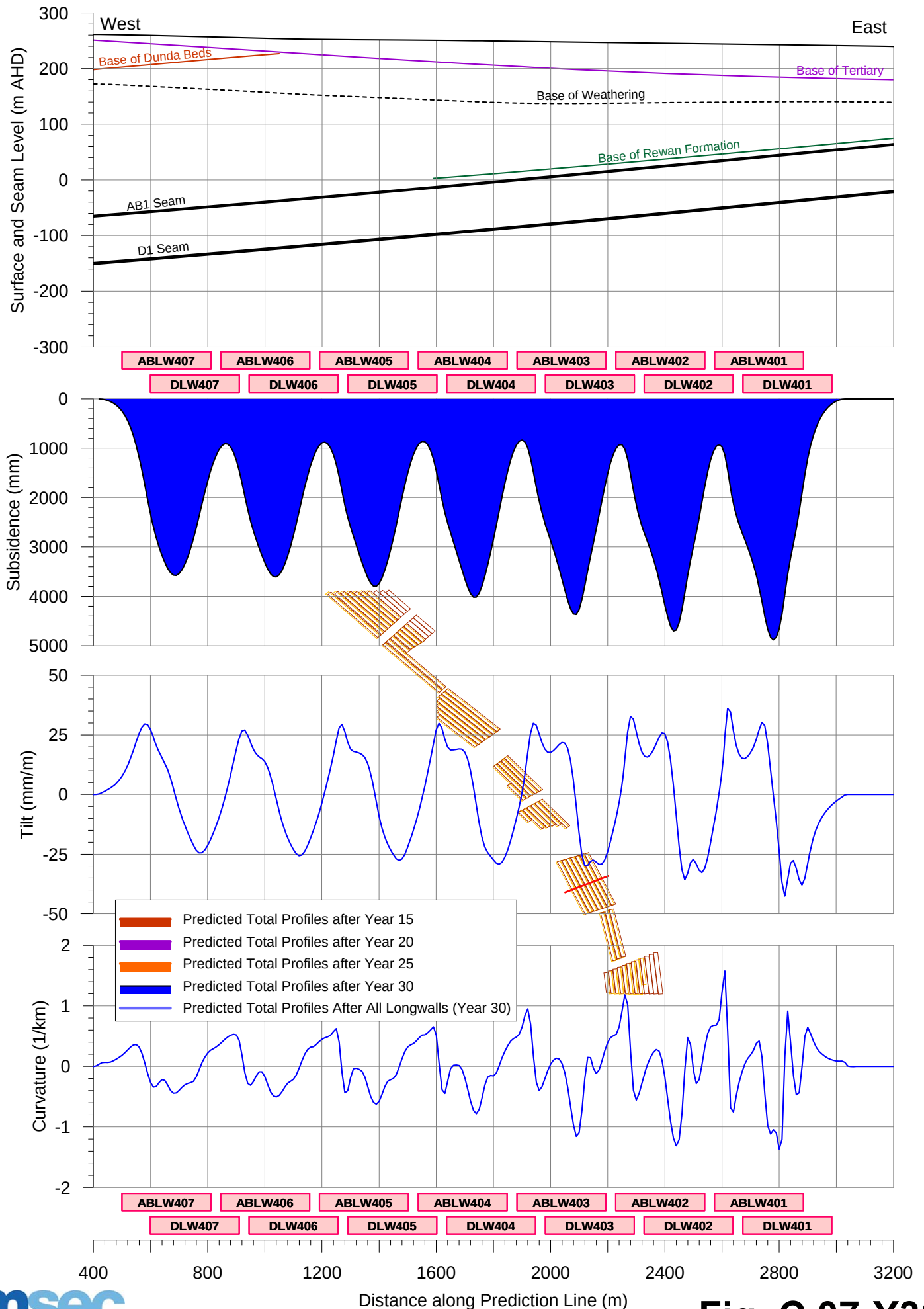
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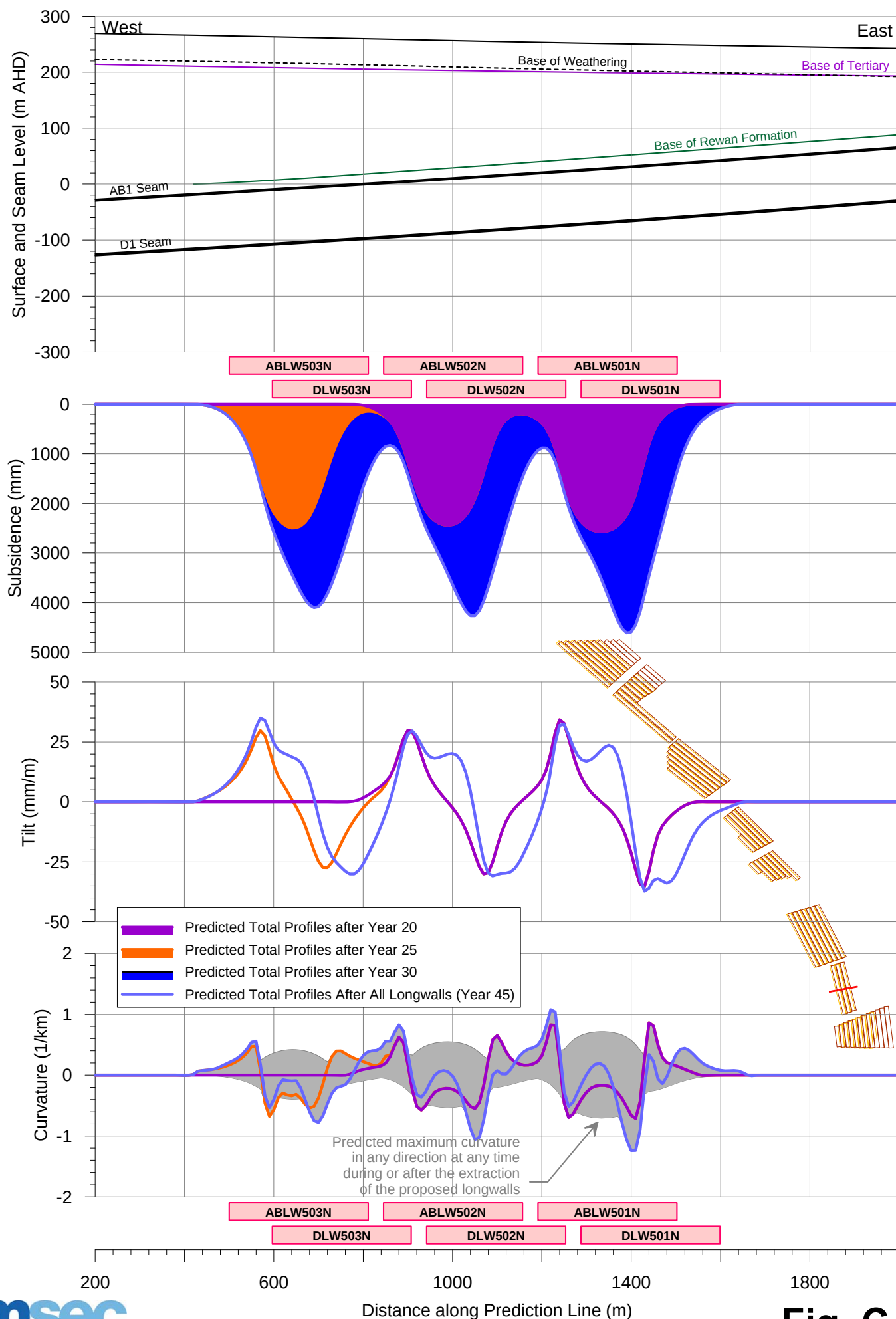
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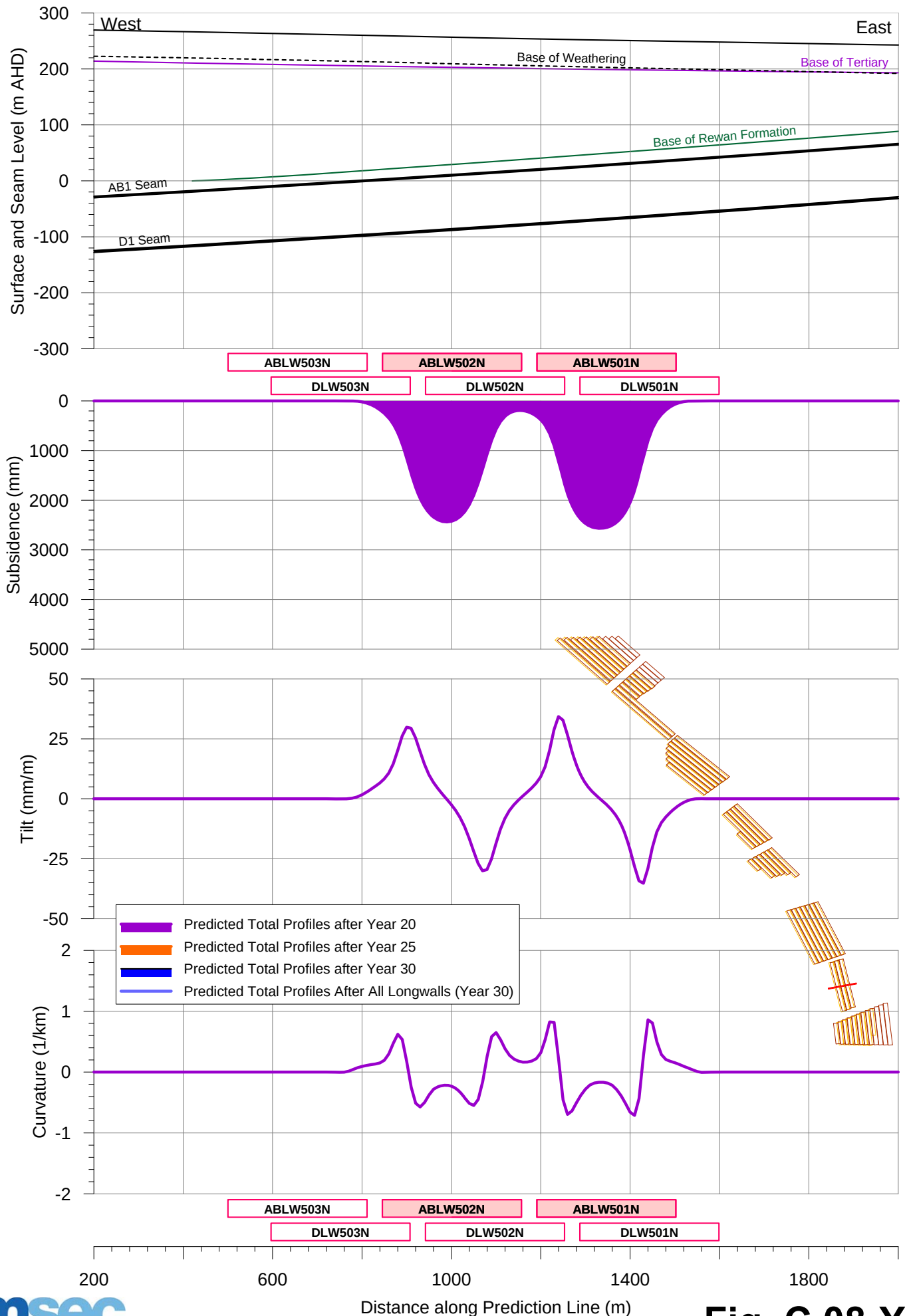
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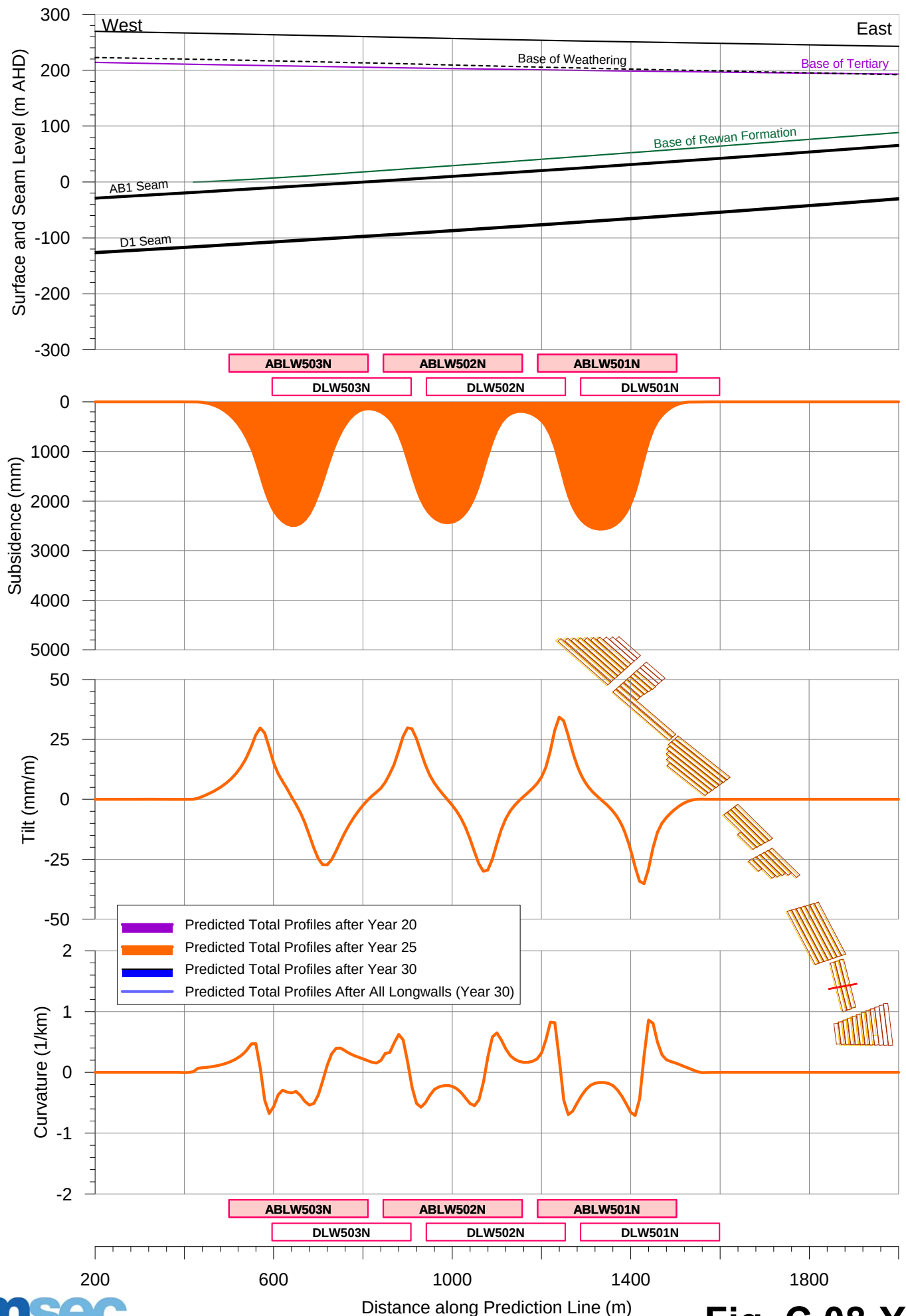
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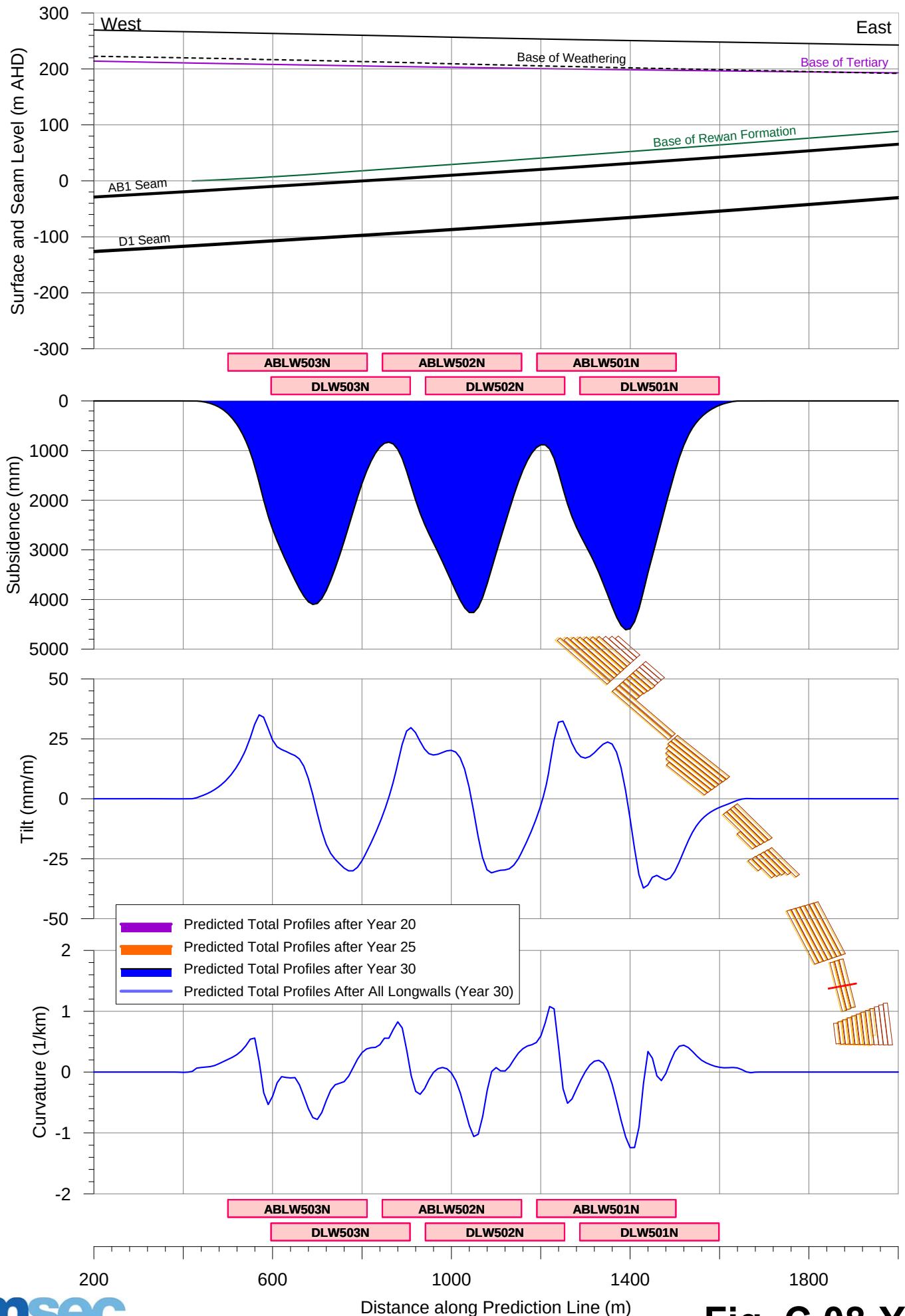
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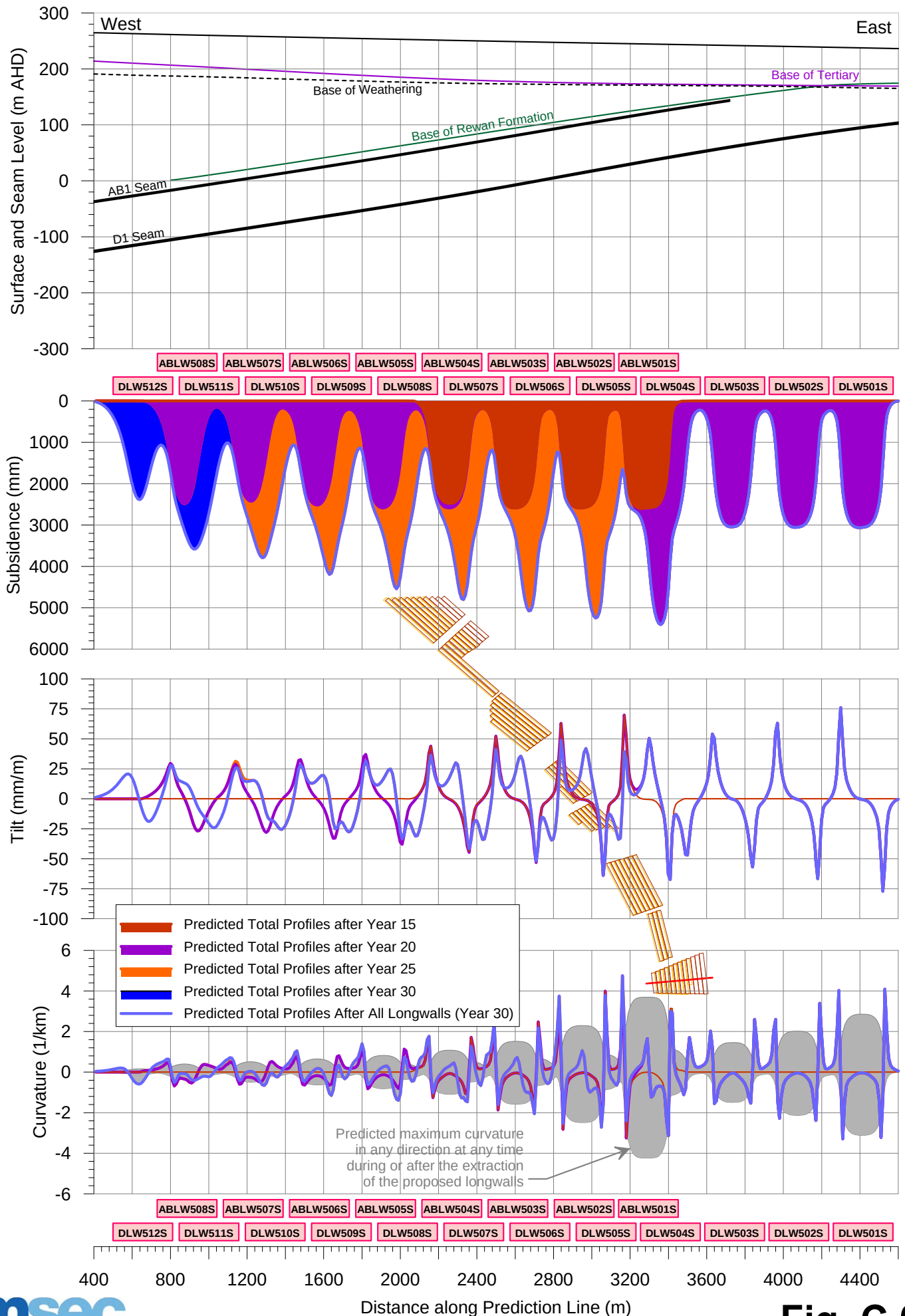
