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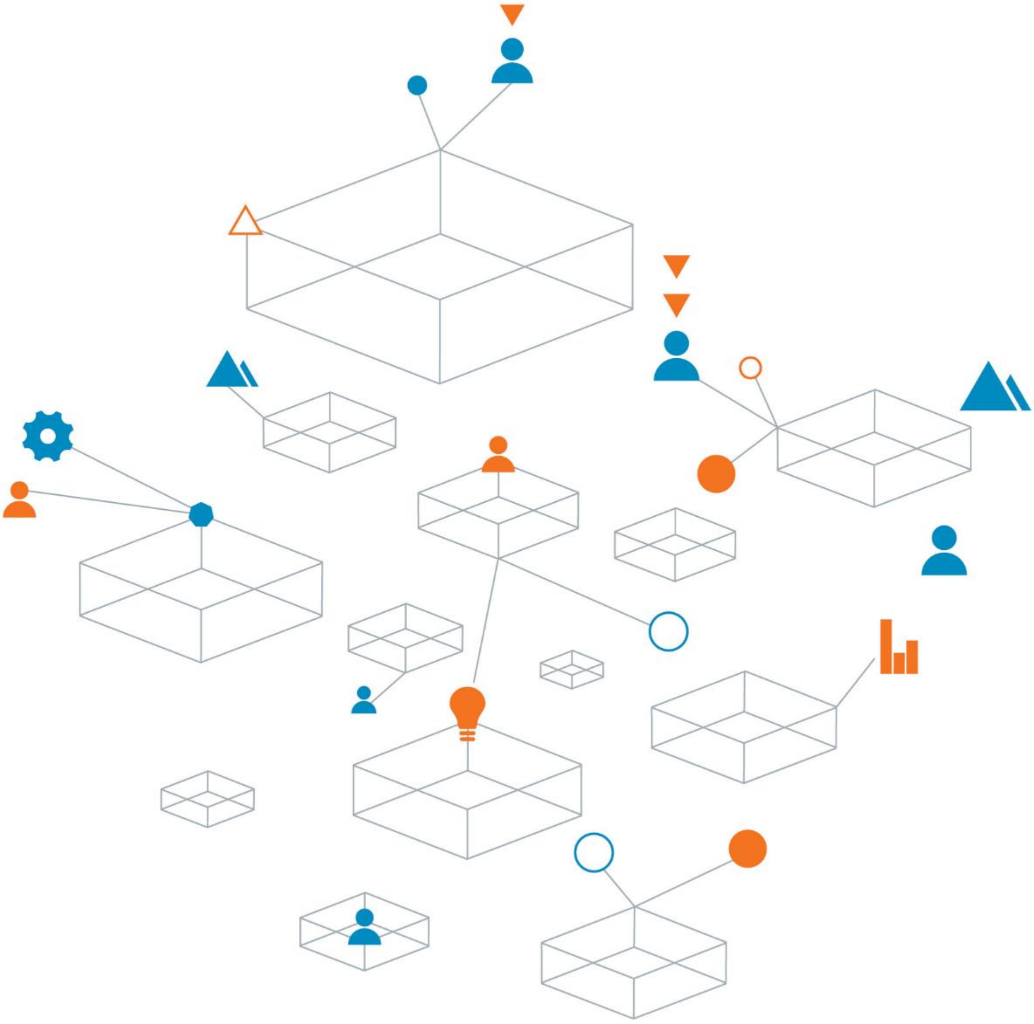
Arrow Energy Pty Ltd
Surat Gas Project - Subsidence monitoring and prediction
754-MELENP268280-AA

10 December 2021



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Surat Gas Project - Subsidence monitoring and prediction

Prepared for
Arrow Energy Pty Ltd

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1. Introduction

As part of a previous programme of work for the Arrow Energy Pty Ltd (Arrow) Surat Gas Project (SGP) Monitoring and Management Plan (WMMP), Coffey prepared the Arrow SGP Stage 1 CSG WMMP Subsidence Technical Memorandum (the Technical Memorandum) for Arrow, dated 25 September 2018.

The Technical Memorandum addressed InSAR observations and groundwater monitoring data available in 2018 (covering the period July 2012 to December 2015), and provides:

- Assessment of the long-term subsidence associated with proposed Arrow SGP operations based on:
  - A review of ground movement observations and groundwater level monitoring carried out in proximity to existing Arrow domestic CSG projects (these current domestic CSG projects do not form part of the SGP)
  - Estimates of subsidence based on predicted groundwater drawdown from the Environmental Impact Statement (EIS) and the Supplementary Report to the EIS (SREIS).
- An assessment of risks posed by subsidence to assets within or in close proximity to Arrow SGP operations
- Recommendations for additional ground movement monitoring such as strategically located geodetic monitoring and extensometers
- Recommended trigger levels for the SGP
- Recommendations for continuing monitoring for the Arrow SGP.

Arrow continues to monitor subsidence with TRE Altamira, and is progressing installation of real-time ground movement monitoring devices. With the ongoing monitoring, Arrow has observed that:

- Arrow Daandine Expansion (DXP – production fields that are not part of the WMMP for the SGP) areas close to CSG extraction fields operated by others have shown observed ground movement greater than that assessed in the memorandum. The earlier modelling work considered only the effects of Arrow SGP operation, as required by the WMMP. It is expected that movement greater than predicted result from subsidence impacts related to CSG extraction within the DXP, which were not included in the modelling for the memorandum.
- Whilst Interferometric Synthetic Aperture Radar (InSAR) is conducted across Arrow's tenements, reliable data for assessment of ground movement is limited in areas of cropping due to data quality not meeting coherence thresholds due to frequent changes in the character of the ground surface reflection.

This report builds on work carried out for the Technical Memorandum and covers the following items:

- InSAR ground movement monitoring data over the period August 2015 to June 2019
- Historical InSAR ground movement monitoring data over the period December 2006 to March 2011 and July 2012 to November 2017
- Assessment of the uniformity of ground movement
- Groundwater level monitoring and its relation to observed ground movement
- Assessment of the compressibility of the Walloon Coal Measures based on observed relationships between groundwater drawdown and ground movement at several locations
- Discussion of natural ground movements not related to CSG extraction
- Discussion of the theoretical mechanism of subsidence and the results of illustrative numerical modelling
- Predictions of future subsidence based on InSAR ground movement monitoring data to June 2019 and predicted groundwater drawdowns from the updated UWIR (Underground Water Impact Report for the Surat Cumulative Management Area) regional scale three-dimensional numerical model (Office of Groundwater Impact Assessment, 2019b).
- A comparison on aquifer compressibility parameters based on observed drawdown and settlement with those based on unconfined compressive strength (UCS) test results in the relevant units.

- Recommendations for additional subsidence monitoring methods.

The information contained in this report is based on the following sources, which were provided by Arrow unless otherwise indicated:

- InSAR ground movement monitoring data downloaded from the TRE Altamira website
- Historical InSAR data
- Groundwater monitoring records for boreholes in and around the SGP area
- Arrow SGP CSG well extraction records
- Unconfined compressive strength test results on core samples
- Geological information provided in the following publicly available reports:
    - Surat Basin Stratigraphic Framework, Appendix D – Surat Basin Geological Model, QGC Pty Ltd, dated April 2012.
    - The geology, stratigraphy and coal seam gas characteristics of the Walloon Subgroup – northeastern Surat Basin, Scott, S.G, (2008), PhD thesis, James Cook University
- Groundwater modelling data from a regional scale three-dimensional numerical model. The model is calibrated to additional observations and draws upon the material presented in the following publicly available reports:
    - Groundwater Modelling Report – Surat Cumulative Management Area, Office of Groundwater Impact Assessment, dated October 2019
    - Underground Water Impact Report for the Surat Cumulative Management Area, Office of Groundwater Impact Assessment, dated July 2019.

2. Background

This report addresses subsidence and groundwater levels in the Arrow SGP operations and surrounding areas. The Arrow operations are developed in a series of Drainage Areas shown in Figure 1. The drainage areas define the extent of individual well fields which will be developed.

The Arrow operations area totals 61,000 km^2 with projected CSG groundwater production of 575 GL over 40 years involving up to 6,500 wells.

Production drilling of Arrow's non-SGP Surat Basin gas fields started in 2005. Initial development began at Kogan North, followed by Tipton West, Daandine and Stratheden. The target coal seams in the Surat Basin are the Walloon Coal Measures.

Other organisations also have CSG developments in the Surat Basin. These are to the west of the Arrow SGP as shown in Figure 2.

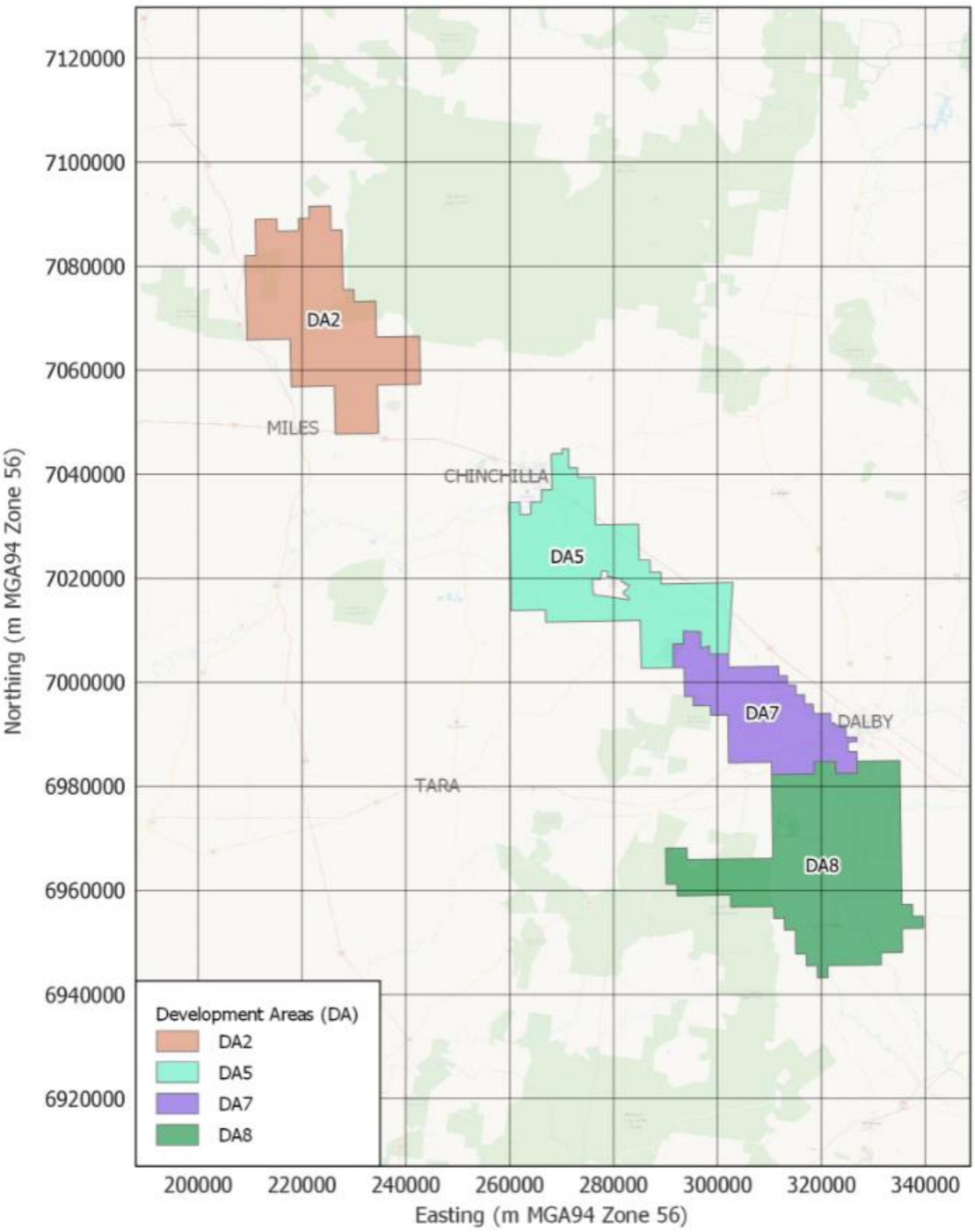


Figure 1: Drainage areas of the Arrow SGP

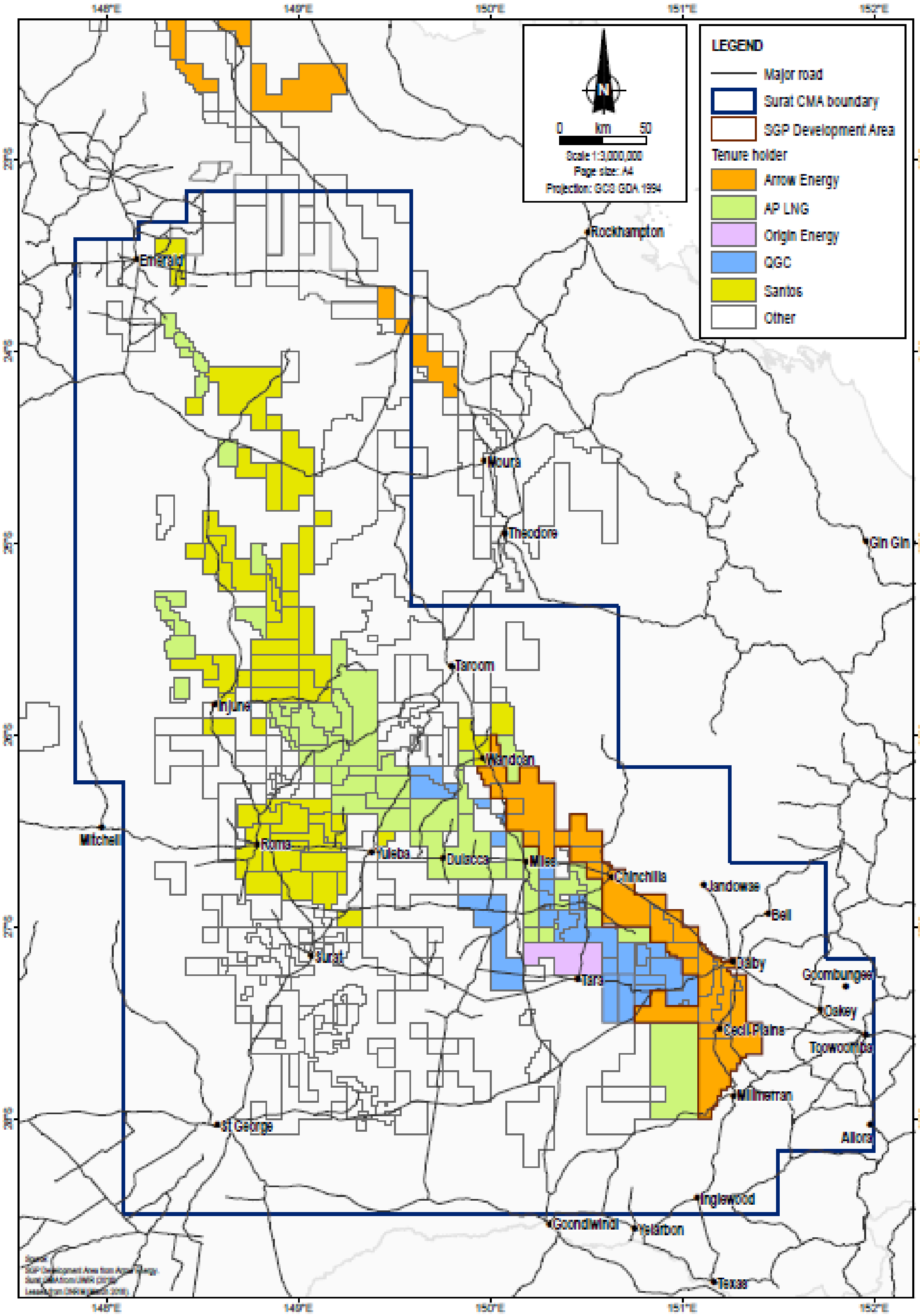


Figure 2: Arrow Surat Gas Project tenements in relation to tenements held by others

2.1. Cause of subsidence

Coal seam gas occurs within coal formations through adsorption to the surface of the coal under hydrostatic pressure. Depressurisation of the coal seams below a threshold by groundwater extraction reduces hydrostatic pressure and liberates the gas from the formation. As the pressure falls, the gas migrates to the extraction wells. This process requires substantial lowering of groundwater pressure.

At any point below the ground surface, the weight of overlying strata is supported partly by water pressure and partly by the fabric of the rock mass. Any reduction in water pressure therefore results in an increased proportion of the load being carried by the rock mass, leading to compression of the rock. This is known as an increase in effective stress. The combined compression over the thickness of rock strata affected by reduced water pressure results in subsidence at the ground surface.

This process commonly occurs during dewatering for construction. In construction projects, the materials involved are typically soils, which are much more susceptible to settlement than the coal measure rocks within which groundwater is depressurised for CSG production. Engineering methods for assessment of ground movements due to changes in effective stress are well developed. These assessments require knowledge of the mechanical properties of the ground and the changes in groundwater pressure over the full ground profile.

In addition to the above mechanism, liberation of adsorbed gas from coal surfaces can result in a reduction in coal volume and provide a further component of subsidence. Sorption-induced compaction has been measured in laboratory studies at around one per cent (for carbon dioxide and methane combined) of the coal thickness (Robertson, 2005). The extent of this effect will relate to the initial adsorbed gas content and the quantity of gas released.

The properties governing the contraction of coal due to gas removal from seams in the Walloon Coal Measures are not available. Robertson (2005) reported a strain of 0.001 for a gas pressure change of 500 kPa (equivalent to pressure under 50 m of water) in a bituminous coal seam. While it is unclear if this value would relate to Surat Basin coals, it does give an indication of potential for shrinkage due to reduction in gas content.

2.2. Geological setting

The Arrow SGP is located at the north eastern part of the Surat Basin. Figure 3 sets out the typical stratigraphic profile within the Surat Basin in areas of Arrow SGP operations. The Walloon Coal Measures is the host formation of the coal seam gas. It includes the Juandah Coal Measures and the Taroom Coal Measures, which are the target strata normally screened in Arrow SGP wells. The lower permeability and relatively thin Tangalooma Sandstone unit separates the Juandah Coal Measures from the Taroom Coal Measures.

Overlying the Walloon Coal Measures are the Kumbarilla Beds comprising the Gubberamunda Sandstone, the Westbourne Formation and the Springbok Sandstone. The Kumbarilla Beds are generally of low permeability and act to separate groundwater pressure changes in the Walloon Coal Measures from the overlying alluvial sediments of the Condamine Alluvium.

The Condamine Alluvium is present in lower lying areas flanking the Condamine River. In these areas the alluvium is up to 150 m thick and comprises a mixture of sand and clay. It comprises a mixture of unconsolidated sand and clay sedimentary depositions from the Condamine river and its tributaries. Department of Natural Resources, Mines and Energy (2018) report that The Central Condamine Alluvium is composed of interlayered beds of riverine, floodplain and lakebed alluvial deposits of different ages sourced from basalts in the east and Jurassic sediments and older geological formations in the south and west. Deep sand and gravel beds, which lie under clay strata under the surface sheetwash and other alluvium in the Condamine River valley, provide storage for the aquifer water resource.

Underlying the Walloon Coal Measures is the Eurombah (Durabilla) Formation. This aquitard reduces the influence of drawdown on the geological units below the Walloon Coal Measures.

The upper units of the Kumbarilla Beds which overlie the coal measure rocks are truncated by erosion at the eastern margin of the basin, where Arrow SGP operations are concentrated. As a result, the Gubberamunda Sandstone is not present in some Arrow SGP tenements. This is also true of the Westbourne Formation and Springbok Sandstone, such that in the east of some Arrow SGP tenements the coal measures subcrop underneath the Condamine Alluvium. Low permeability clays at the base of the Condamine Alluvium, as well as low permeability, weathered and unweathered sediments interbedded in the coal measures, also act to separate groundwater pressures between the alluvium and the coal measures.

The thickness of the Walloon Coal Measures varies over the Surat Basin. In particular along the eastern margin, where the Walloon Coal Measures are truncated at the erosional contact with the Springbok Sandstone.

Figure 4 presents contours of the thickness of the Walloon Coal Measures, as presented by Office of Groundwater Impact Assessment (2019c). Within the Arrow tenements shown on the figure, the thickness of the Walloon Coal Measures ranges between approximately 20 m and 450 m.

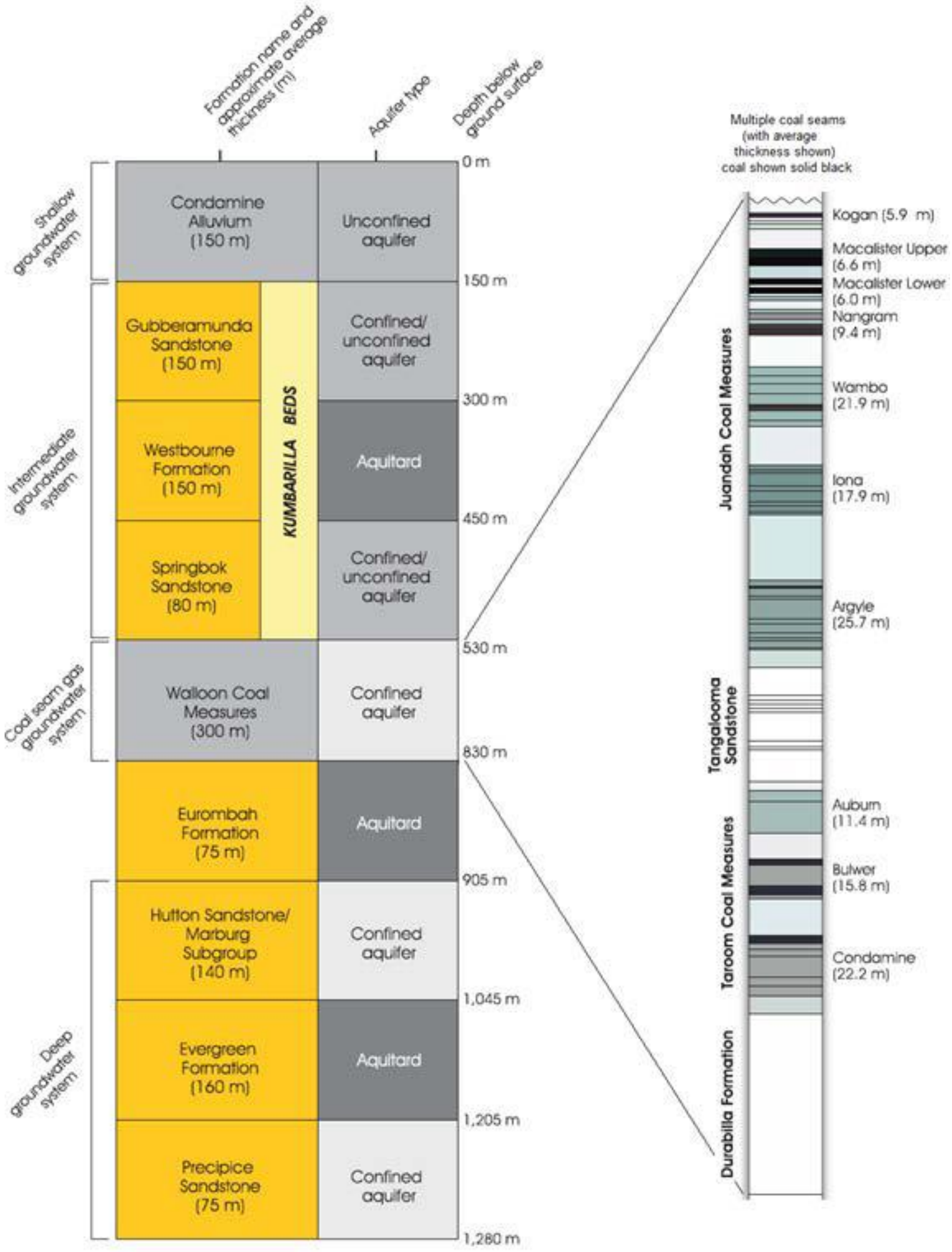


Figure 3: Typical stratigraphic profile within the Surat Basin in the Arrow SGP tenements

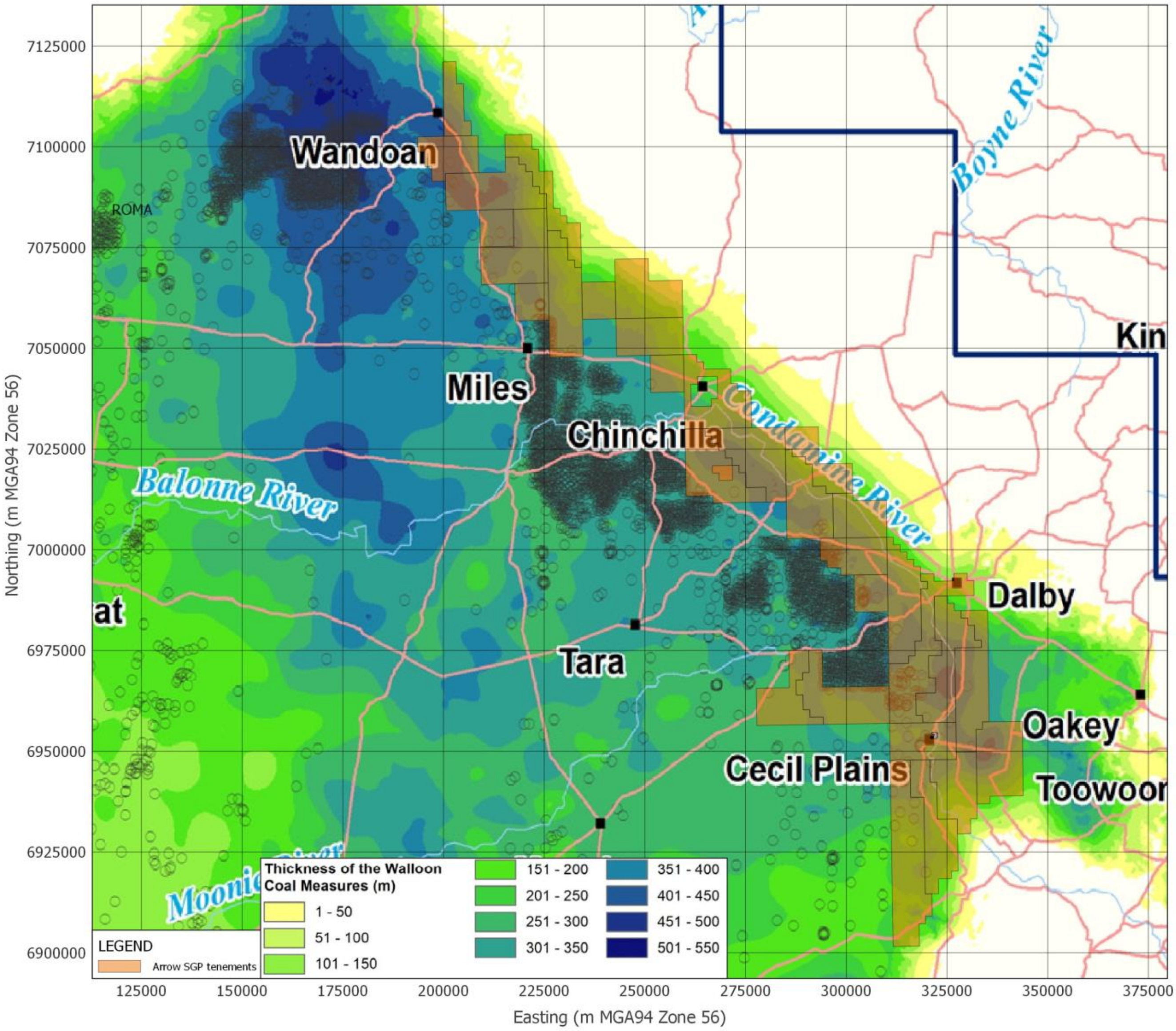


Figure 4: Walloon Coal Measures thickness (m) (adapted from Office of Groundwater Impact Assessment, 2019c)

Figure 5 shows a conceptual model of the north eastern Surat Basin, as presented by Office of Groundwater Impact Assessment (2019a). In the figure, it is indicated that that the regional dip in the area between Dalby and Chinchilla is generally towards the west and south west, along with the regional groundwater flow direction in the rock units. In the overlying Condamine Alluvium near Dalby and Chinchilla, groundwater is indicated to flow in a north westerly direction.

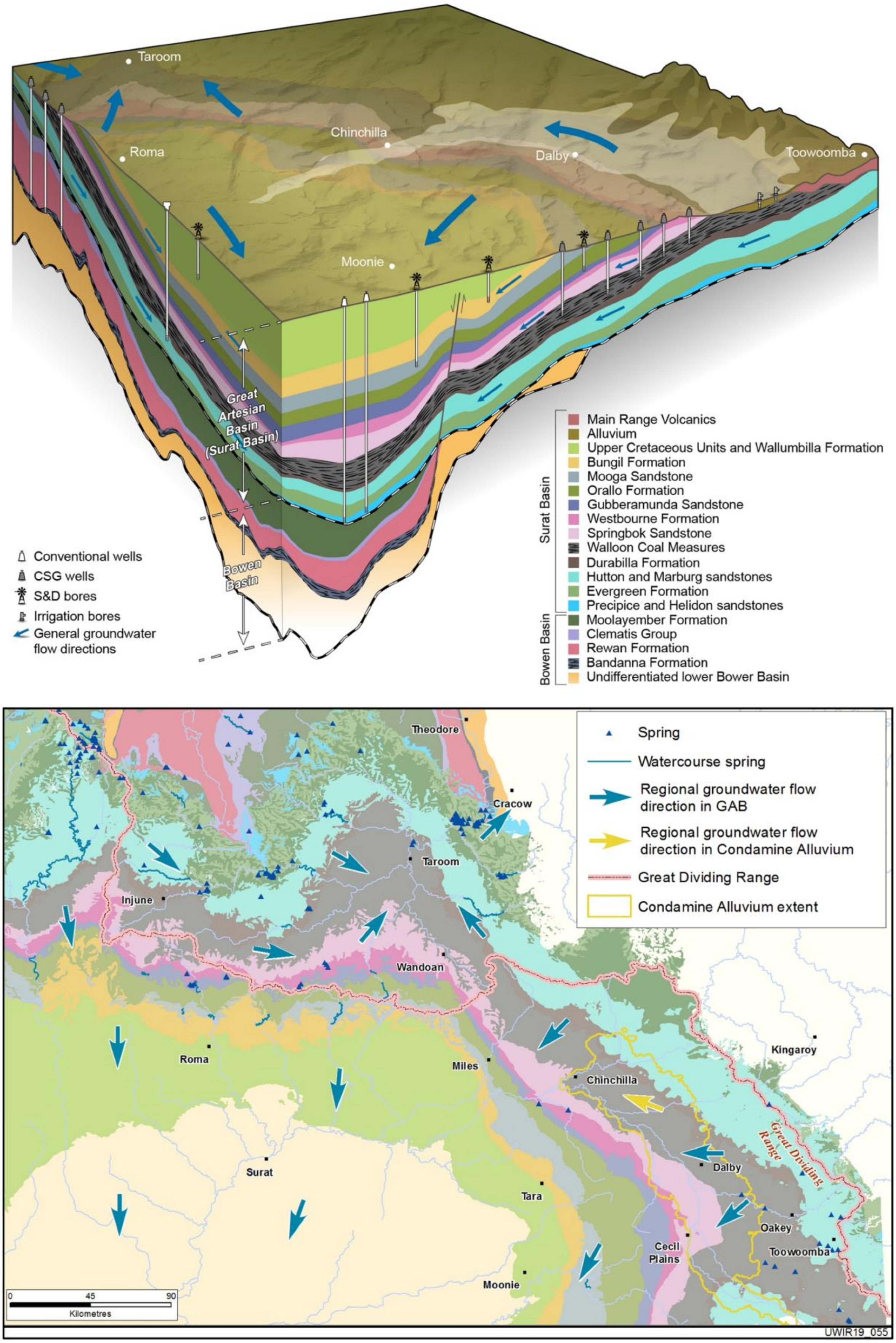


Figure 5: Conceptual model of the main groundwater systems in the north eastern Surat Basin (after Office of Groundwater Impact Assessment, 2019a)

3. Subsidence assessment

3.1. Interferometric Synthetic Aperture Radar (InSAR)

The TRE Altamira website (https://site.tre-altamira.com/company/our-technology/) and the Sentinel Online technical website (https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/product-overview/interferometry) provide good introductions to InSAR technology, as summarised below:

> *Synthetic Aperture Radar (SAR) satellites acquire images of the Earth's surface by emitting electromagnetic waves and analysing the reflected signals. All SAR satellites travel from the north pole towards the south pole for half of their trajectory (descending orbit) and from the south towards the north pole for the other half (ascending orbit). As a consequence, the same area of interest is revisited along the two orbits with ascending and descending imageries collected over it through time.*
>
> *A SAR signal contains amplitude and phase information. Amplitude is the strength of the radar response and phase is the fraction of one complete sine wave cycle (a single SAR wavelength). The phase of the SAR image is determined primarily by the distance between the satellite antenna and the ground targets.*
>
> *Interferometric SAR (InSAR) exploits the phase difference between two complex radar SAR observations of the same area, taken from slightly different sensor positions, and extracts distance information about the Earth's terrain.*

Several satellites are currently collecting SAR data, as shown in Figure 6. The InSAR data used in this report was collected by the Sentinel-1 satellite for the period August 2015 to June 2019 and by the Radarsat-2 and ALOS-1 satellites for the periods July 2012 to November 2017 and December 2006 to March 2011, respectively.

The Sentinel-1 satellite is part of the European Union's Copernicus project, which provides processed datasets stretching back for years and decades through six thematic streams of Copernicus services. The information services, as well as the data from which they are derived, are accessible on a full, free and open basis by anyone. Further information can be found on https://www.copernicus.eu/en.

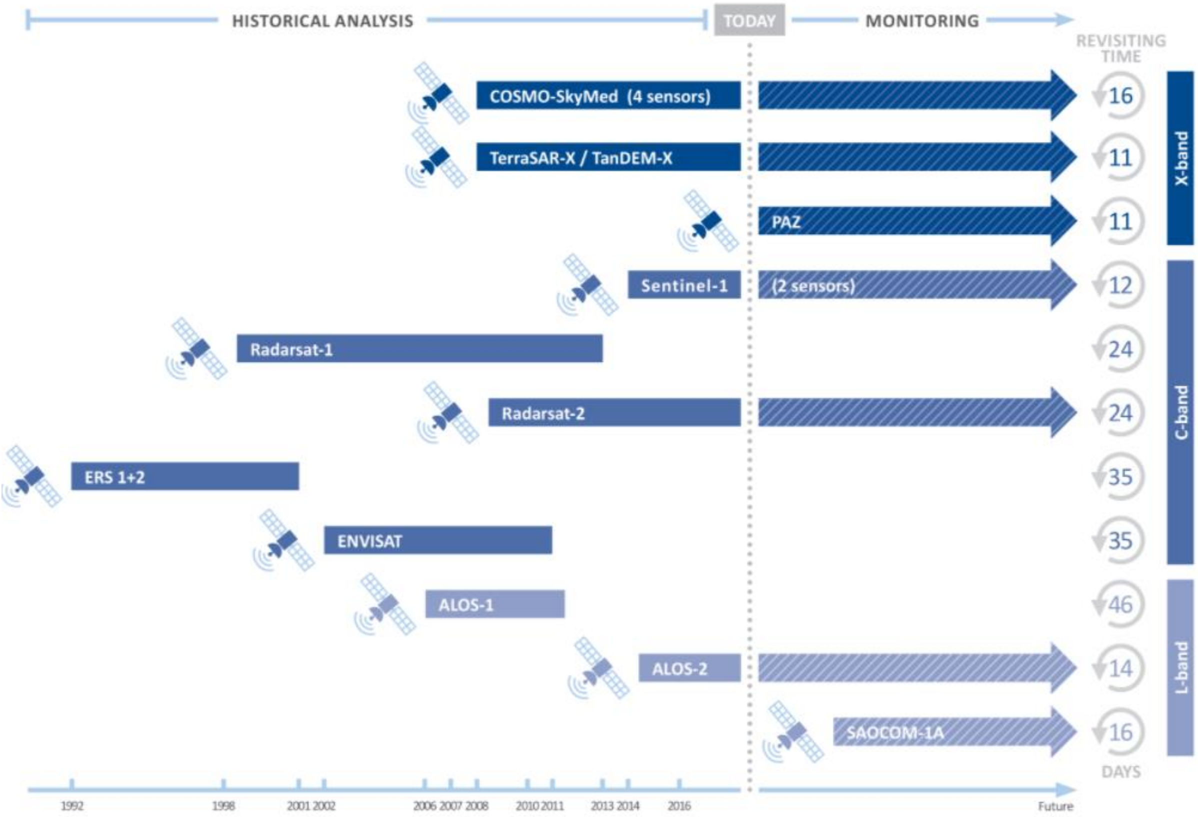


Figure 6: Satellites collecting SAR data historically and planned into the future (https://site.tre-altamira.com/company/our-technology/)

3.2. Subsidence monitoring

InSAR ground movement monitoring data for the period August 2015 to June 2019 was downloaded from the TRE Altamira website derived from InSAR data captured by the Sentinel-1 satellite. This consisted of two datasets, one covering tenements owned by QGC Pty Ltd (QGC) and the other covering tenements owned by Arrow. The data covered the Arrow tenements from north to south and the QGC tenements to the west. Ground movement readings were typically spaced at weekly intervals over the period from August 2015 to June 2019.

The data was processed by Coffey to assess ground movement observations over large and small spatial scales and to assess the development of ground movement with time.

Figure 7 shows the observed downward ground movement from August 2015 to June 2019. The InSAR data covered an area slightly larger than that shown in the figure, however the observed ground movement from August 2015 to June 2019 was negligible in areas not shown in the figure. Areas of upward ground movement are not shown in the figure.

The majority of the observed downward ground movement shown in Figure 7 is in either the area approximately 30 km west and south west of Dalby or the area approximately 40 km south and south west of Chinchilla. The largest ground movement is occurring on leases owned by QGC. The observed ground movement is generally between 20 mm and 60 mm with a small number of areas with ground movement over 60 mm and one location (near 262,000 mE, 7,012,000 mN MGA94 Zone 56) where observed ground movement was over 100 mm.