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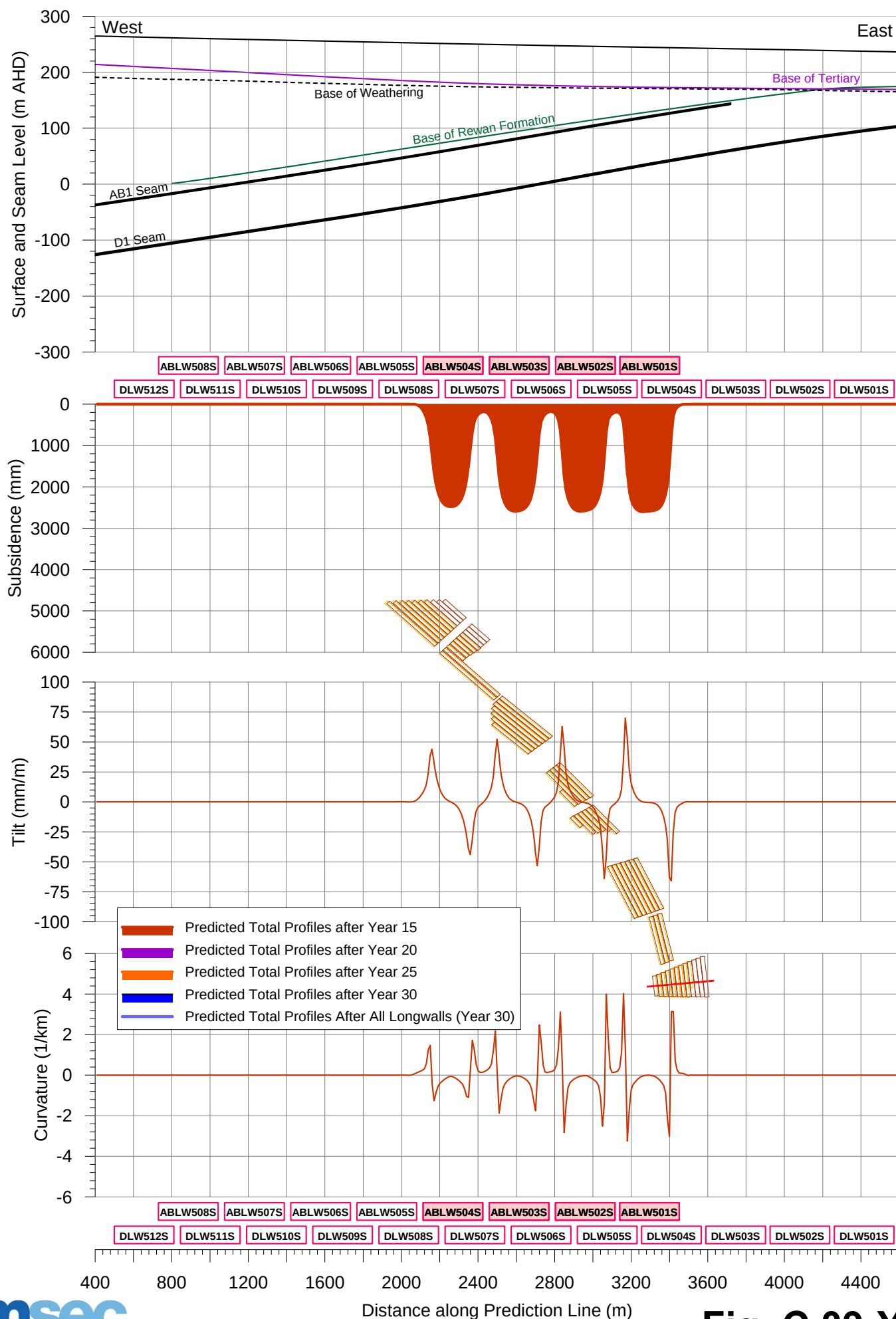
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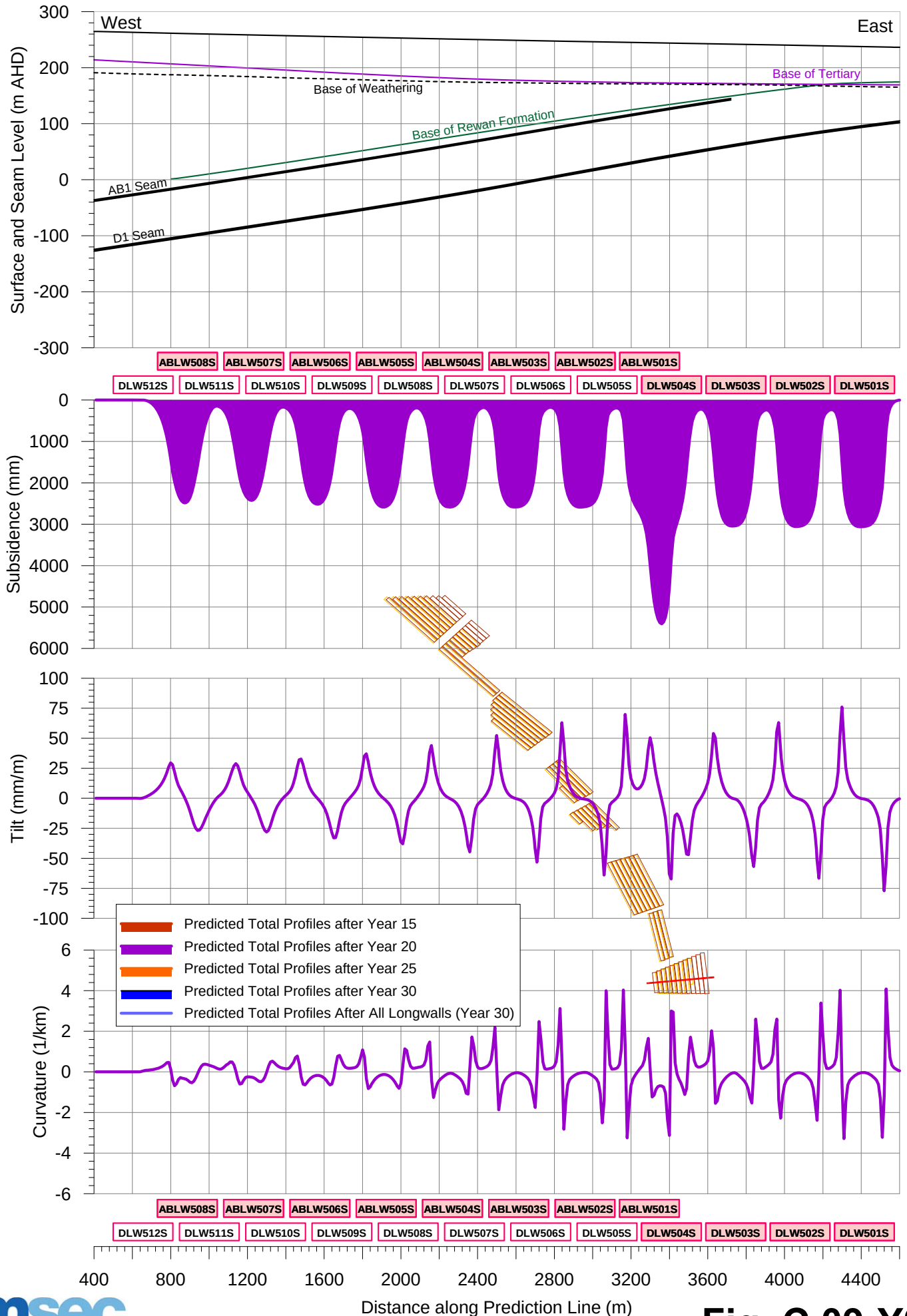
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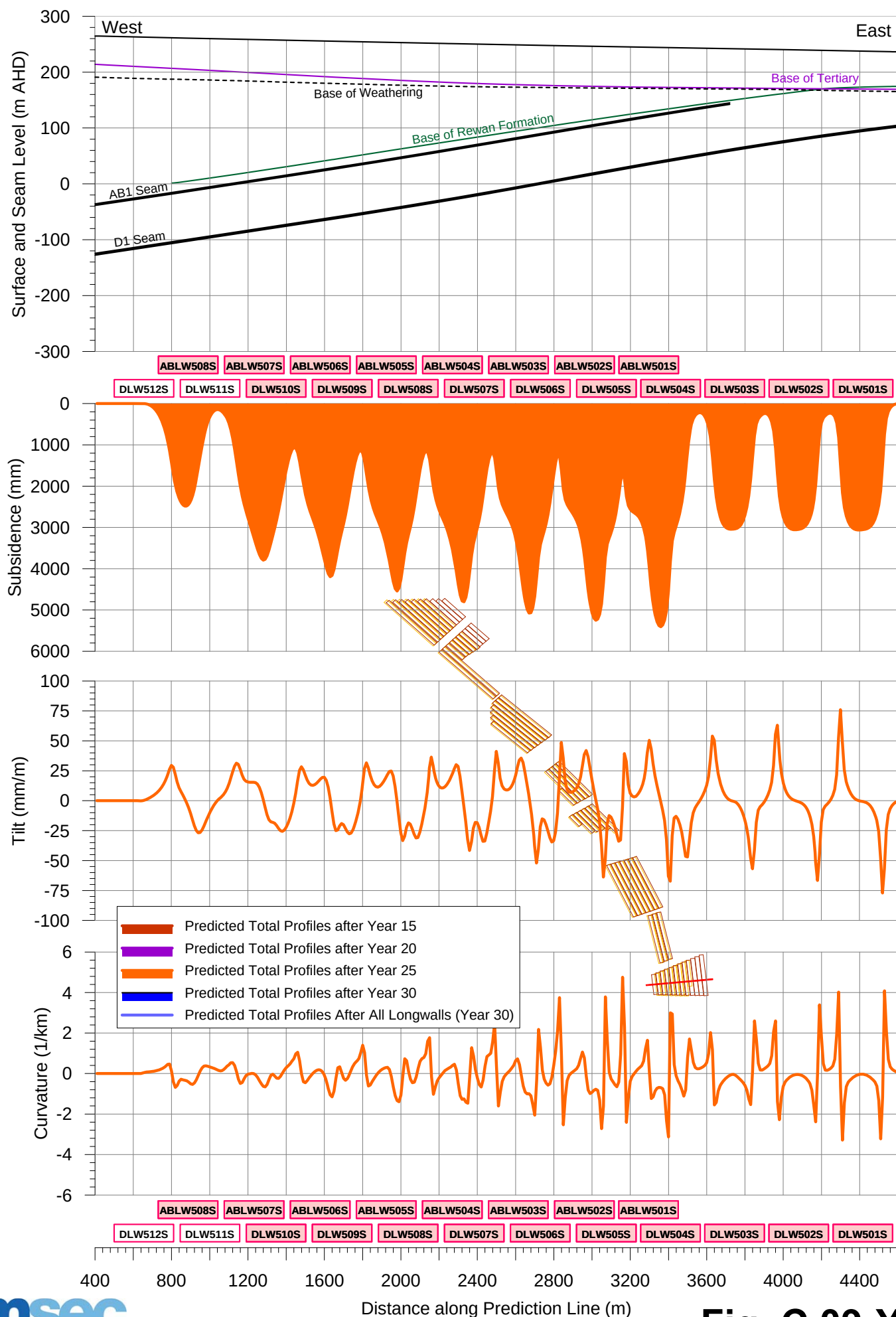
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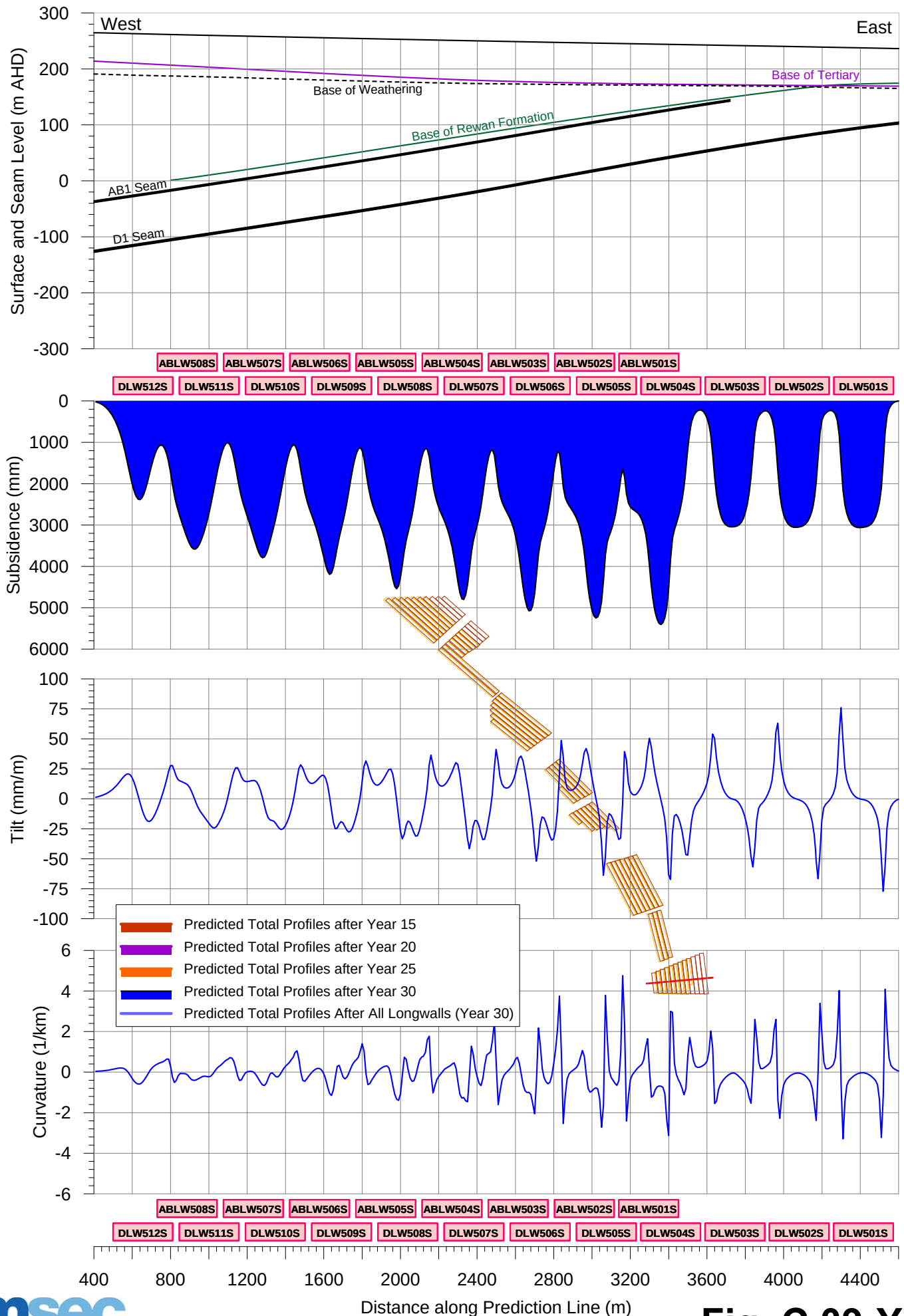
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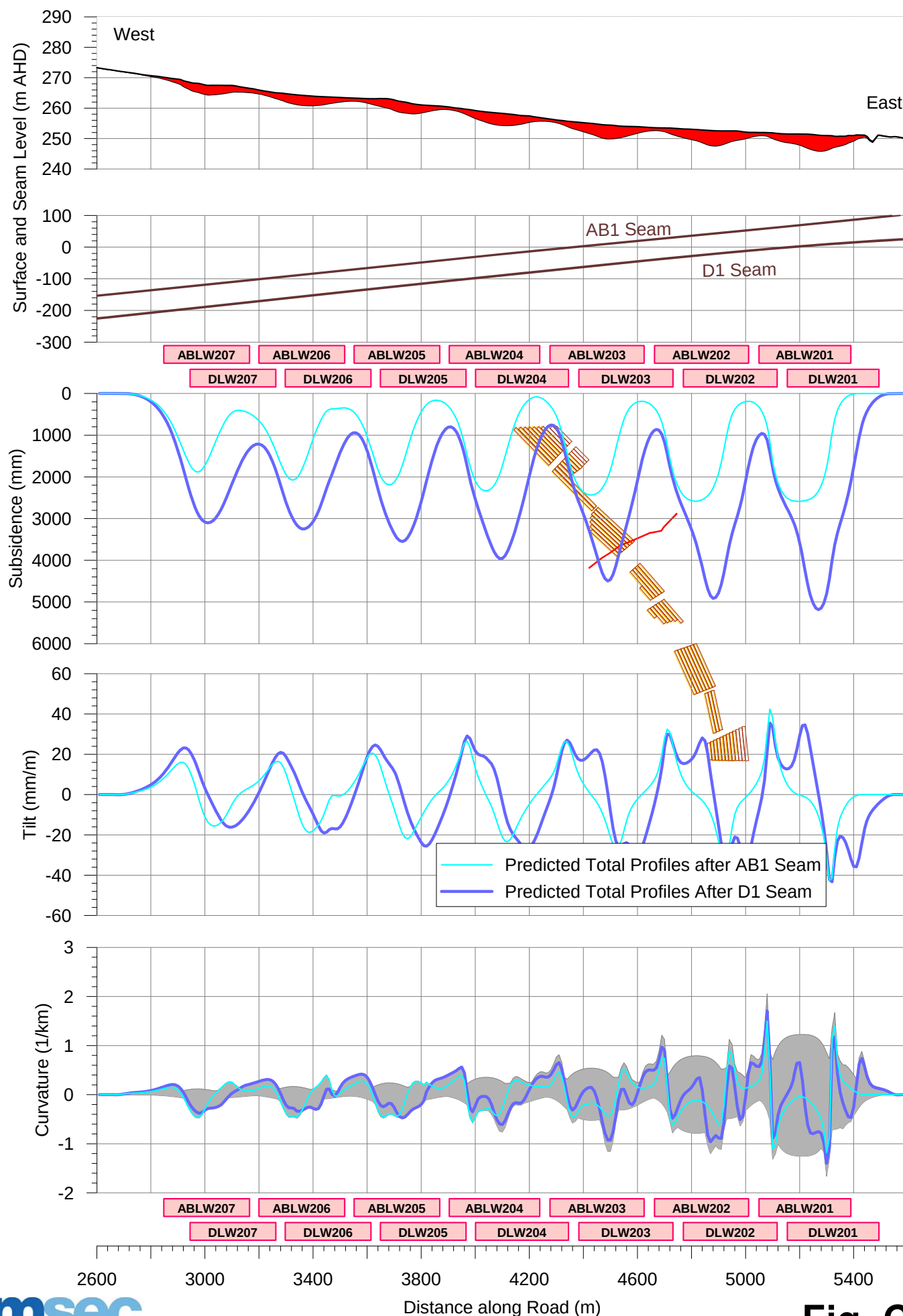
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 9 due to AB1 and D1 Seams - Year 25



Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 9 due to AB1 and D1 Seams - Year 30



Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Moray Carmichael Boudnary Rd due to AB1 and D1 Seams



Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Shuttleworth Carmichael Rd due to the Extraction of AB1 and D1 Seams

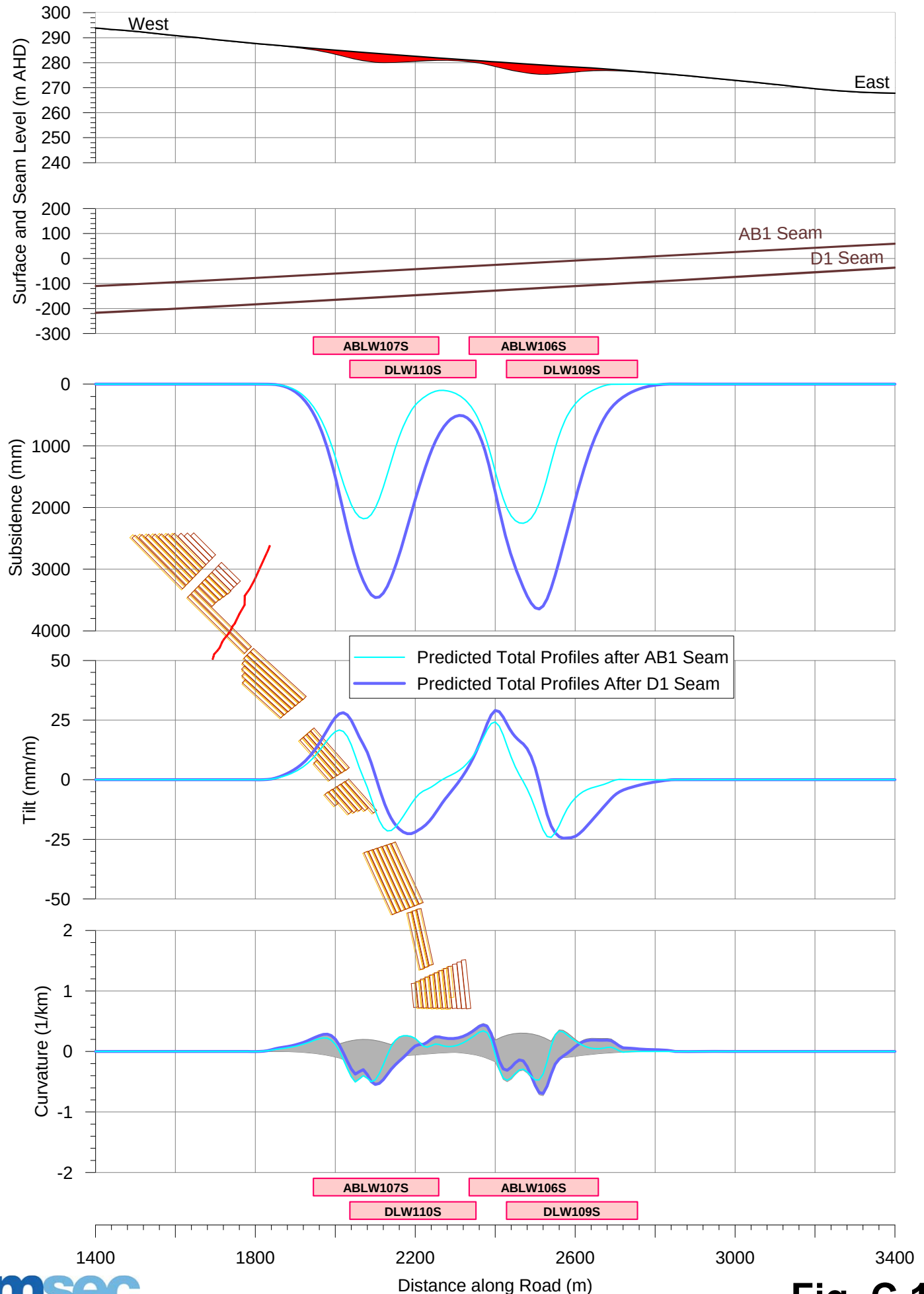
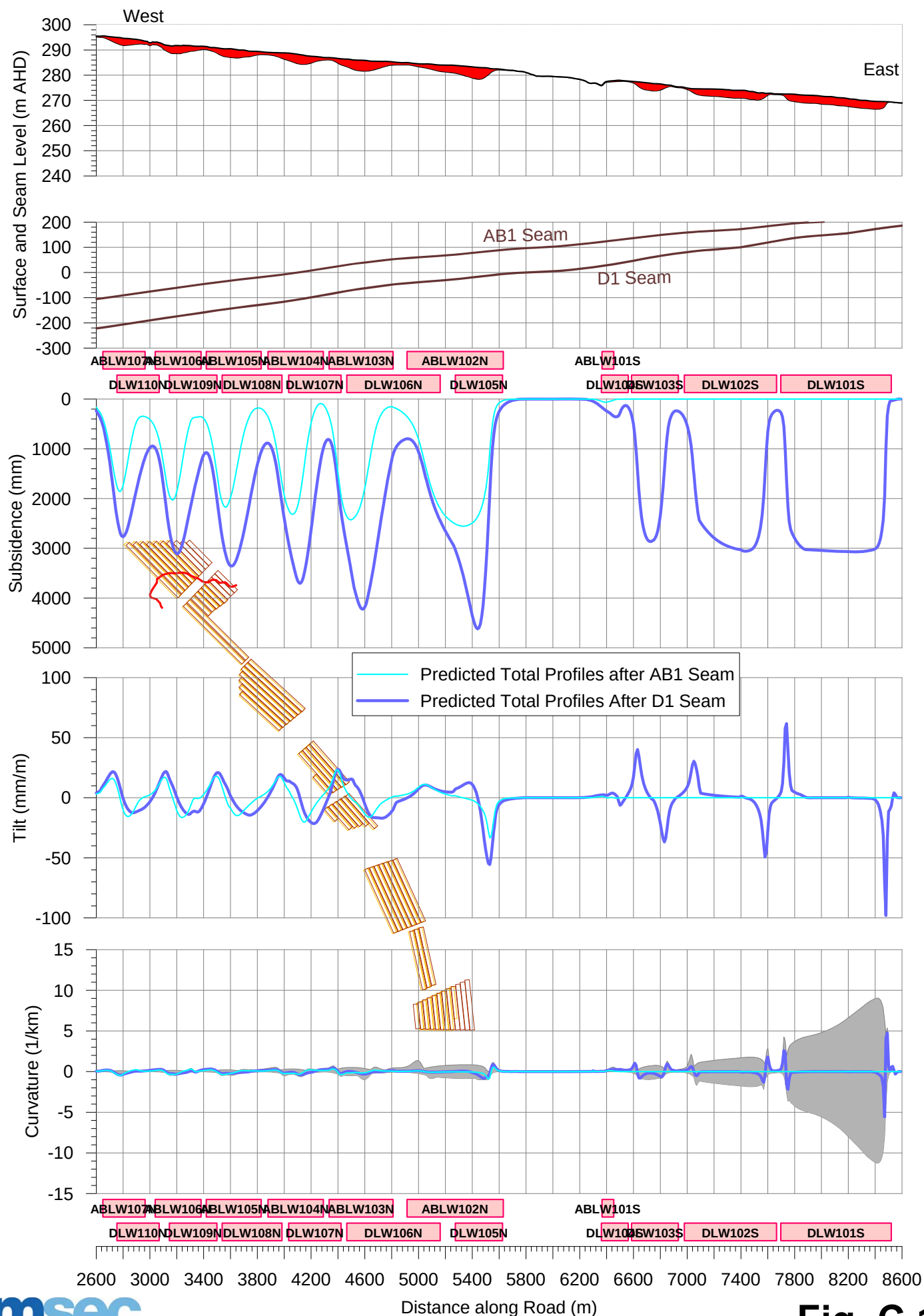
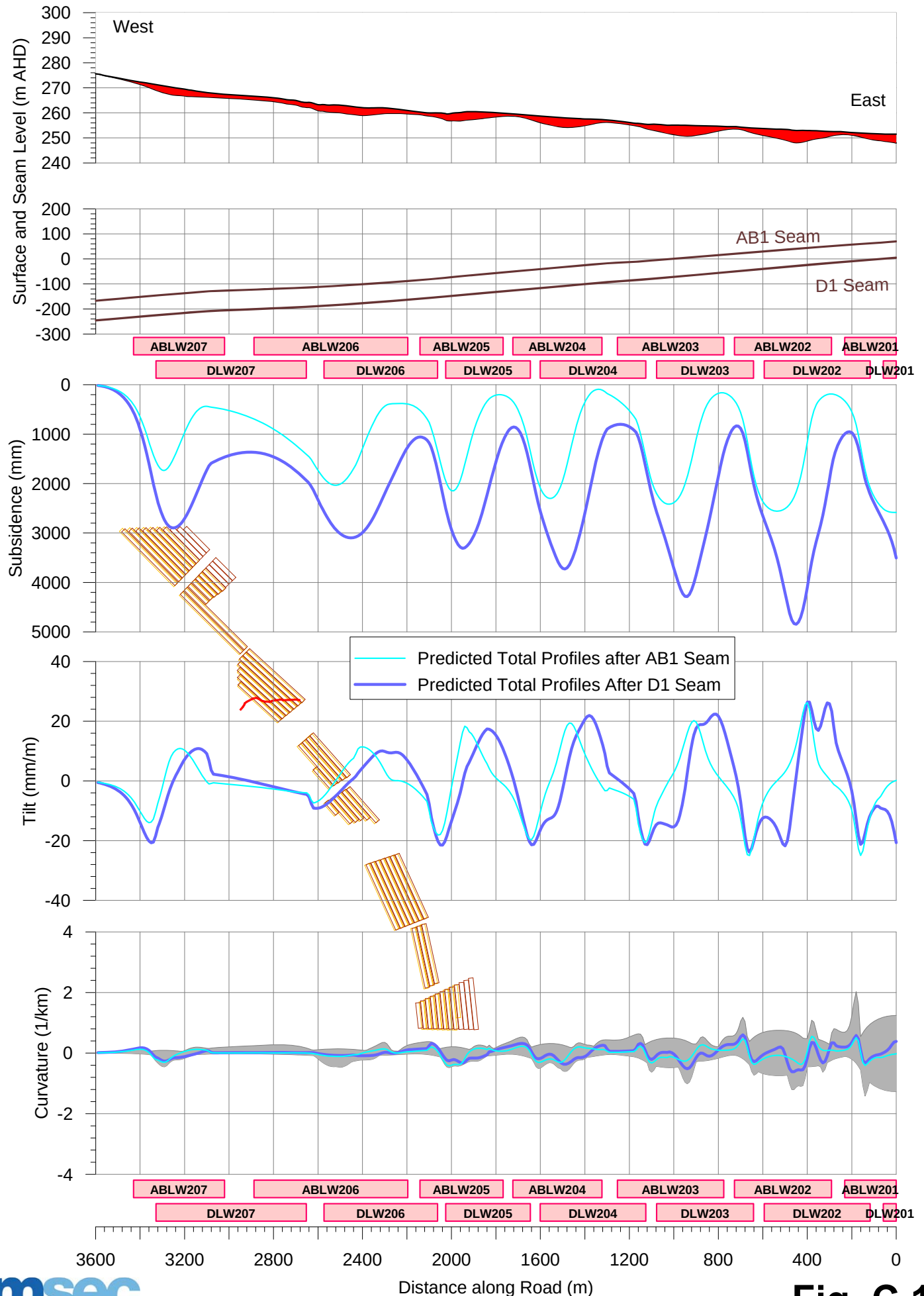