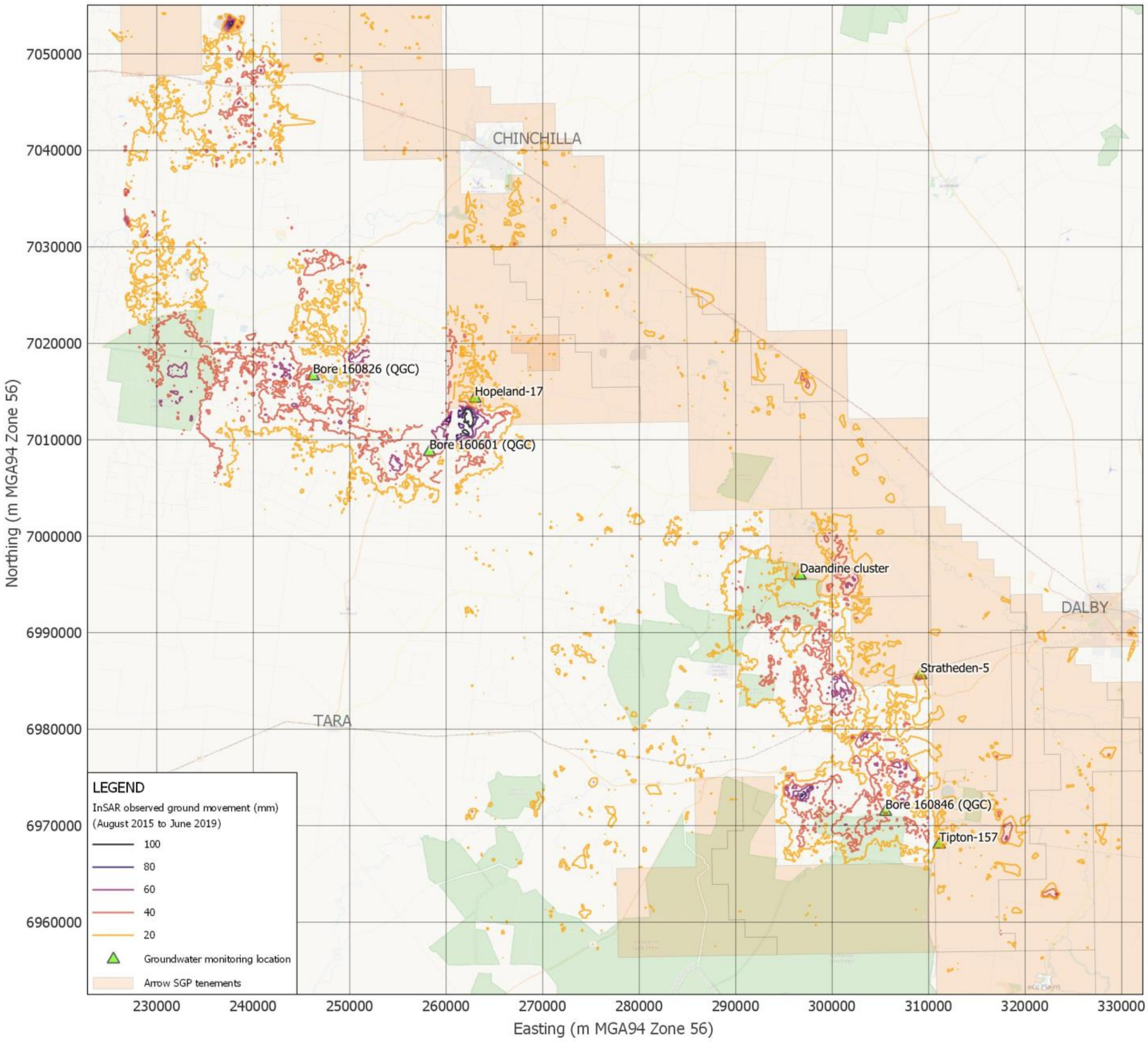


Figure 7: InSAR observed downward ground movement from August 2015 to June 2019

Figure 8 shows a closer view of the observed ground movement around the Daandine and Tipton CSG fields. At the southern part of the Daandine field, ground movement of just over 60 mm was observed between August 2015 and June 2019. Also shown in Figure 8 are five section lines used to assess the uniformity of ground movement and the development of ground movement with time as discussed in Section 3.3.

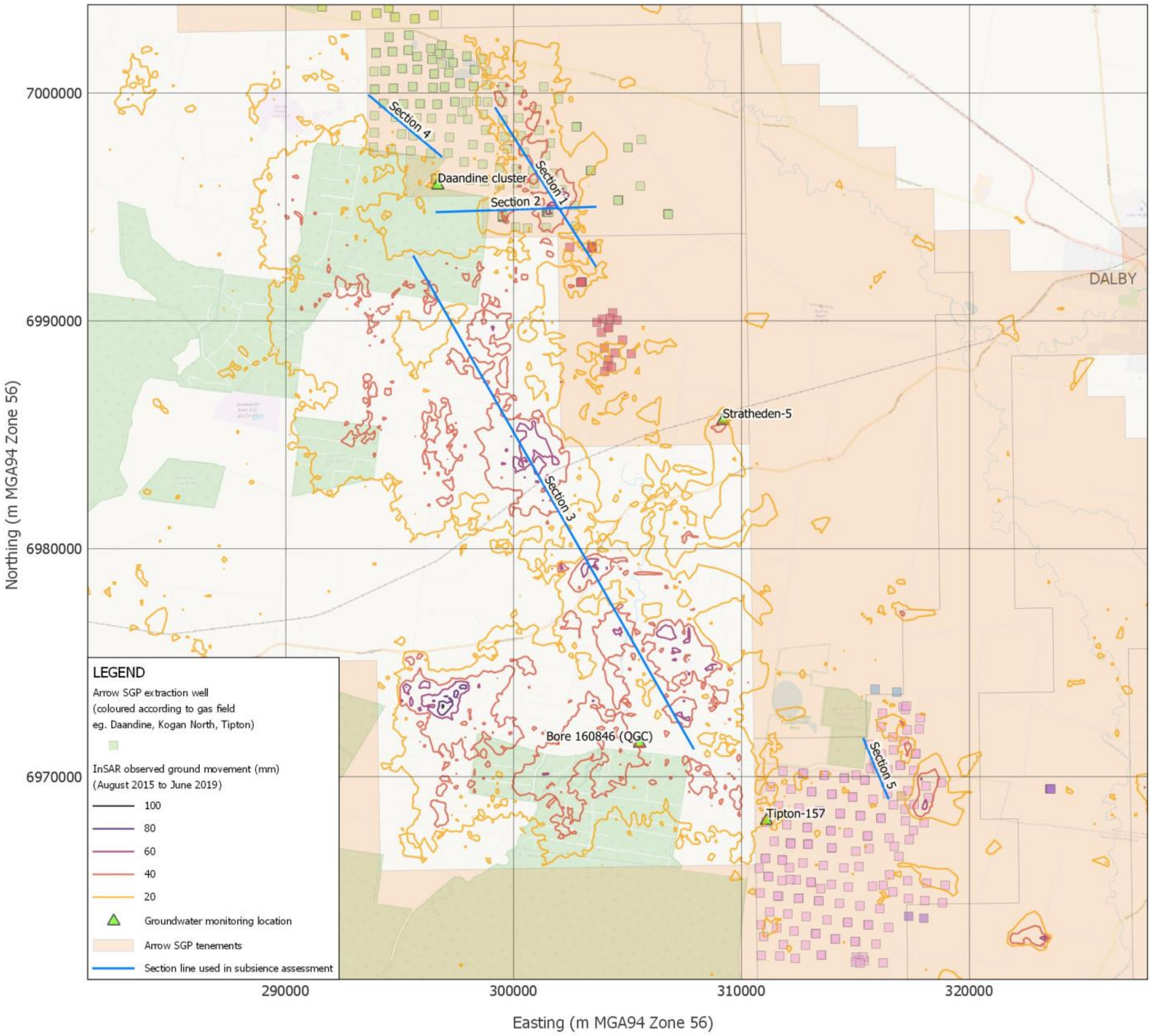


Figure 8: InSAR observed downward ground movement from August 2015 to June 2019 around the Daandine and Tipton areas

3.2.1. Historic InSAR data

Historic InSAR monitoring data was provided by Arrow covering the following time periods:

- December 2006 to March 2011 (the ALOS data)
- July 2012 to November 2017 (the RSAT2 data)

The ALOS data was derived from InSAR data captured by the ALOS-1 satellite and covered the majority of the Arrow tenements, providing InSAR ground movement monitoring data typically spaced at fortnightly intervals over the period from December 2006 to March 2011.

Figure 9 shows the observed ground movement from December 2006 to March 2011 provided in the ALOS data. The observed ground movement is generally less than 40 mm. Several localised areas of ground movement over 60 mm appear (from a visual inspection of the data against satellite imagery), to be related to developments such as farm dams and are in areas where CSG extraction is unlikely to have taken place between December 2006 and March 2011. There were two areas west and south of Dalby, as shown in Figure 9, where the data showed indicated downward ground movement was less than 20 mm resulting in an absence of contours in the marked areas.

The RSAT2 data was derived from InSAR data captured by the Radarsat-2 satellite and covered the Arrow tenements, providing InSAR ground movement monitoring data typically at fortnightly intervals over the period from July 2012 to November 2017.

Observed ground movement between July 2012 to November 2017, as provided in the RSAT2 data, was generally below 20 mm and no notable areas of settlement were observed.

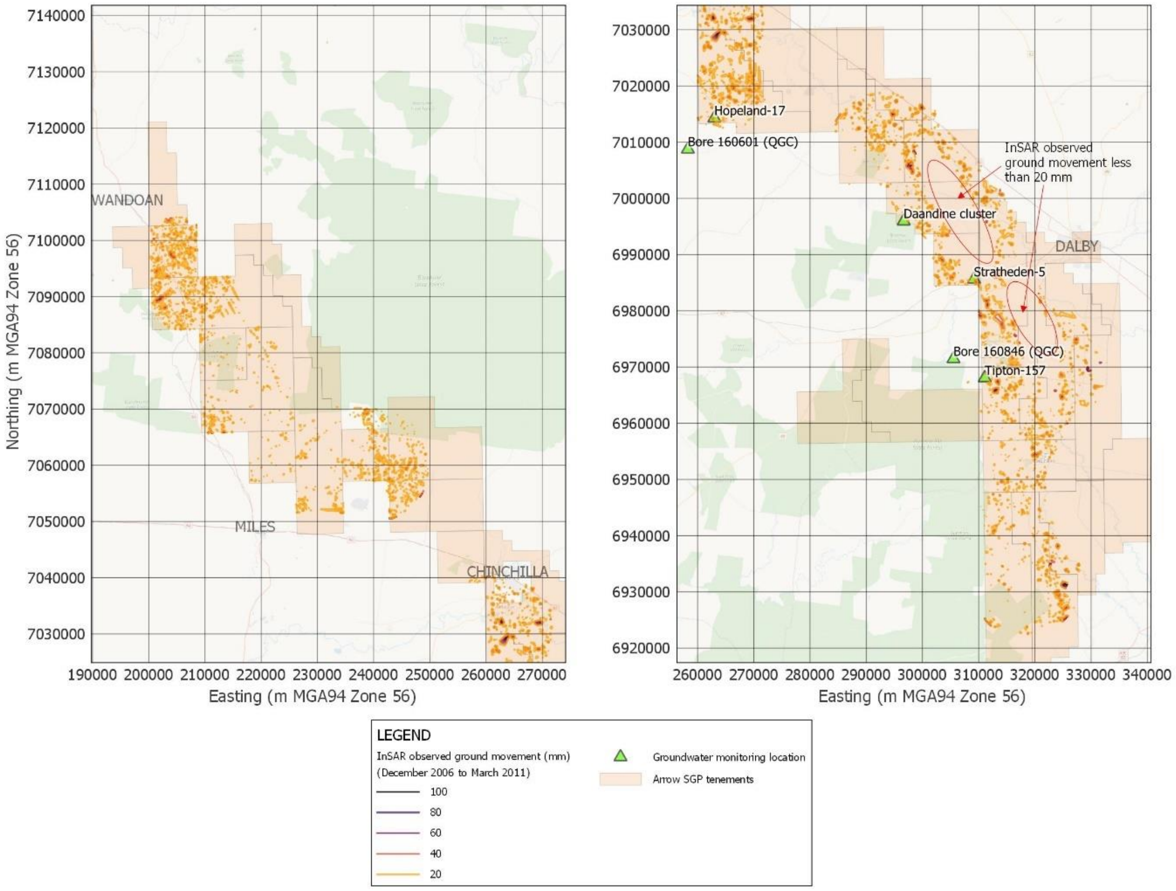


Figure 9: InSAR observed ground movement from December 2006 to March 2011

Figure 10 shows a close up of observed subsidence from December 2006 to March 2011 at the Daandine and Tipton CSG fields. The majority of observed subsidence in these areas is less than 40 mm.

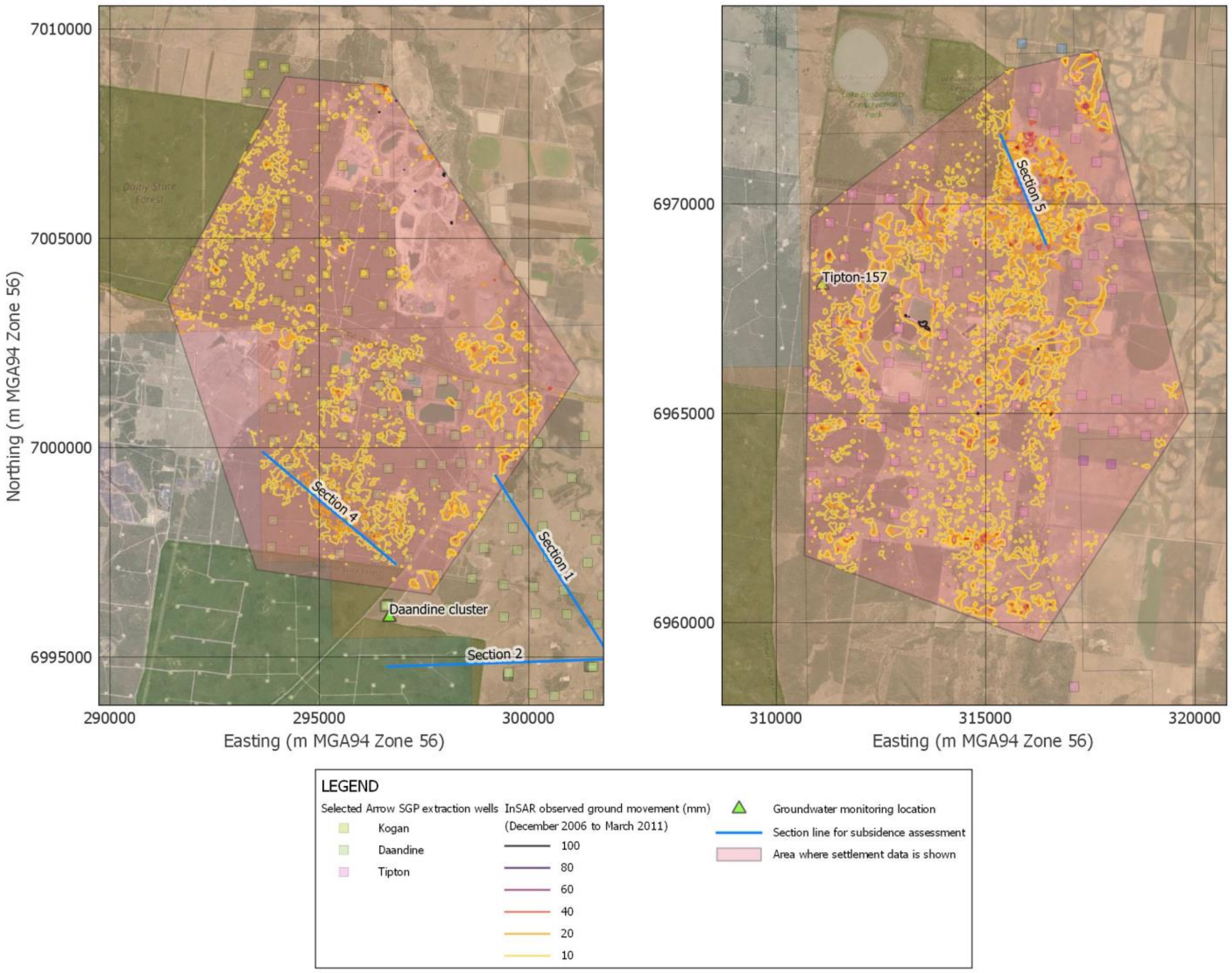


Figure 10: InSAR observed ground movement from December 2006 to March 2011 around the Daandine (left) and Tipton (right) areas

3.3. Uniformity of subsidence

3.3.1. Subsidence between August 2015 and June 2019

This section considers ground movement monitoring data derived from InSAR data captured by the Sentinel-1 satellite. This data shows ground movement since August 2015 and does not show ground movement that occurred prior to August 2015. The data includes ground movement related to all other non-CSG influences and no attempt has been made to remove ground movement related to non-CSG influences from the data.

To illustrate the uniformity of observed ground movement, figures showing an interpretation of observed ground movement along selected section lines are presented. The figures were developed by obtaining InSAR data within 150 m of a given section line, averaging the cumulative ground movement data observed for the months of May and June for a given year, and then applying a centred moving average window for 20 data point groups along the alignment. To illustrate the variability in the raw data, the individual datapoints for the June 2019 period are shown on the figures. This relatively simple method provides a reasonable assessment of the variability of subsidence along a given line. It should be noted that the interpretation of the observed ground movement along selected section lines does not take into account or illustrate what is occurring in the transverse direction away from the section lines.

Figure 11, Figure 12 and Figure 14 present the observed subsidence since August 2015 along Section 1, Section 2 and Section 3, shown in Figure 8. The figures show the observed subsidence at June 2016, June 2017, June 2018 and June 2019. The ground movement shown on the figures refers ground movement since August 2015, with a negative value indicating a decrease in elevation and a positive value indicating an increase in elevation since August 2015.

Average monthly groundwater production over the period June 2016 to June 2019, from extraction wells located on Arrow tenements within 500 m from the section lines, are shown. Where these wells are located at similar locations along the section and are hard to differentiate, the production from several wells are grouped together. Groundwater production rates from extraction wells located on QGC tenements are not shown as the data was not available for this report.

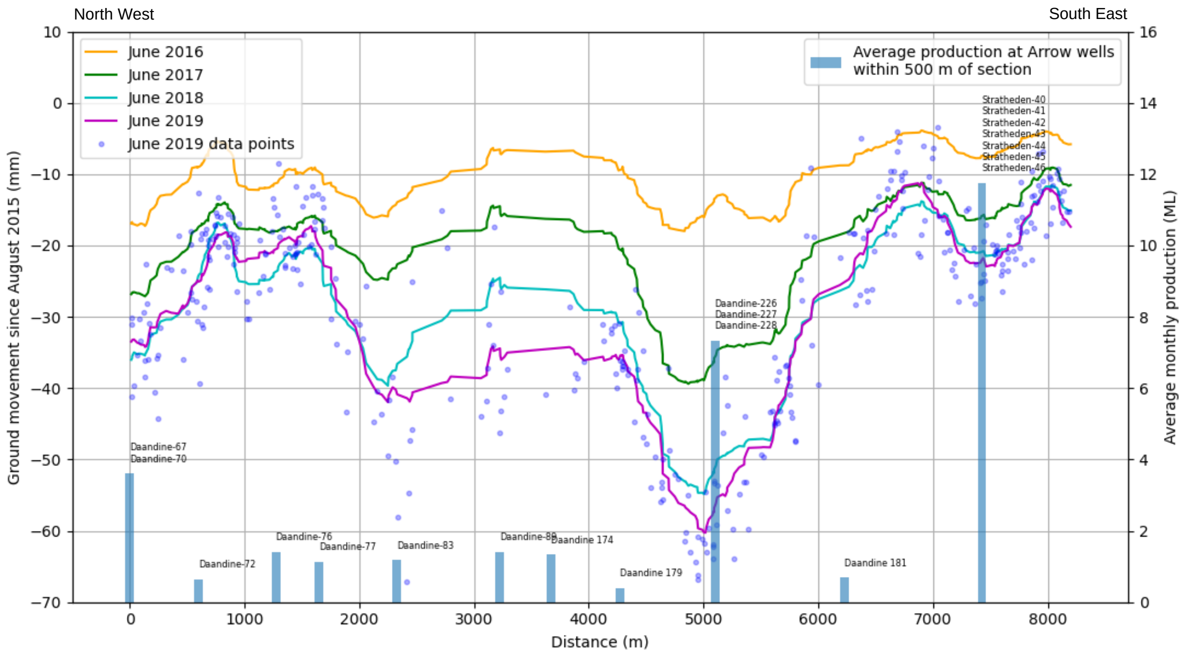


Figure 11: Observed ground movement since August 2015 along Section 1

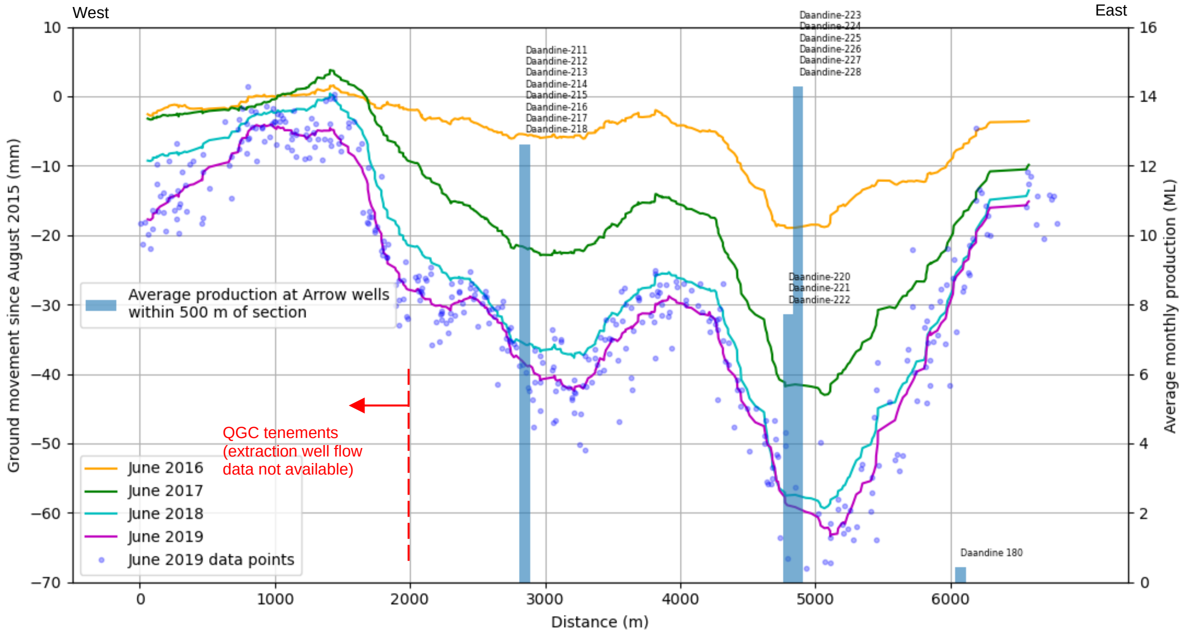


Figure 12: Observed ground movement since August 2015 along Section 2

Section 1 and Section 2 are through a part of the Daandine CSG field which has notable InSAR observed ground movement since August 2015, as shown in Figure 13. This figure suggests that the observed south east to north west ground movement trough relates to two extraction areas, as noted in the figure. Around the Daandine 99 well, the 20 mm ground movement contour is located approximately 1 km south east of the well. Around Daandine 220 to Daandine 228, the 20 mm ground movement contour is located just under 1.5 km south east of those wells. The average monthly extraction volumes for these wells are shown in Table 1.

The maximum gradient to the east of the Daandine 99 and Daandine 220 to 228 wells is approximately 20 mm over 200 m, or 1 in 10,000. This can be seen from the contours of observed ground movement between August 2015 and June 2019, shown in Figure 13.

Table 1: Average monthly extraction volumes for selected wells at the Daandine CSG Field

Extraction well	Average monthly extraction volume (ML)	Period
Daandine 99	1.0	Jul 2015 - Jun 2019
Daandine 220	2.9	Jan 2016 - Jun 2019
Daandine 221	3.8	Jan 2016 - Jun 2019
Daandine 222	0.9	Jan 2016 - Jun 2019
Daandine 223	1.6	Jan 2016 - Jun 2019
Daandine 224	4.2	Jan 2016 - Jun 2019
Daandine 225	1.1	Jan 2016 - Dec 2018
Daandine 226	3.9	Jan 2016 - Jun 2019
Daandine 227	2.0	Jan 2016 - Jun 2019
Daandine 228	1.3	Jan 2016 - Dec 2018

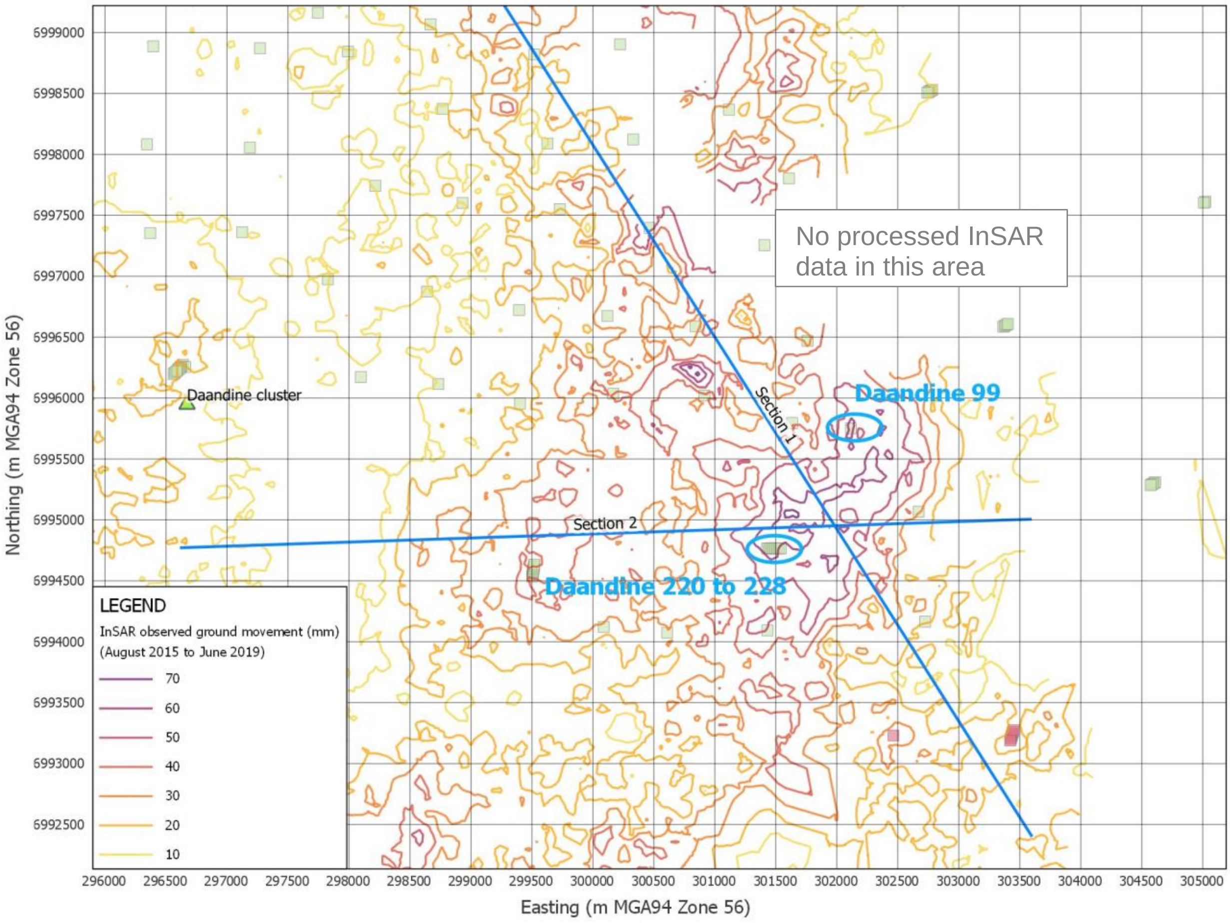


Figure 13: Observed ground movement at the Daandine CSG Field between August 2015 and June 2019

Figure 14 presents settlement along Section 3, which crosses from the north west to south east through leases owned by QGC, as shown in Figure 8. The extraction rates for CSG wells in this area were not available for this report, however the observed settlement provides a useful illustration of observed slope gradients and the inferred subsidence zone of influence around CSG wells.

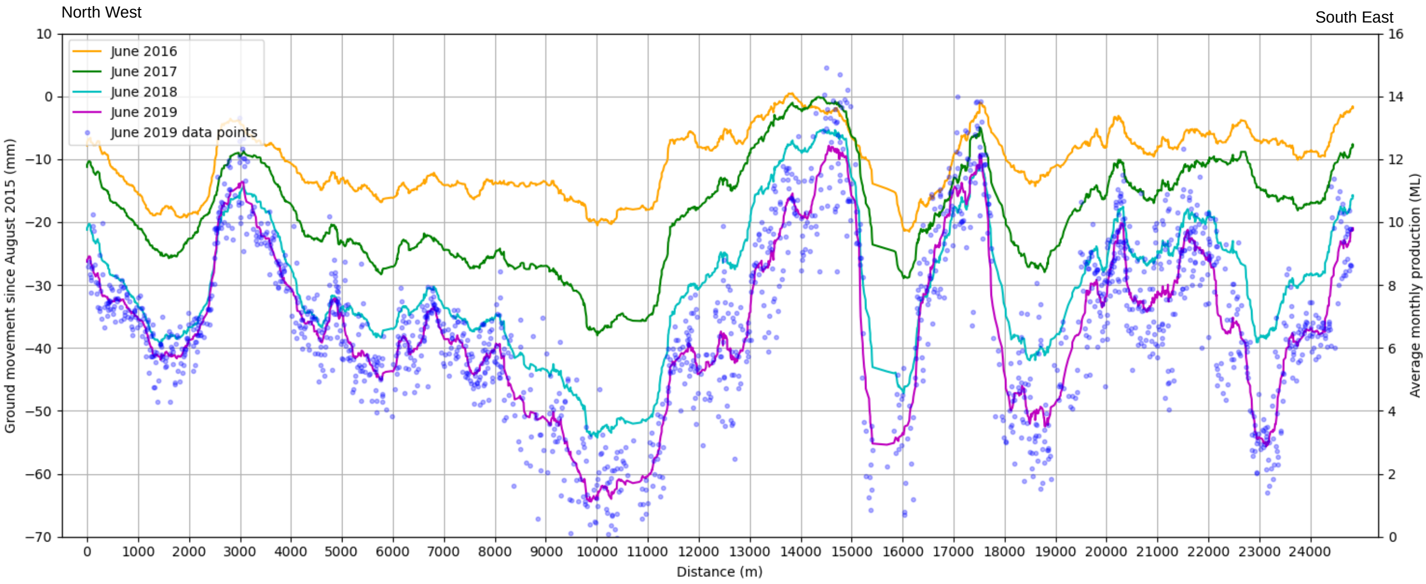


Figure 14: Observed ground movement since August 2015 along Section 3 (section location shown in Figure 8)

Between chainage 14,500 m and 16,500 m, a notable ground movement trough can be seen, which looks similar in appearance to the one discussed above at the Daandine CSG Field. Around the northern part of the depression, a slope gradient of approximately 20 mm over 100 m, or 1 in 5,000 is apparent. The 20 mm ground movement contour is located approximately 600 m to the north west and 1,200 m to the south east of the centre of the depression.

A notable area of ground movement to the west of this area appears not be related to CSG extraction. The satellite image shows no wells in the area, as can be seen from Figure 16. It is noteworthy that the maximum ground movement between August 2015 and June 2019 in this area is over 70 mm, slightly higher than that observed at the trough to the east which is more likely to be related to CSG extraction.

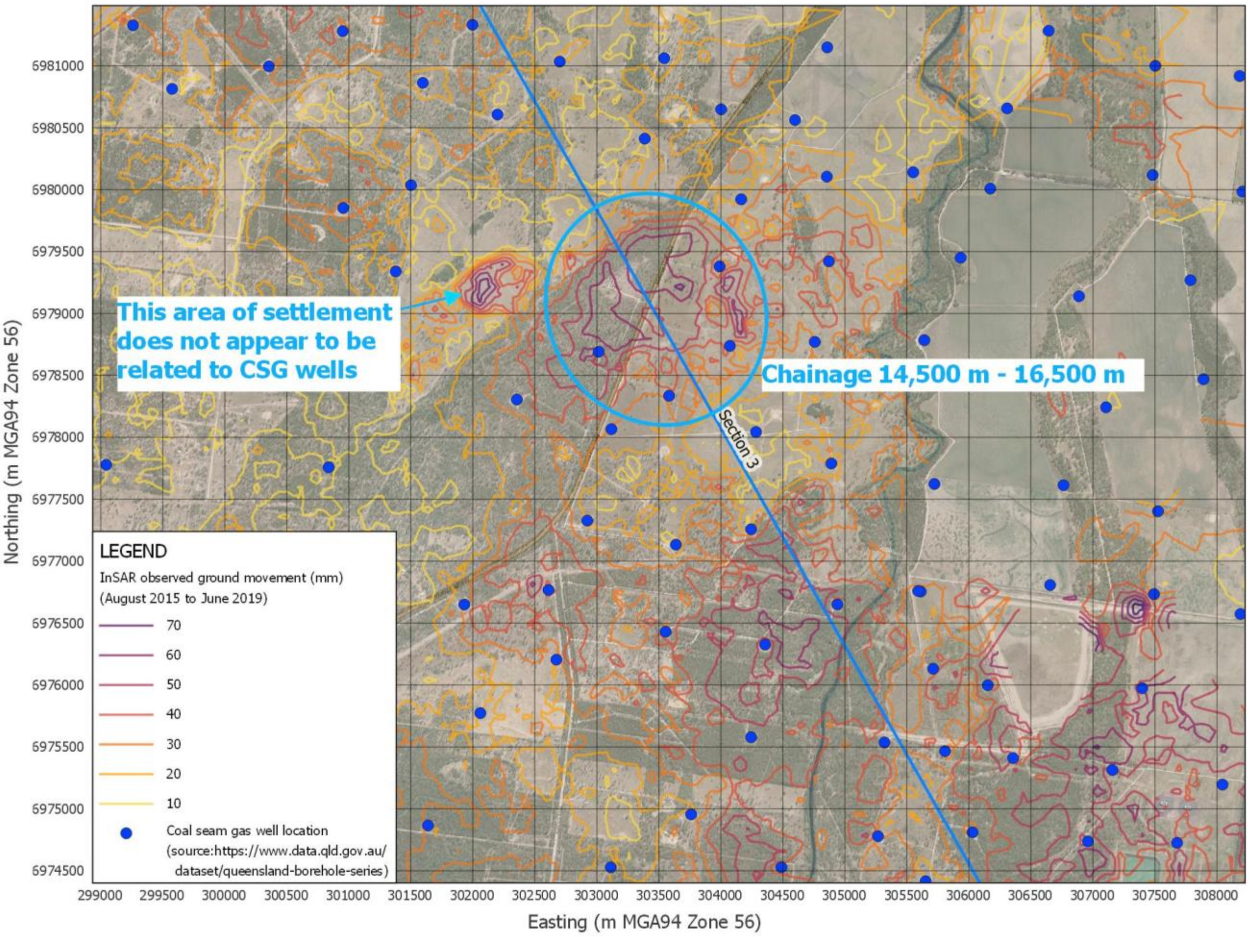


Figure 15: Downward movement along part of Section 3 (on tenements owned by QGC) between August 2015 and June 2019

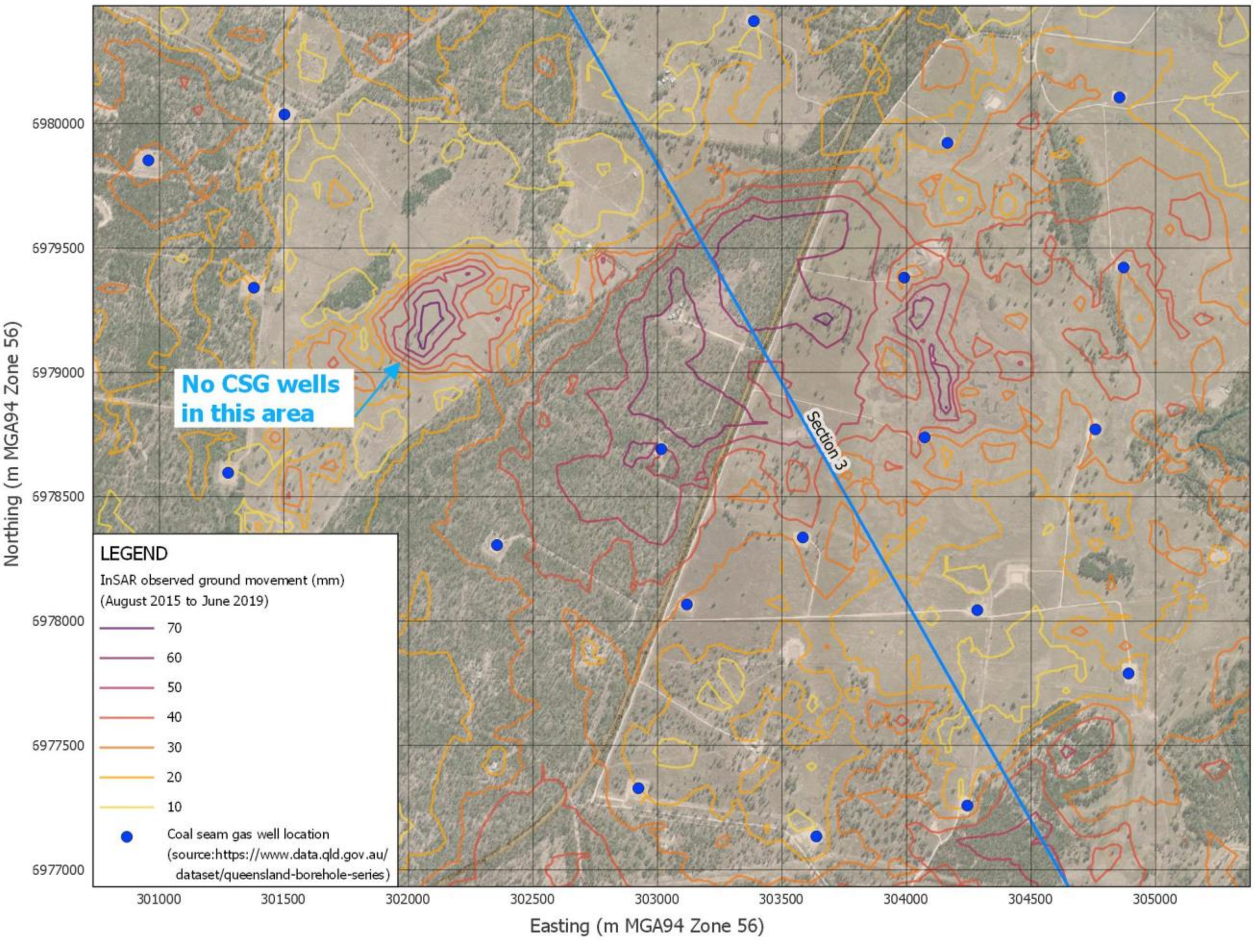


Figure 16: Area of downward movement (on a tenement owned by QGC) which appears to be unrelated to CSG extraction

3.3.2. Subsidence between December 2006 to March 2011

This section considers ground movement monitoring data derived from InSAR data captured by the ALOS-1 satellite. The data includes ground movement related to all other non-CSG influences and no attempt has been made to remove ground movement related to non-CSG influences from the data.

Figure 17 shows observed ground movement from December 2006 to March 2011 at selected locations at the Daandine and Tipton CSG fields based on the ALOS data. Figure 18 and Figure 19 present the observed ground movement along Section 4 and Section 5. The ground movement shown on Figure 18 and Figure 19 refers to ground movement since December 2006, with a negative value indicating a decrease in elevation and a positive value indicating an increase in elevation compared to December 2006.

The observed ground movement from December 2006 to March 2011 along Section 4 and Section 5 appears to be less pronounced than that observed between August 2015 and June 2019 along the sections shown in Figure 11, Figure 12 and Figure 14.

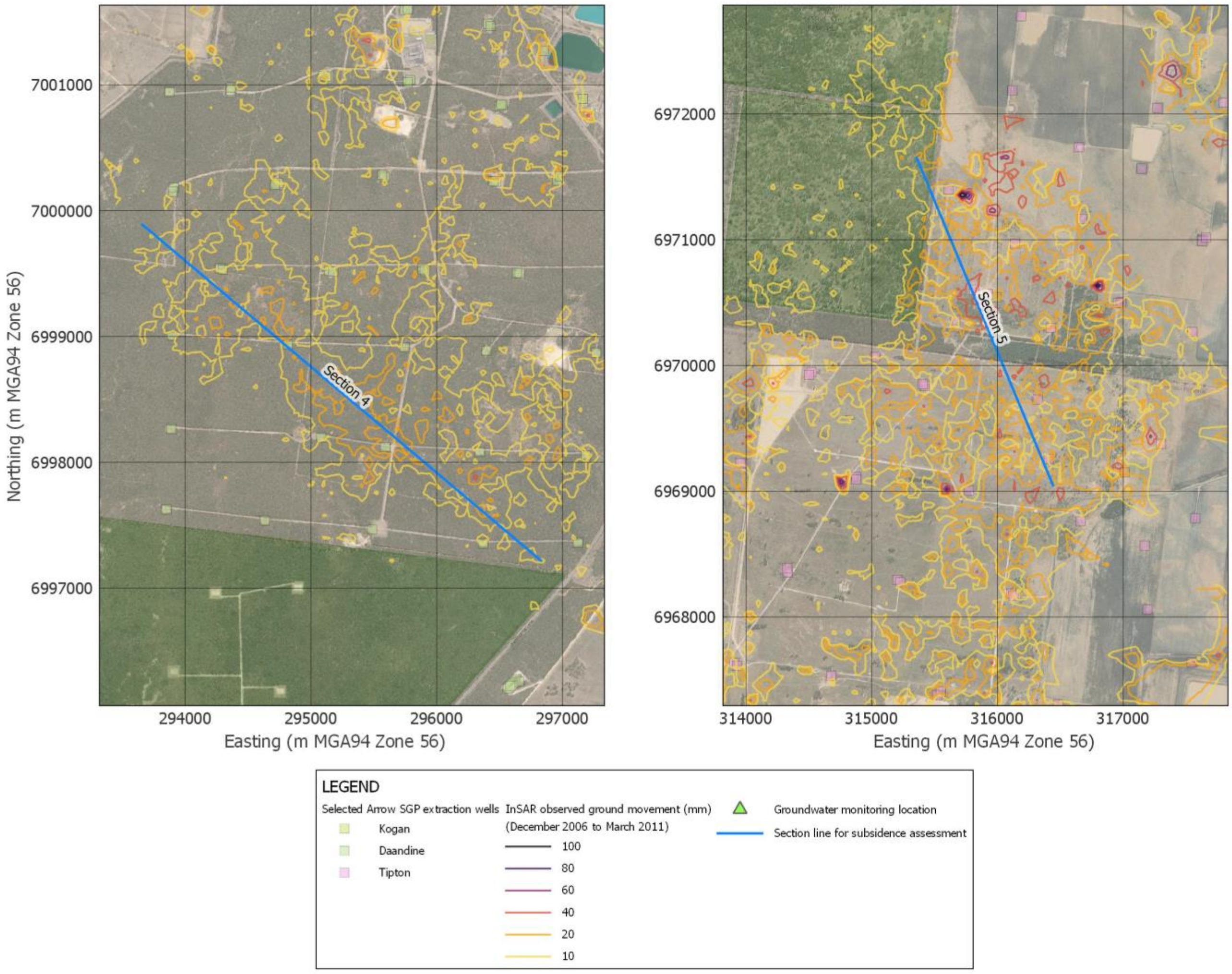


Figure 17: InSAR observed ground movement from December 2006 to March 2011 around the Daandine (left) and Tipton (right) areas showing locations of Section 4 and Section 5

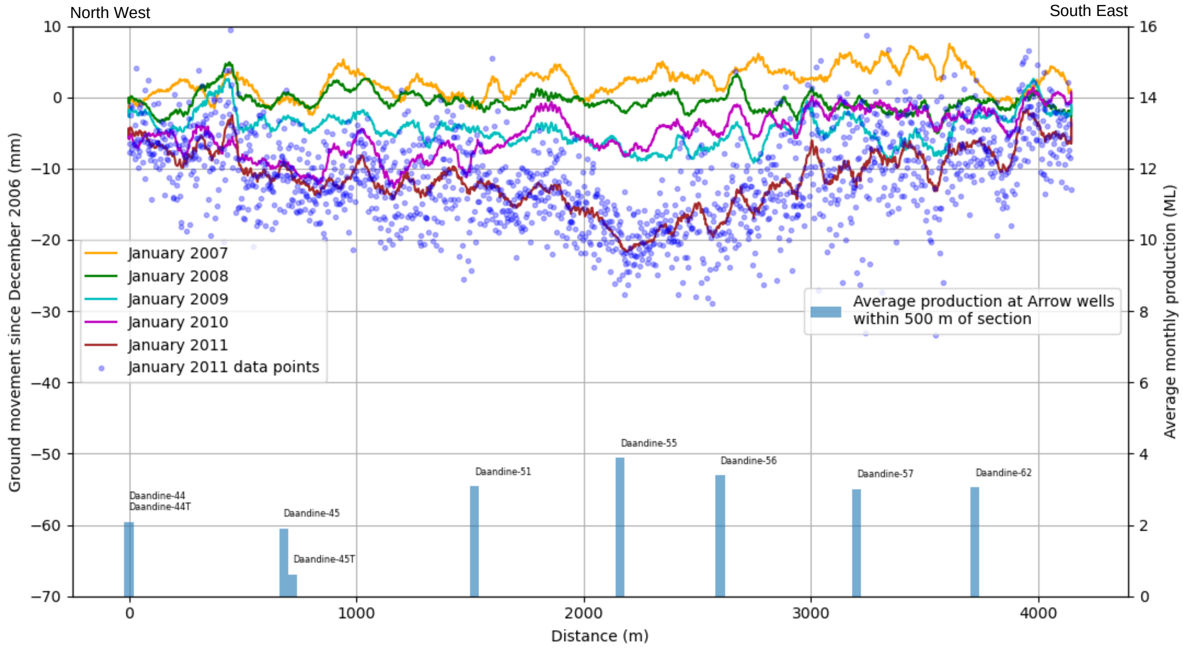


Figure 18: Observed ground movement since August 2006 along Section 4

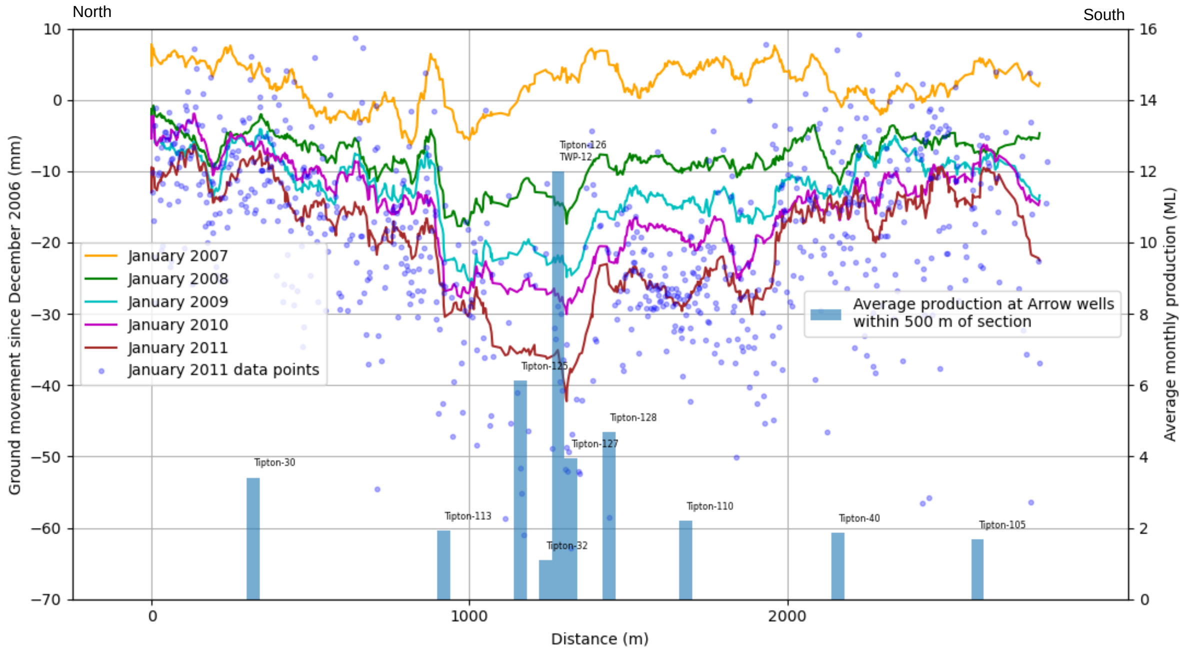


Figure 19: Observed ground movement since August 2006 along Section 5

3.4. Groundwater level monitoring and subsidence

A large number of groundwater monitoring bores are in operation in the Surat Basin in support of CSG operations. Monitoring data from these bores is accessible via the Queensland Globe service provided by the Queensland Government.

Groundwater monitoring data for a large number of bores within and around the SGP area were provided by Arrow. At certain locations, monitoring of groundwater levels within the Walloon Coal Measures is available.

The Daandine Cluster bores are located at the southern end of the Daandine CSG field. The Hopeland-17 bore is located at the Hopeland CSG field, approximately 38 km north west of the Daandine Cluster. Bore 160601 is located approximately 8 km south west of the Hopeland CSG field, on a lease owned by QGC. Bore 160846 is located approximately 5 km north west of the Tipton CSG field, on a lease owned by QGC. The locations of these bores are shown in Figure 7.

Figure 20 presents the measured groundwater levels from September 2014 to October 2019 for bores at the Daandine Cluster. Observed ground movement from August 2015 to June 2019 is also shown on the figure, based on the average of InSAR results for monitoring points located within a 150 m radius circle centred at this area.

Groundwater monitoring at the Daandine Cluster shows drawdown in the Lower Juandah Coal Measures and the Taroom Coal Measures of 70 m between June 2015 and January 2017. From January 2017 the drawdown rate reduces to approximately 50 m every 3 years.

Between June 2015 to January 2017 approximately 10 mm of ground movement was observed. From around March 2017 the rate of ground movement reduces to approximately 7 mm every 3 years.

Groundwater level observations for the other geological units with groundwater monitoring shown in Figure 20 are summarised below:

- Westbourne Formation: Groundwater levels increased by approximately 2 m to 3 m between September 2014 and October 2019.
- Springbok Sandstone: Groundwater levels increased by approximately 7 m between September 2014 and October 2019.

- Hutton Sandstone: Groundwater levels decreased by approximately 2 m between September 2014 and October 2019.

This suggests that the groundwater levels in the overlying and underlying geological units were not influenced significantly by the drawdowns in the Walloon Coal Measures over the monitoring period shown in Figure 20.

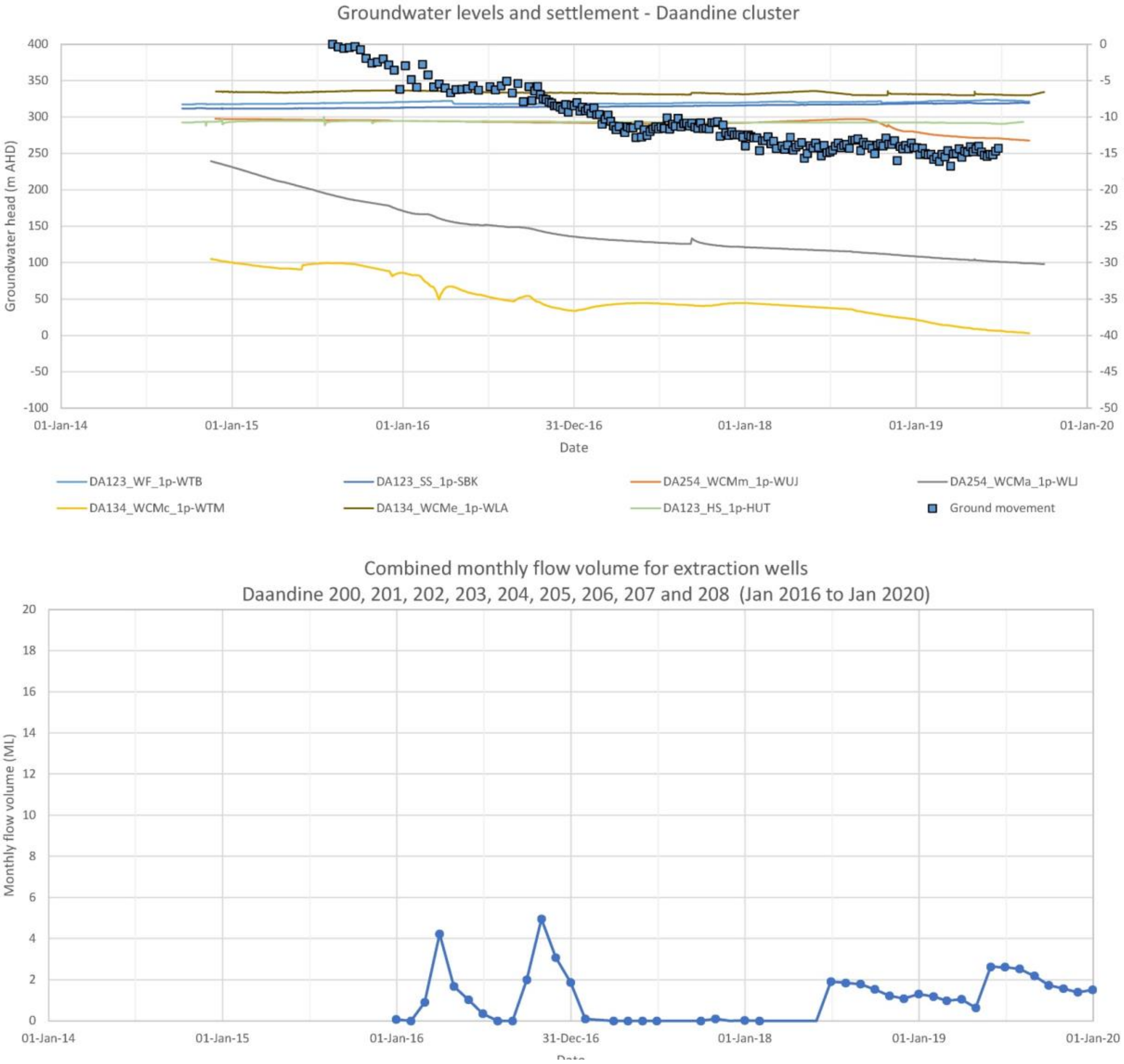


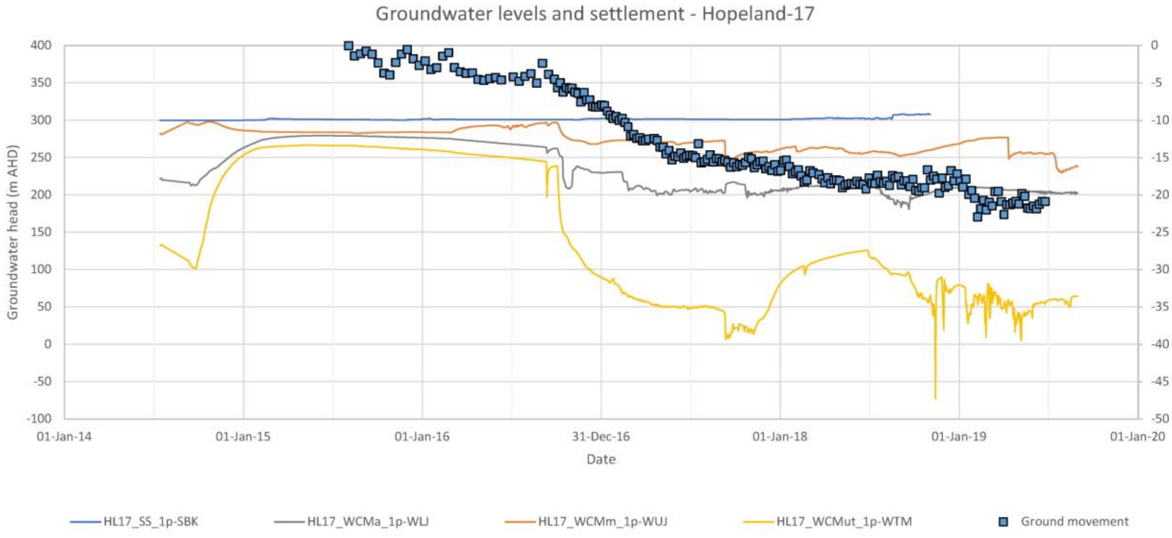
Figure 20: Groundwater drawdown, observed ground movement and combined monthly flow volume at the Daandine Cluster

Figure 21 presents measured groundwater levels from July 2014 to October 2019 at the Hopeland-17 bore. Observed ground movement from August 2015 to June 2019 is also shown on the figure.

Groundwater monitoring at the Hopeland-17 bore shows drawdown in Taroom Coal Measures of 200 m between June 2016 and June 2019. Over the same period the drawdown in the Upper Juandah and Lower Juandah Coal measures was approximately 70 m.

Between June 2016 and June 2019 approximately 20 mm of ground movement was observed.

The groundwater levels in the Springbok Sandstone (monitoring location HL17_SS_1p-SBK) appear not to have been influenced by the drawdowns in the Walloon Coal Measures (HL17_WCMa-1p-WLJ, HL17_WCMm-1p-WUJ and HL17_WCMut-1p-WTM) over the monitoring period shown in Figure 21. It is noteworthy that during a period of groundwater level rise from late 2017 to mid 2018 when groundwater levels recorded in the Upper Taroom (HL17_WCMut-1p-WTM) rose by approximately 100 m there was no corresponding reduction in ground surface settlement.


Groundwater levels and settlement - Hopeland-17

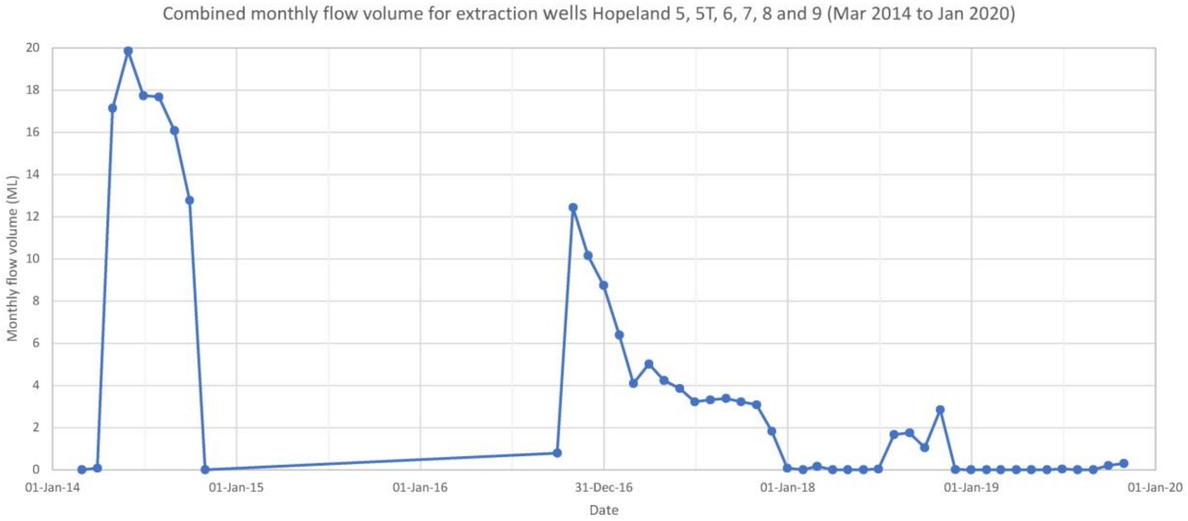

Combined monthly flow volume for extraction wells Hopeland 5, 5T, 6, 7, 8 and 9 (Mar 2014 to Jan 2020)

Figure 21: Groundwater drawdown, observed ground movement and monthly flow volumes at Hopeland-17

Figure 22 presents measured drawdown from December 2014 to January 2019 at Bore 160601. Observed ground movement from July 2015 to April 2019 is also shown on the figure.

Groundwater monitoring at Bore 160601 shows drawdown in Taroom Coal Measures of 250 m (monitoring location 160601_WCMta_1p_WTM) between January 2016 and January 2018. Over the same period the drawdown in the Upper Juandah (160601_ WCMuj_1p_WUJ) and Lower Juandah (160601_ WCMlj_1p_WLJ) Coal Measures was approximately 50 m.

Between January 2016 and January 2018 approximately 30 mm of ground movement was observed.

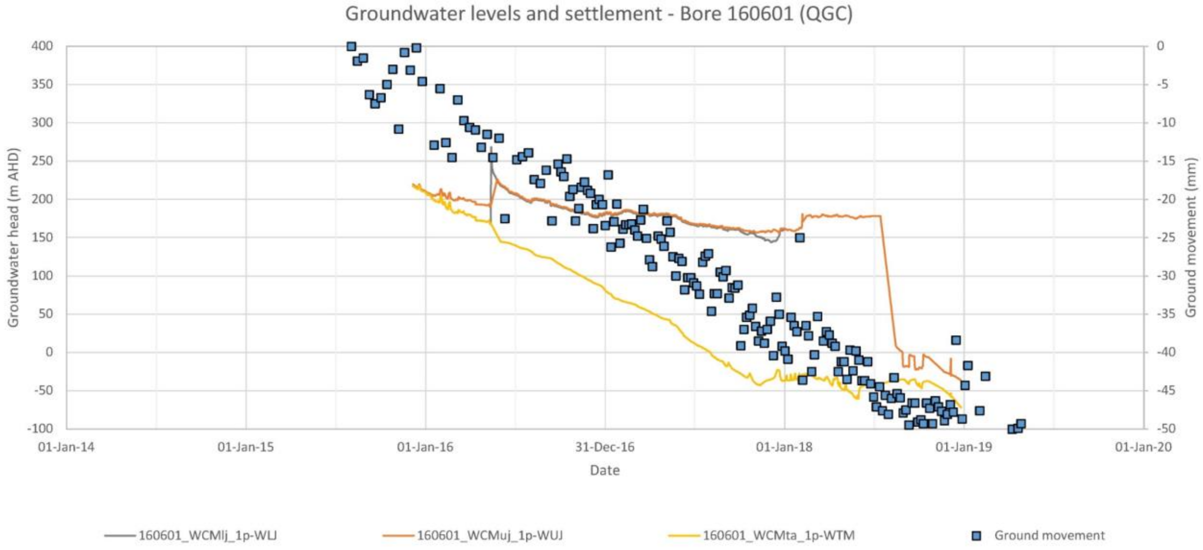


Figure 22: Groundwater drawdown and observed ground movement at Bore 160601 (QGC)

Figure 23 presents measured drawdown from January 2016 to April 2017 at Bore 160846. Observed ground movement from July 2015 to August 2019 is also shown on the figure.

Groundwater monitoring at Bore 160846 shows drawdown in the Lower Juandah and the Taroom Coal Measures of 30 m between July 2016 and December 2016. Monitoring records in the Upper Juandah Coal Measures do not run for a sufficient time interval to assess drawdown there.

Between July 2016 and December 2016 approximately 5 mm of ground movement was observed.

During 2016 an increase in groundwater levels of approximately 20 m was observed in the Springbok Sandstone.

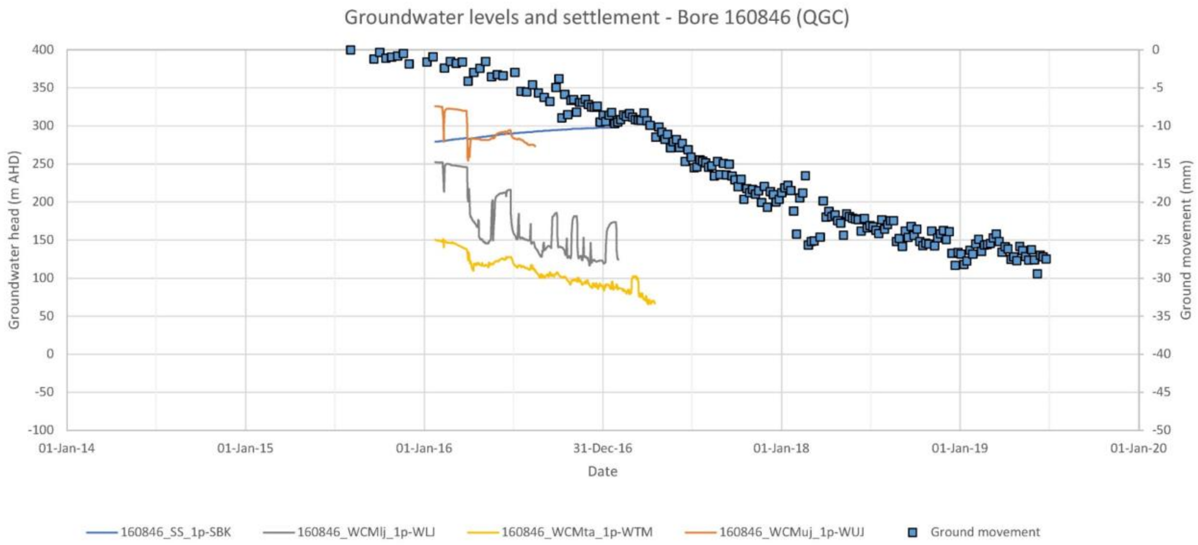


Figure 23: Groundwater drawdown and observed ground movement at Bore 160846 (QGC)

Note that in Figure 20, Figure 21, Figure 22 and Figure 23, the groundwater monitoring points are labelled according to the geological units they are screened in. The last three letters in their names refer to the following geological units:

- WTB: Westbourne Formation
- SBK: Springbok Sandstone
- WUL: Upper Juandah Coal Measures
- WLJ: Lower Juandah Coal Measures
- WTM: Taroom Coal Measures
- WLA: Lower aquitard of the Walloon Coal Measures
- HUT: Hutton Sandstone
- EVG: Evergreen Formation

3.5. Compressibility of the Walloon Coal Measures

The assessment of observed settlement as a function of groundwater level drawdown in the Walloon Coal Measures can be used to assess the compressibility of the geological units comprising the Walloon Coal Measures at the area where the observations were carried out.

The thickness of the Juandah Coal Measures and the Taroom Coal Measures, for the purposes of assessing their compressibility, were taken from a regional-scale numerical groundwater flow model developed by the Office of Groundwater Impact Assessment. The model is described further in Section 6.1. The Juandah Coal Measures were taken to be represented by model layers 11, 12, 13 and 14 and the Taroom Coal Measures by model layers 15 and 16, as shown in Figure 42 in Section 6.1.

Table 2 summarises the observed groundwater drawdowns and corresponding surface settlements, along with the adopted thickness of the Juandah Coal Measures and the Taroom Coal Measures, at each of the locations where groundwater level monitoring and settlement observations were described in Section 3.4.

Table 2: Observed groundwater drawdown and corresponding surface settlement

Location (refer to Figure 7)	**Juandah Coal Measures**		**Taroom Coal Measures**		**Surface settlement (mm)**
	Thickness (m)	Groundwater drawdown (m)	Thickness (m)	Groundwater drawdown (m)	
Daandine Cluster - 1	203.1	70	119.3	70	10
Daandine Cluster - 2	203.1	50	119.3	50	7
Hopeland-17	206.4	70	123.7	200	20
Bore 160601	212.8	50	125.6	250	30
Bore 160846	208.7	30	126.0	30	5

Subsidence can be assessed by considering the mechanical properties of each component within the geological profile together with predictions of water pressure changes, to predict the compression of each stratigraphic component. The total subsidence experienced at the surface can then be assessed by integrating the individual component compressions.

Subsidence associated with this mechanical process is expressed using the following relationship (which is based upon integration of one dimensional settlement of an elastic material under pore-pressure change – stress stain relationships as described in Sanderson (2012)):

$$\delta = \int_{z=\infty}^{z=0} \delta u \; \alpha \; \frac{(1+\upsilon')(1-2\,\upsilon')}{(1-\upsilon')E'} \; dz$$

Where:

δ is the subsidence at the ground surface

z is the depth below the ground surface

δu is the pore pressure change at depth z below the ground surface

υ' is the Poisson's ratio of the ground at depth z

α is the Biot's coefficient of the ground at depth z

E' is the drained Young's modulus of the ground at depth z

Using the above relationship, assuming α = 0.85 and υ' = 0.25, and recognising that relatively limited groundwater drawdown is occurring in the geological units outside the Walloon Coal Measures, an assessment of the Youngs Modulus values providing the best fit, in a least squares sense, to the observed settlement at the five observation points in Table 2, resulted in the following values:

- Juandah Coal Measures: E' = 23.2 GPa
- Taroom Coal Measures: E' = 4.2 GPa

This combination was found to provide the smallest sum of squared differences between modelled and observed settlement. Figure 24 shows modelled versus observed settlement at each of the locations using the adopted Youngs Modulus values. The modelled versus observed settlement at the five observation points can be seen to be reasonably close. The data has a root mean square error (sum of squared differences between modelled and observed settlement) of less than 2 mm.

It should be noted that the assessed Youngs Modulus values incorporate the combined stiffness of the coal seams and stiffer interbedded materials such as sandstone and siltstone. For this assessment, the Juandah Coal Measures was based on four layers of the regional-scale numerical groundwater flow model developed by the Office of Groundwater Impact Assessment, as shown in

Figure 42. This likely incorporates a significant proportion of stiffer interbedded materials in the unit, increasing the value of the assessed Youngs Modulus.

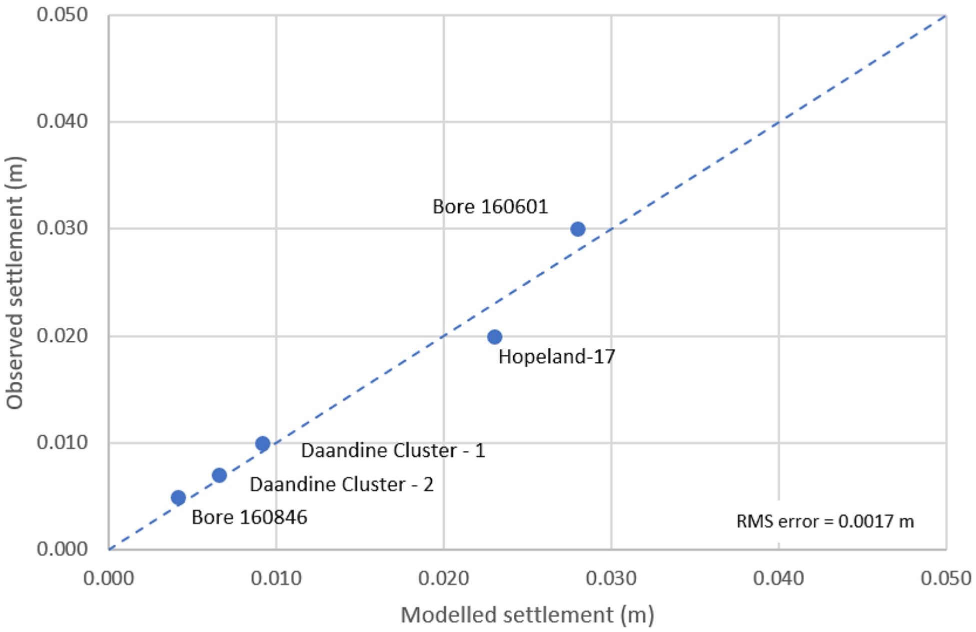


Figure 24: Comparison of observed and modelled settlement using adopted Young's modulus values

3.5.1. Unconfined compressive strength testing

The results of several unconfined compressive strength (UCS) tests on rock cores at the Daandine, Kogan North, Tipton and Meenawara CSG fields were provided by Arrow. The Meenawarra CSG field is located approximately 10 km south of Tipton. The results of the UCS tests are included here for comparison with the compressibility parameters assessed in Section in 3.5. It is noted that Arrow indicated that the core samples were up to 10 years old. This is likely to have some influence on the results of the UCS tests.

Table 3 presents a summary of the UCS test depths, confining pressures and reported tangent modulus values. Figure 25 shows the reported tangent modulus versus depth for the test results shown in Table 3. The figure includes the drained Young’s Modulus values for the Taroom Coal Measures and the Juandah Coal Measures assessed in Section in 3.5. There does not appear to be a correlation with depth evident in the test results.

It is apparent from Figure 25 that the reported tangent modulus for the UCS tests is close to the drained Young’s Modulus for the Taroom Coal Measures assessed in Section in 3.5, however it is notably lower than the assessed drained Young’s Modulus for the Juandah Coal Measures.

The UCS test results are included in Appendix A.

Table 3: UCS test depths, confining pressures and reported tangent modulus values

Location	Depth from (mbgl)	Depth to (mbgl)	Confining pressure (MPa)	Tangent modulus (GPa)
Daandine 4 - 114304	140.0	140.7	3.5	4.3
Daandine 4 - 114306	202.5	202.8	5.1	15.1
Daandine 4 - 114,307	306.6	306.9	7.6	3.7
Daandine 4 - 114308	320.2	320.4	7.9	3.8
Daandine 4 - 114309	423.1	423.2	10.7	2.0
Daandine 4 - 114310	451.1	451.3	11.2	3.0
Kogan North 76 - 114311	200.0	200.1	5.0	4.8
Kogan North 76 - 114312	271.5	271.8	6.7	9.0
Kogan North 76 - 114313	298.3	298.4	7.4	4.5
Tipton 26A - 114314	282.7	282.9	7.0	5.2
Tipton 26A - 114,315	471.4	471.6	11.7	5.7
Meenawarra 16 - 114327	203.9	204.1	5.1	3.2
Meenawarra 16 - 114317	263.6	263.9	6.6	4.0
Meenawarra 16 - 114318	267.3	267.5	6.6	3.0
Meenawarra 16 - 114319	282.4	282.5	7.0	4.0
Meenawarra 16 - 114320	363.7	363.9	9.1	6.6
Meenawarra 16 - 114321	419.9	420.0	10.4	2.6
Meenawarra 16 - 114323	435.7	435.9	10.7	3.5
Meenawarra 16 - 114324	470.1	470.3	11.5	6.1
Meenawarra 16 - 114325	478.5	478.6	11.9	3.4

The tangent modulus values reports are typically reported for greater than 30% of the deviator stress required to fail the samples. This is substantially greater than the stress change induced by groundwater level reduction. The tangent modulus at lower deviator stress levels (of 1 to 2 MPa) more consistent with the change induced by CSG related groundwater drawdown is greater and often more than twice the reported tangent modulus value. The tangent modulus values presented in Figure 25 are assessed to typically understate the modulus relevant to settlement assessment by more than a factor of 2.