Fig. C.11

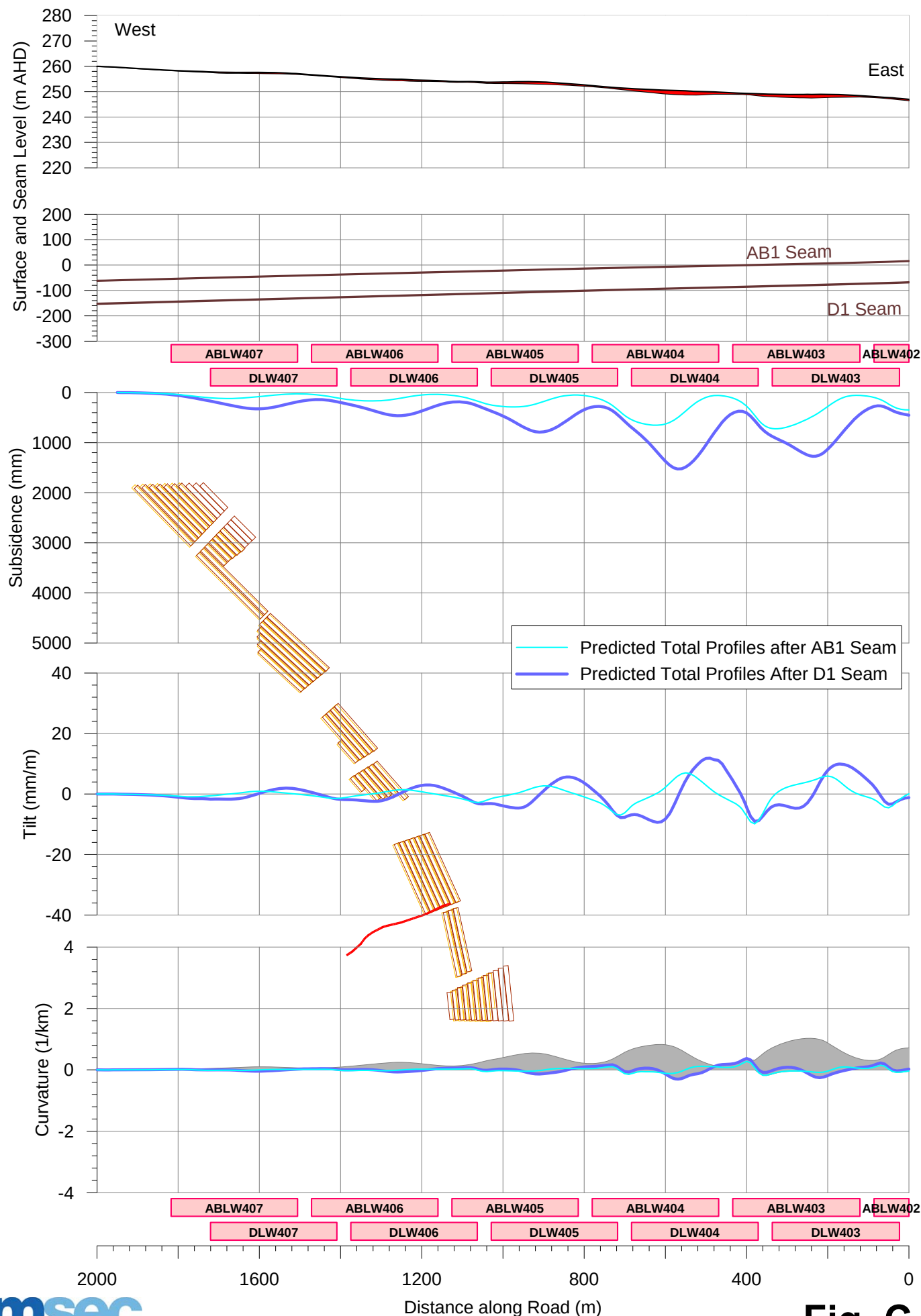
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Tributary 1 due to the Extraction of AB1 and D1 Seams



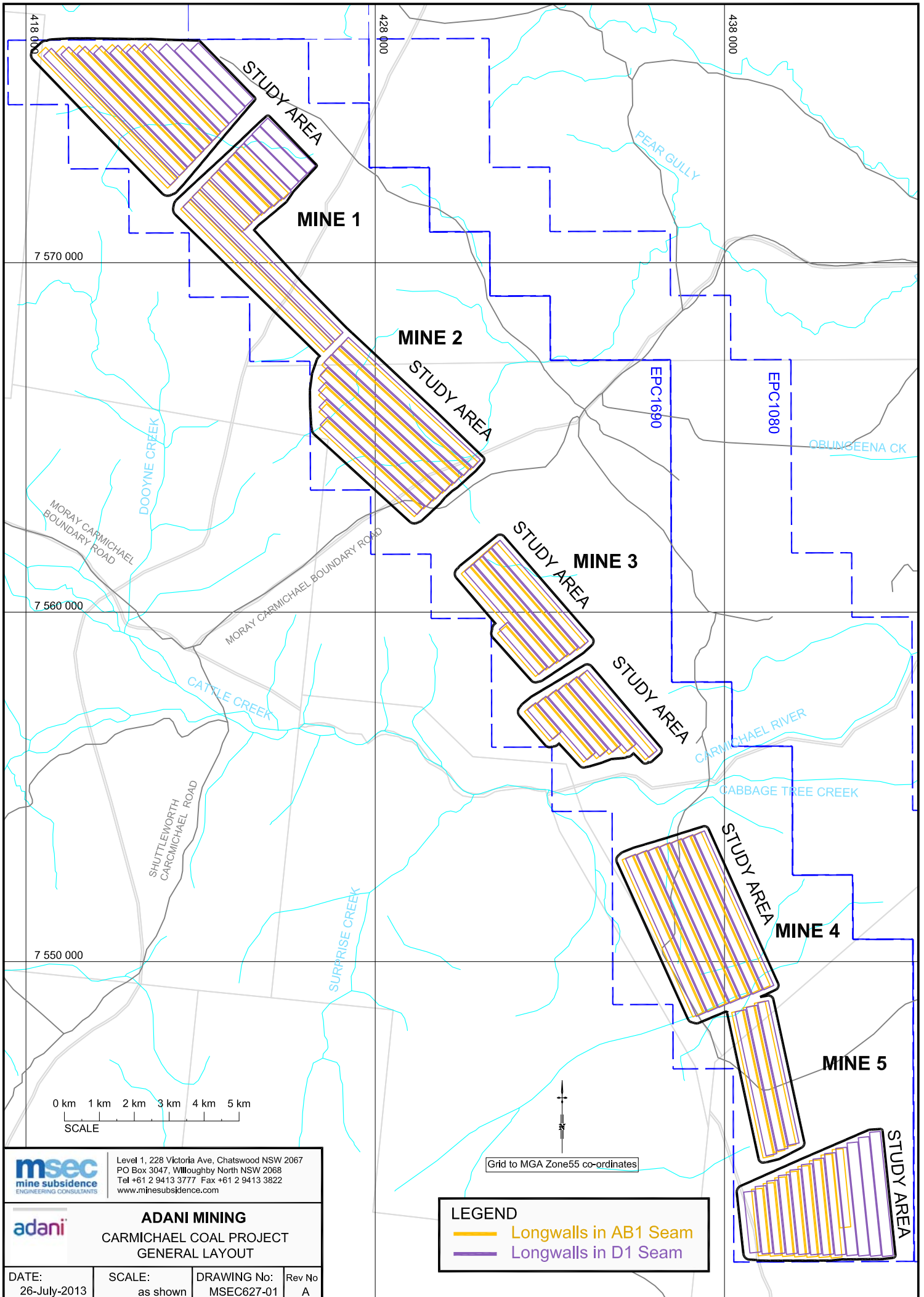
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Tributary 2 due to the Extraction of AB1 and D1 Seams

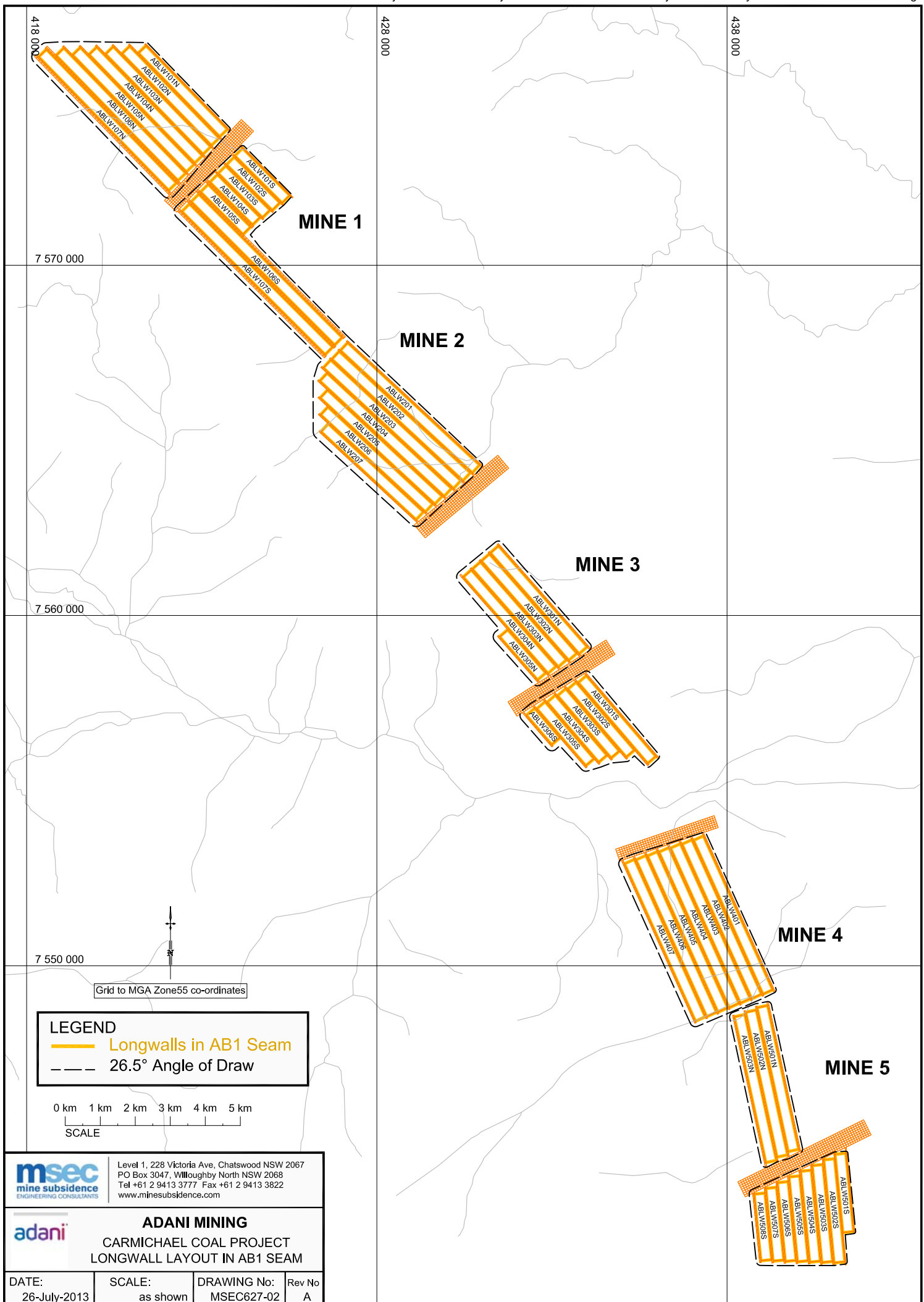


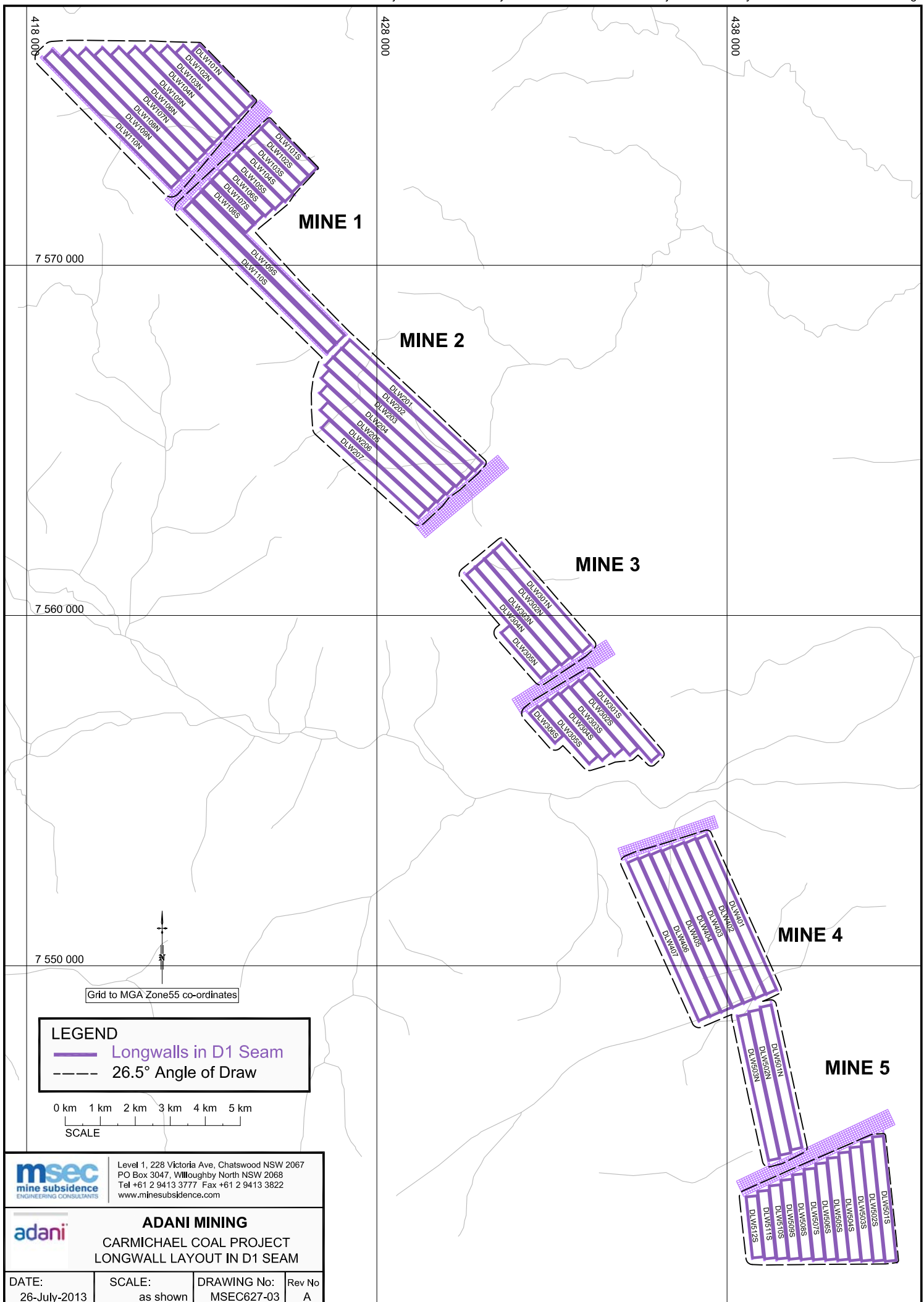
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Tributary 3 due to the Extraction of AB1 and D1 Seams