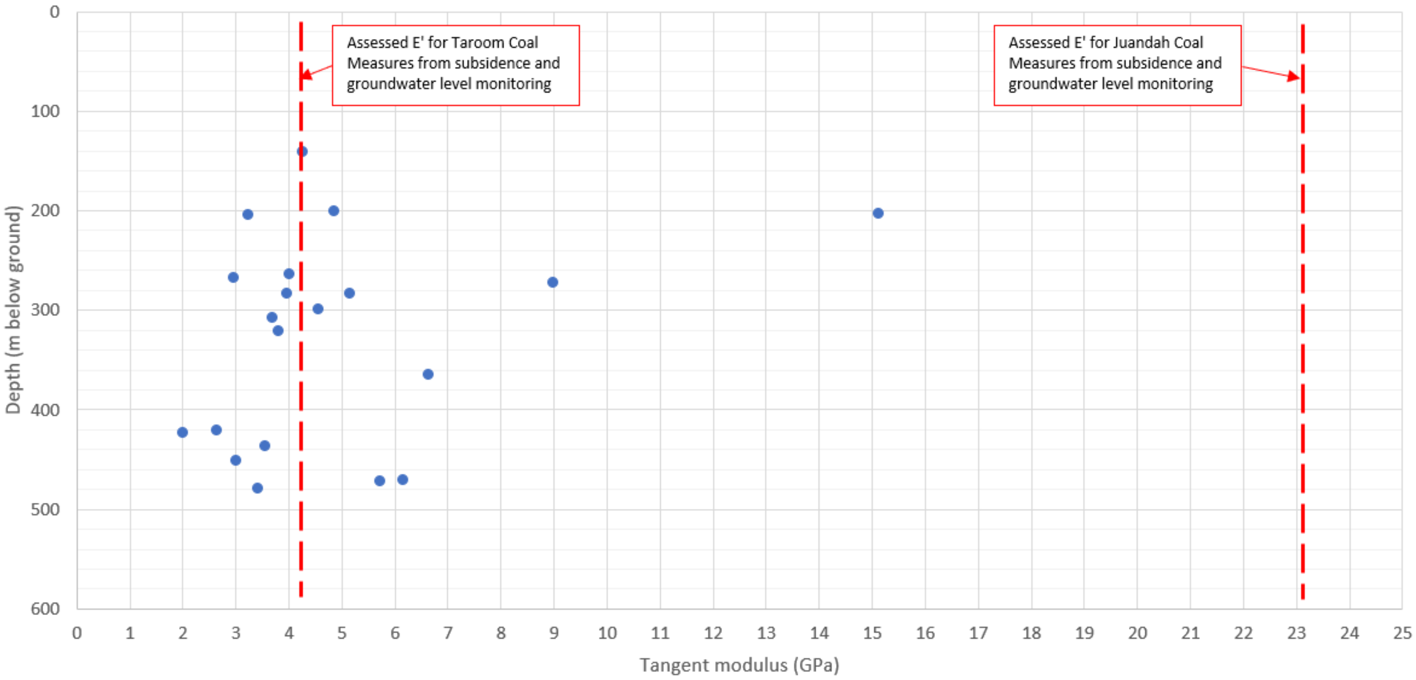


Figure 25: Tangent modulus from UCS testing versus depth

3.5.2. Wireline test results

Geophysical downhole survey information for boreholes at 22 locations shown in Figure 26 was provided by Arrow. This information provided profiles of interpreted Young's Modulus and unconfined compressive stress for depths up to 1200 m.

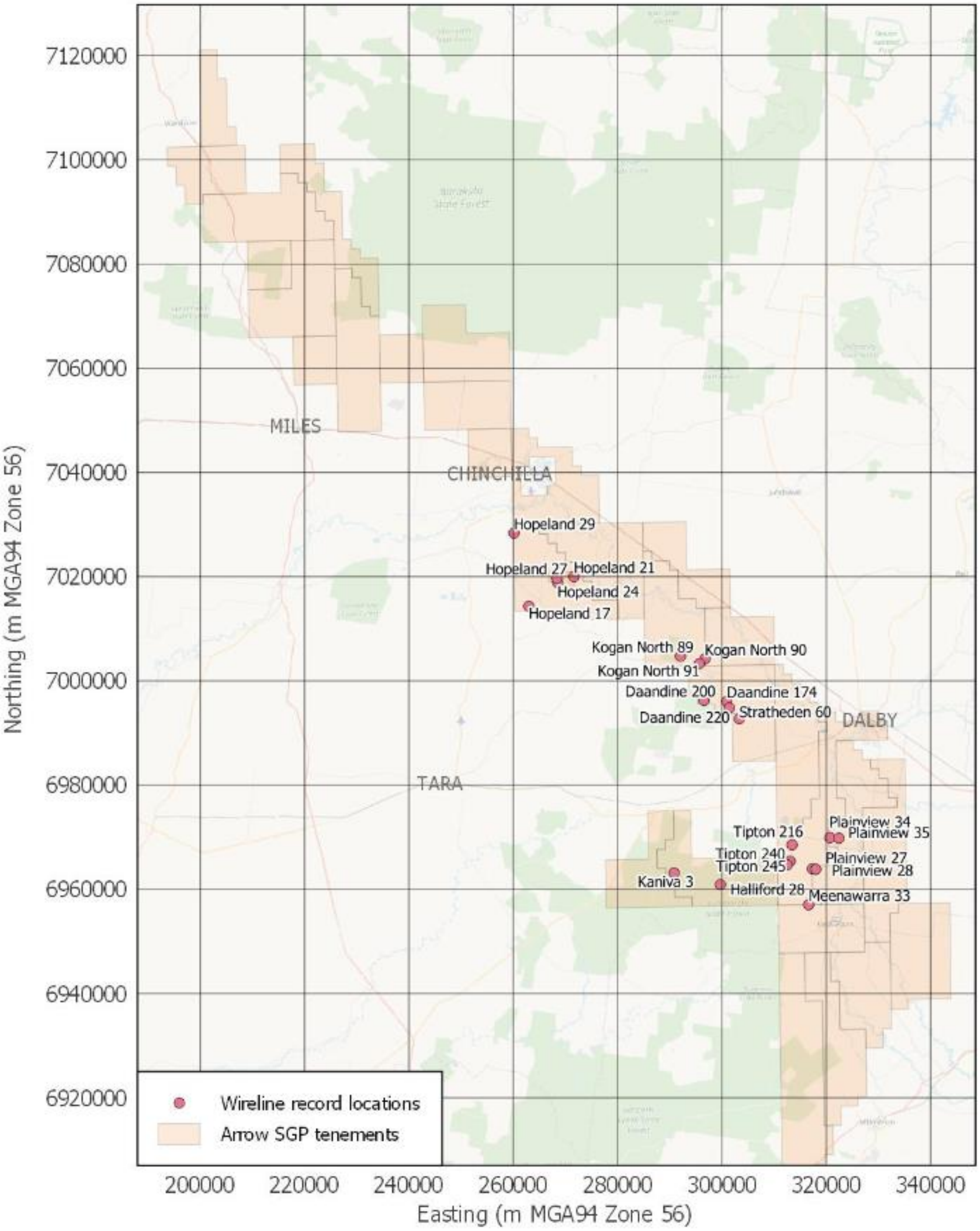


Figure 26: Wireline geophysical testing locations

The results showed dynamic Young's Modulus values which varied with lithology and gradually increased with depth. Dynamic Young's Modulus values obtained using geophysical methods are higher than those applying for long term processes included development of settlement in response to groundwater level reduction. Fei et al (2016) (reported in Mahmoud et al - 2019) provide an empirical correlation for conversion from dynamic to static Young's Modulus based on triaxial testing of 22 sandstone core samples:

$$E_{static} = 0.564\, E_{dynamic} - 3.4941$$

where : E_{static} is the static (long term) Young's modulus in GPa

$E_{dynamic}$ is the dynamic (short term) Young's modulus in GPa.

Eissa and Kazi (1988) (as reported by Mahmoud et al - 2019) proposed a relationship which takes account of the density of the material :

$$log_{10}(E_{static}) = 0.02 + 0.77\ log_{10}(\gamma\ E_{dynamic})$$

where : E_{static} is the static (long term) Young's modulus in GPa

$E_{dynamic}$ is the dynamic (short term) Young's modulus in GPa

Y is the density in t/m^3.

Figure 27 shows the interpreted dynamic Young's modulus for the wireline results from Hopeland-17 borehole. Appendix B provides plots of the interpreted dynamic Young's modulus for the 22 boreholes for which wire line results are available. These are grouped by location. The results were smoothed by averaging over 20 consecutive readings. The variability is attributed to changes in lithology with lower values interpreted to be associated with higher coal content. The empirical correlation proposed by Fei et al (2016) applies to sandstone and is not considered appropriate for material with high coal content.

The dynamic modulus values shallower than 600 m depth generally range between 5 and 30 GPa with increasing modulus with depth for depths greater than 600 m are noted in the records from Hopeland-17. Using the empirical relationships noted above and assuming that the higher modulus values are associated with sandstone and the lower modulus values are associated with high coal content and adopting 1.4 t/m^3 as the density for high coal content material the dynamic modulus range of 5 GPa to 30 GPa is assessed to correspond to a static modulus range of 5 GPa to 16 GPa. This is reasonably consistent with the range of UCS test results discussed in Section 3.5.1 when the difference between initial modulus and the reported tangent modulus is taken into account.

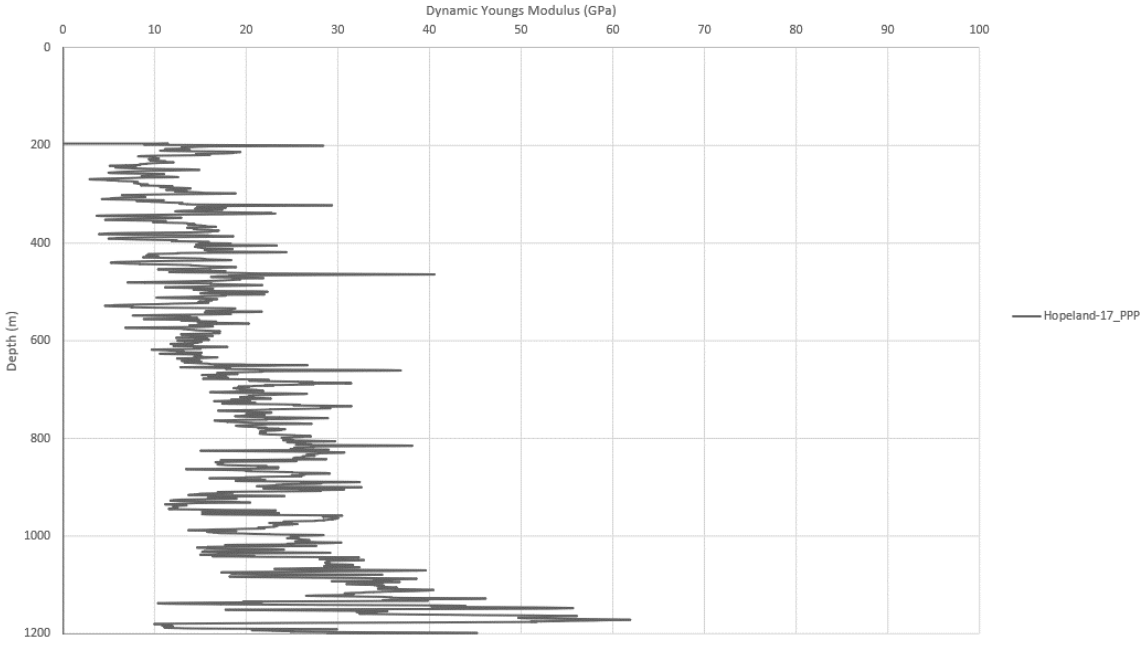


Figure 27: Sample wireline test interpretation of dynamic Young's modulus – Hopeland-17

4. Natural (non-CSG) ground movements

4.1. Natural processes

Movement of the ground surface can arise from shrink swell behaviour of the upper soils under the influence of wetting and drying associated with rainfall and evaporation on soil suction. The effect is important for the design of shallow building foundations for houses. Reactive clay soils are sensitive to this process which is limited to the upper soil profile. The depth of influence of soil suction ranges between 1.5 m and in excess of 4 m, depending on climatic conditions. In the Brisbane Ipswich area soil suction changes are considered to occur to depths up to 2.3 m. Australian Standard AS 2870-2011 Residential Slabs and Footings (Standards Australia (2011)) provides a basis for assessment of ground movement associated with these processes. The magnitude of surface soil movement associated with this process depends on the combination of the reactive nature of the surface soils (propensity to shrink and swell in response to change in moisture content) and the natural variation in moisture content in the upper soil profile associated with climatic conditions. Design soil movements associated with shrink swell movement of up to 75 mm are nominated for extreme cases.

Soil moisture changes associated with growth of vegetation receive special mention in AS 2870-2011, as these can result in local ground movement affecting the performance of house foundations.

Ground movement over time interpreted from InSAR measurements is illustrated in Figures 20 to 23. Of these figures the ground movement interpreted to be associated with coal seam gas extraction masks movement associated with seasonal variation. In Figure 20, which shows interpreted movement at the Daandine Cluster an annual cyclical component of ground movement can be discerned with settlement varying within a 5 mm band around the general trend. The small seasonal variations are clear in this case, as the interpreted ground movement related to coal seam gas extraction is small (15 mm over four years).

4.2. Subsidence monitoring in areas with no CSG activity

Observed ground movement in areas with no CSG activity was assessed by considering InSAR observations in three reference areas close to Dalby, as shown in Figure 28. These areas were indicated by Arrow as having minimal CSG activity.

InSAR data at total of six locations were assessed, including one location just outside the three reference areas, located on the Condamine River, as shown in Figure 28. The six locations were chosen based on the availability of InSAR data points, which were quite limited in Area 1 and Area 3. The locations A1-1, A1-2 and A3-1 are on farm properties. A2-1 is on a residential block of land in Dalby and A2-2 is on a cleared, non-farmed area just outside Dalby. Condamine-1 is on a lightly vegetated area within 100 m of the Condamine River.

Figure 29 shows the observed ground movement between August 2015 and June 2019 at the closest InSAR monitoring point to the six reference locations. At points A1-1 and A1-2, which are located on farmland, ground movement of up to 30 mm from the reference level at August 2015 is observed, similarly for point A3-1, which is located near a residence on a farm property.

For the remaining points, A2-1, A2-2 and Condamine-1, ground movement over the monitoring period is generally within 10 mm of the reference level at August 2015.

An assessment of the effects of averaging ground movement from InSAR monitoring points within 150 m of the six locations showed the results to be comparable, with some smoothing of the short term variability in the data evident, as shown in Figure 30. It is not clear why there appears to be less smoothing apparent at A3-1 and Condamine-1 as these locations had a similar number of InSAR monitoring points which were averaged as for A1-1, A1-2 and A2-1.

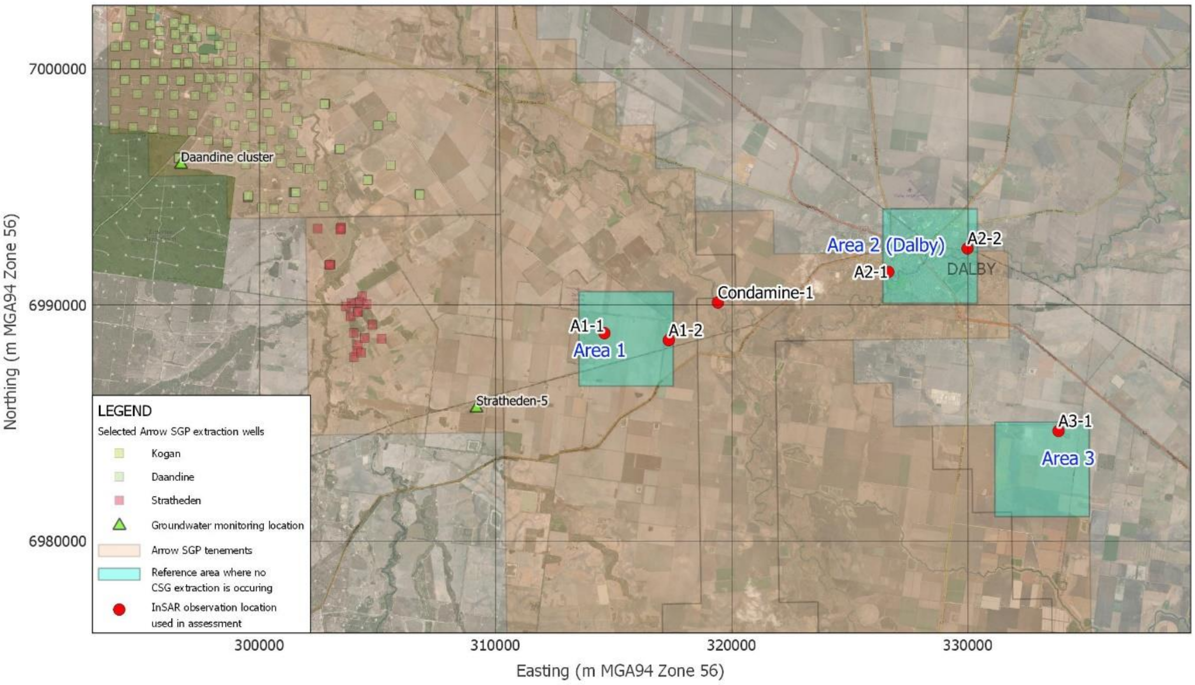


Figure 28: Areas with minimal CSG activity

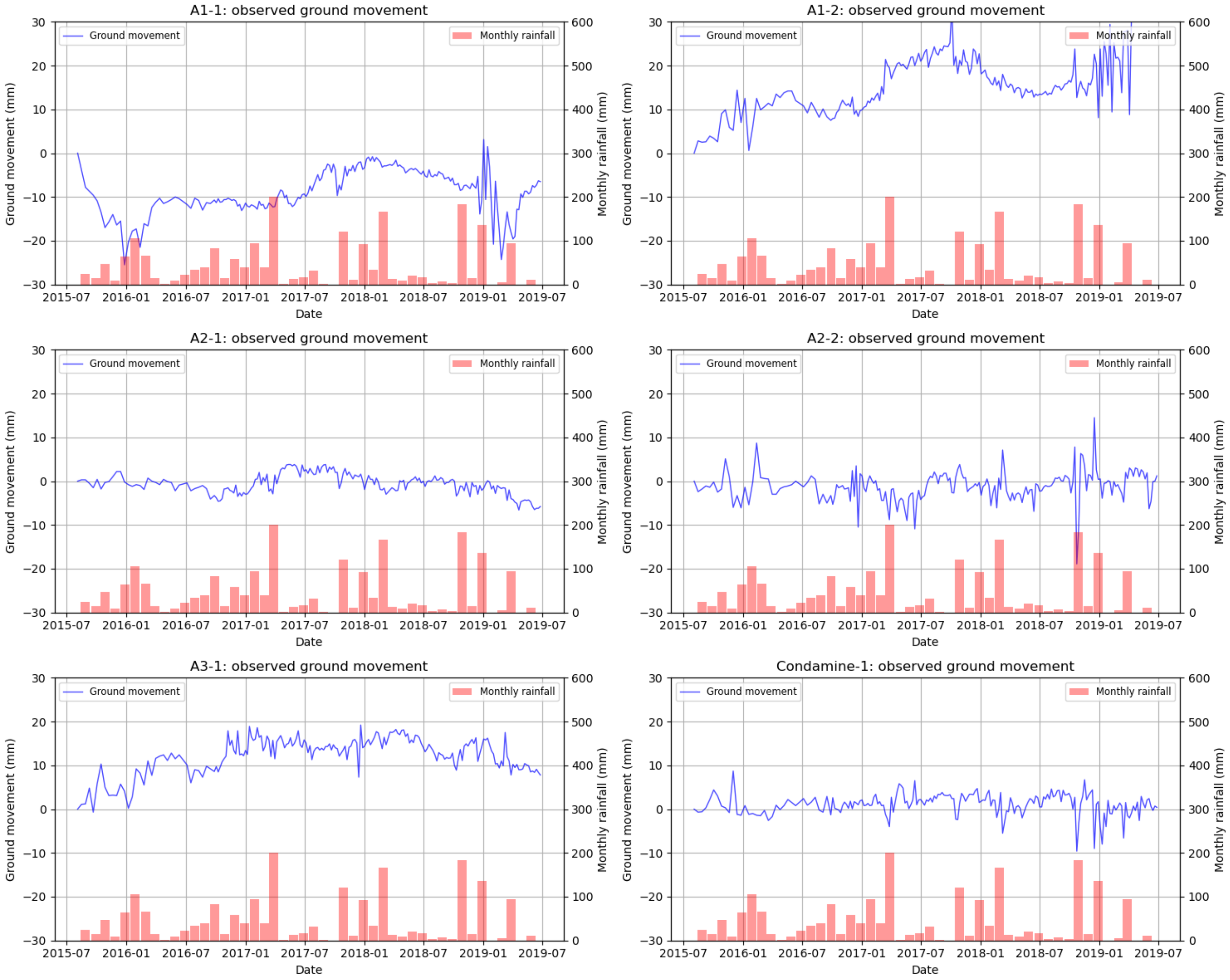


Figure 29: Observed ground movement between August 2015 and June 2019 at the closest InSAR monitoring point to six reference locations with minimal CSG activity

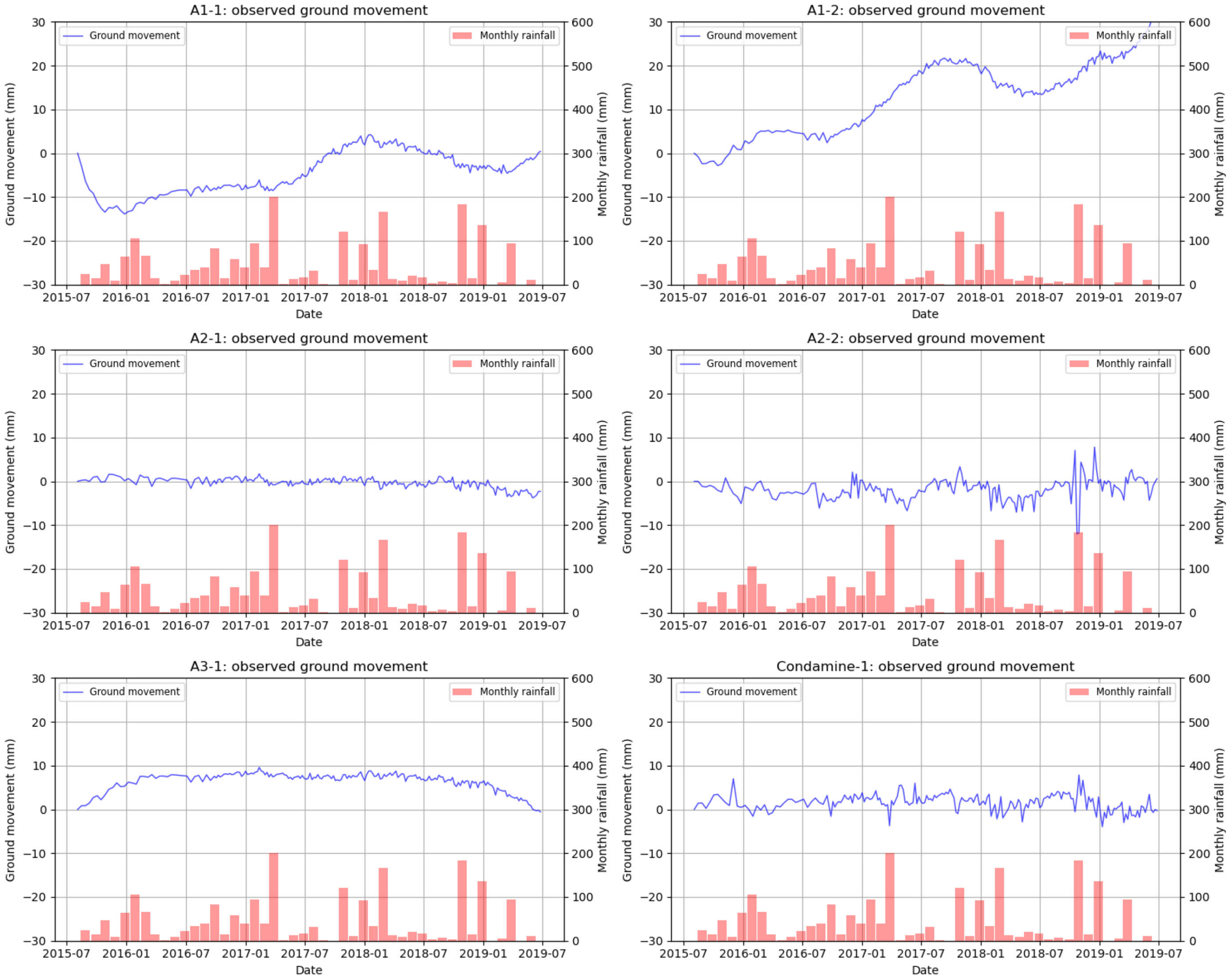


Figure 30: Observed ground movement between August 2015 and June 2019 averaged for InSAR monitoring points within 150 m of six reference locations with minimal CSG activity

4.2.1. Variability of InSAR results

Consideration of the results shown in Figure 29, particularly for points A2-2 and Condamine-1, indicate that InSAR results are likely to show variability of up to ±10 mm from the mean value in non-farmed areas with light vegetation. This variability appears to be related to noise within the InSAR data rather than actual ground movements, as the spikes in the (ground movement) time series typically occur over a single time point only. This noise can be reduced by averaging readings over a small number of consecutive times.

Ground movement can arise from shrink and swelling behaviour of clay rich soils. Particularly where surface soils are subject to periodic inundation and desiccation. Vertical movement as much as 200 mm was interpreted from LIDAR records of field under strip cropping (Data farming 2021).

Australian Standard AS 2870-2011 Residential Slabs and Footings, provides a procedure for site classification according to potential shrink swell movement. Classifications range from S (slight) where movement is not expected to exceed 15 mm to E (extreme) were soil movement in excess of 75 mm is assessed. The assessment of soil movement is based upon the results of testing of the shrink swell potential of the upper soil and the potential soil suction moisture change (arising from change in soil moisture content) over a depth of influence under climatic conditions. The depth of influence is up to 4 m and depends upon the climatic variability. This guidance is provided for development of low-rise residential buildings. Movements associated with inundation and desiccation in an irrigated farming setting are likely to be more severe than that experienced in areas developed for low rise residential use.

A2-1, located on a residential property in Dalby, shows noticeably less variability. This suggests that noise within the InSAR data at a particular location is dependent on the uniformity of conditions present at that location.

Short term variabilities in InSAR results that are not related to actual ground movements can be reduced by averaging results over a number of consecutive dates and by averaging over a number of closely located InSAR monitoring points, as shown in Figure 30.

The results show minor movements typically within 10 mm at each site. For points A1-1 and A1-2, however, there is a rise in the ground surface of up to 30 mm over the period 2016 to 2019. The reasons for this ground movement is not known, but it may relate to irrigation and other agricultural activities such as cultivation to enhance water ingress at or near those areas.

5. Theoretical basis

5.1. Numerical modelling

To illustrate the theoretical prediction of subsidence in response to groundwater drawdown in the Walloon Coal Measures, two representative locations were assessed using the proprietary finite element software Plaxis 2D, version 2018.01. The assessment, for illustrative purposes only, is a simplification of the highly three-dimensional geological and groundwater conditions over the Arrow SGP project area.

Representative locations at the Arrow domestic gas well Daandine 99 and the Arrow exploration pilot well Hopeland 7 were selected for the assessment. At each location, elevations for the top and the base of the Juandah Coal Measures and the Taroom Coal Measures were adopted based on levels provided in the regional scale numerical groundwater model described in Section 6.1. To simplify the analysis, the material above the Juandah Coal Measures and below the Taroom Coal Measures was considered to be uniform, isotropic and elastic with a Young’s Modulus of 100 GPa (adopted as to minimise any internal settlement in these layers) and Poisson’s Ratios of 0.25. The Juandah Coal Measures and the Taroom Coal Measures were also considered to be uniform, isotropic and elastic material, with drained Young’s Modulus values as derived in Section 3.5, and Poisson’s Ratios of 0.25.

The monthly groundwater extraction at these wells, as provided by Arrow, are shown in Figure 31 and Figure 32. The elevations of the well screen intervals are provided in Table 4.

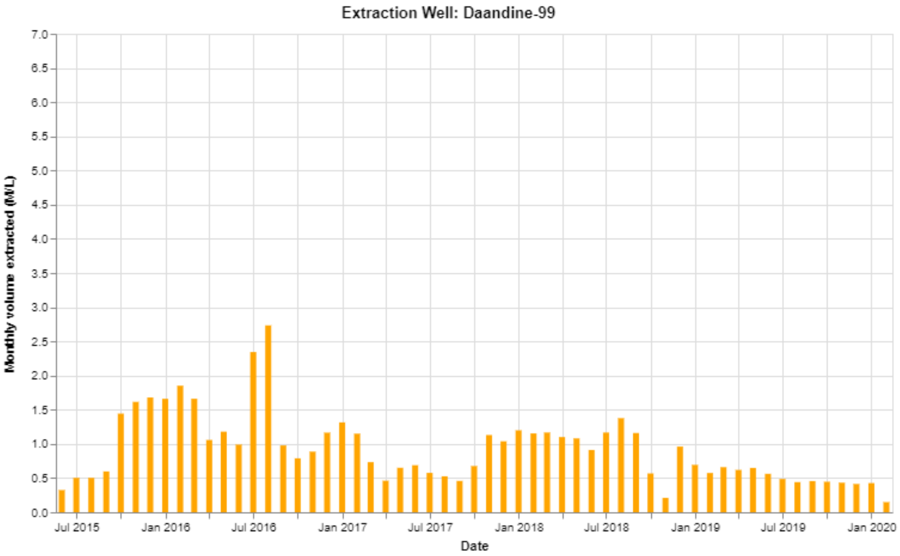


Figure 31: Groundwater extraction rates at Daandine 99

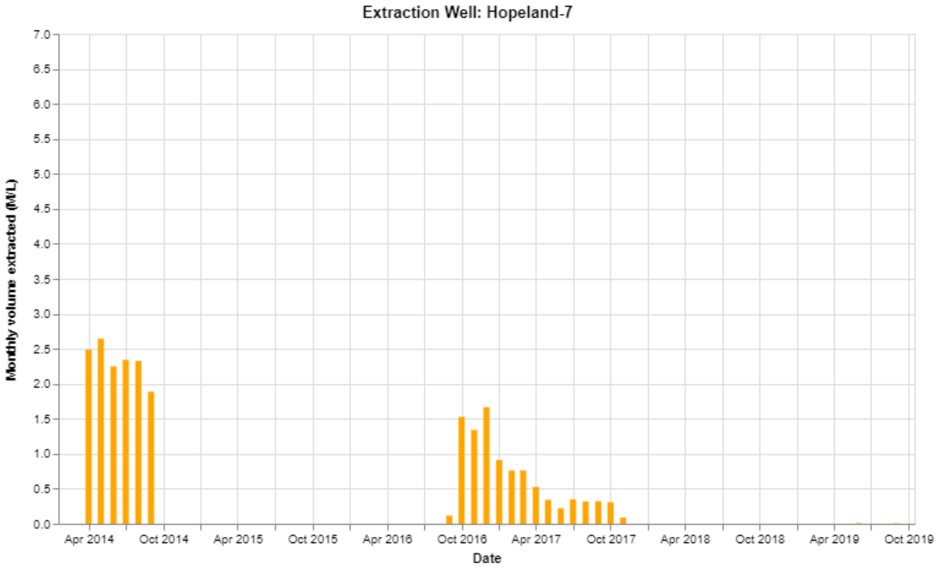


Figure 32: Groundwater extraction rates at Hopeland 7

A two-dimensional radially symmetric model was developed, with a radial extents of 125 m to 5,000 m and vertical extents from the ground surface to -800 mAHD. Constant groundwater head conditions equal to the long term groundwater level away from the wells, as assessed from groundwater monitoring data, were applied at 5,000 m radial distance, and at 800 m depth below ground. At 125 m radial distance, a groundwater head 30 m higher than elevation was applied to elevations equal to the well screened interval. These equated to drawdowns at Daandine 99 of 143 m (at the top of screen elevation) to 387 m (at the base of the screen elevation) with a linear variation between. At Hopeland 7 the drawdowns were 206 m (at the top of screen elevation) to 515 m (at the base of the screen elevation) with a linear variation between.

Based on provided groundwater extraction rates at wells within a 500 m radius, and on permeability data for the Walloon Coal Measures provided in the Underground Water Impact Report for the Surat Cumulative Management Area (Office of Groundwater Impact Assessment, 2019a), the horizontal and vertical permeability of the Juandah Coal Measures and the Taroom Coal Measures were varied in the model until a reasonable match to provided groundwater extraction rates at wells within 500 m radius from the given well was obtained. Table 5 provides details of the adopted model geometry and initial groundwater levels.

Table 4: Adopted model geometry and initial groundwater levels

Model name	Model 1	Model 2
Arrow SGP extraction well	Daandine 99	Hopeland 7
Easting (m MGA94 Zone 56)	302118	263153
Northing (m MGA94 Zone 56)	6995751	7014548
Top of well screen (m AHD)	152	79
Base of well screen (m AHD)	-92	-230
Surface elevation (m AHD)	325	315
Top of Juandah Coal Measures (m AHD)	247	79
Top of Taroom Coal Measures (m AHD)	33	-122
Top of Durabilla Formation (m AHD)	-92	-246
Initial groundwater level (m AHD)	315	300

5.1.1. Results

For Model 1, representing the Daandine 99 extraction well, horizontal and vertical permeabilities for the Juandah Coal Measures and the Taroom Coal Measures equal to 2.0 x 10^{-9} m/s and 2.0 x 10^{-11} m/s respectively resulted in groundwater flows from the well of approximately 1.4 ML/month, which is considered to be similar to the extraction rates shown in Figure 31. Note that the vertical permeability was set at 0.01 times the horizontal permeability, based on permeability assessments for the Walloon Coal Measures provided by the Office of Groundwater Impact Assessment (2019b). The permeabilities of the Juandah Coal Measures and the Taroom Coal Measures were set to be equal for the purposes of this illustrative assessment.

Figure 33 and Figure 34 show the modelled groundwater drawdown at the adopted top of the Taroom Coal Measures and the corresponding modelled ground movement, respectively. Figure 35 shows the observed ground movement along a section line extending from approximately the location of Daandine 99 to the east where there is limited activity from other CSG extraction wells.

It is apparent from these figures that the modelled ground movement under predicts the observed ground movement. Note however that approximately 1 km to the south west of Daandine 99 are extraction wells Daandine 220 to Daandine 228, as shown in Figure 13, which have a combined average flow rate approximately 21 ML / month over the period August 2015 to June 2019. This is likely to produce additional ground movement around Daandine 99 which is not accounted for in the model.

The modelled ground movement presents similar characteristics to the observed movement in two regards. Firstly, the form of the modelled ground movement versus distance curve appears to remain relatively constant as time progresses. This is clearly apparent in the observed ground movement shown in Figure 35. Secondly, the modelled ground movement curves indicate that the majority of ground movement occurs during the early stages of groundwater extraction. In Figure 34, after one year, approximately 55 % of the total ground movement after five years has already occurred. After two years 72 % has occurred. This behaviour is apparent, albeit to a lesser extent, in the observed ground movement shown in Figure 35.