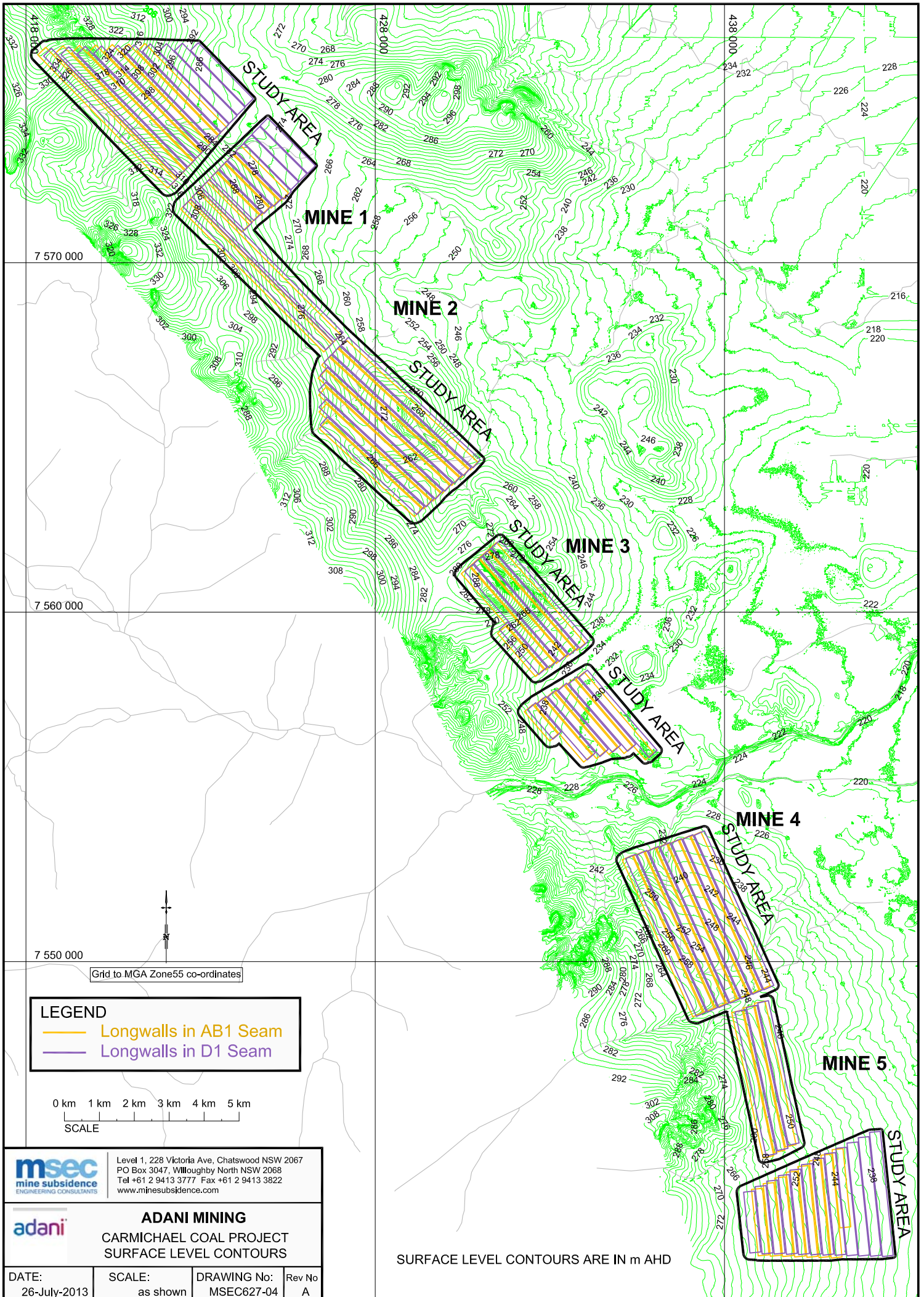


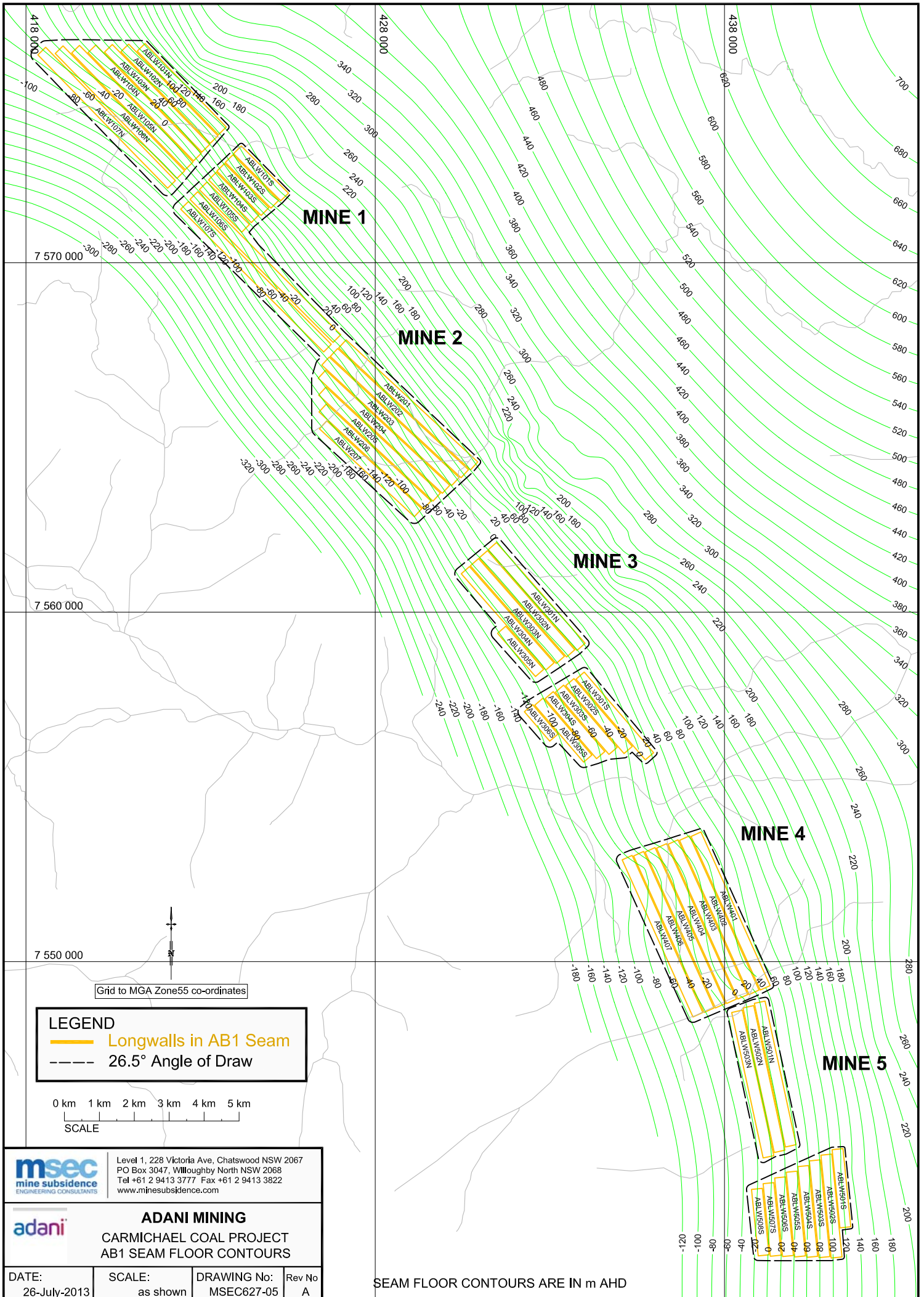
APPENDIX D. DRAWINGS

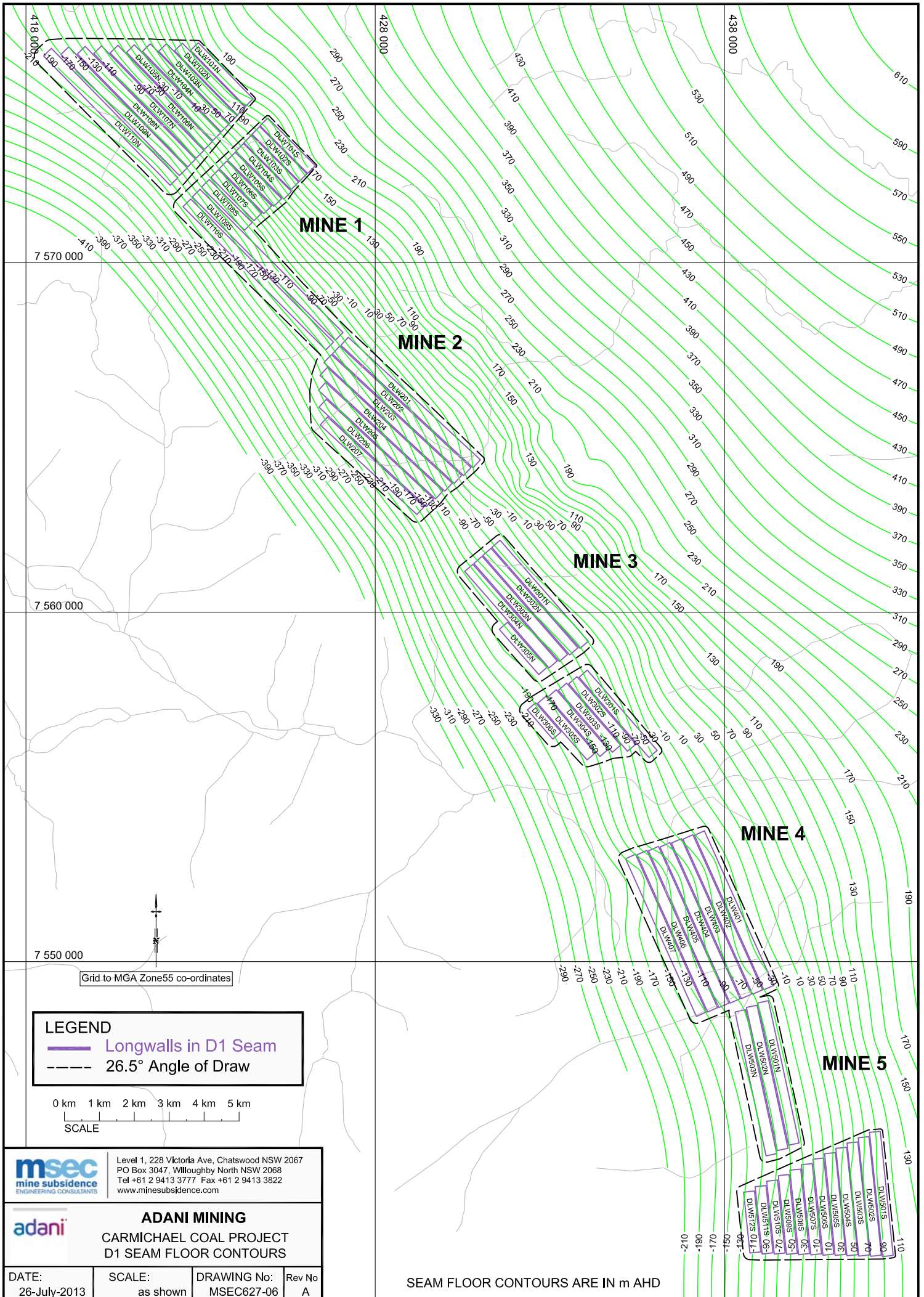


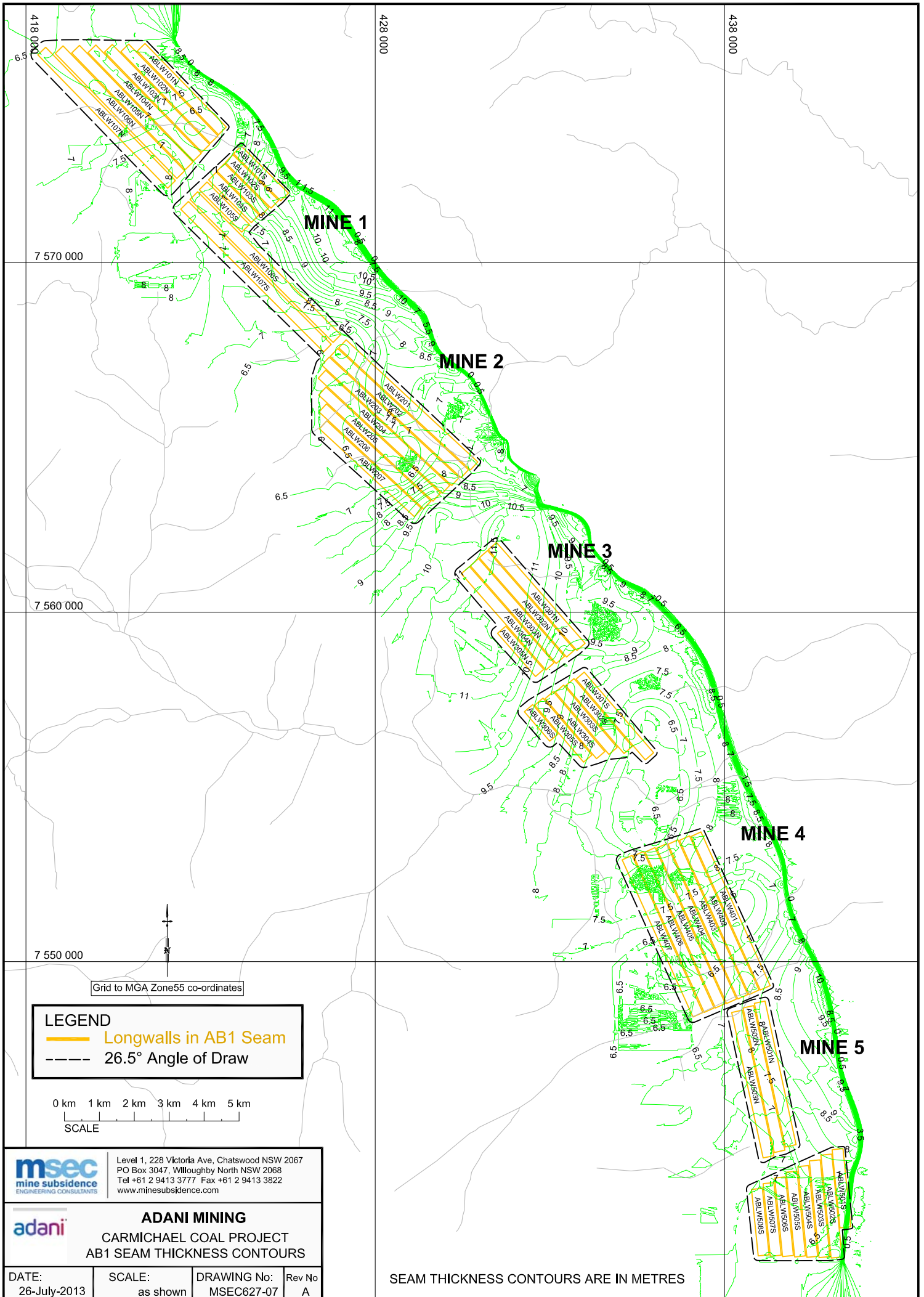




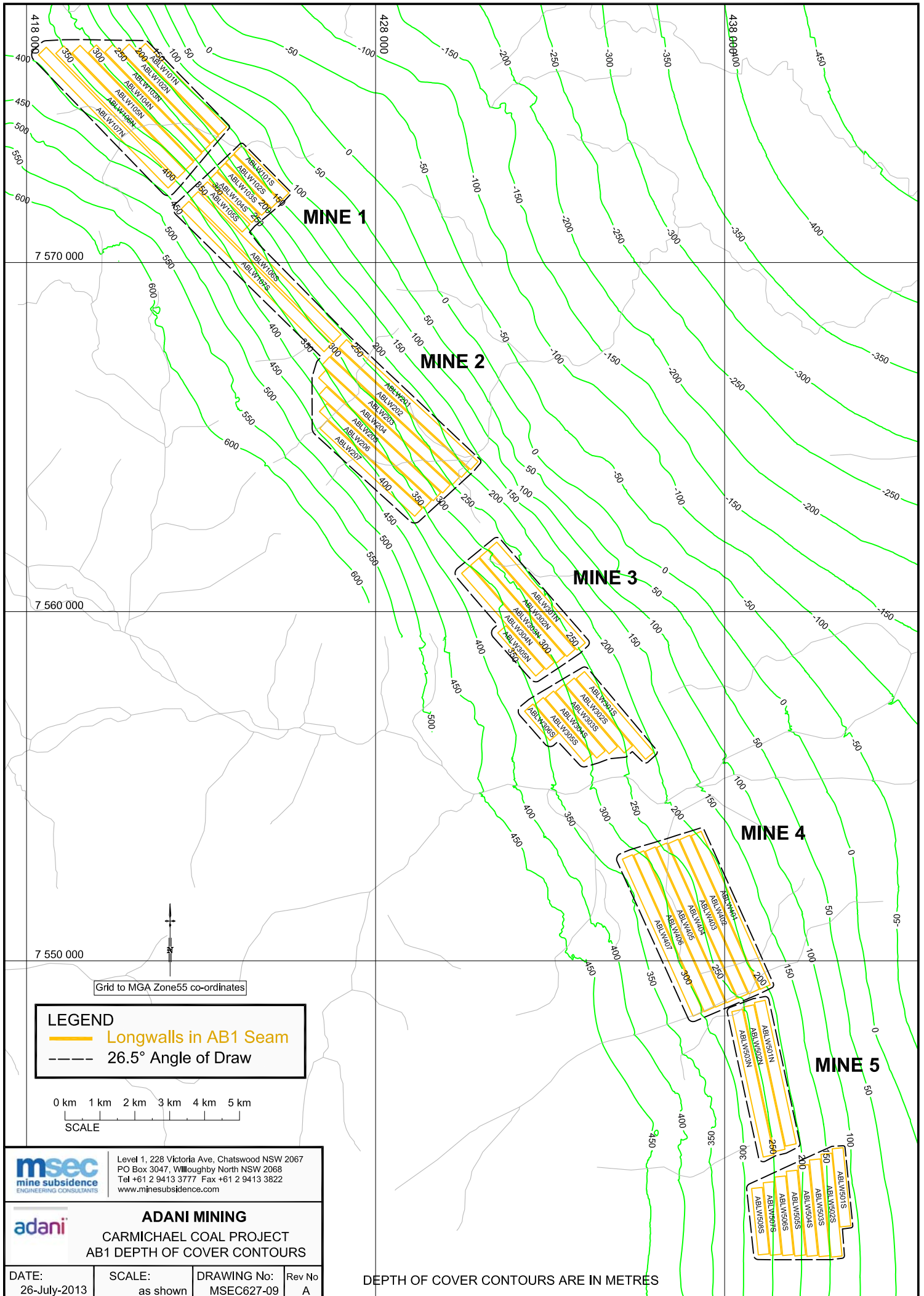


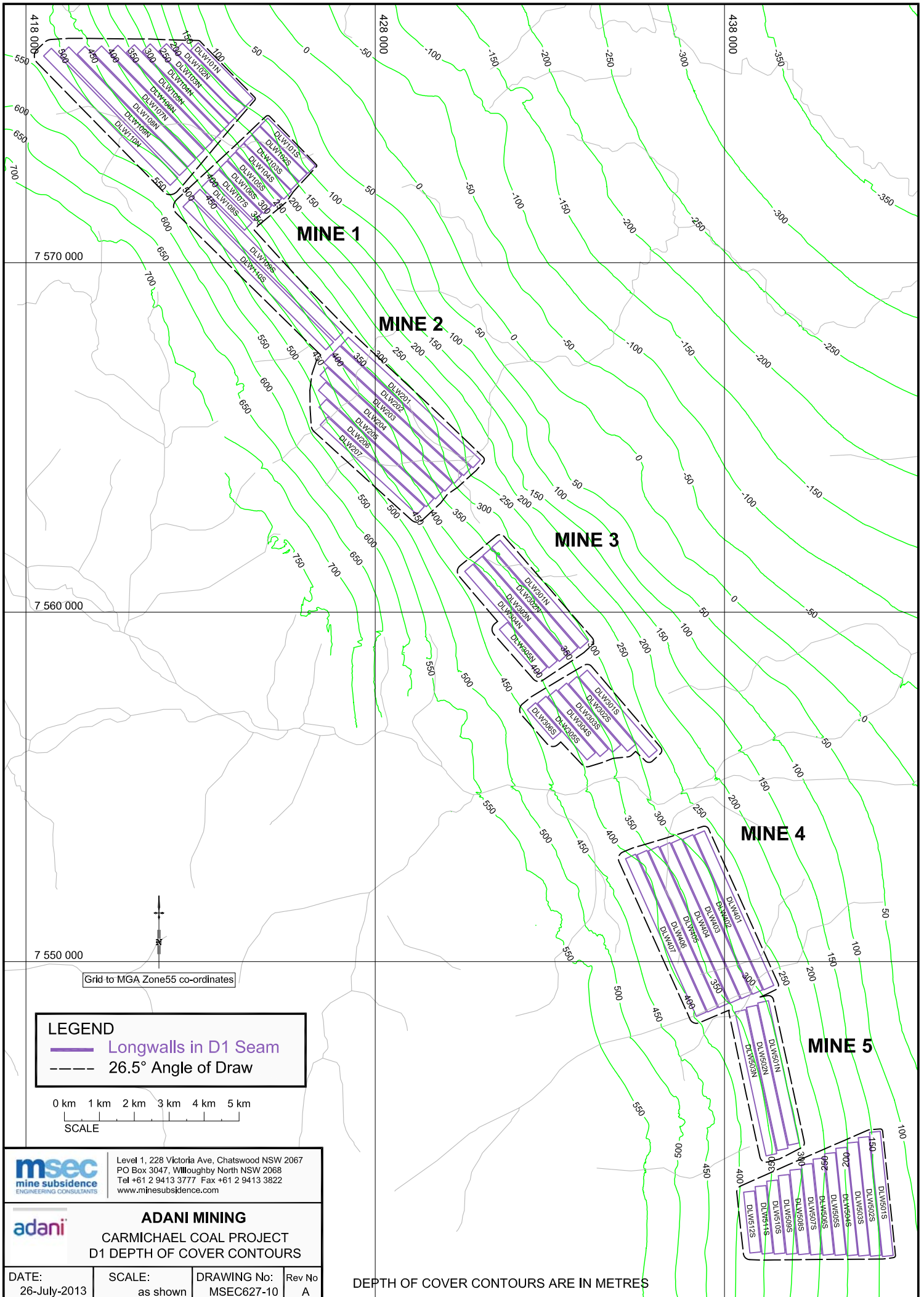


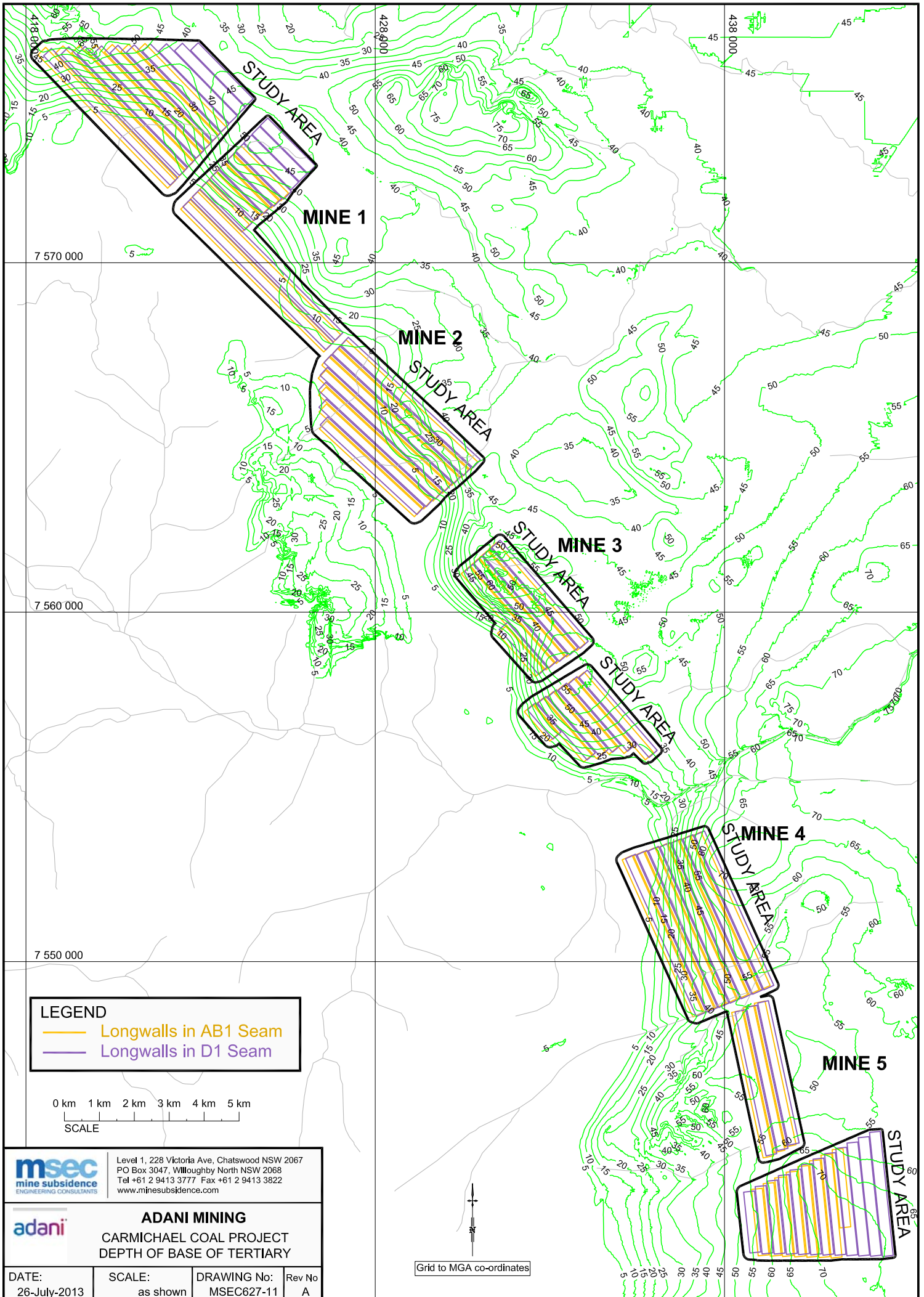


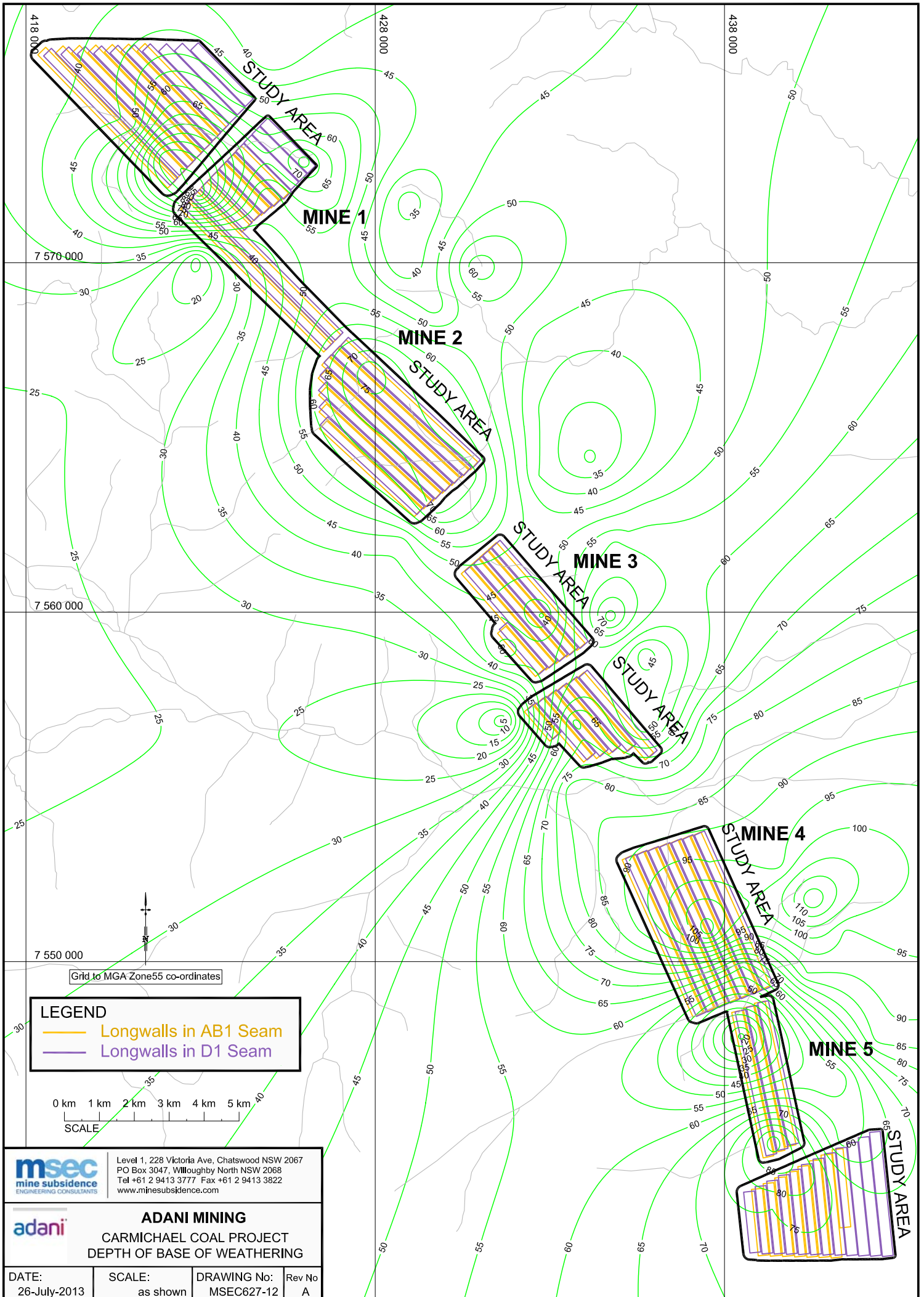


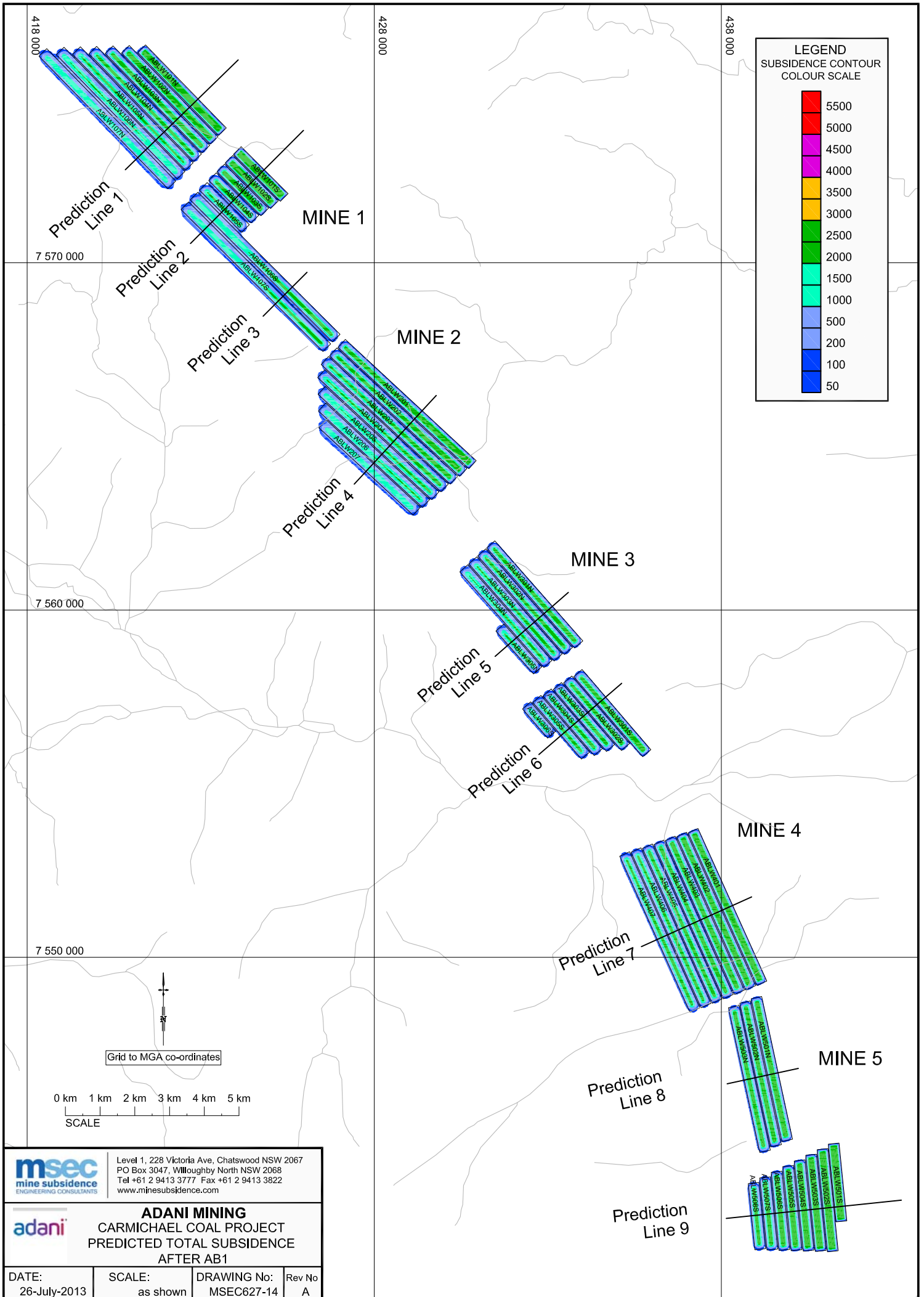