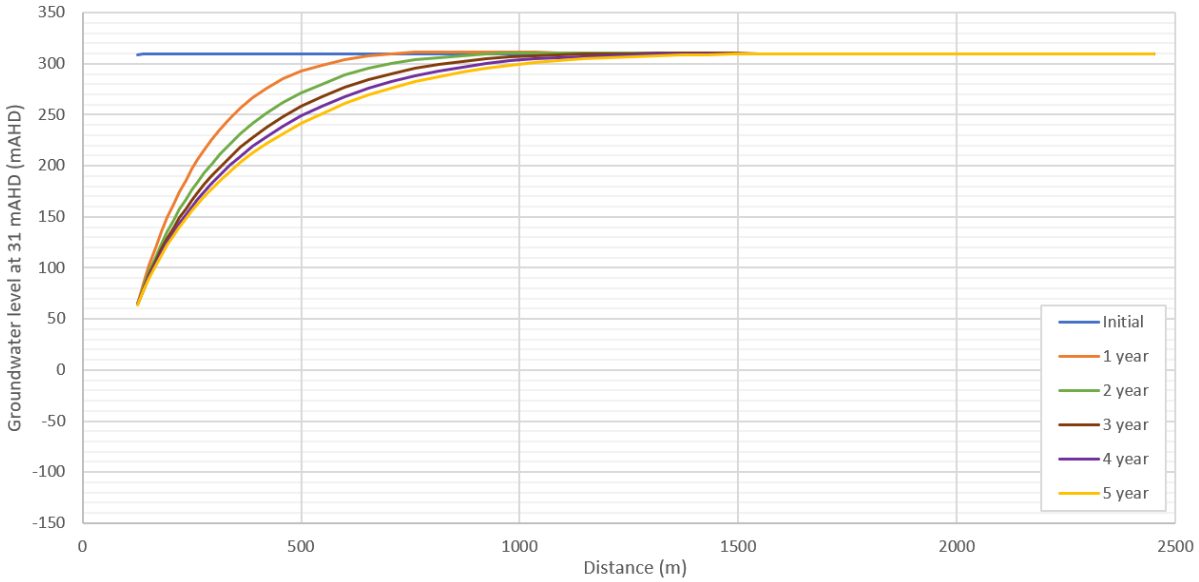


Figure 33: Modelled groundwater drawdown at Daandine 99 at the adopted top of Taroom Coal Measures (33 mAHD)

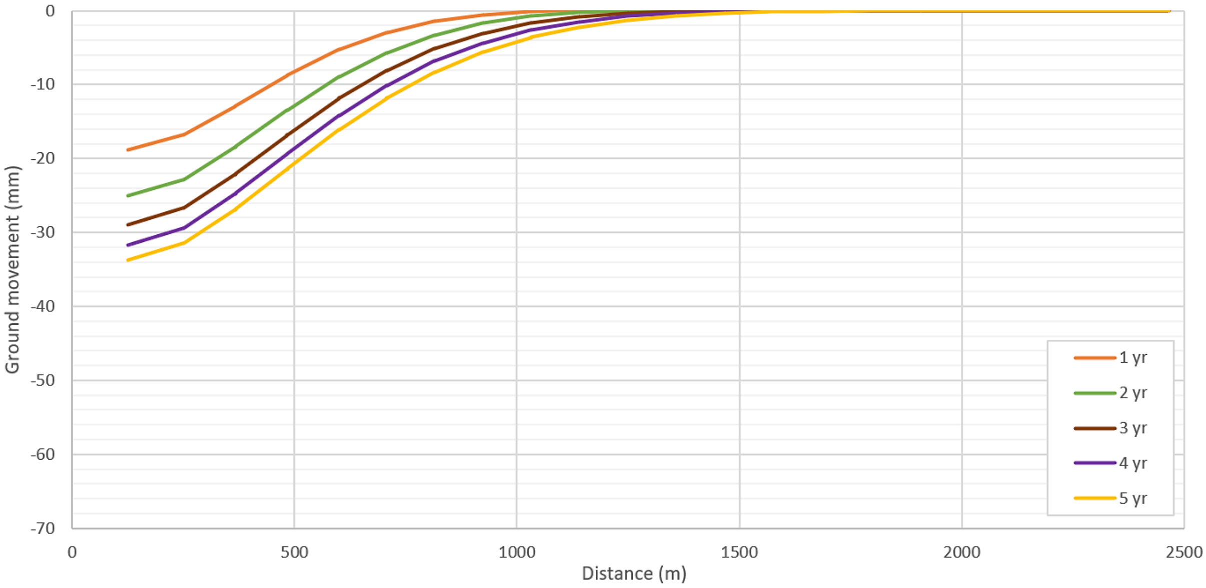


Figure 34: Modelled ground movement at Daandine 99

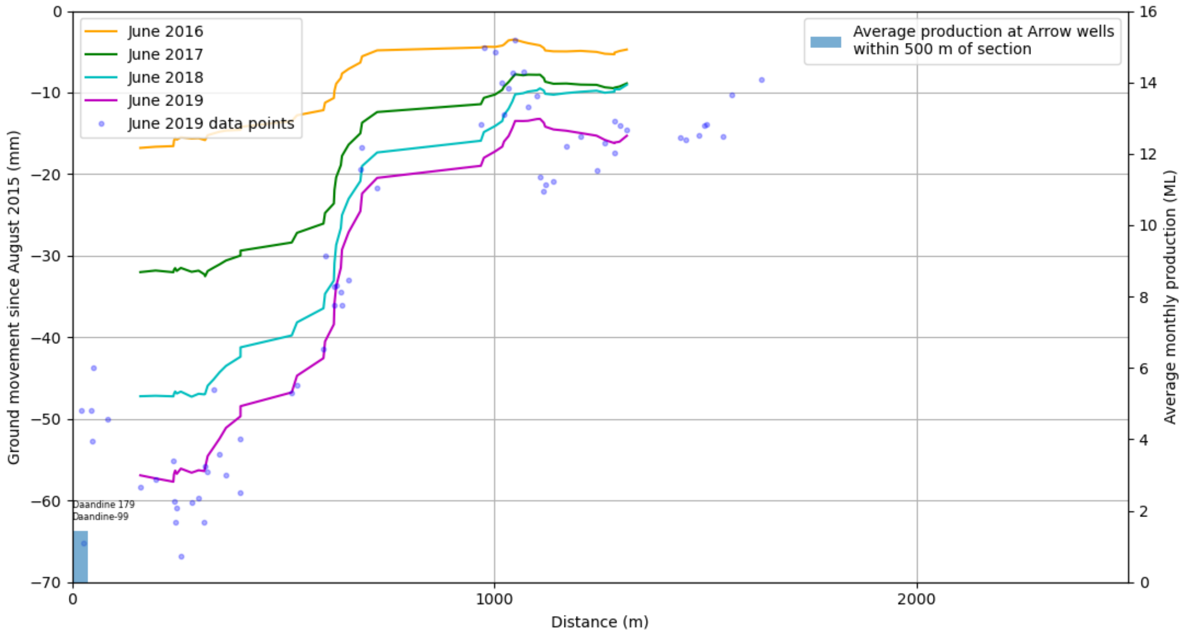


Figure 35: Observed ground movement at Daandine 99

For Model 2, representing the Hopeland 7 extraction well, horizontal and vertical permeabilities for the Juandah Coal Measures and the Taroom Coal Measures equal to 6.0 x 10^{-9} m/s and 6.0 x 10^{-11} m/s respectively resulted in groundwater flows from the well of approximately 6 ML/month. This considered to be similar to the combined extraction rates of wells within 500 m of Hopeland 7. Note that the vertical permeability was set at 0.01 times the horizontal permeability, based on permeability assessments for the Walloon Coal Measures provided by the Office of Groundwater Impact Assessment (2019b). The permeabilities of the Juandah Coal Measures and the Taroom Coal Measures were set to be equal for the purposes of this illustrative assessment.

Figure 36 and Figure 37 show the modelled groundwater drawdown at the adopted top of the Taroom Coal Measures and the corresponding modelled ground movement, respectively. Figure 38 shows the observed ground movement along a section line extending from approximately the location of Hopeland 7 to the east where there is limited activity from other CSG extraction wells. In the area where Hopeland 7 is located, there are five other extraction wells, with the group arranged in an approximately 300 m x 300 m square shape in plan. Average flow rates over the period August 2015 to June 2019 from the extraction wells in the group are shown on Figure 38.

The modelled ground movement at Hopeland 7 over predicts the observed ground movement. This might be explained by the fact that groundwater extraction at this area was relatively intermittent between August 2015 and June 2019, as illustrated in Figure 37. This was also typical of the five other extraction wells located within 500 m of Hopeland 7.

As was observed for the results at Daandine 99, the form of the modelled and observed ground movement versus distance curves at Hopeland 7 appear to remain relatively constant as time progresses. It is challenging to assess the percentage of observed ground movement occurring with time at Hopeland 7, as the majority of the groundwater extraction for extraction wells located within 500 m of Hopeland 7 was carried out over a short period from October 2016 to December 2017.

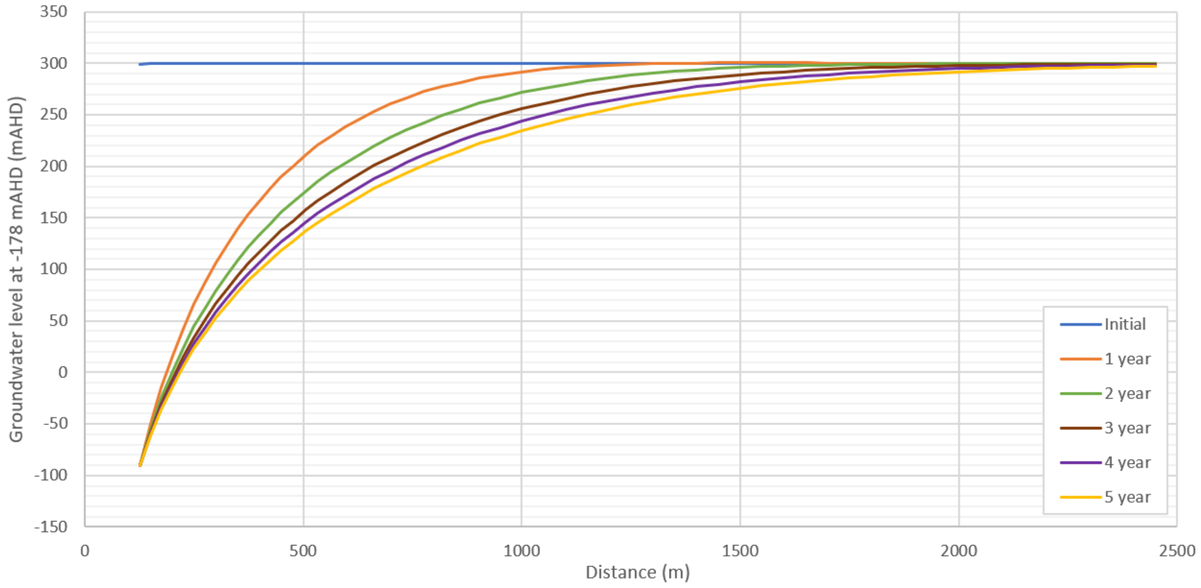


Figure 36: Modelled groundwater drawdown at Hopeland 7 at the adopted top of Taroom Coal Measures (-122 mAHD)

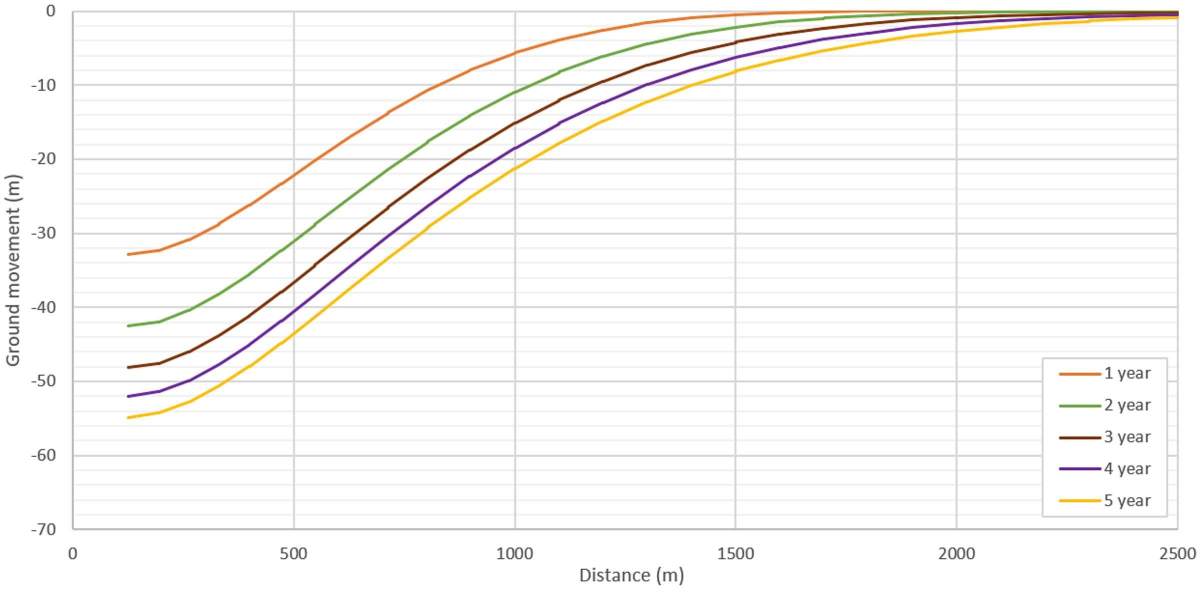


Figure 37: Modelled ground movement at Hopeland 7

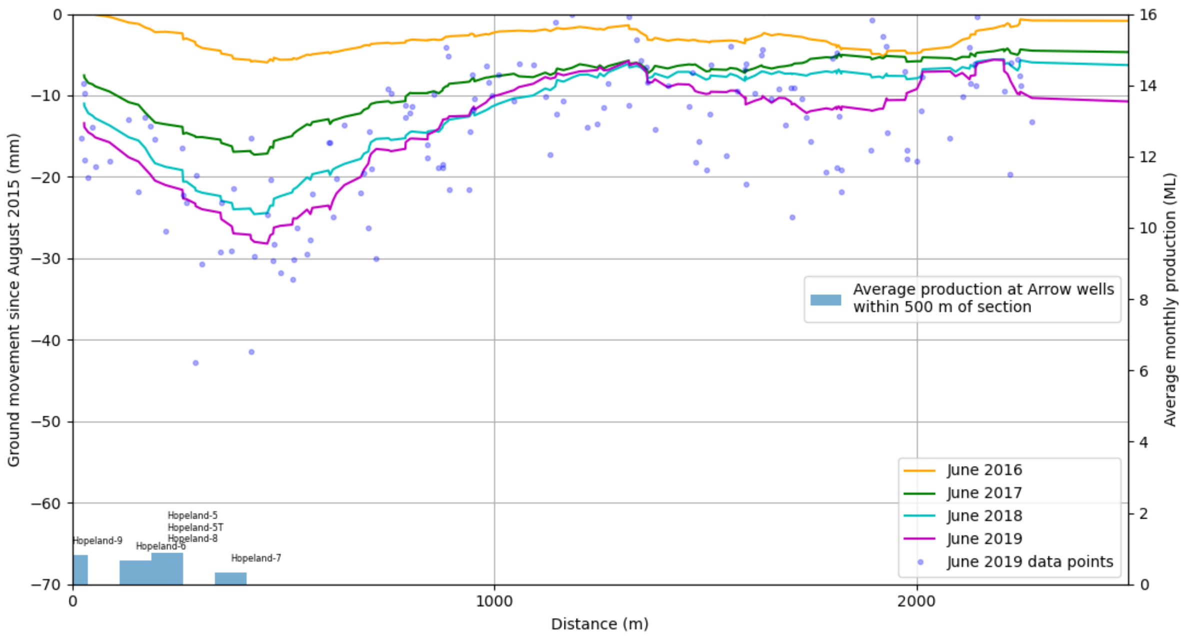


Figure 38: Observed ground movement at Hopeland 7

A report prepared by the University of Queensland (2019) provides details of numerical modelling carried out to assess surface subsidence resulting from groundwater drawdown in the coal bearing formations of the Surat Basin. The modelling is similar to that described above, although the authors have investigated additional phenomena such as desorption-induced shrinkage of the coal seams.

The University of Queensland (2019) model results in approximately 110 mm subsidence after three years of groundwater extraction for the model geometry and parameters considered in that report. We note that the permeability values adopted in that report appear to be isotropic, and the model described appears to show significant depressurisation in the rock units from the base of the coal bearing formations down to the base of the model, and this would result in additional subsidence. It is noted, however, that the groundwater level observations at the Daandine bore cluster, shown in Figure 20, indicate that relatively little drawdown is occurring in the Hutton Sandstone or Evergreen Formation which both underly the Walloon Coal Measures.

5.2. Analytical method

Lu and Lin (2006) considered the settlement induced by groundwater extraction from a point located in a semi-infinite, saturated, uniform and isotropic poro-elastic medium, as illustrated in Figure 39.

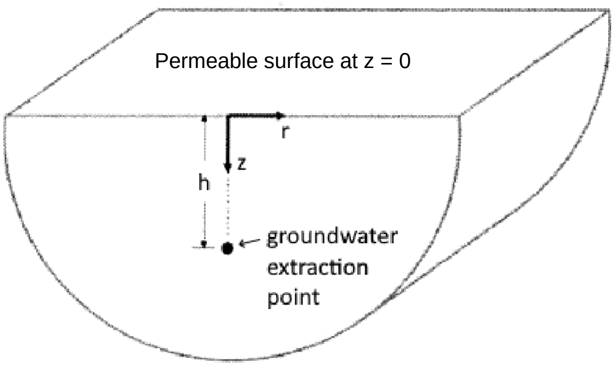


Figure 39: Groundwater extraction from a point in a semi-infinite poro-elastic medium (adapted from Lu and Lin,2006)

The work of Lu and Lin (2006) provides a convenient illustration of the development of vertical and horizontal surface displacement with time using the following dimensionless parameters:

- Dimensionless radius $\frac{r}{h}$
- Time factor $\frac{c_v\, t}{h^2}$

Where:

r is the radial distance from the groundwater extraction point

h is the depth of the groundwater extraction point

t is the time since groundwater extraction commenced

c_v is the coefficient of consolidation, given by:

$$c_v = \frac{(1 - v')\, E' k}{\gamma_w\, (1 + v')(1 - 2v')}$$

Where:

E' is the drained Young's modulus of the elastic medium in kPa

k is the hydraulic conductivity of the elastic medium in m/s

v' is the Poisson's ratio of the elastic medium

γ_w is the unit weight of water (kN/m^3)

Figure 40 and Figure 41 present the normalised vertical and horizontal displacement profiles at the ground surface based on the dimensionless (or normalised) radius and the time factor.

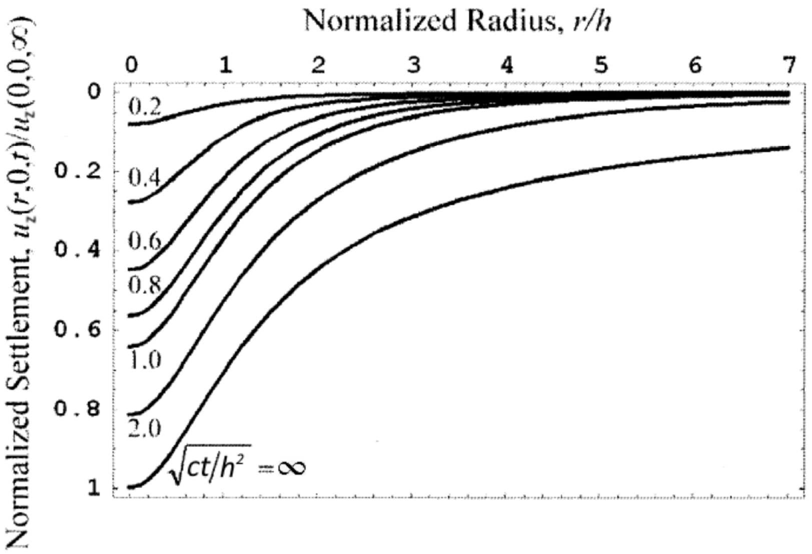


Figure 40: Normalised vertical displacement profile u_z at the ground surface (after Lu and Lin, 2006)

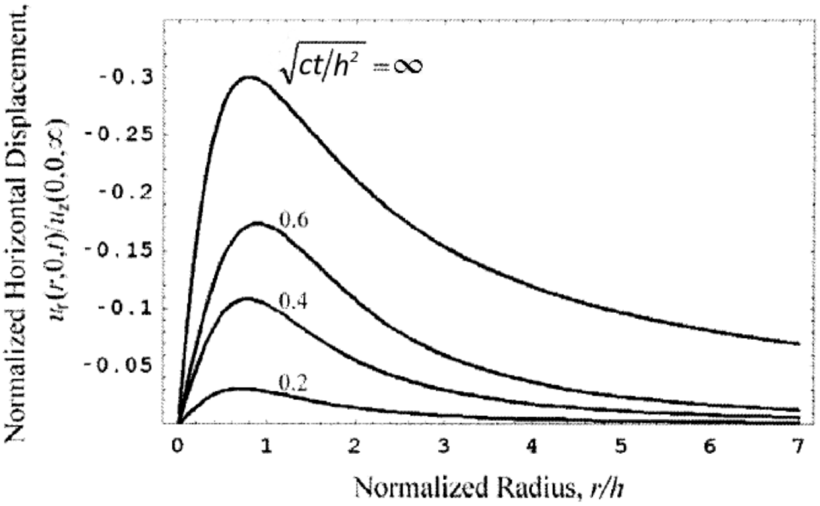


Figure 41: Normalised horizontal displacement profile u_r at the ground surface (after Lu and Lin, 2006)

Figure 40 and Figure 41, while based on the simplified situation of a uniform elastic medium and groundwater extraction from a point source, provide guidance on the progression of settlement with time. In addition to this, Figure 41 indicates that at a radial distance approximately equal to the depth below ground of the groundwater extraction point, the magnitude of the horizontal displacement at the ground surface is approximately 30% of the magnitude of the maximum vertical displacement at a radial distance of zero.

The predicted percentage of the total settlement which would occur in the first year for the Daandine model discussed in Section 5.1, can be assessed as follows:

- Adopt the following material parameters:
    - Average drained Young’s modulus for the Juandah Coal Measures and the Taroom Coal Measures as *E’* = 13.7 GPa, as assessed in Section 3.5
    - horizontal hydraulic conductivity k_x = 2.0 x 10^{-9} m/s
- This results in a coefficient of consolidation c_v = 3.3 x 10^{-3} m^2/s, using the formula given above.
- The time factor after one year of groundwater extraction from a well screen midpoint located h = 355 m below ground is $\sqrt{\frac{c_v t}{h^2}} = 0.77$.
- Figure 40 can be used to assess that approximately 55% of the total settlement at the ground surface above the extraction point would occur in the first year. This is a very similar result to that indicated by the numerical modelling shown in Figure 34.

6. Predicted subsidence

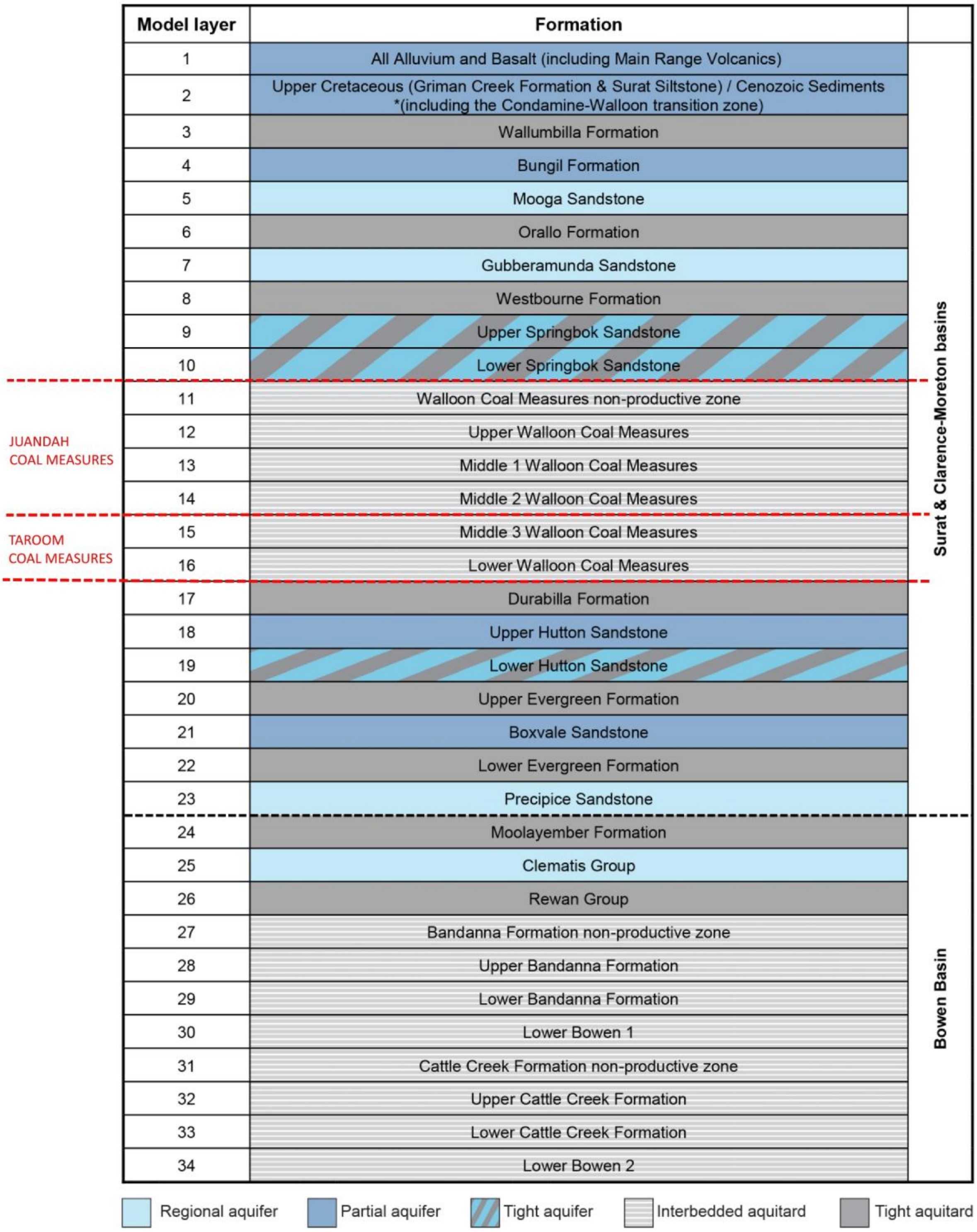
6.1. Numerical model

The results from a regional-scale numerical groundwater flow model developed by the Office of Groundwater Impact Assessment were provided to Coffey by Arrow. The groundwater model and results are discussed in the *Groundwater Modelling Report – Surat Cumulative Management Area* (Office of Groundwater Impact Assessment, 2019b).

The model incorporates historical and predicted drawdown resulting from CSG operations across the Surat Cumulative Management Area. This includes CSG activities by several organisations including Arrow.

The domain of the model covers an area of around 460 km × 650 km encompassing the entire Arrow SGP area. The model domain is discretised into cells of 1.5 km × 1.5 km in plan. The model consists of 34 layers, as shown in Figure 42. For the purposes of subsidence prediction, the Juandah Coal Measures were taken to be represented by model layers 11, 12, 13 and 14 and the Taroom Coal Measures by model layers 15 and 16.

Figure 43 presents the thickness of the Walloon Coal Measures, Juandah Coal Measures and the Taroom Coal Measures as represented in model, according to the adopted model layers for the Juandah Coal Measures and the Taroom Coal Measures as shown in Figure 42. In the Figure 43, the Walloon Coal Measures comprises of the model layers representing the Juandah Coal Measures combined with the model layers representing the Taroom Coal Measures.



	Model layer	Formation	
	1	All Alluvium and Basalt (including Main Range Volcanics)	Surat & Clarence-Moreton basins
	2	Upper Cretaceous (Griman Creek Formation & Surat Siltstone) / Cenozoic Sediments *(including the Condamine-Walloon transition zone)	
	3	Wallumbilla Formation	
	4	Bungil Formation	
	5	Mooga Sandstone	
	6	Orallo Formation	
	7	Gubberamunda Sandstone	
	8	Westbourne Formation	
	9	Upper Springbok Sandstone	
	10	Lower Springbok Sandstone	
JUANDAH COAL MEASURES	11	Walloon Coal Measures non-productive zone	
	12	Upper Walloon Coal Measures	
	13	Middle 1 Walloon Coal Measures	
	14	Middle 2 Walloon Coal Measures	
TAROOM COAL MEASURES	15	Middle 3 Walloon Coal Measures	
	16	Lower Walloon Coal Measures	
	17	Durabilla Formation	
	18	Upper Hutton Sandstone	
	19	Lower Hutton Sandstone	
	20	Upper Evergreen Formation	
	21	Boxvale Sandstone	
	22	Lower Evergreen Formation	
	23	Precipice Sandstone	
	24	Moolayember Formation	Bowen Basin
	25	Clematis Group	
	26	Rewan Group	
	27	Bandanna Formation non-productive zone	
	28	Upper Bandanna Formation	
	29	Lower Bandanna Formation	
	30	Lower Bowen 1	
	31	Cattle Creek Formation non-productive zone	
	32	Upper Cattle Creek Formation	
	33	Lower Cattle Creek Formation	
	34	Lower Bowen 2	

Figure 42: Model layers (adapted from Office of Groundwater Impact Assessment, 2019)

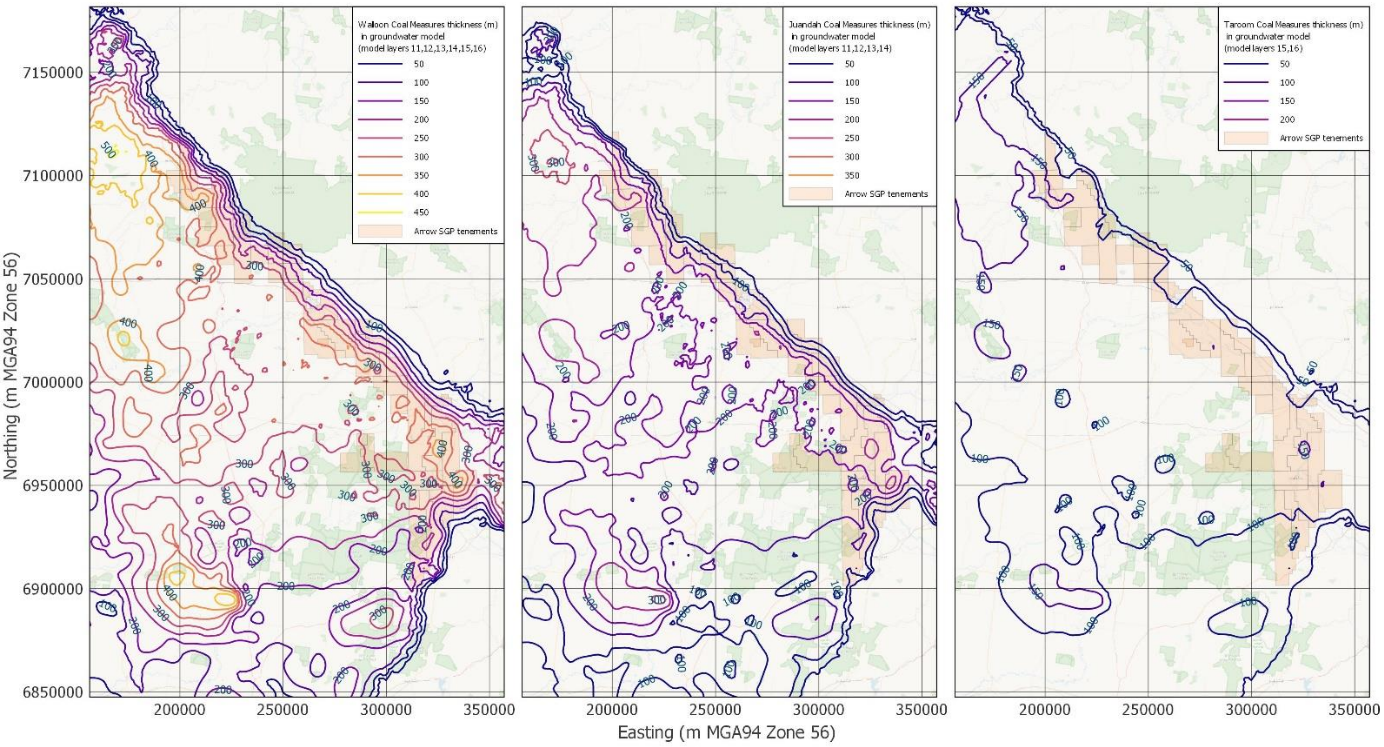


Figure 43: Thickness (m) of the Walloon Coal Measures, Juandah Coal Measures and the Taroom Coal Measures as represented in the Office of Groundwater Impact Assessment numerical groundwater model, as shown in Figure 42

6.2. Predicted drawdown

The predicted groundwater level drawdown in the lower Springbok Sandstone (model layer 10), the lower Walloon Coal Measures (model layer 16) and the upper Hutton Sandstone (model layer 18) at 2030, 2050 and 2100 are shown in Figure 44, Figure 45 and Figure 46, respectively. The predicted groundwater drawdowns are the decrease in groundwater head since the model starting date of January 1995.

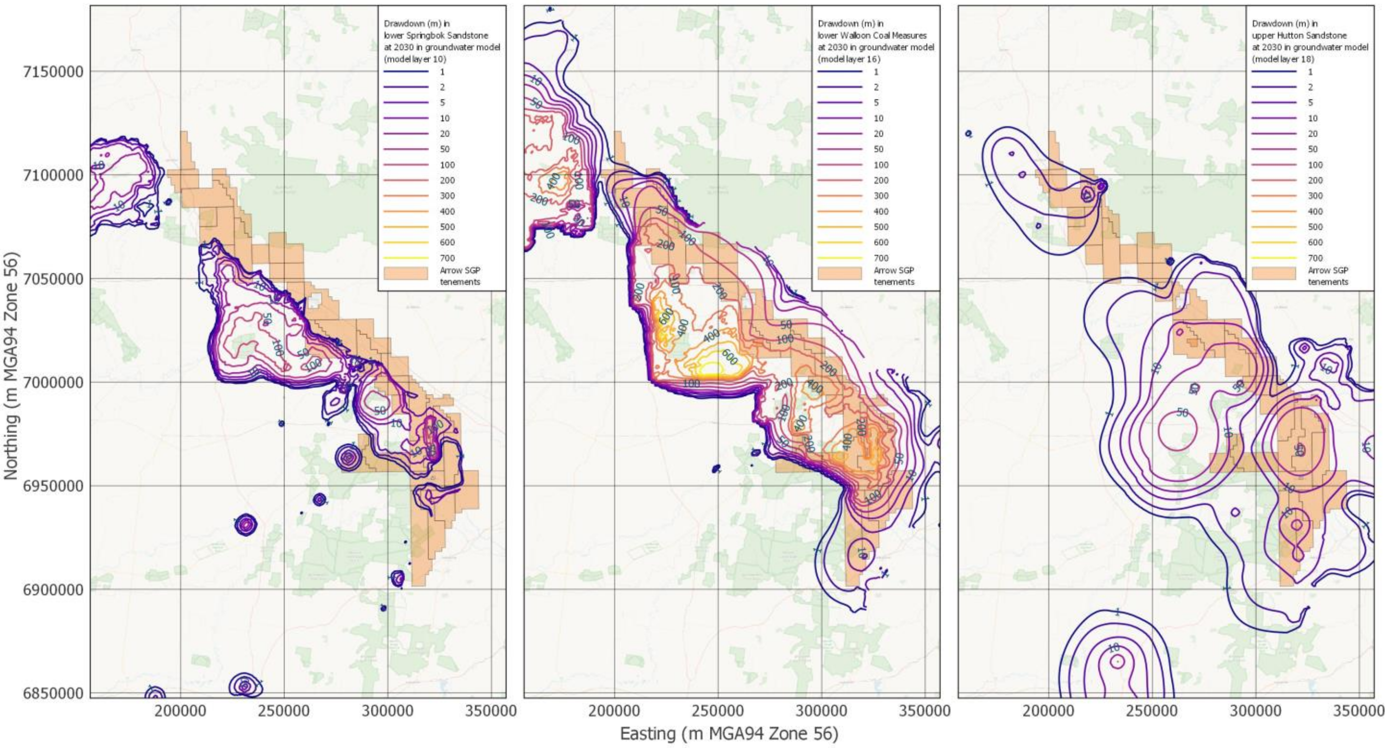


Figure 44: Modelled drawdown in the lower Springbok Sandstone, lower Walloon Coal Measures and the upper Hutton Sandstone in 2030

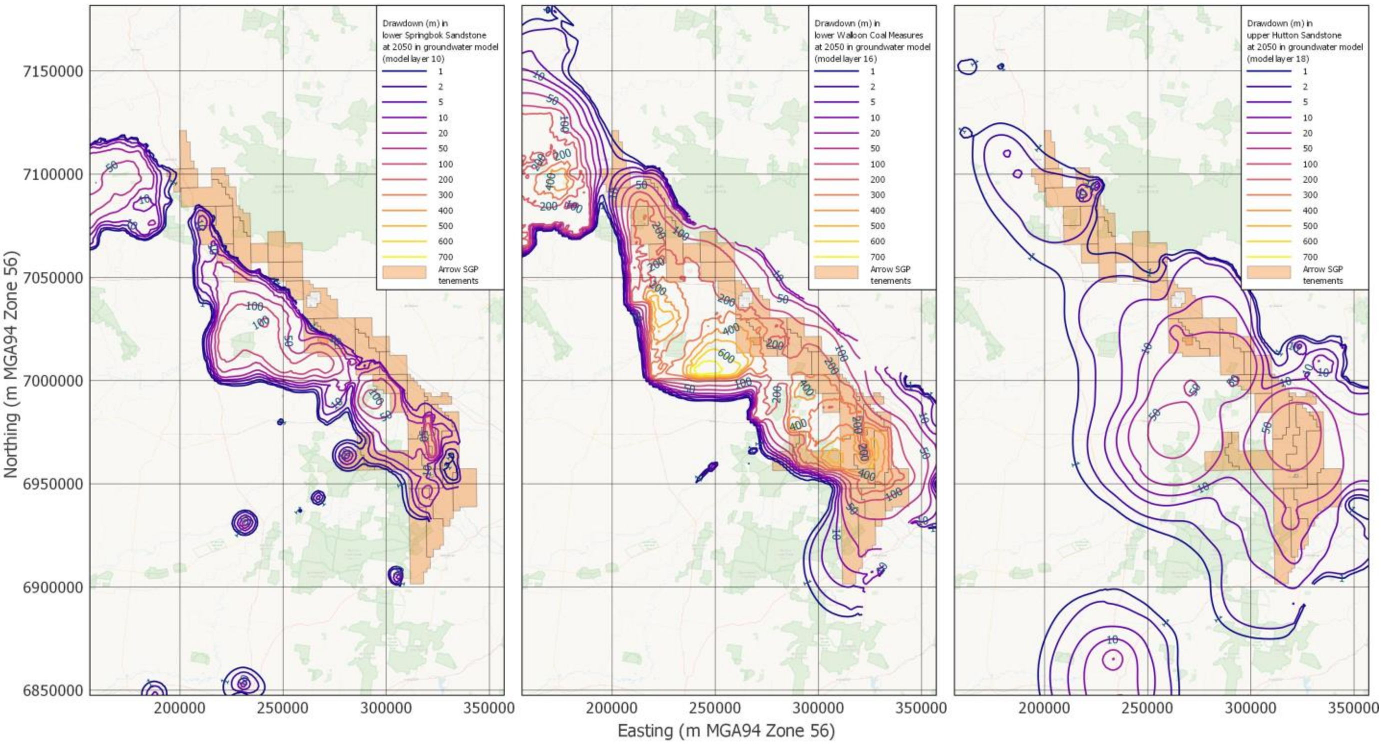


Figure 45: Modelled drawdown in the lower Springbok Sandstone, lower Walloon Coal Measures and the upper Hutton Sandstone in 2050

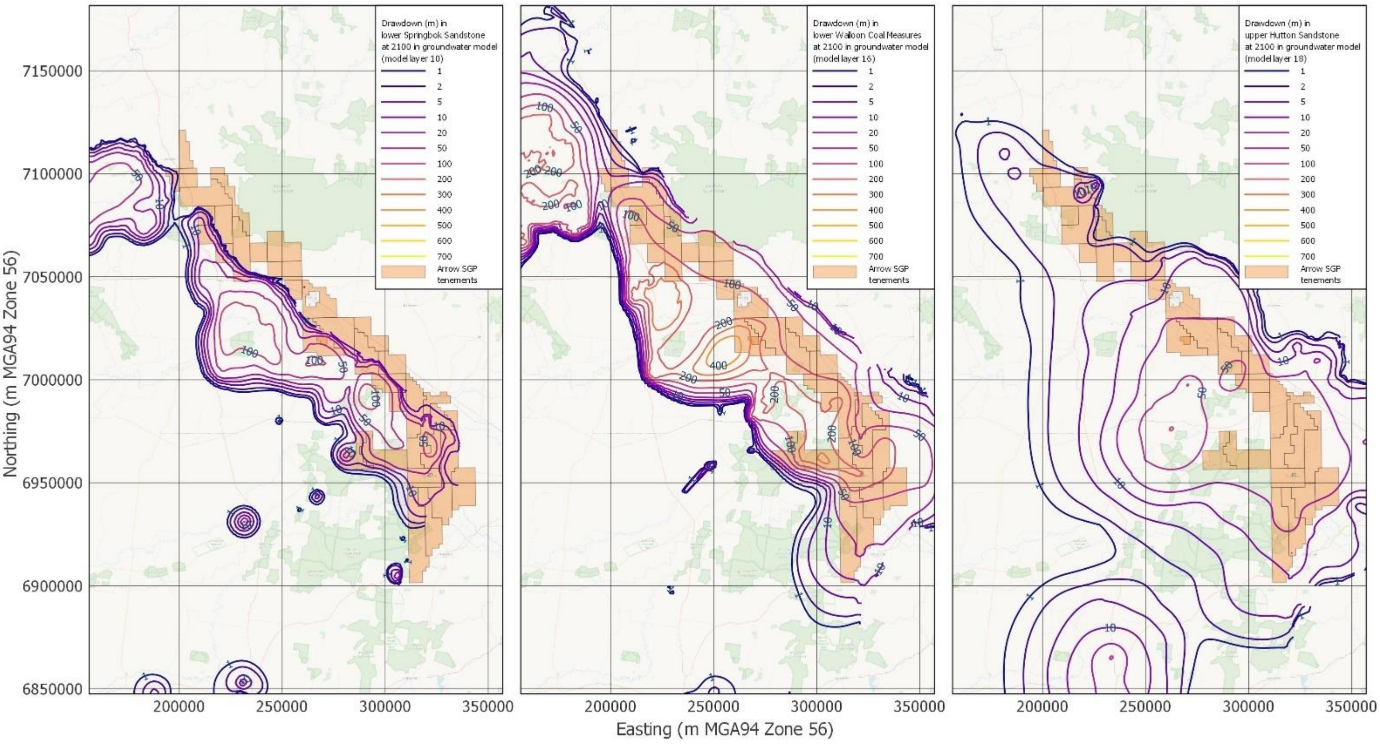


Figure 46: Modelled drawdown in the lower Springbok Sandstone, lower Walloon Coal Measures and the upper Hutton Sandstone in 2100

6.3. Predicted subsidence

Based on the assessment of the drained Young’s Modulus of the Juandah Coal Measures and the Taroom Coal Measures, as described in Section 3.5, an assessment of the predicted subsidence was carried out according the method described in Section 3.5 with a Biot coefficient of 0.85 and Poisson’s ratio of 0.25 assumed for each of the geological units included in the assessment.

Subsidence was assessed by considering the predicted groundwater drawdowns in the model layers shown in Table 5. The adopted drained Young’s Modulus values are shown in the table. The thickness of each of the model layers was taken from the model. Drained Young’s Modulus values for the Lower Springbok Sandstone and the Upper Hutton Sandstone were adopted based on previous experience with similar projects. Based on the modelled drawdowns shown in Figure 44 and Figure 45, the predicted subsidence is not considered to be highly sensitive to the adopted drained Young’s Modulus values for these units.

Ground movement observations at the Hopeland-17 bore, as shown in Figure 21 indicate that ground levels may not rebound notably following a recovery of groundwater levels. In the figure, the groundwater level increase in the Taroom Coal Measures from December 2017 to July 2018 in the borehole did not lead to an upward movement in the surface elevation at that location. To account for this, the predicted subsidence in 2050 is assessed by considering the maximum groundwater drawdown for each point in each of the model layers shown in Table 5 between 2030 and 2050. Prior to 2030, the groundwater model does not indicate notable recovery in groundwater levels will have taken place.

The drained Young’s modulus values used in the assessment of predicted subsidence are based on observations of groundwater level drawdown and associated subsidence during actual coal seam gas extraction. As such, the drained Young’s modulus values used in the assessment incorporate compression related to increases in effective stress and the liberation of gas.

Table 5: Adopted drained Young's Modulus for the model layers used in subsidence prediction

Model layer	Formation	E' (Gpa)
10	Lower Springbok Sandstone	30.0
11	Walloon Coal Measures non-productive zone	23.2
12	Upper Walloon Coal Measures (Juandah Coal Measures)	23.2
13	Middle 1 Walloon Coal Measures (Juandah Coal Measures)	23.2
14	Middle 2 Walloon Coal Measures (Juandah Coal Measures)	23.2
15	Middle 3 Walloon Coal Measures (Taroom Coal Measures)	4.6
16	Lower Walloon Coal Measures (Taroom Coal Measures)	4.6
17	Durabilla Formation	10.0
18	Upper Hutton Sandstone	30.0

The predicted subsidence in 2020, as shown in Figure 47, compares favourably to observed ground movement, considering the cumulative observed ground movement shown in Figure 7 and Figure 9 in the area between and to the west of the Daandine and Tipton CSG fields, which is generally below 75 mm. This is similar to the predicted subsidence shown in Figure 47 (area between approximately 7,000,000 mN and 6,960,000 mN MGA94 Zone 56).

The predicted subsidence in 2030 indicates the 10 mm subsidence contour will run approximately along the western and north western boundary of the Arrow SGP tenements. Settlement on the Arrow SGP tenements is predicted to be below 75 mm except for a small area at the Daandine CSG field and a larger area around the Tipton CSG field, where the maximum predicted subsidence is over 100 mm but less than 125 mm.

The predicted subsidence in 2050 shows a slight expansion in area in most places compared to 2030. The predicted 10 mm subsidence contour runs along or just outside the western and north western boundaries of the Arrow SGP tenements. The maximum predicted subsidence on the Arrow SGP tenements in 2050, located near the Tipton CSG field, is slightly over 125 mm.

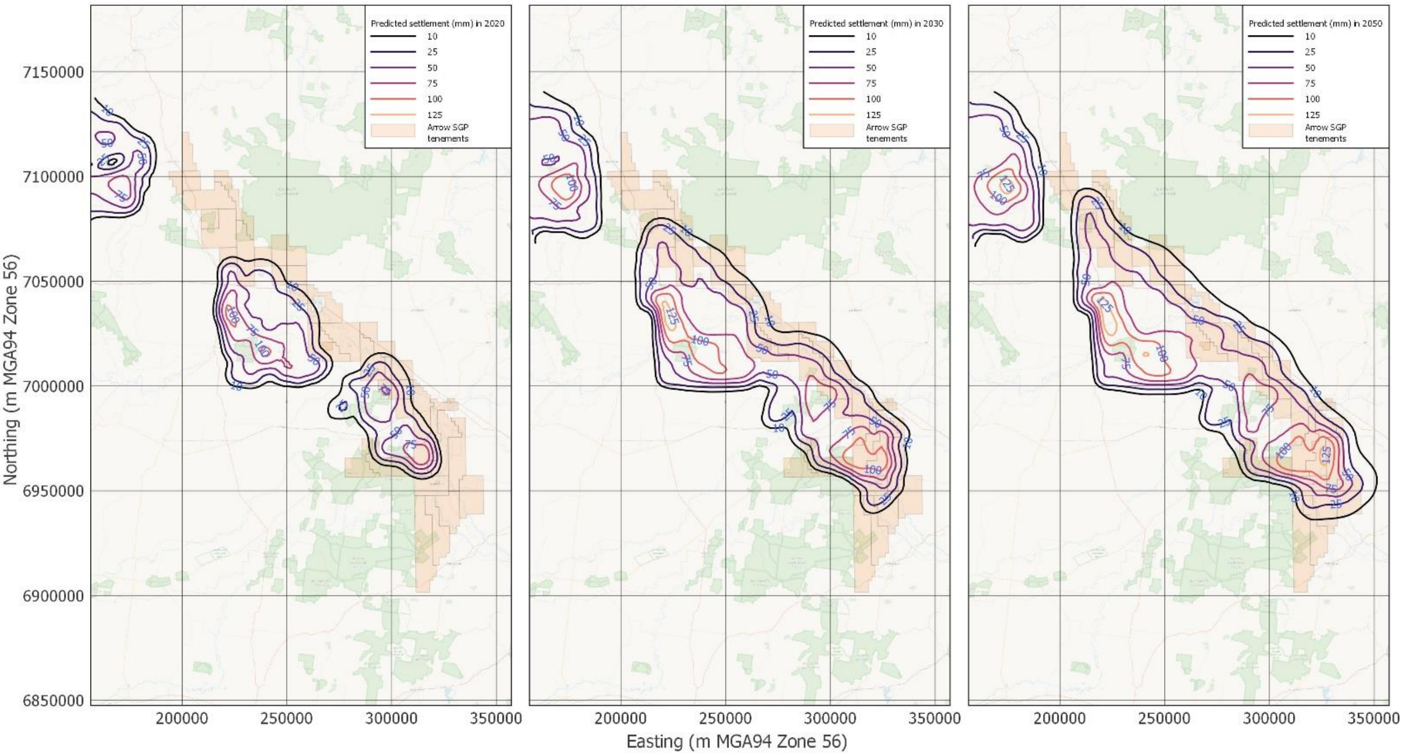


Figure 47: Predicted settlement in 2020, 2030 and 2050 based on drawdowns provided in the numerical groundwater model

7. Risk Assessment

An assessment of risk associated with the development of ground subsidence associated with the Arrow SGP was carried out.

Risks associated with subsidence are developed though a consideration of the likelihood of impacts of a nominated magnitude and the consequence of such an event. Subsidence can have an impact on the following assets:

- Linear infrastructure – roads, pipelines, rail lines, power lines, irrigation canals
- Buildings and structures
- Rivers and streams
- Farm irrigation systems
- Swamps and low lying areas.

A review of the existing use of the areas within the Arrow SGP and in the vicinity reveals the following assets:

- Roads, rail lines, power lines, pipelines
- Farmland including irrigation on land laser levelled land
- Forested areas
- Small dams
- Condamine River and tributaries
- Farmhouses and other small buildings
- Mines and mine infrastructure

The potential impacts upon these assets are discussed in the following sections. In considering potential impacts consideration needs to be given to absolute magnitude and the differential settlement or change in gradient.

Potential impacts on general farmland, small dams, and river flow for movements of less than 100 mm over distance of 1 km are not considered likely to result in adverse impacts and these have not been considered further. Mines and mine infrastructure are typically subject to ground movement associated with the mining operation and are considered unlikely to be adversely affected by the magnitudes of subsidence anticipated. Hence, they are not considered further. Farmhouses, farm sheds and other small buildings can be assessed under the criteria for other buildings and structures.

Laser levelling and other surface profile modification techniques are carried out for farms to facilitate the distribution of rainfall runoff and the efficient use of irrigation water. Subsidence occurring after farm levelling has taken place could potentially affect performance.

Data Farming (2021) advise that, based on analysis of slopes over the Arrow tenement:

- most cropping paddocks of the Darling Downs have slopes ranging from 0.12% to 0.5%, which equates to 1.8m to 7.5m vertical drop over a typical 1500m long paddock
- in the ‘technically’ flattest of furrow irrigation paddocks which have a slope of 0.06%, the average vertical difference from top to bottom is 0.42 m for a 700 m long field
- seven percent (7%) of dryland and nine percent (9%) of irrigated land has slopes of less than 0.06%, which is considered too flat to drain effectively
- areas of dryland cropping lands that are farmed at less than 0.06% will suffer waterlogging losses in heavy rainfall years, though during drought years with limited rainfall, the ponded areas may in fact lead to the highest yields due to soil water accumulation in these areas.

Based on these observations, changes in ground slope resulting from CSG induced ground movement which result in slope changes in excess of 0.06 % (600 mm in 1 km) could be significant for areas where existing ground slope is flatter than 0.12 % as this would result in more than 50% change in slope.

Risk screening and investigation criteria are currently being developed by Arrow. A three-step assessment process is proposed, involving:

(1) Initial assessment of InSAR data against a screening level

- The screening level criteria being observed settlement rates of over 8 mm / yr (for > 50% of sampling points in 1 km by 1 km block).

(2) Further investigation of potential impacts on three asset classes (where potential subsidence is identified in the screening assessment)

- The investigation level criteria being observed changes in gradient of 300 mm per km (where the existing slope is > 600 mm per km) or a 50% change to existing gradient (where the existing slope is < 600 mm per km).

(3) Further investigation using conventional survey and checking movement against trigger thresholds based on the local conditions. These include:

- A demonstrable loss in any relevant metric including crop yield and
- Evaluation of the following parameters indicating a material alteration to the surface of the property:
  - Development of new local low points, or
  - Gradients to existing low points, or
  - Catchment area of low points, or
  - Inundation of an area not previously known to be, or could reasonably be assumed to have been, inundated, or
  - Total variation in slope, or
  - Total drainage from the property.

7.1. Risk assessment approach

The risk management strategy for the Arrow SGP should comprise the following:

- Formulate a risk assessment and mitigation measures register.
- Adopt appropriate design to reduce residual risk to acceptable levels.
- Implement appropriate field monitoring during various stages of construction.
- Conduct additional geotechnical investigations at the appropriate time.

The risk assessment is further discussed below.

Risks associated with subsidence caused by CSG extraction are assessed using the approach set out in the Australian and New Zealand Standards Association Handbook SA/SNZ HB 89:2013. Within this framework, an ‘event’ is considered as CSG induced subsidence movement affecting an existing asset. The likelihood of subsidence of a particular magnitude has been assessed by reference to the subsidence measured to date, and the predictions for future subsidence. The consequence of an event of particular magnitude is assessed based on the nature of an asset and its sensitivity to movement.

The risk associated with a particular event is assessed based on the likelihood of movement above a particular magnitude and the sensitivity of the asset affected. A consequence/likelihood matrix approach has been adopted for assessment of risks. The definition and risk evaluation matrix are recommended to be reviewed following consideration by Arrow for consistency with their corporate risk stance.

For the purpose of this assessment the following definitions of likelihood and consequence are adopted:

Table 6: Likelihood category definition

Likelihood Category	Description
Rare	The event may not occur or if it does it will occur over less than 0.1% of the lease area
Unlikely	The event may occur over a small proportion 1% of the lease area
Possible	Instances of the event would occur in a number of places though not more than 10% of the area
Probable	Will occur over most of the area
Certain	The event will occur over a widespread area

Table 7: Consequence category definition

Consequence	Description
Insignificant	Little influence
Minor	Noticeable influence without serious consequences Damage caused tolerated with possible compensation payment (less than $10,000)
Medium	Rectification works or substantial additional monitoring required (costs less than $1,000,0000) Local press critical of outcome
Major	Substantial rectification works in excess of $5m required Environmental damage requiring intervention or remedial works National press critical of outcome
Catastrophic	Serious environmental consequences Damage with major disruption to public facilities Loss of life or serious injury to people

The risk evaluation matrix in Table 8 is employed.

Table 8: Risk Matrix

Likelihood Category Rating	**Consequence Category Rating**				
	Insignificant	**Minor**	**Medium**	**Major**	**Catastrophic**
Rare	Very Low	Very Low	Low	Medium	High
Unlikely	Very Low	Low	Medium	High	High
Possible	Low	Medium	High	High	Very High
Probable	Medium	High	High	Very High	Very High
Certain	High	High	Very High	Very High	Very High

7.2. Linear Infrastructure

The sensitivity of various structures to subsidence including roads, rail lines and pipelines are discussed in Commonwealth of Australia (2014). Table 9 summarises material from that document.

Table 9: Thresholds of adverse impact from ground movement – Linear infrastructure

Asset	**Guideline**	**Potential impacts from SGP induced subsidence**
Pipelines	Tensile strain less than 2% Slope change less than 1/140 Sewer pipeline 0.4% grade change	Negligible
Roads and highways	0.3 % over a chord length of 10 m	Negligible
Rail lines	Operation of railway services over areas affected by mine subsidence has proven manageable.	Negligible
Drainage channels	Slope change relative operating gradients should be checked	Slope changes unlikely to significant

7.3. Buildings and structures

Guidelines for assessment of settlement impacts upon buildings exist for assessment of potential impacts from activities such as construction dewatering. Damage is a function of differential settlement rather than the absolute value and damage is also a function of horizontal strain. Figure 48 by Burland (2012) provides an indication of the significance of differential movement on buildings. Results are presented in the form of damage categories for differing levels relative to deformation.

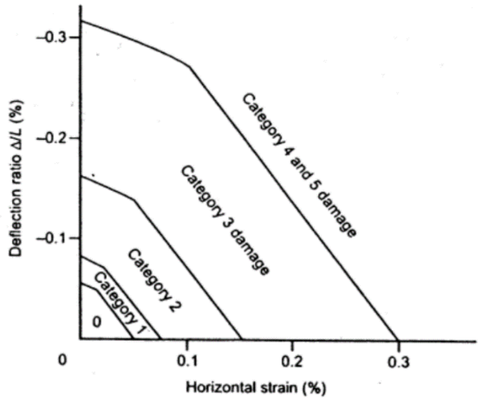


Figure 48 - Damage categories for buildings as a result of ground movement (Burland, 2012)

In Category 0 damage is described as negligible, limited to minor hairline cracks. Category 1 corresponds to minor architectural damage and Categories 4 and 5 correspond to major damage and risk of instability.

The deflection ratio is a measure of the change in vertical movement between two points and is illustrated in Figure 49.

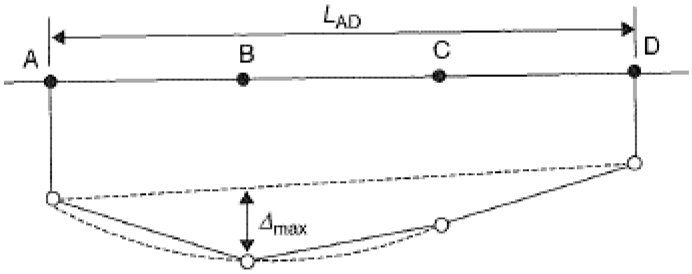


Figure 49 - Definition of deflection ratio (Burland, 2012)

As subsidence associated with SGP arises from compression of geological units at depth the changes at the surface will be gradual and no measurable horizontal strain is anticipated at the ground surface.

Rather than use of deflection ratio, use of differential settlement is adopted for assessment of the significance of differential movement for structures. For a uniform curvature, the maximum differential settlement (the gradient of settlement) would be four times the deflection ratio (maximum departure over a chord divided by the length of the chord). Taking a deflection ratio of 0.025% (half the limit for Class 0 damage, which is defined by Burland as negligible with hairline cracks less than about 0.1 mm), this corresponds to a deflection gradient (change in deflection per unit length) of 0.1% or 1/1000. This is considered a conservative threshold for damage to buildings and other structures.

7.4. Dams

A water storage dam approximately 800 m by 450 m in area is present to the north of the Daandine CSG field. It is constructed using a raised perimeter embankment. Other water storages are present within or near Arrow SGP (including raw water dams, treated water dams and brine dams, and farm water storages such as ring tanks).

Tensile strains associated with CSG related subsidence could potentially result in cracking of embankment materials. For a compacted clay core, tensile strain of less than 0.5% is considered unlikely to have a material influence on its performance in a water retaining structure. Tensile strains approaching this magnitude are assessed as being highly unlikely to arise from subsidence induced by SGP CSG extraction.

No major dams are present within or in proximity to the Arrow SGP in the Surat Basin. If major dams where failure would cause significant risk to human life or the environment are to be constructed in the area (either project related or for other purposes) it is recommended that a separate assessment be made of subsidence potential and susceptibility as part of design studies.

7.5. Rivers and watercourses

Dafny and Silburn (2013) note that:

> *The Condamine plain occupies the area between Ellangowan (E151.67º, S27.92º) and Chinchilla (E150.72°, S27.74°), southern inland Queensland. It stretches over an area of about 7,000 km^2, and is ~190 km long. Its upstream and downstream edges are narrow, but most of floodplain is 15-40 km wide. The topography drops steadily from the south-west to the north-east, from +400 m near Ellangowan to +350 m near Dalby and to +310 m near Chinchilla, with an overall topographic gradient of 0.5 m/km.*

Using the existing topographic gradient as a guide it is assessed that subsidence leading to changes in gradient of less than 10% of the existing gradient (10% x 0.5 m/km = 0.050 m/km) would be unlikely to have significant impact on the performance of the Condamine River or tributary watercourses. In addition, the deformation associated with coal seam gas extraction does not extend to affect the Condamine River itself. It is apparent that this would not be a significant consideration.

8. Trigger Level Development

It is clear from the discussion of potential impacts of subsidence on existing assets that absolute ground movement is generally less important than the differential movement over the extent of a relevant asset. Sensitivity to horizontal strain has been noted as relevant for a range of built assets including dams, buildings, pipelines and roads. The form of subsidence which has been recorded to date indicates that development of horizontal strain will be extremely small. As a result, trigger levels proposed in Table 7 below do not include consideration of horizontal strain and risk associated with horizontal strain on these built assets is considered negligible.

Review of potential impacts on various assets indicates that differential settlement or change in slope is more relevant than total subsidence. A two-step assessment process is proposed. Initial assessment would involve identification of areas where significant subsidence is occurring based upon the cumulative subsidence since October 2020 (or the time when CSG development for the SGP commences for areas where CSG development commences at dates after October 2020) reported from InSAR monitoring results.

It is proposed that this initial assessment involve identification of areas where ground movement exceeds 8 mm/yr over a 1 km by 1 km area or where cumulative subsidence greater than 100 mm occurs. To improve efficiency, this should be carried out using a contouring process with care taken to avoid the inclusion isolated InSAR monitoring points which may potentially be showing noise in their data based on a comparison to data at nearby InSAR monitoring points. In areas where this level of movement is recorded, the data should be assessed to identify regions where the triggers nominated in Table 10 occur. The triggers nominated in Table 10 take account of workshop findings from a workshop on 25 August 2021 involving farmers, State Government(OGIA and Gasfields Commission representatives) and Arrow representatives.

Changes in slope for farmland which has low existing slope is more significant than for fields with steep gradient. Data farming (2021) assesses that with SGP tenements that most cropping paddocks have slopes ranging from 0.12% to 0.5%. It is therefore appropriate to consider farmland steeper than 0.03% (300 mm per km) separately from farmland with flatter slope. For the farmland with existing slope in excess of 300 mm per km a slope change of 100 mm per km is considered unlikely to affect overall performance. For farmland with shallower slopes changes in slope the land would already be poorly draining so small changes in slope would not change the poorly draining nature of the land.

Data farming (2021) advise that the flattest slopes for furrow irrigated paddocks is 0.06% and also notes that dryland cropping lands farmed with slopes at less than 0.06% will be subject to waterlogging in heavy rainfall years and ponding of rainfall during low rainfall periods. It is therefore considered that slopes on existing irrigated farmland less than 0.06% could be considered as essentially flat. Small changes in slope would seem unlikely to be detrimental to farmland in this category. For land with slope close to 0.06% a change of 100 mm over 1 km (0.01% is considered a reasonable trigger level. For land with slope greater than 0.09% a change of slope of 15% is not anticipated to affect performance significantly.

It is noted that the changes in ground slope from June 2016 to June 2019 indicated from review of sections interpreted from InSAR data in Figure 11, Figure 12 and Figure 14 showed changes in the gradient less than 0.02% with the steepest changes over distances less than 200 m in length.

Table 10: Proposed subsidence monitoring trigger levels – stage 2 assessment

Trigger Description	Trigger Level	Relevant Assets	Basis for Selection / Comment
Differential settlement	0.001 m/m	Buildings, structures Roads, railways Pipelines	Selected for buildings as the most sensitive item in this group. See Section 6.3 Threshold is unlikely to be critical for roads, railways or pipelines Not relevant to bushland or farmland – apply only to dwellings, built up areas, railways, roads and pipelines.
Change in slope	No trigger level	Dryland farms with existing slopes less than 0.03% no trigger level is nominated. Irrigated farms with slopes less than 0.06% no trigger level is nominated	Dryland farms with slopes less than 0.03% are already poorly draining. Irrigated farms with slopes less than 0.06% are too flat to successfully apply furrow irrigation.
Change in slope	100 mm over 1 km (0.01%)	Farmland with existing slopes ranging from 0.03% to 0.09%	Farmland with low existing gradient a small change (100 mm over 1 km) is considered relevant.
Change in slope	15% change in gradient	Farmland with existing slopes greater than 0.09%	A change in slope of more than 15% of the existing gradient is considered relevant where existing slopes are above 900 mm over 1 km..
Change in slope	50 mm/km	Flood flow in major water courses	Taken as 10% of the topographic gradient of the Condamine Plain Apply only to the main channel of the Condamine River.

Application of these trigger levels would require identification of existing slopes of farmland within or adjacent to SGP tenements.

The trigger levels nominated in Table 7 are anticipated to be conservative. Coffey recommend that exceedance of these triggers levels be followed by a review of affected facilities present in the affected area, and a review of potential detrimental effects and the development of mitigation measures as appropriate.

8.1. Assessment of subsidence against trigger levels

The identification of areas of subsidence in breach of the trigger levels set out in Table 10 should be carried out as follows:

- Obtain available InSAR subsidence data, from which the cumulative ground movement since commencement of SGP operations at the location can be assessed.
- Crop the InSAR data to a buffer of 5 km around areas of active CSG production.
- From this smaller dataset, identify and extract a 2 km buffer around the region/s where cumulative ground movement since commencement of SGP operations at the location is greater than 100 mm or where ground movement of 8 mm/yr or greater is occurring over 1 km by 1 km areas. A contouring process, potentially with some minor smoothing is recommended. This will assist in identifying regions rather than individual InSAR monitoring points. For areas where InSAR has poor coherence or coverage for farming property (or other sensitive areas) within 3 km of active CSG production wells, acquire LIDAR.

- From this smaller dataset, identify regions where the gradient of cumulative ground movement since commencement of SGP operations at the location is greater than 20 mm over 1 km (or 0.002%).
- Carry out the following on this smaller dataset:
    - Mark for review any areas located on farmland.
    - For areas not marked for review in the previous step, identify regions where the gradient of cumulative ground movement since commencement of SGP operations at the location is greater than 1 in 1000. Mark these areas for review of Buildings, structures, roads, railways or pipelines.
- For the areas marked for review, remove those areas where ground movement is obviously related to non CSG development such as dam construction or land clearing.

Following the identification of those areas which breach the trigger levels set out in Table 10, these areas should then be subject to a review to assess the potential impact/s in detail, taking into account the domestic, industrial and agricultural infrastructure and any areas of environmental or cultural significance present in these areas.

The process of identification of areas breaching trigger levels based in InSAR monitoring data lends itself to automation. An automated or semi-automated identification process is likely to lead to consistent results and be less error prone than a manual identification process involving a visual assessment of InSAR data on maps.

8.2. Predicted subsidence gradients

The predicted subsidence due to combined Arrow SGP operations and CSG extraction by other operators is assessed as having a maximum value of slightly over 125 mm, as shown in Figure 47. The steepest predicted gradient is 50 mm over 4 km, east of the Tipton CSG field. This is well below the adopted trigger levels for protection of buildings, road, railways, pipelines of 1 in 1000 and for protection of field irrigation systems and the flow in the Condamine River of 50 mm/km.

8.3. Uncertainties

While the predicted subsidence would not breach the adopted trigger levels it must be recognised that the assessment is based on limited data and contains uncertainty. The assessment is sensitive to the adopted values of:

- modulus of the coal measure rocks,
- volume loss of coal associated with removal of coal seam gas
- predicted groundwater drawdown.

Whilst there is some uncertainty in these parameters, it is noted that CSG extraction by Arrow and other proponents has been occurring for several years, and observed subsidence is generally of the order predicted by the models.

It is recommended that the subsidence assessment is reviewed periodically as additional groundwater monitoring and InSAR data become available.

9. Monitoring Program Development

The current monitoring program provides groundwater level monitoring and monitoring of subsidence using InSAR technology. The interpretation of subsidence responses, and the prediction of future subsidence, requires good quality groundwater level monitoring over the depth of the affected ground, and collocated ground movement measurements.

While InSAR technology provides high resolution and wide coverage, it is recommended that alternative geodetic measurement of ground movement are taken at selected locations to provide a ground-truthing check on the InSAR results. It is recommended that locations for geotechnical ground movement monitoring are collocated with groundwater monitoring bores which provide coverage of the full ground profile potentially influenced by Arrow SGP operations. It is recommended that these instrumented sites are located at the centre of selected Arrow SGP well fields and are installed to provide baseline information prior to the initiation of production pumping in the area.

Measures which can be of value in assessment of subsidence impacts include:

- Tiltmeters can measure small changes ground slope.
- Survey using traditional or GPS methods.
- Extensometers.
- Condition assessments of structures at risk.

Of these methods use of extensometers and survey to ground truth the results of InSAR monitoring are considered most useful. Extensometers allow identification of the horizons in the ground profile contributing to surface settlement. It is considered that tiltmeters would be subject to shallow influences unrepresentative of movements originating from Arrow SGP activities.

Where coherence of InSAR radar response is poor within 3 km of operating CSG wells use of LIDAR survey should be used to assess ground movement.

Figure 50 sets out locations Arrow plan for establishment of subsidence monitoring stations. These stations would comprise:

- Groundwater monitoring at multiple locations including within, above and below the Walloon Coal Measures.
- Geodetic ground movement (vertical) monitoring monument (installed to avoid shrink swell movement of the upper soils).
- In addition, at one location (Longswamp 38, 39 and 40) separate ground movement monitoring of the upper and lower parts of the Condamine alluvium and the Springbok Sandstone is planned.

In addition, at one location (Longswamp 38, 39 and 40) separate ground movement monitoring of the upper and lower parts of the Condamine alluvium and the Springbok Sandstone is planned..

These locations are considered to provide appropriate coverage of the areas potentially affected by Arrow operations.

Measurement of settlement and extensometers are recommended on a quarterly basis. Groundwater level measurement is recommended to be continuous using data loggers.

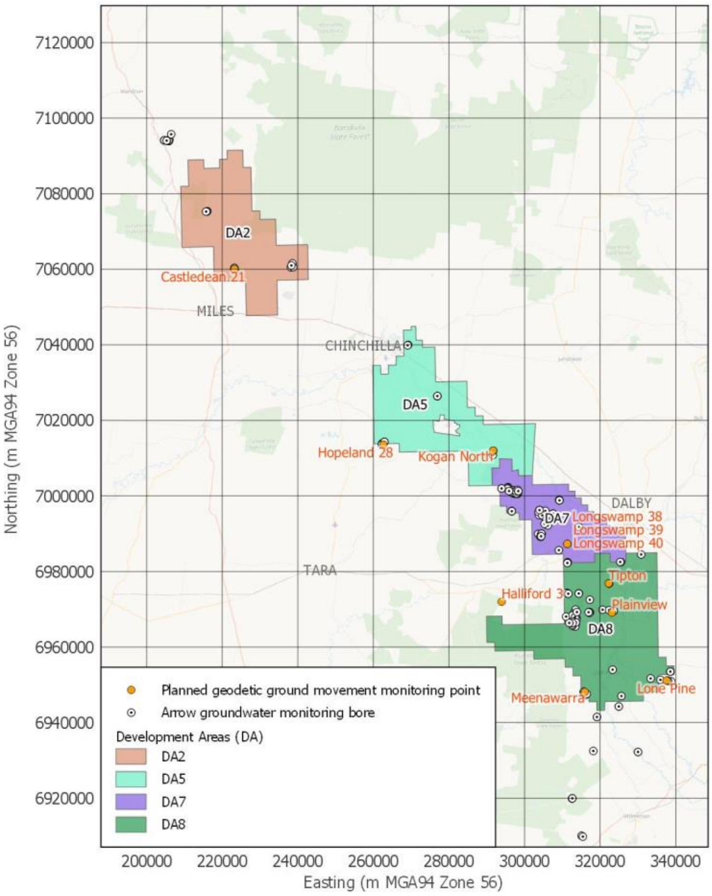


Figure 50: Planned subsidence monitoring stations

10. Reporting recommendations

Monitoring of subsidence and groundwater level variation based on existing data indicates that settlement is gradual and accompanies groundwater level drawdown. The changes develop gradually over months and years, and as a result it is recommended that a review of subsidence is carried out on an annual basis. It is recommended that surveillance reports are prepared annually providing diagnostic plots of drawdown and ground movement for each of the subsidence monitoring stations. Annual review and reporting is recommended covering:

- Changes from the baseline condition.
- Incremental changes in groundwater level and ground movement over the previous twelve months.
- Review of ground movement monitoring against adopted trigger level.
- Review of trigger levels.
- Consideration of complaints in relation to ground movement.
- Recommendations for actions in response to breaches of trigger levels.
- Recommendations in relation to the future frequency of monitoring, repair or investigation of instruments producing inconsistent results, revision of trigger levels.

11. References

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Appendix A - UCS test results

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110051-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	6/11/2020
		Report Date	10/11/2020
Project	Surat Subsidence Study		
Client ID	Daandine 4 - 114304	**Depth (m)**	140.02-140.70
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.8	Moisture Content (%)	3.0
Sample Height (mm)	144.9	Wet Density (t/m^3)	2.10
Duration of Test (min)	12:23	Dry Density (t/m^3)	2.03
Rate of Strain (%/min)	0.05	Bedding (^{o})	40
Mode of Failure	Shear	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	60		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	3.50				
Deviator Stress (MPa)	30.7				
Axial Strain (με)	9288				
Diametral Strain (με)	-5622				
Tangent Modulus (GPa)	4.26				
Poisson's Ratio	0.141				

Residual Test Results

Confining Pressure (MPa)	3.50				
Residual Deviator Stress (MPa)	15.9				
Axial Strain (με)	11971				
Diametral Strain (με)	-14870				

Notes/Remarks:

Sample/s supplied by client Tested as received

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The results of the tests, calibrations, and/or measurements included in this document are traceable to Australian/National Standards.