SEAM THICKNESS CONTOURS ARE IN METRES

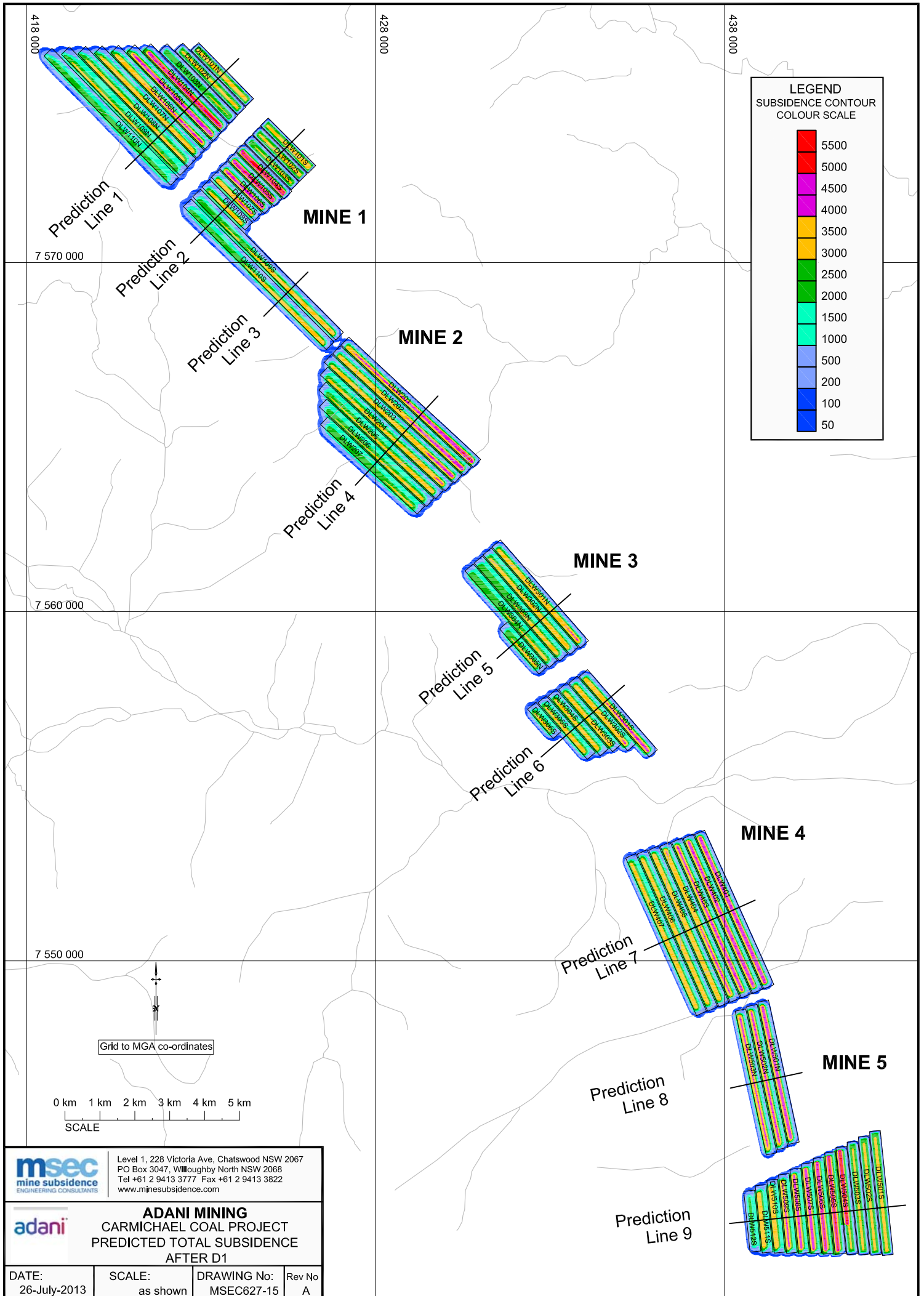




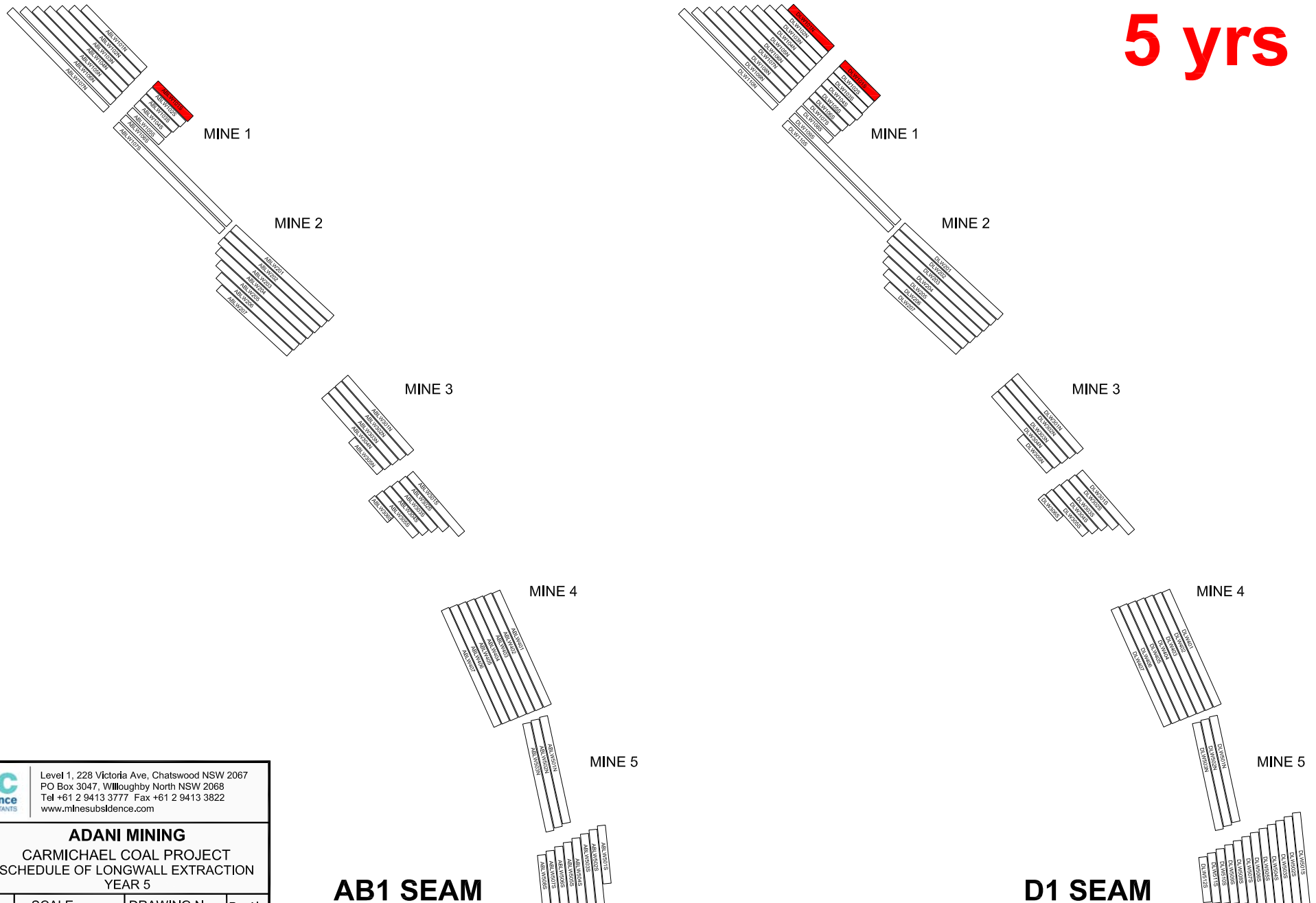








5 yrs

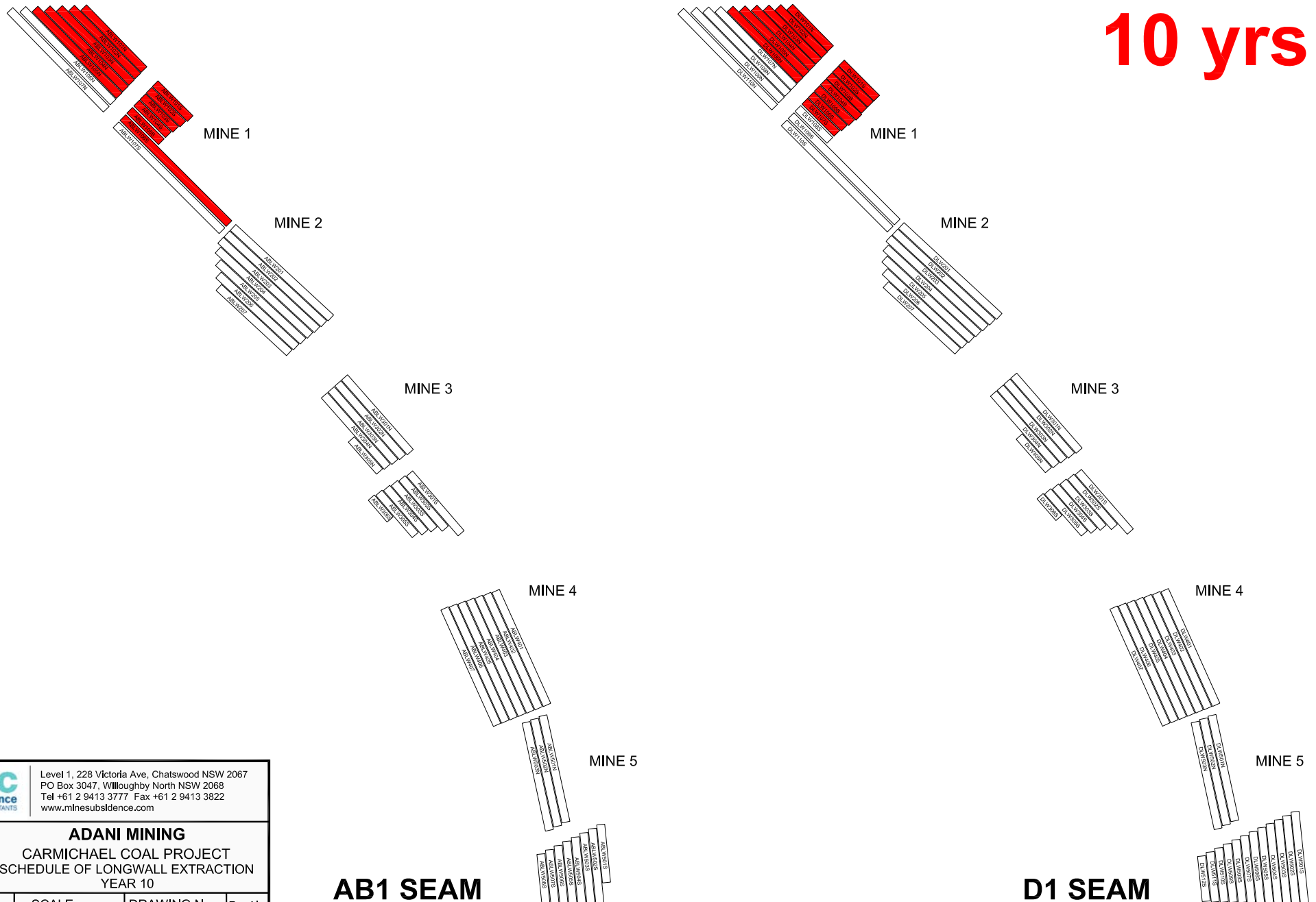


AB1 SEAM

D1 SEAM

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DATE:	SCALE:	DRAWING No:	Rev No
26-July-2013	as shown	MSEC627-17	A

10 yrs

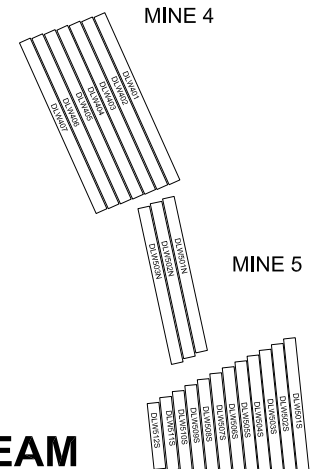
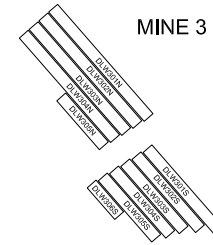