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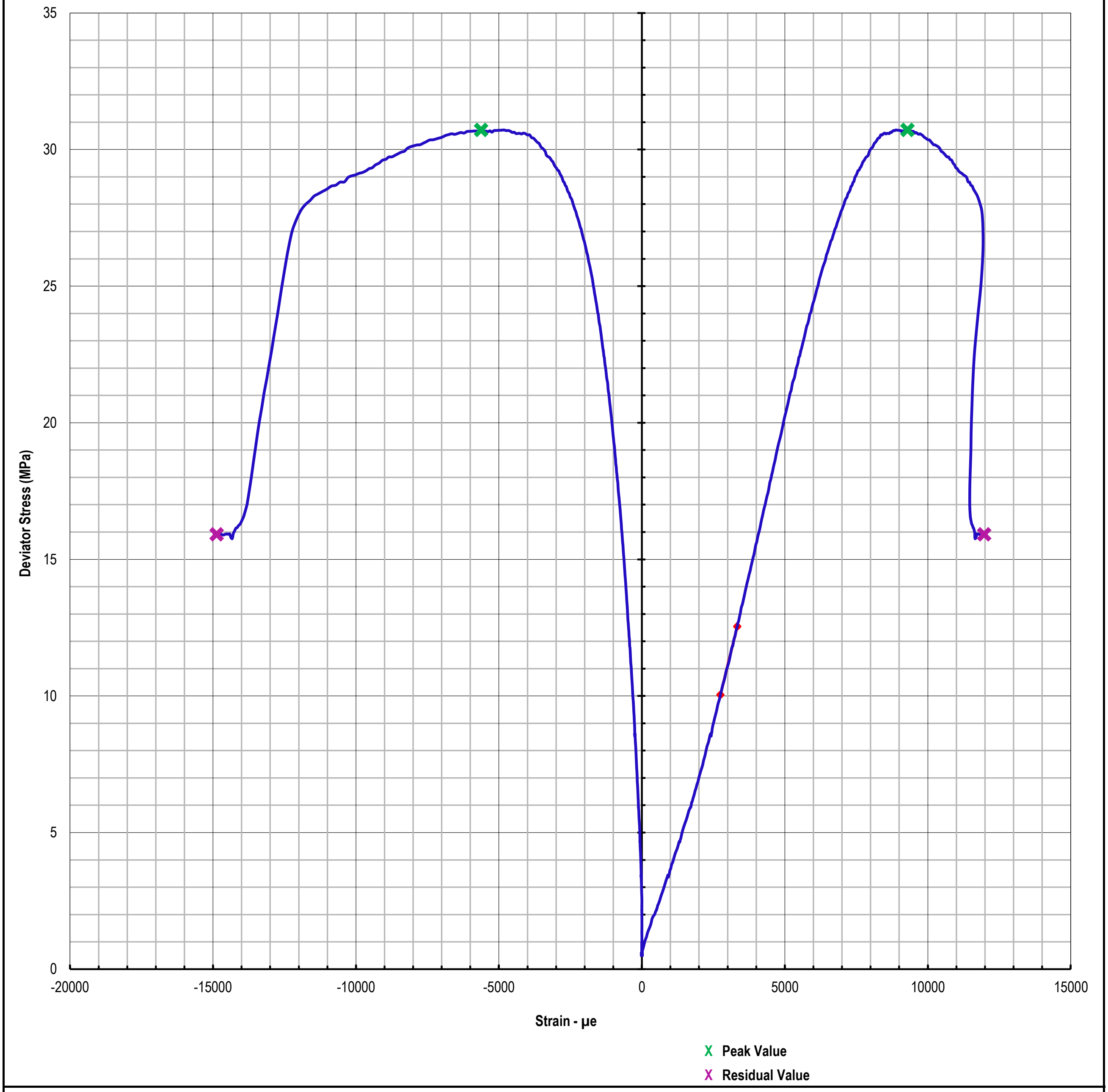
Client	Arrow Energy Pty Ltd	**Report No.**	20110051-RTX

Deviator Stress vs Axial Strain Plots



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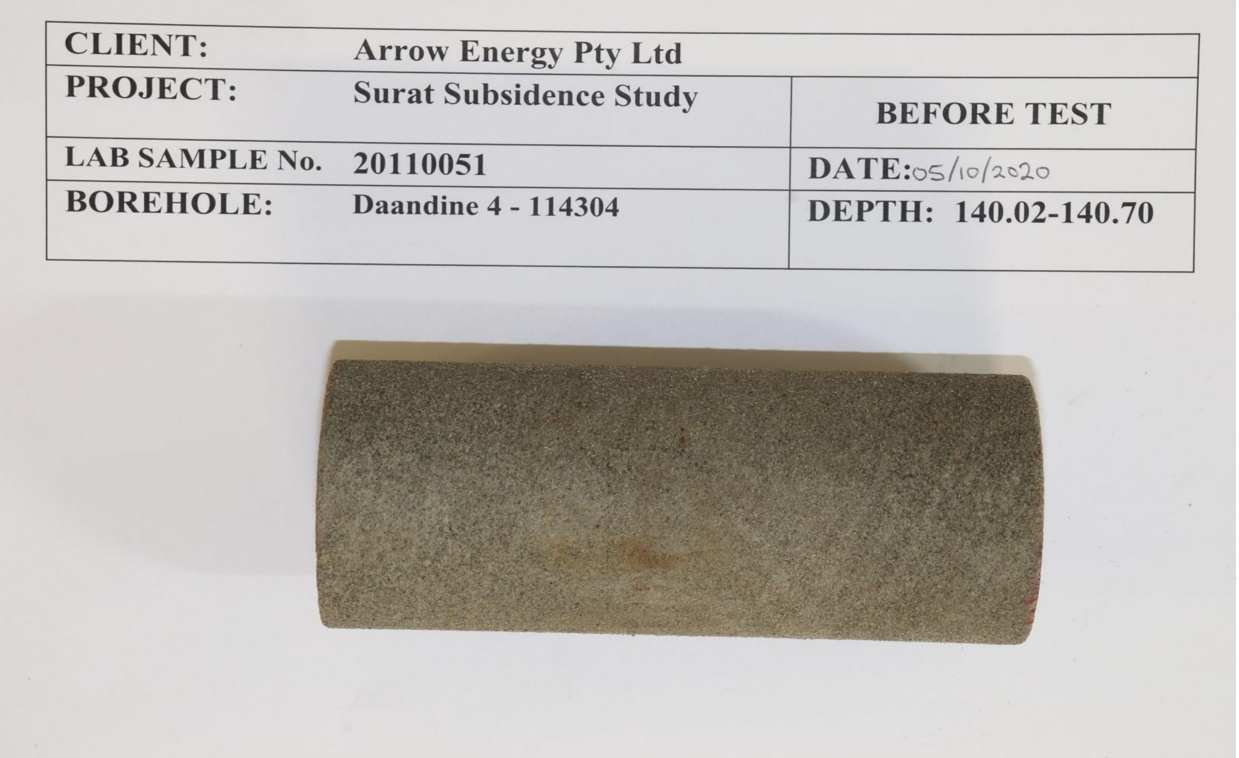
Client	Arrow Energy Pty Ltd	**Report No.**	20110051-RTX

Before and After Test Photos



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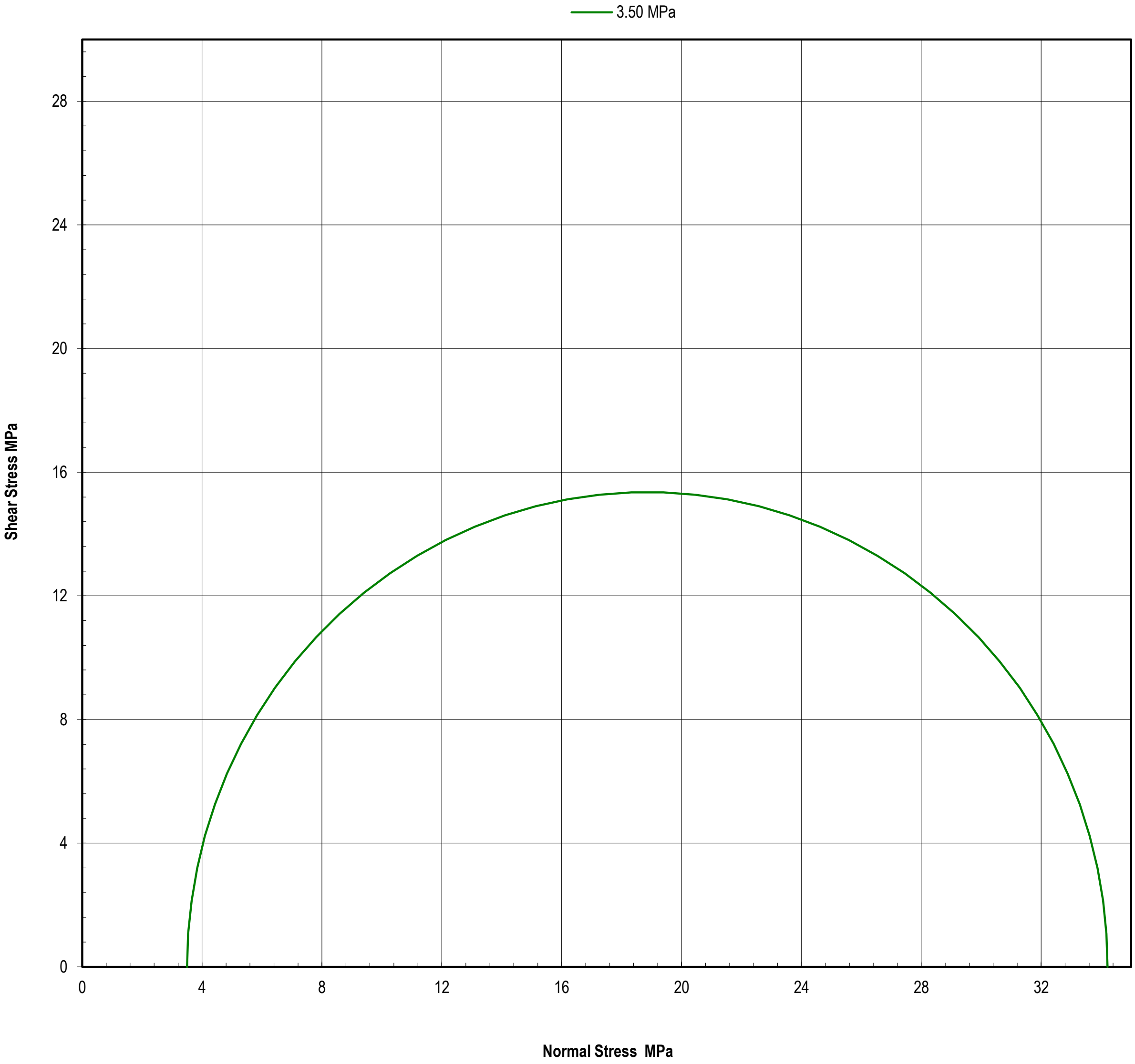
Client Arrow Energy Pty Ltd

Report No. 20110051-RTX

Peak Stress Mohr Circle Plot



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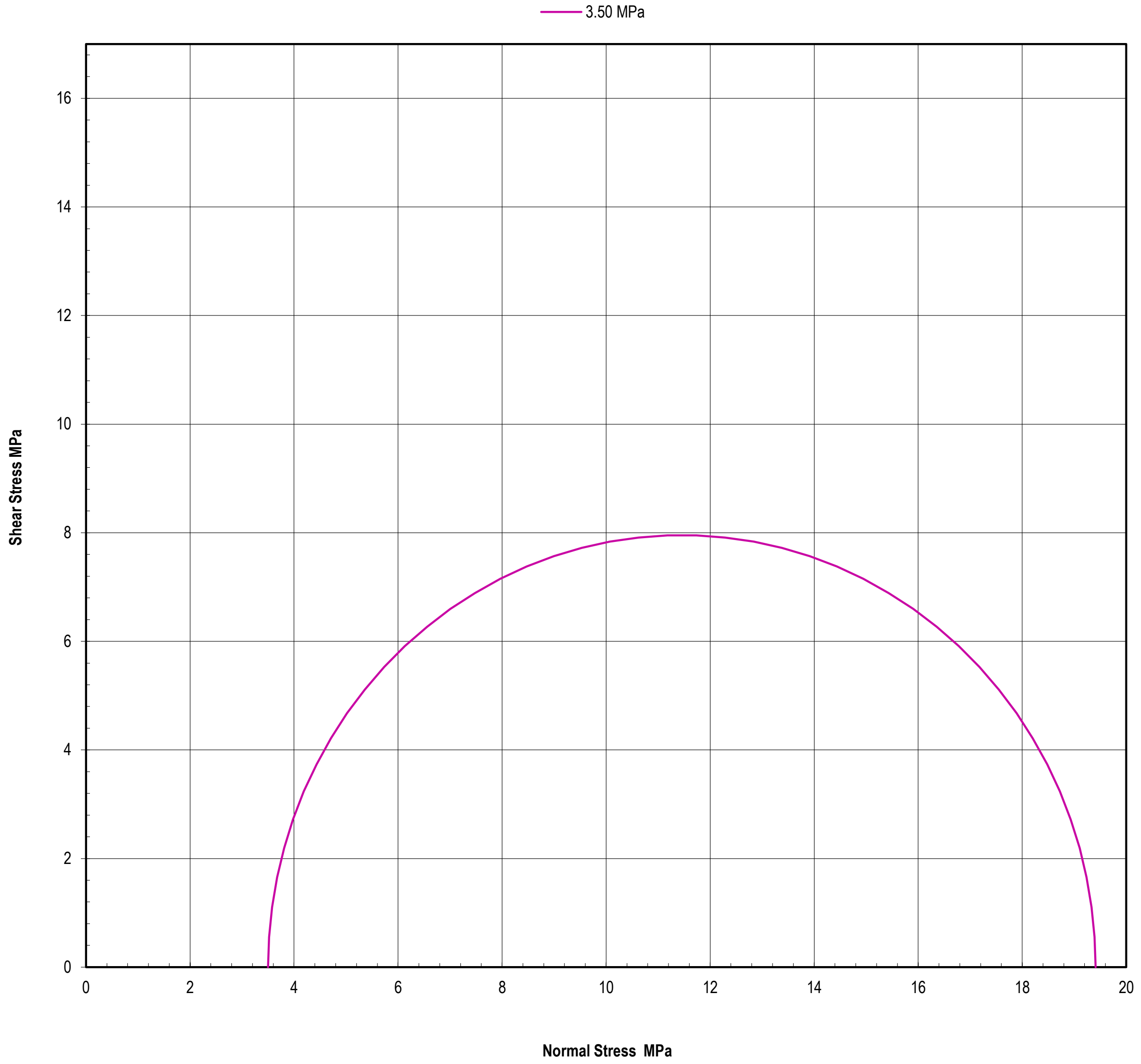
Report No. 20110051-RTX

Residual Stress Mohr Circle Plot



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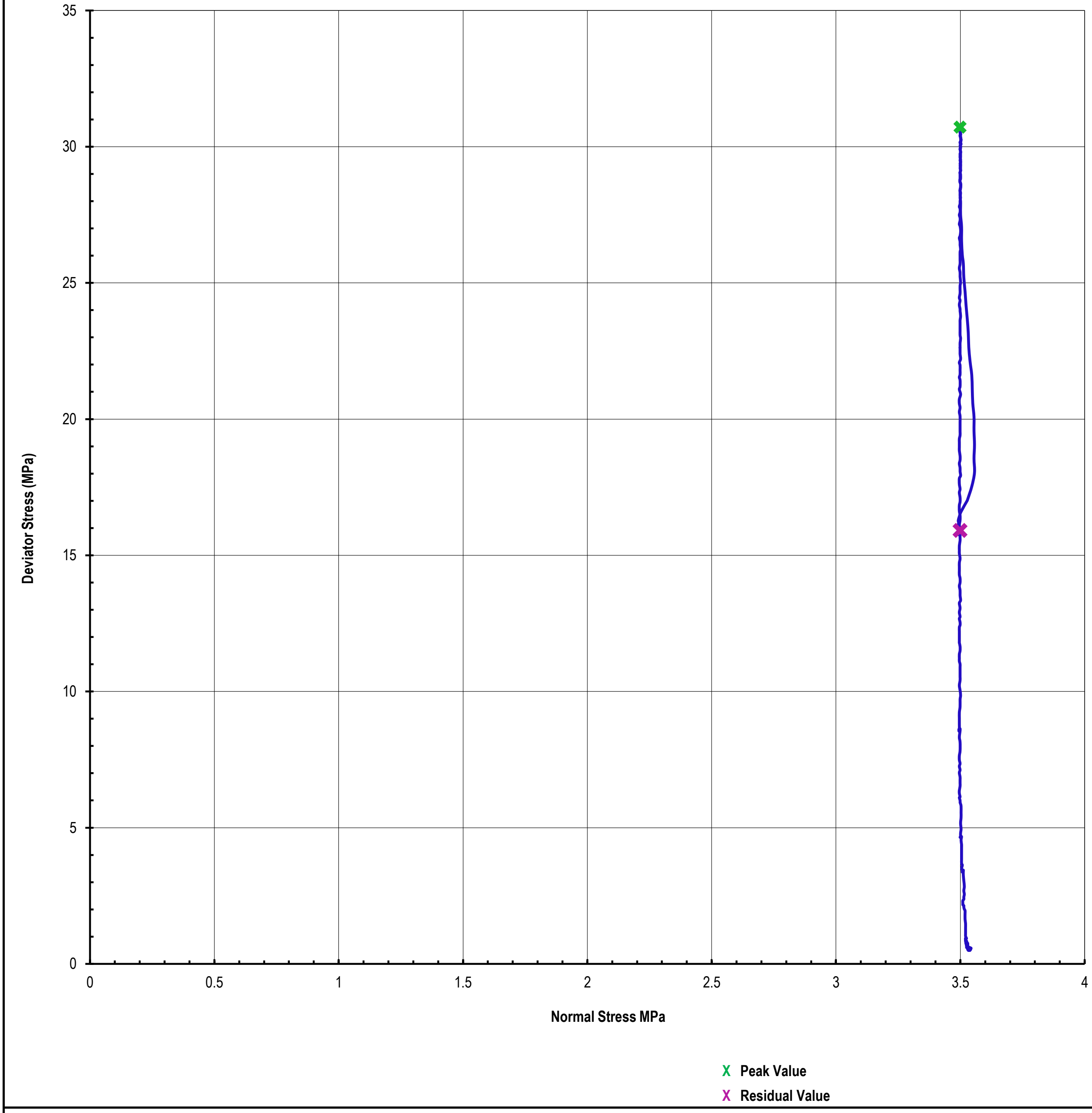
Client Arrow Energy Pty Ltd

Report No. 20110051-RTX

Deviator Stress vs Normal Stress Plot



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Soil Rock Calibration

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Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110052-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	5/11/2020
		Report Date	10/11/2020
Project	Surat Subsidence Study		
Client ID	Daandine 4 - 114306	**Depth (m)**	202.50-202.75
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	61.0	Moisture Content (%)	3.0
Sample Height (mm)	145.0	Wet Density (t/m^3)	2.58
Duration of Test (min)	14:43	Dry Density (t/m^3)	2.51
Rate of Strain (%/min)	0.05	Bedding (^{o})	10
Mode of Failure	Conical	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	70		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	5.10				
Deviator Stress (MPa)	54.0				
Axial Strain (μe)	4214				
Diametral Strain (μe)	-791				
Tangent Modulus (GPa)	15.1				
Poisson's Ratio	0.092				

Residual Test Results

Confining Pressure (MPa)	5.10				
Residual Deviator Stress (MPa)	33.7				
Axial Strain (μe)	4080				
Diametral Strain (μe)	-8155				

Notes/Remarks:

Sample/s supplied by client Tested as received

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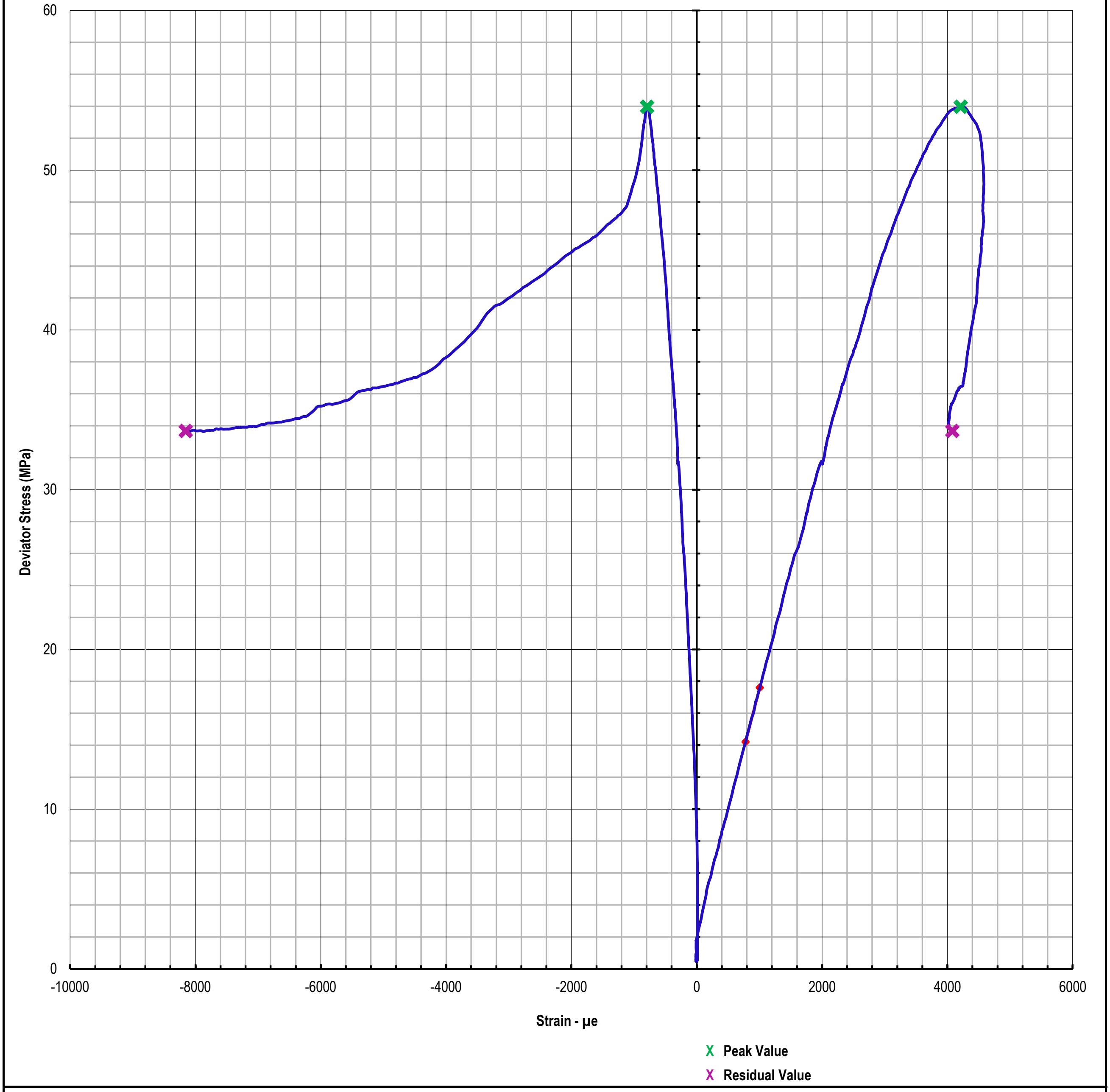
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110052-RTX

Deviator Stress vs Axial Strain Plots



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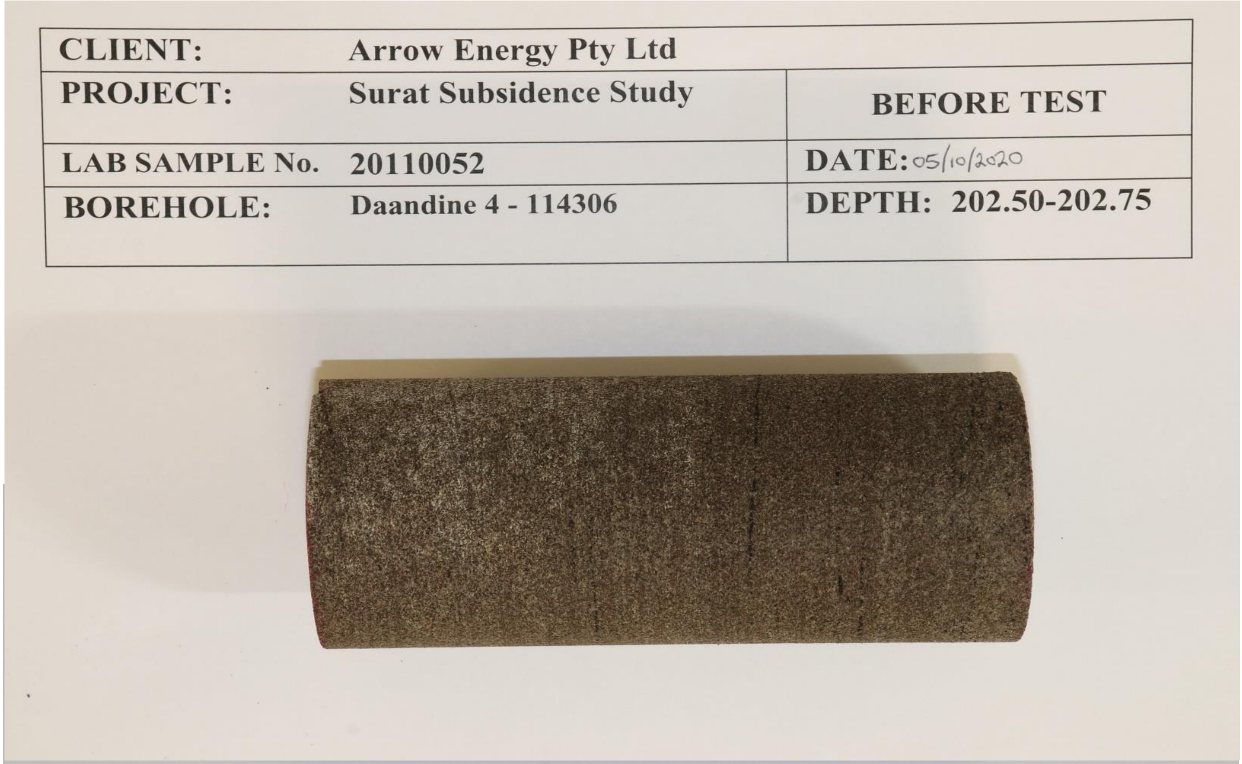
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110052-RTX

Before and After Test Photos



CLIENT:	Arrow Energy Pty Ltd	
PROJECT:	Surat Subsidence Study	BEFORE TEST
LAB SAMPLE No.	20110052	DATE: 05/10/2020
BOREHOLE:	Daandine 4 - 114306	DEPTH: 202.50-202.75

Notes/Remarks:

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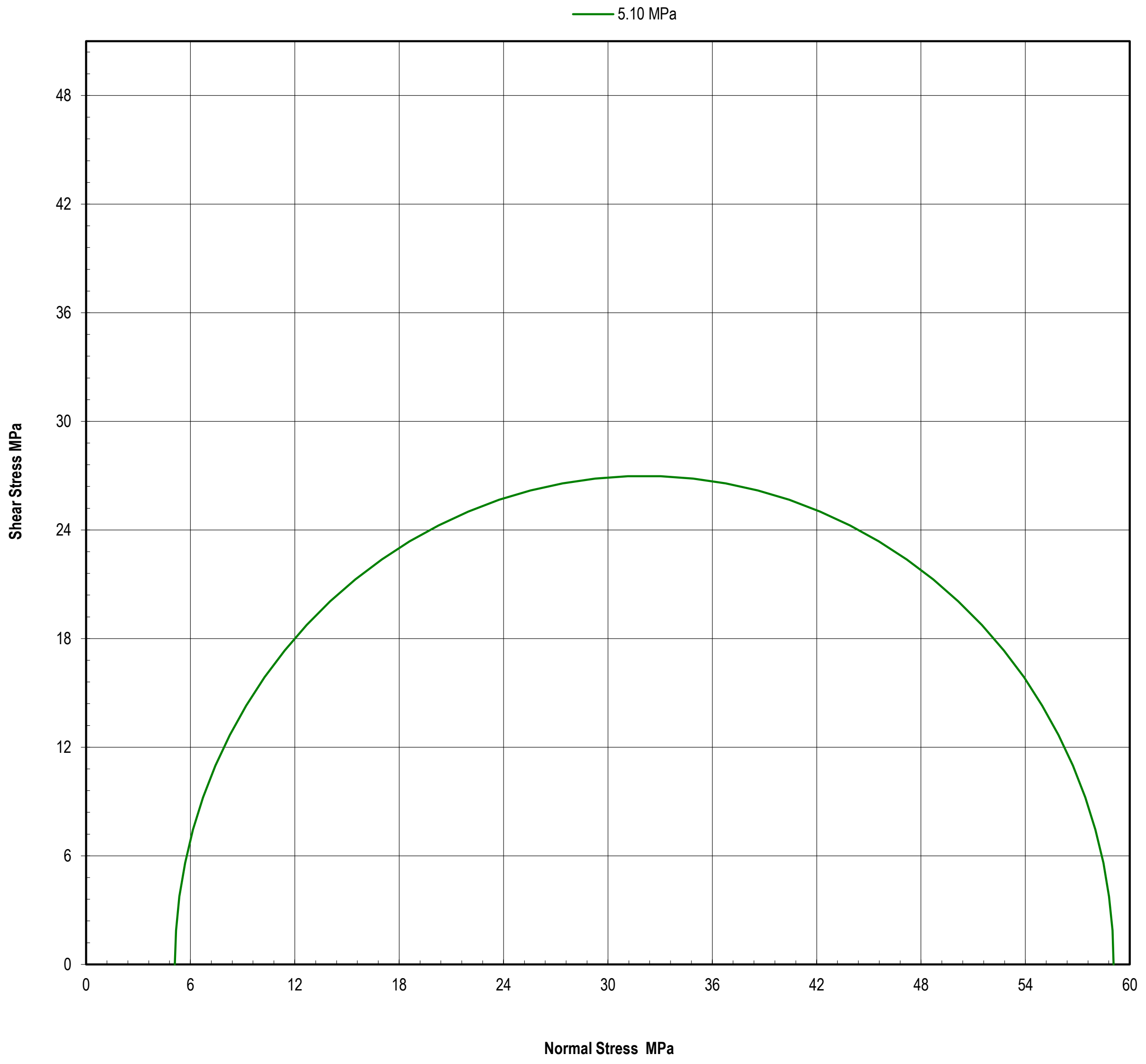
Client Arrow Energy Pty Ltd

Report No. 20110052-RTX

Peak Stress Mohr Circle Plot



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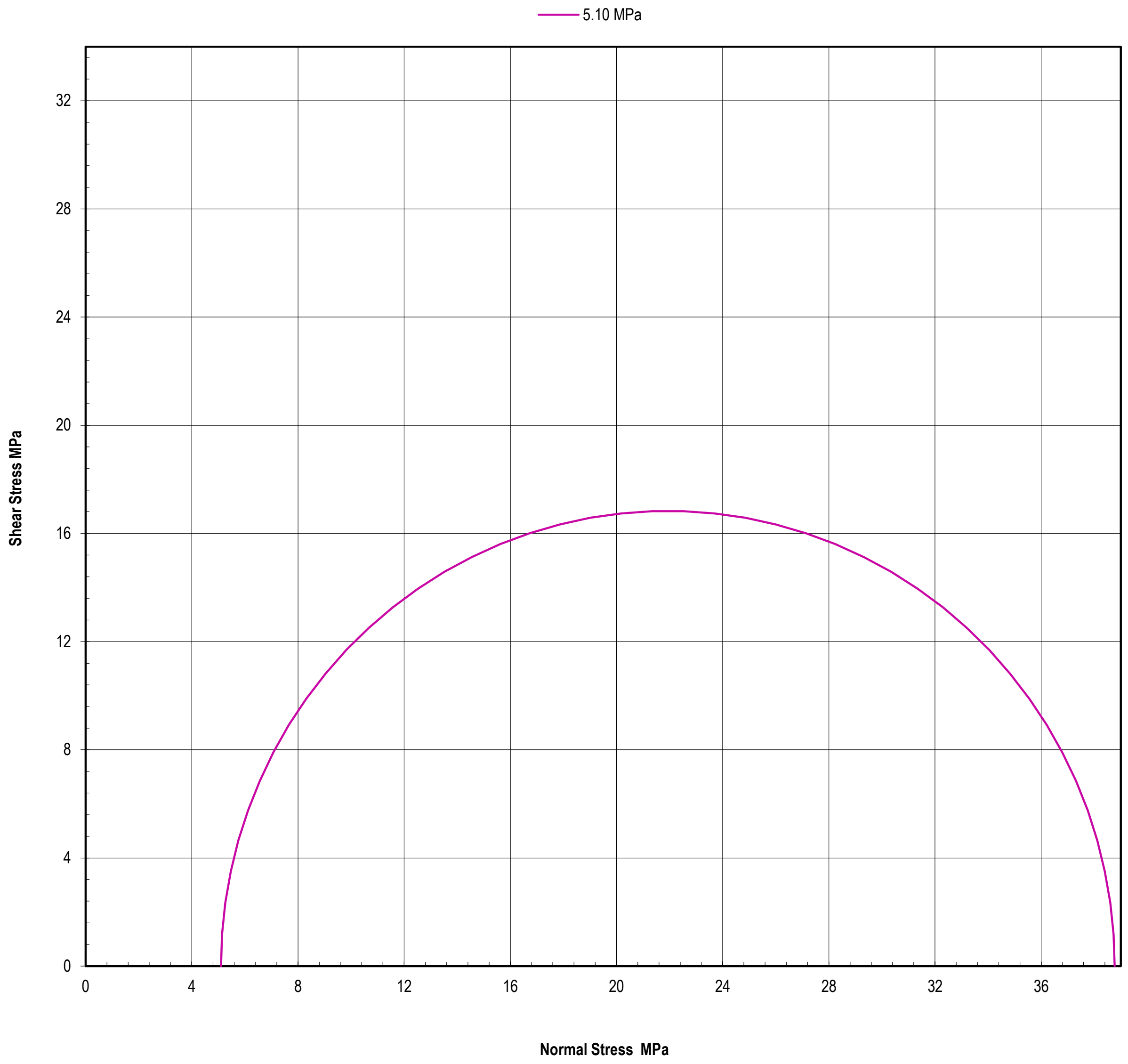
Client Arrow Energy Pty Ltd

Report No. 20110052-RTX

Residual Stress Mohr Circle Plot



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

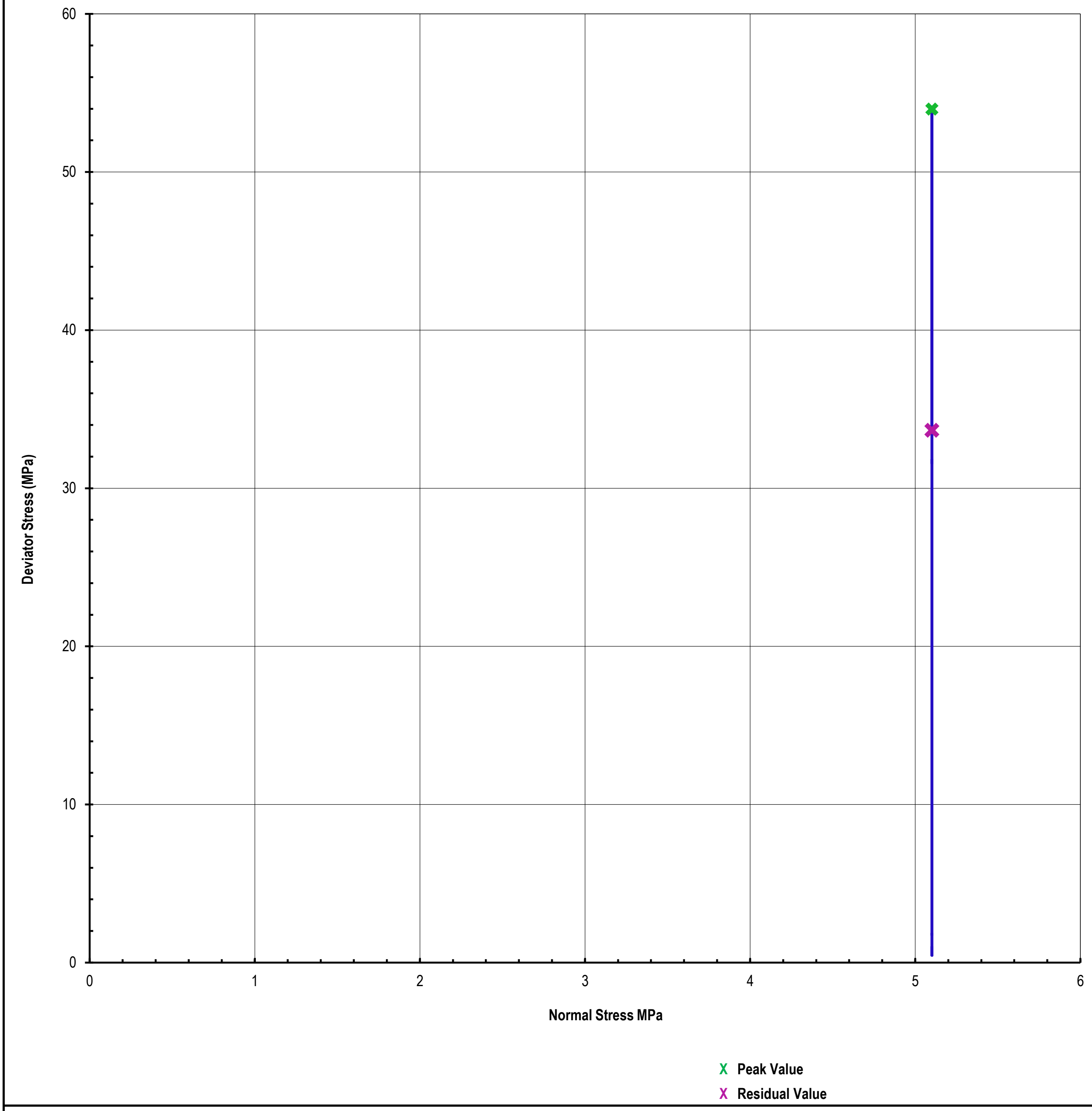
ASTM D7012

Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110052-RTX

Deviator Stress vs Normal Stress Plot



Notes/Remarks:

Graph not to scale

Sample/s supplied by client

Tested as received

Page 6 of 6 REP16601

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Tested at Trilab Brisbane Laboratory

Authorised Signatory

C. Purvis

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110053-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	6/11/2020
		Report Date	10/11/2020
Project	Surat Subsidence Study		
Client ID	Daandine 4 - 114,307	**Depth (m)**	306.64-306.89
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.5	Moisture Content (%)	7.3
Sample Height (mm)	148.8	Wet Density (t/m^3)	2.33
Duration of Test (min)	18:44	Dry Density (t/m^3)	2.18
Rate of Strain (%/min)	0.05	Bedding (^{o})	Nil
Mode of Failure	Shear	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	65		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	7.62				
Deviator Stress (MPa)	31.7				
Axial Strain (μe)	12296				
Diametral Strain (μe)	-4215				
Tangent Modulus (GPa)	3.68				
Poisson's Ratio	0.140				

Residual Test Results

Confining Pressure (MPa)	7.61				
Residual Deviator Stress (MPa)	19.5				
Axial Strain (μe)	18273				
Diametral Strain (μe)	-8623				

Notes/Remarks:

Sample/s supplied by client

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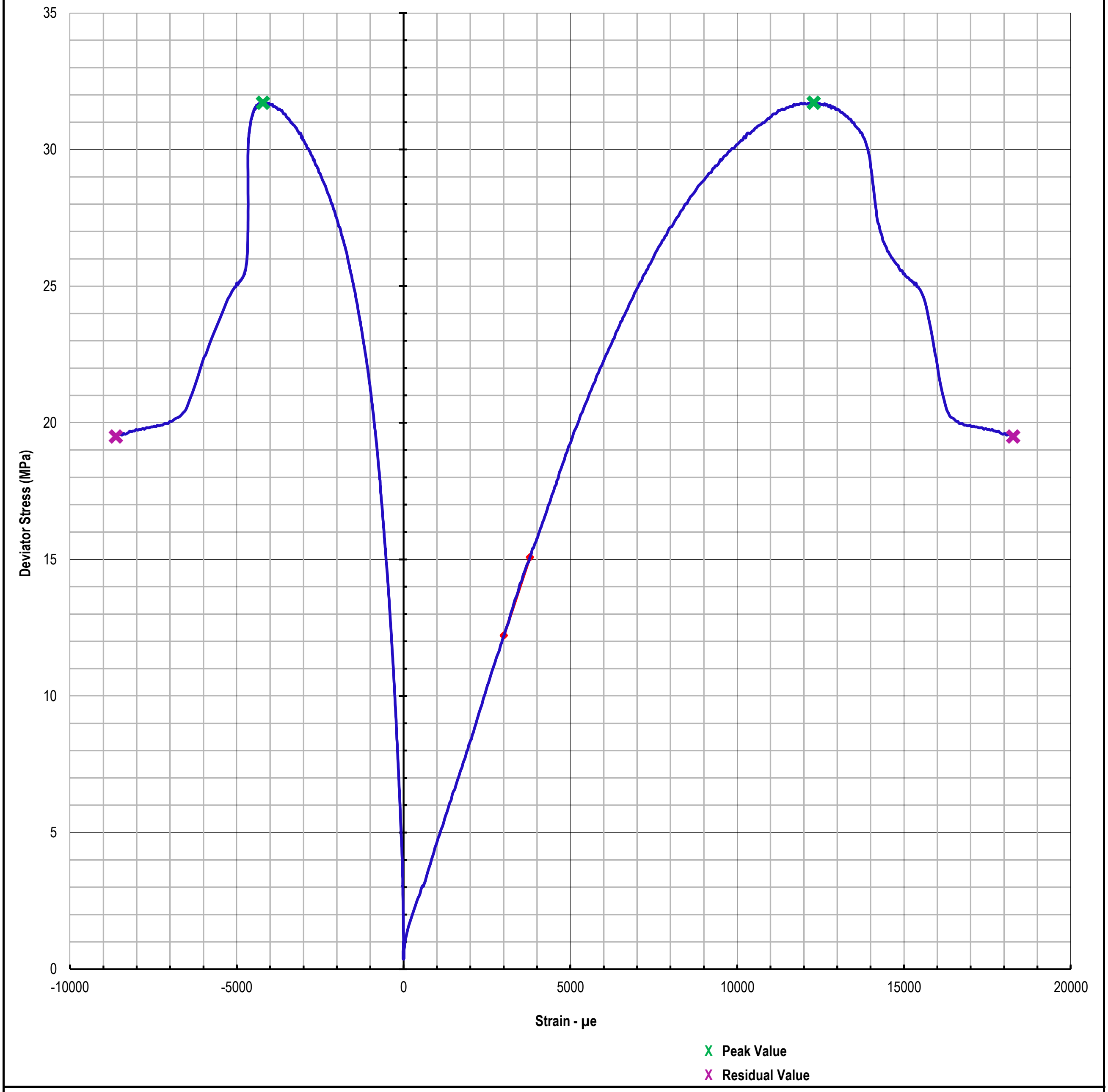
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110053-RTX