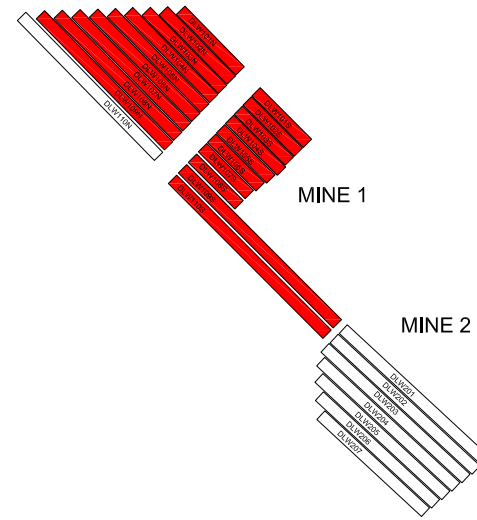
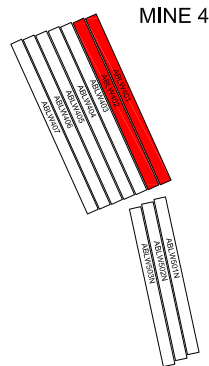
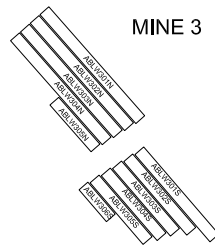
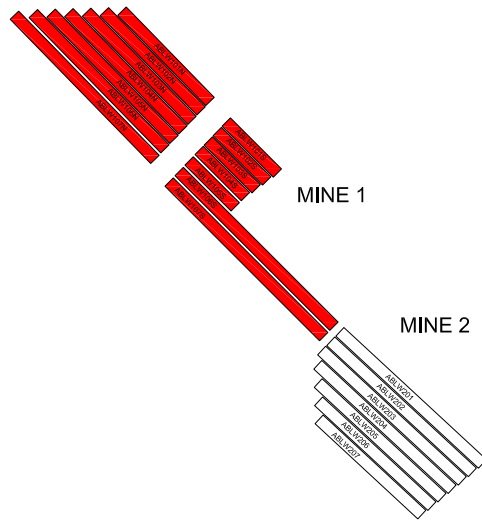


AB1 SEAM

D1 SEAM

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adani ADANI MINING CARMICHAEL COAL PROJECT SCHEDULE OF LONGWALL EXTRACTION YEAR 10			
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15 yrs

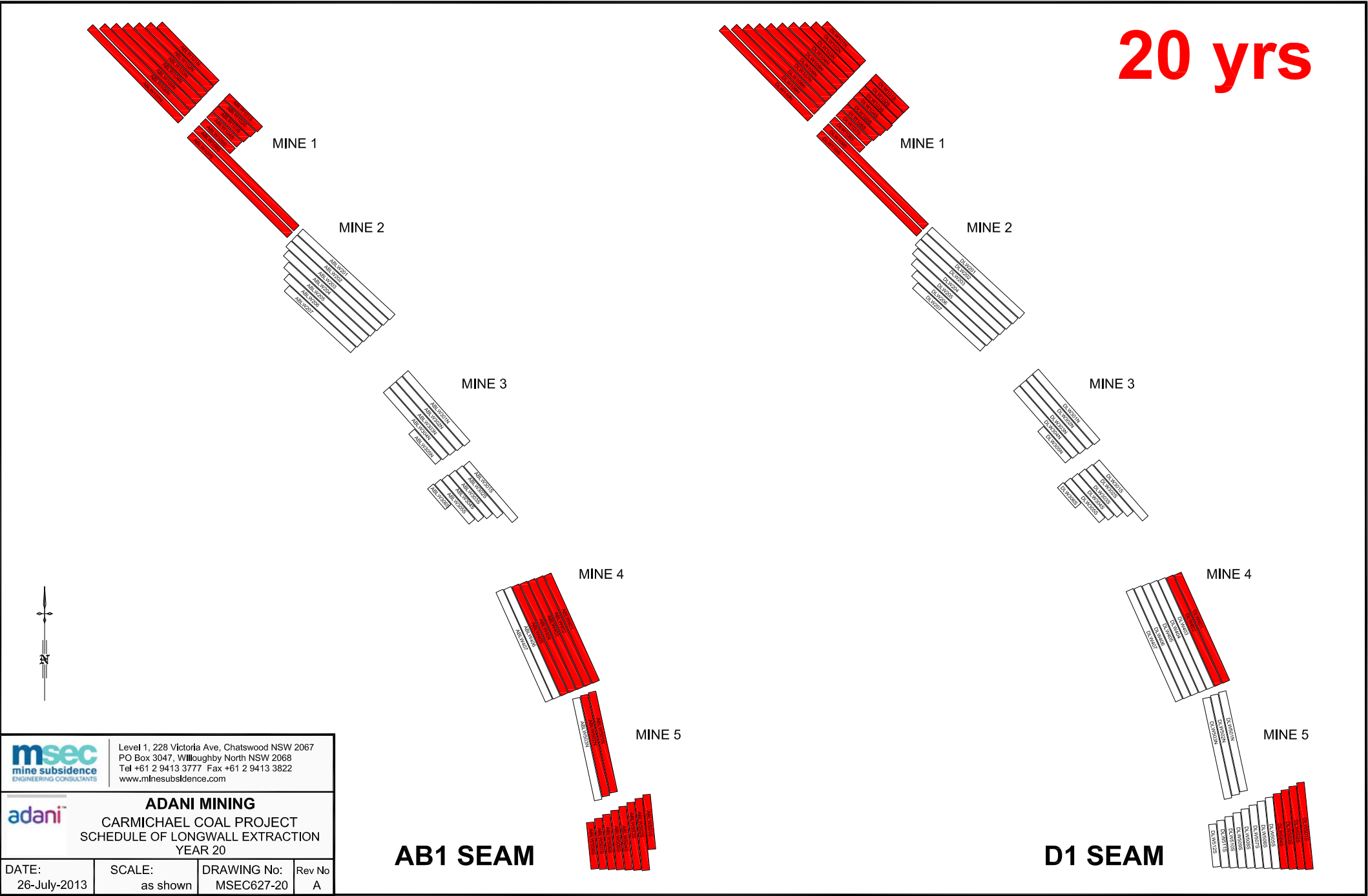


AB1 SEAM

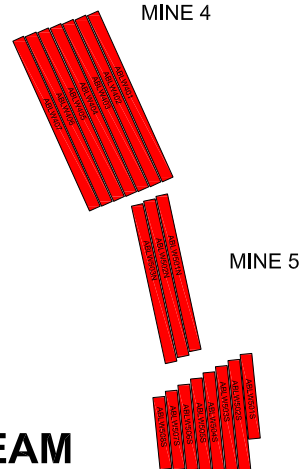
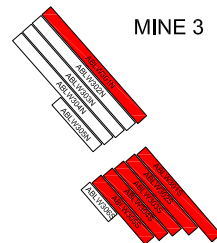
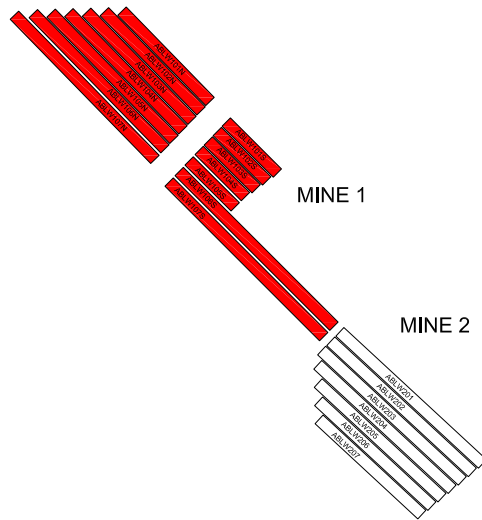
D1 SEAM



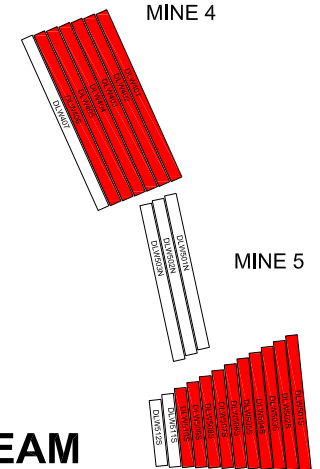
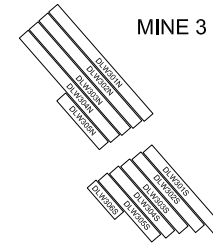
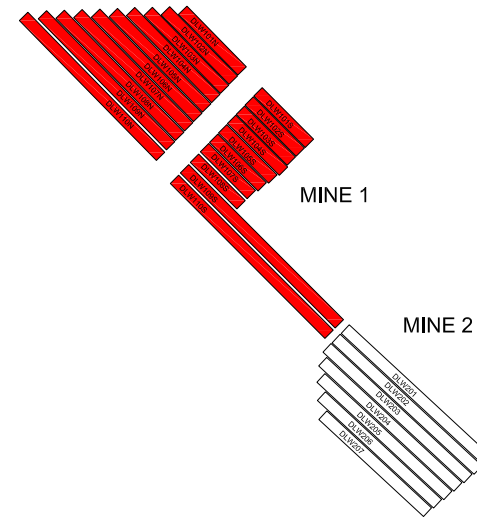
		Level 1, 228 Victoria Ave, Chatswood NSW 2067 PO Box 3047, Willoughby North NSW 2068 Tel +61 2 9413 3777 Fax +61 2 9413 3822 www.minesubsidence.com	
		ADANI MINING CARMICHAEL COAL PROJECT SCHEDULE OF LONGWALL EXTRACTION YEAR 15	
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26-July-2013	as shown	MSEC627-19	A



25 yrs



AB1 SEAM



D1 SEAM



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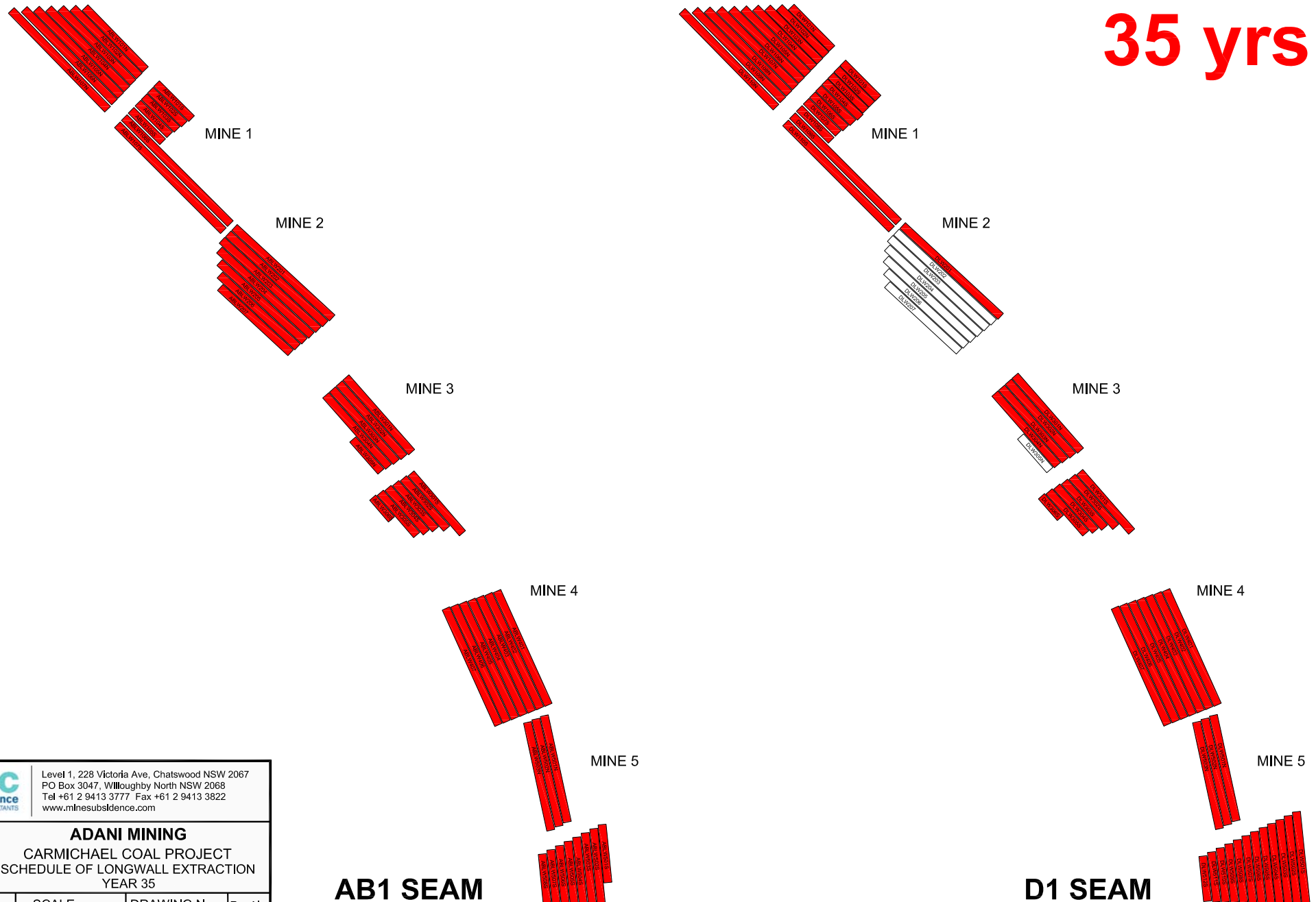
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PO Box 3047, Willoughby North NSW 2068
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adani

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CARMICHAEL COAL PROJECT
SCHEDULE OF LONGWALL EXTRACTION
YEAR 25

DATE: 26-July-2013	SCALE: as shown	DRAWING No: MSEC627-21	Rev No A
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35 yrs



AB1 SEAM

D1 SEAM



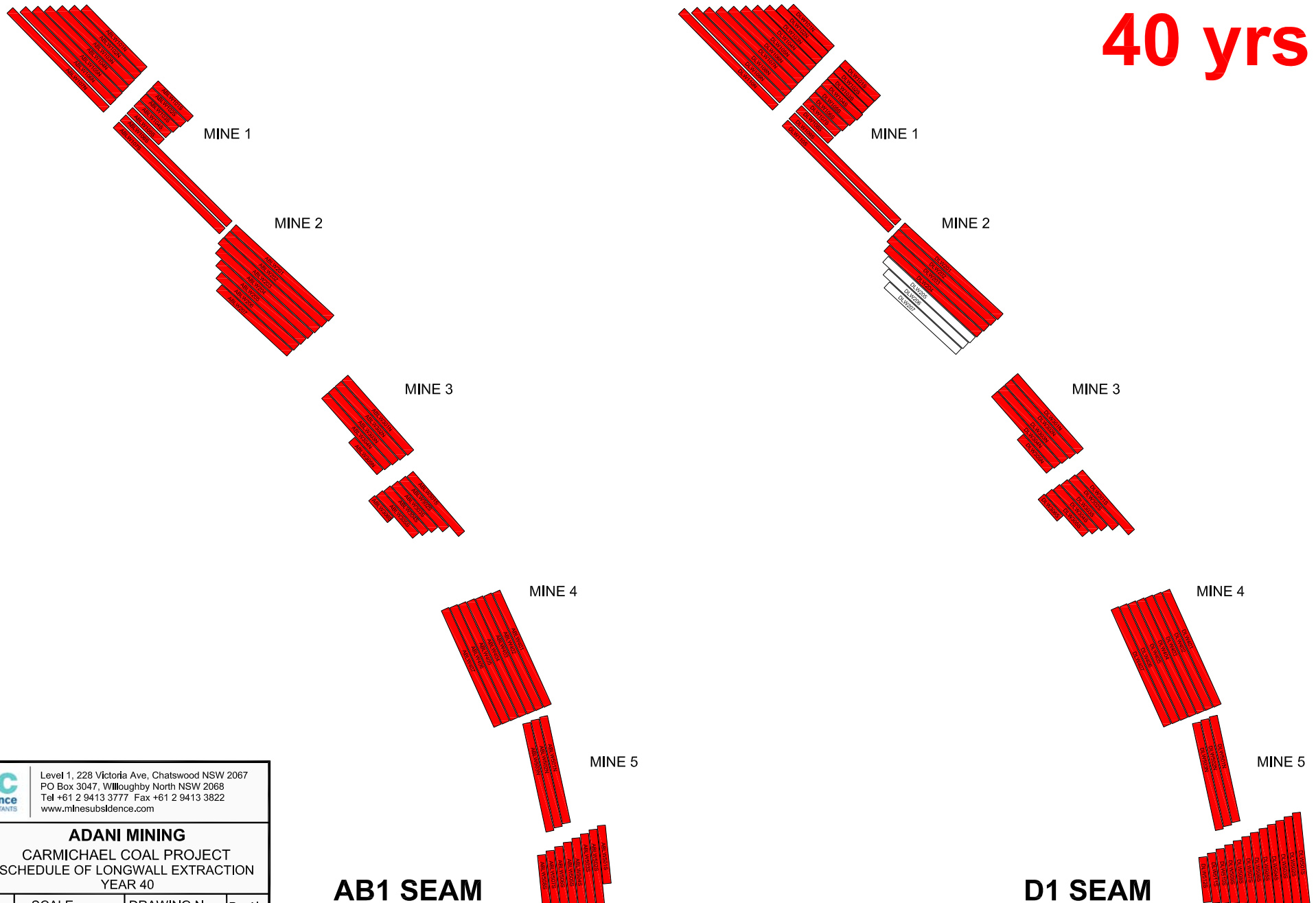
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CARMICHAEL COAL PROJECT
SCHEDULE OF LONGWALL EXTRACTION
YEAR 35

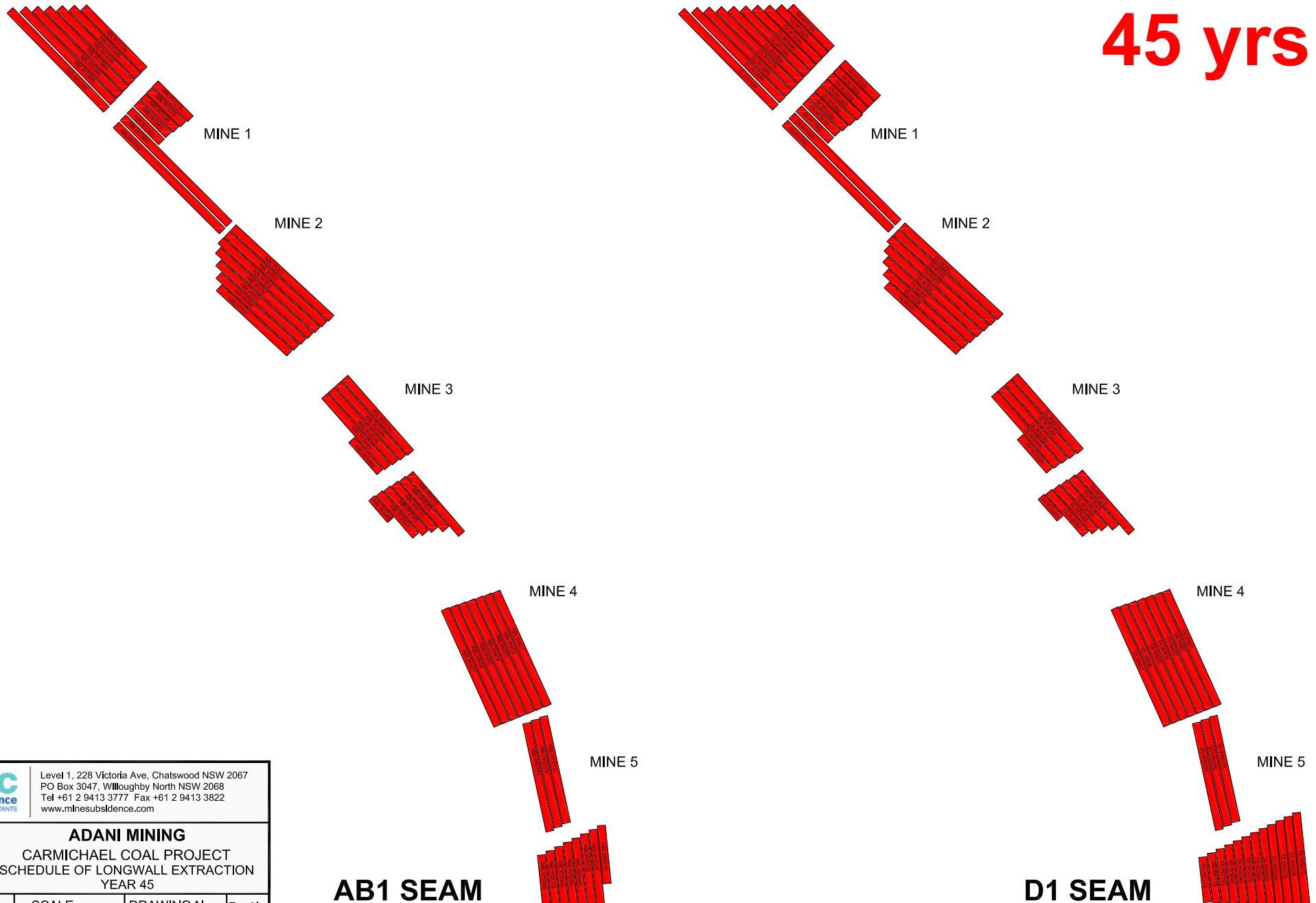
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40 yrs



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adani		ADANI MINING CARMICHAEL COAL PROJECT SCHEDULE OF LONGWALL EXTRACTION YEAR 40	
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45 yrs



AB1 SEAM

D1 SEAM

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adani		ADANI MINING CARMICHAEL COAL PROJECT SCHEDULE OF LONGWALL EXTRACTION YEAR 45	
DATE:	SCALE:	DRAWING No:	Rev No
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