Deviator Stress vs Axial Strain Plots



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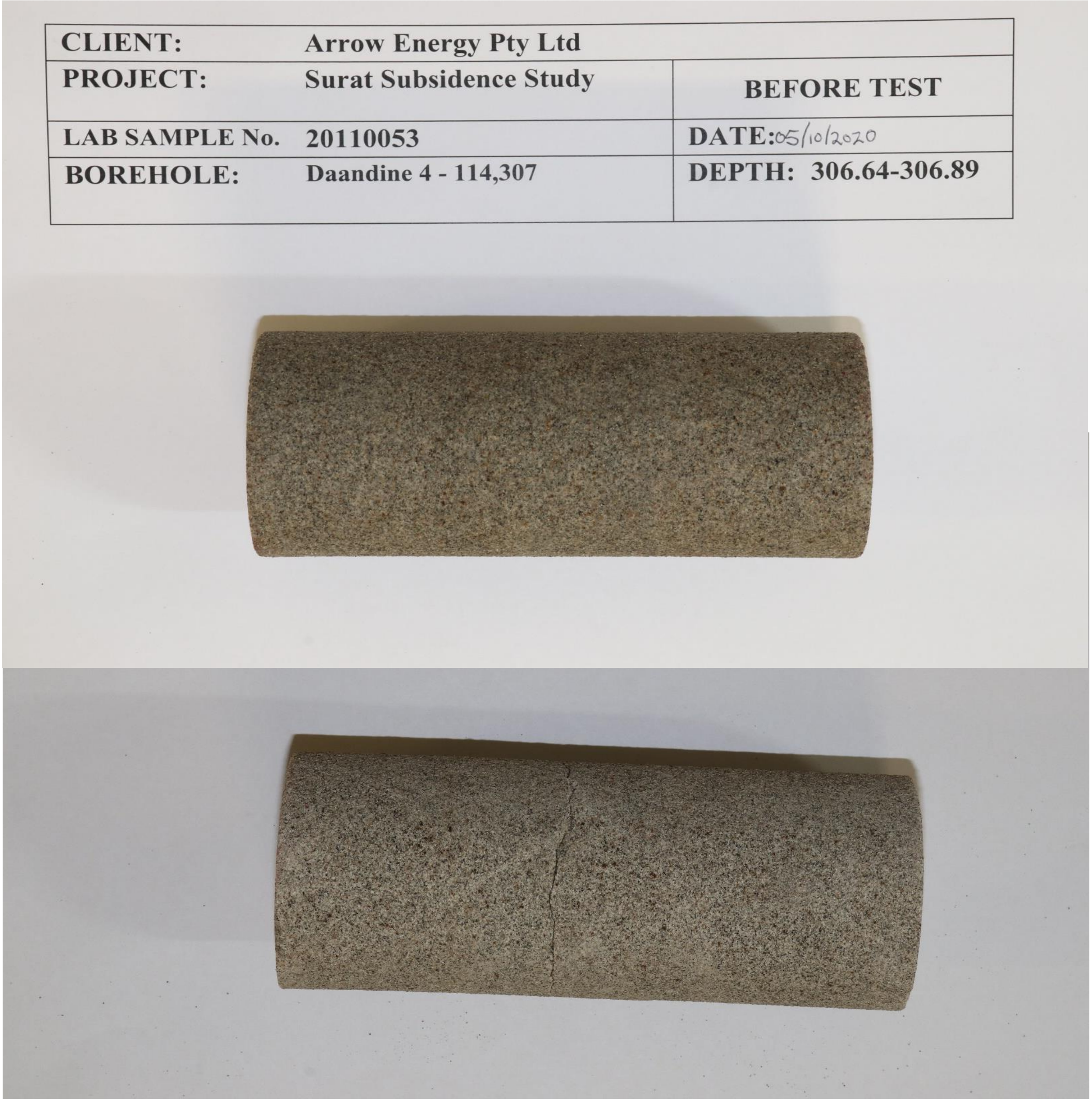
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110053-RTX

Before and After Test Photos



CLIENT:	Arrow Energy Pty Ltd		
PROJECT:	Surat Subsidence Study	BEFORE TEST	
LAB SAMPLE No.	20110053	DATE:	05/10/2020
BOREHOLE:	Daandine 4 - 114,307	DEPTH:	306.64-306.89

Notes/Remarks:

Photo not to scale

Sample/s supplied by client

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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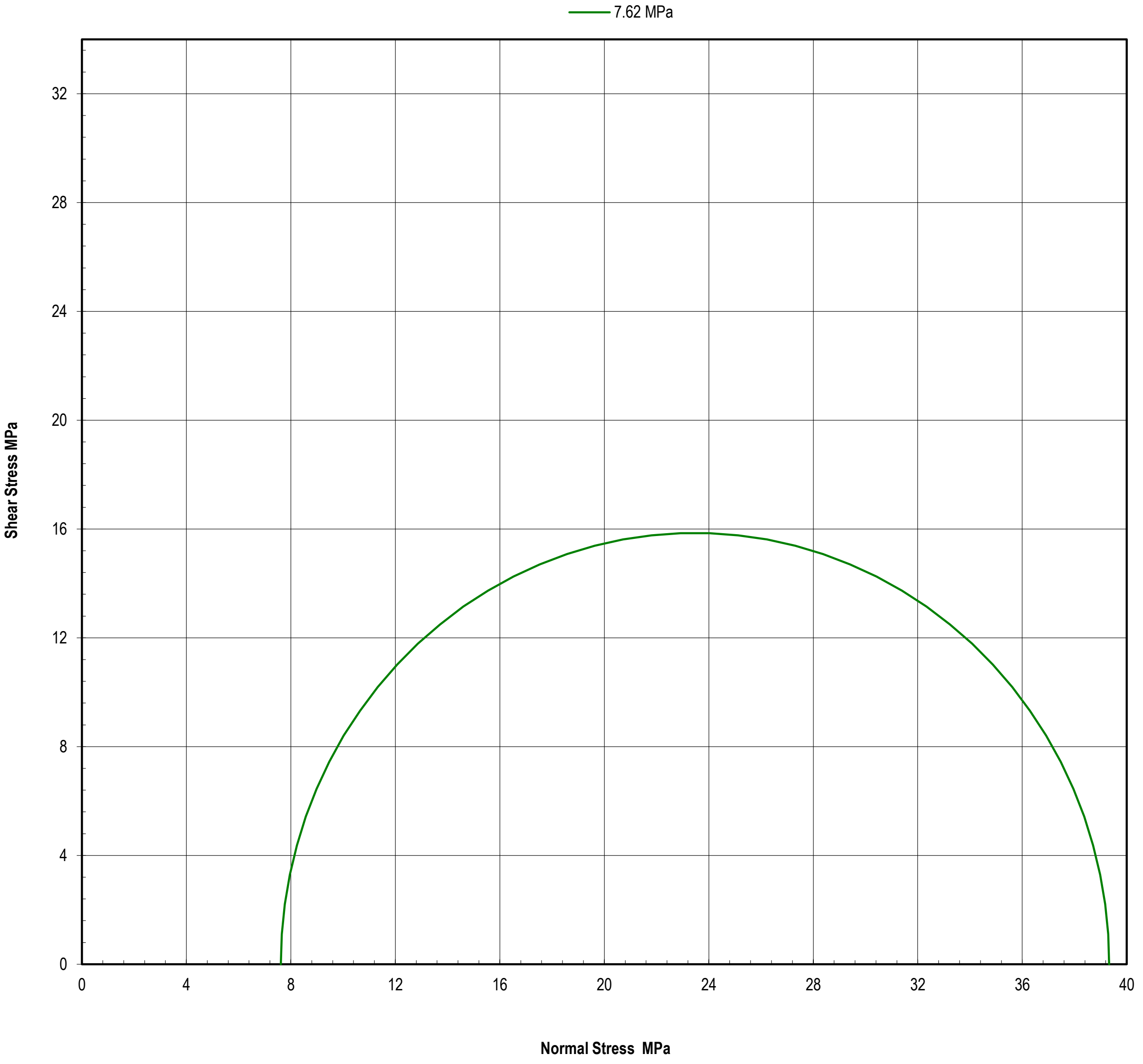
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110053-RTX

Peak Stress Mohr Circle Plot



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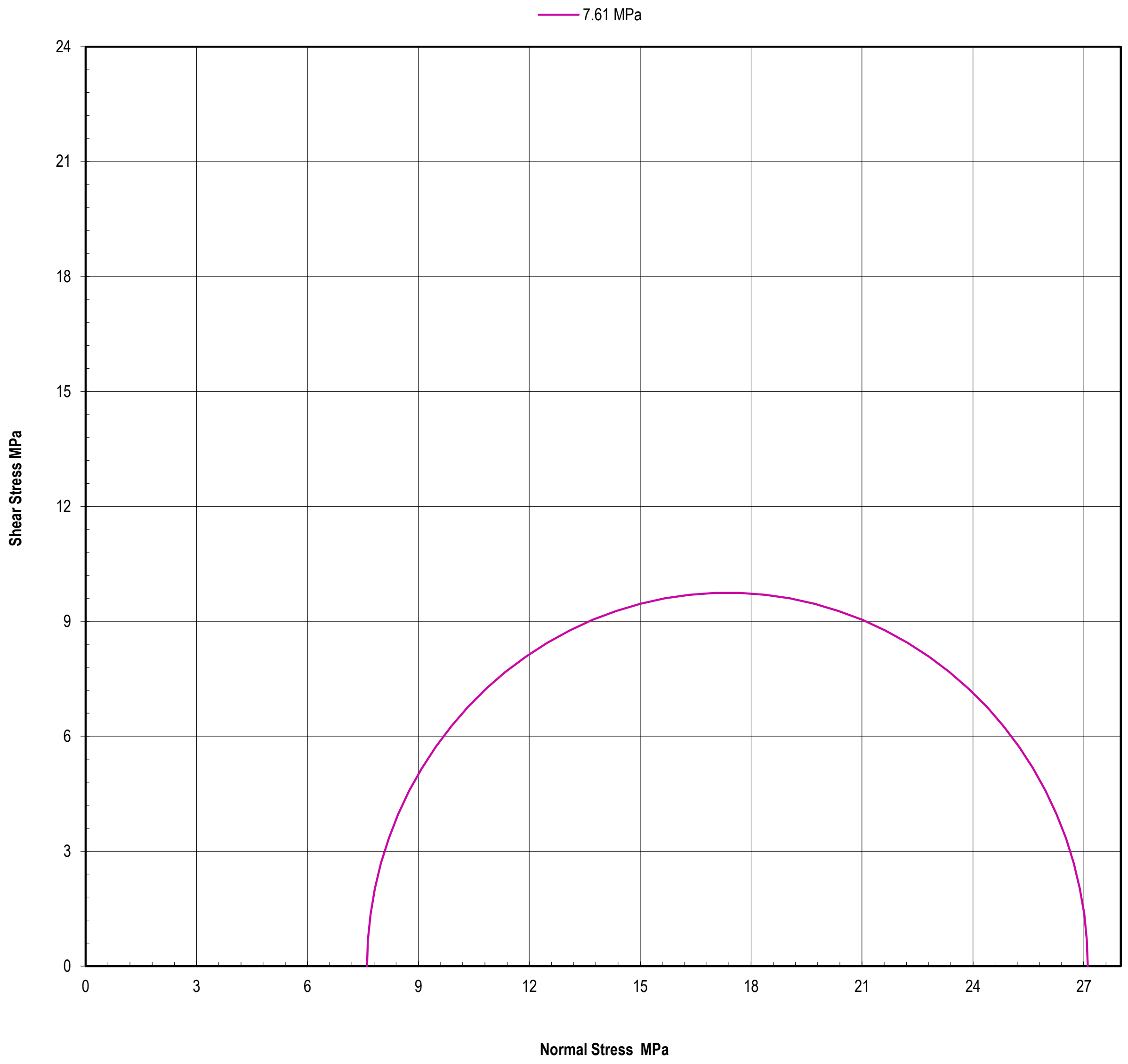
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110053-RTX

Residual Stress Mohr Circle Plot



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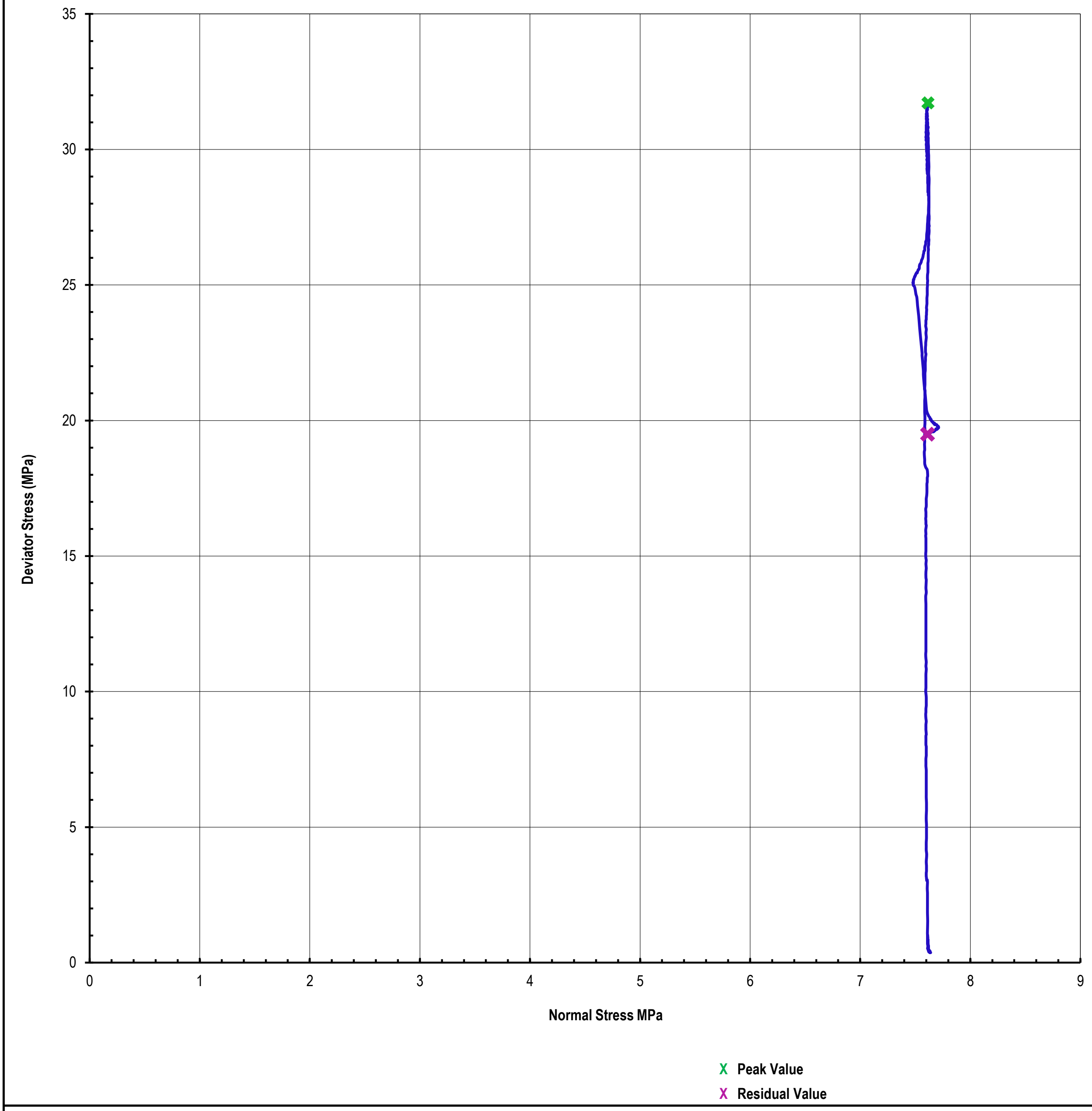
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110053-RTX

Deviator Stress vs Normal Stress Plot



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Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110054-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	6/11/2020
		Report Date	10/11/2020
Project	Surat Subsidence Study		
Client ID	Daandine 4 - 114308	**Depth (m)**	320.21-320.37
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.9	Moisture Content (%)	4.6
Sample Height (mm)	146.4	Wet Density (t/m^3)	2.42
Duration of Test (min)	18:03	Dry Density (t/m^3)	2.32
Rate of Strain (%/min)	0.05	Bedding (^{o})	Nil
Mode of Failure	Shear	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	65		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	7.92				
Deviator Stress (MPa)	43.6				
Axial Strain (με)	15025				
Diametral Strain (με)	-4925				
Tangent Modulus (GPa)	3.80				
Poisson's Ratio	0.132				

Residual Test Results

Confining Pressure (MPa)	7.92				
Residual Deviator Stress (MPa)	21.0				
Axial Strain (με)	20704				
Diametral Strain (με)	-10989				

Notes/Remarks:

Sample/s supplied by client Tested as received

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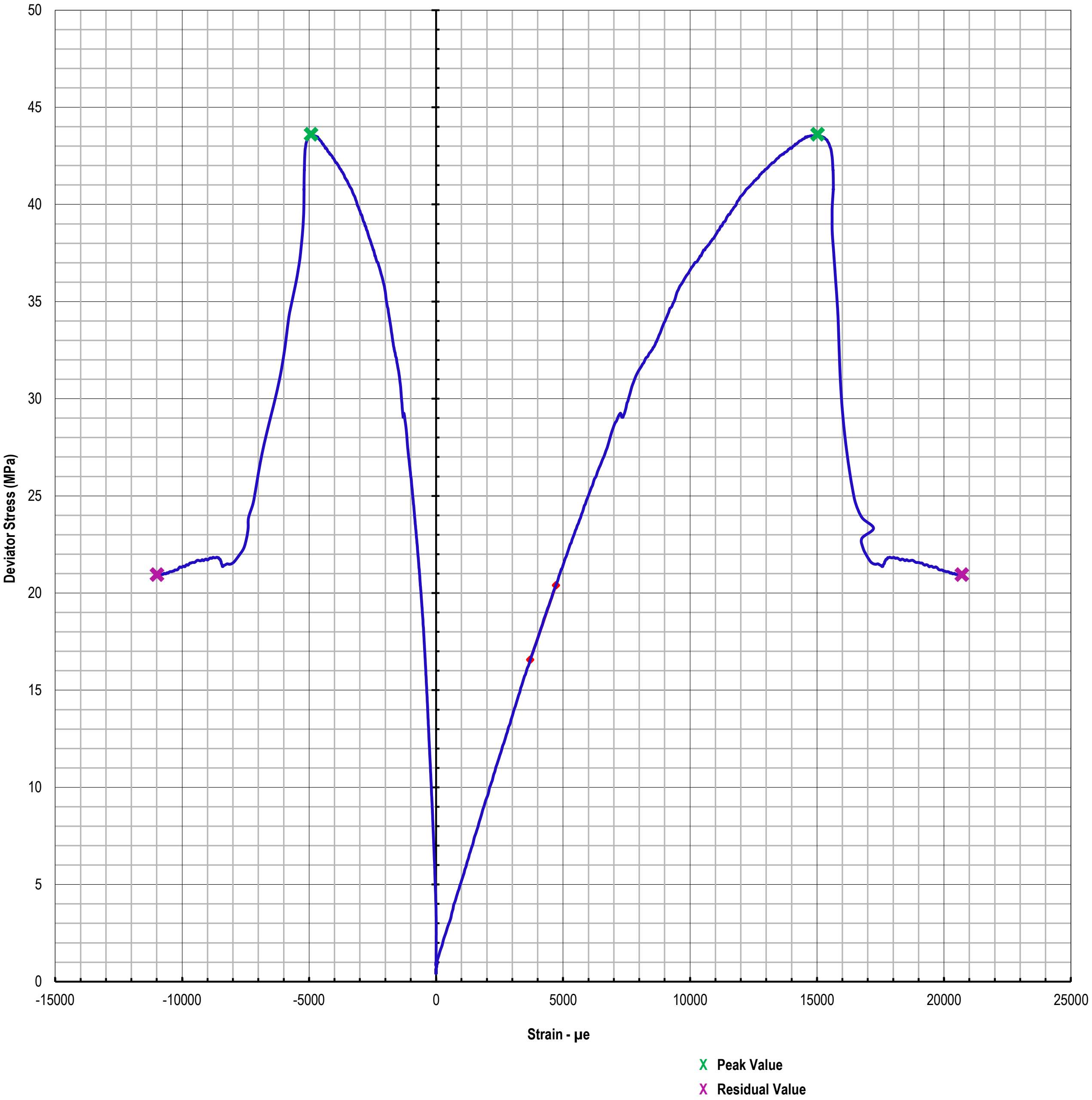
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110054-RTX

Deviator Stress vs Axial Strain Plots



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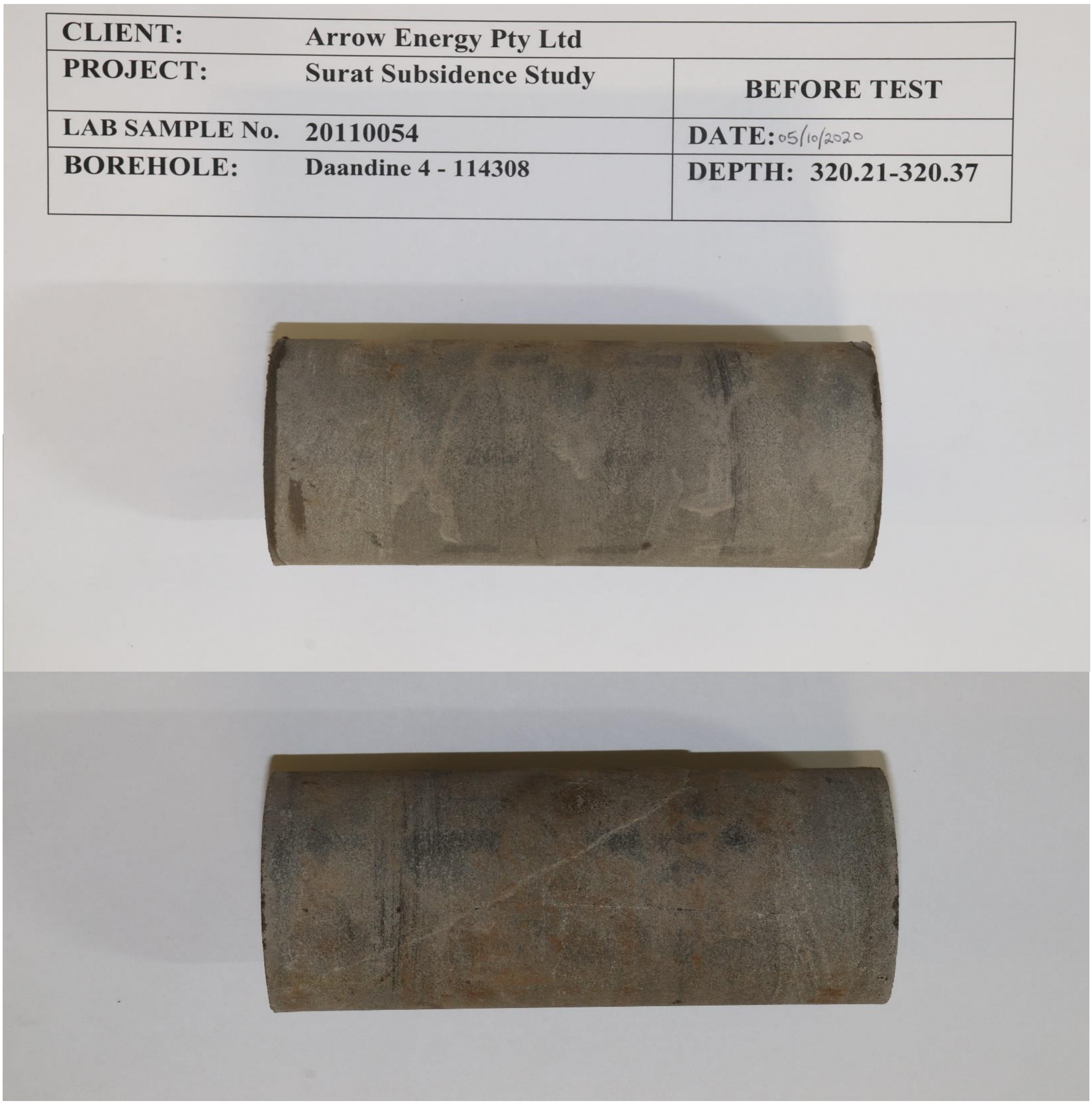
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110054-RTX

Before and After Test Photos



CLIENT: Arrow Energy Pty Ltd
PROJECT: Surat Subsidence Study
BEFORE TEST
LAB SAMPLE No. 20110054
DATE: 05/10/2020
BOREHOLE: Daandine 4 - 114308
DEPTH: 320.21-320.37

Notes/Remarks:

Photo not to scale

Sample/s supplied by client

Tested as received

STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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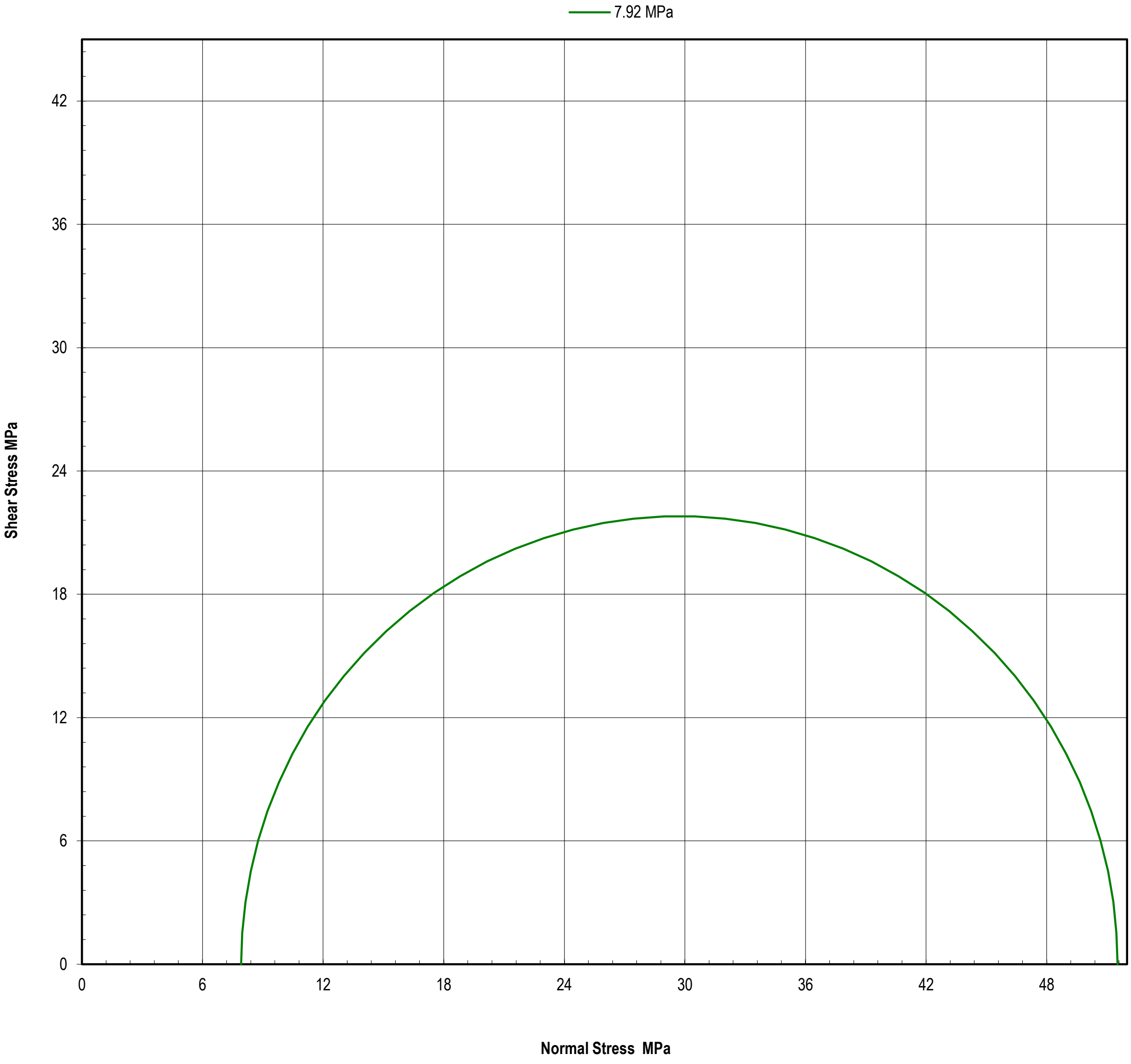
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110054-RTX

Peak Stress Mohr Circle Plot



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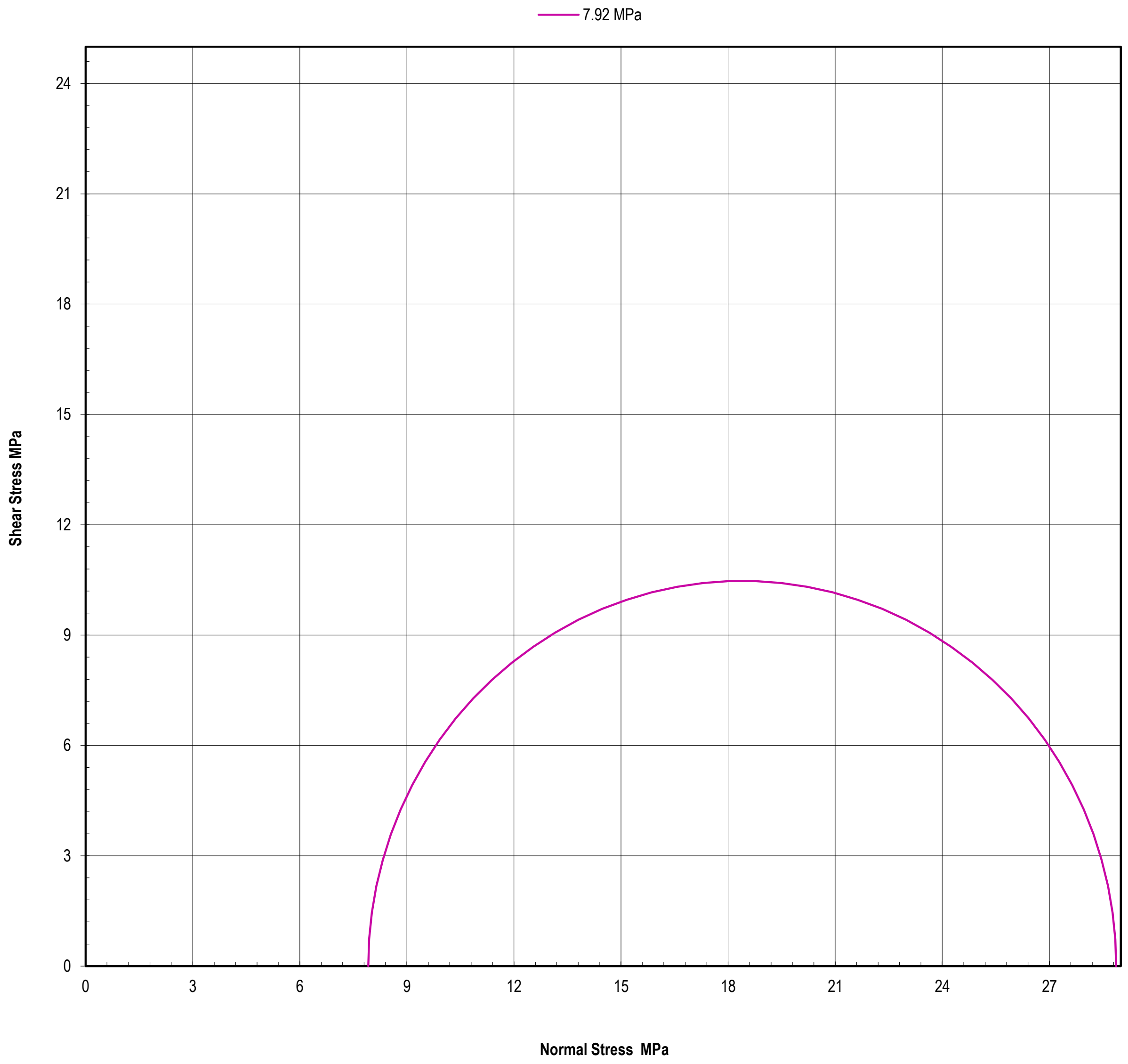
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110054-RTX

Residual Stress Mohr Circle Plot



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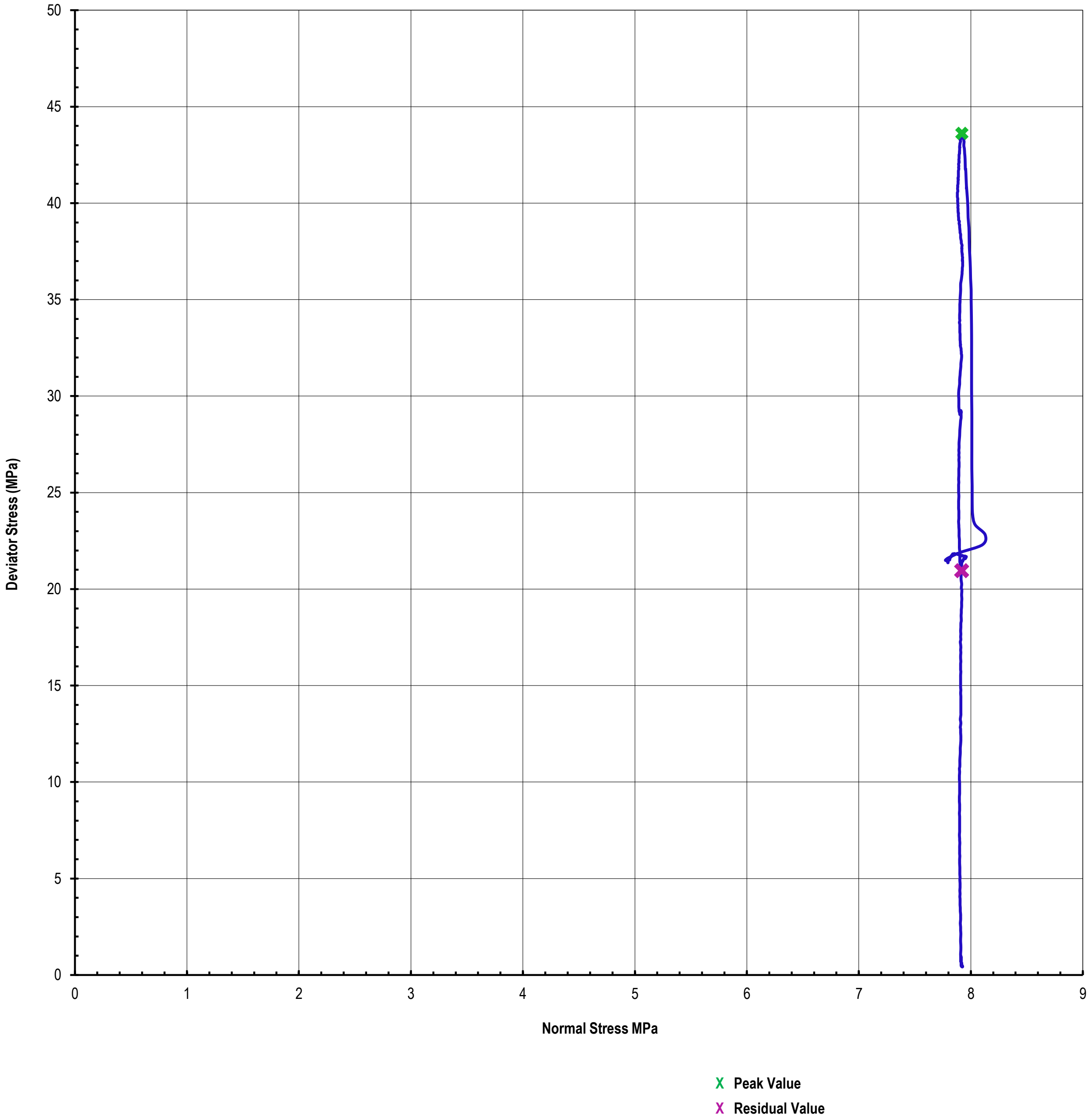
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110054-RTX

Deviator Stress vs Normal Stress Plot



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Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110055-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	6/11/2020
		Report Date	10/11/2020
Project	Surat Subsidence Study		
Client ID	Daandine 4 - 114309	**Depth (m)**	423.07-423.24
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.8	Moisture Content (%)	4.9
Sample Height (mm)	144.7	Wet Density (t/m^3)	2.24
Duration of Test (min)	31:08	Dry Density (t/m^3)	2.14
Rate of Strain (%/min)	0.05	Bedding (^{o})	10
Mode of Failure	Shear	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	75		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	10.70				
Deviator Stress (MPa)	47.2				
Axial Strain (µe)	28960				
Diametral Strain (µe)	-9832				
Tangent Modulus (GPa)	2.00				
Poisson's Ratio	0.172				

Residual Test Results

Confining Pressure (MPa)	10.70				
Residual Deviator Stress (MPa)	23.9				
Axial Strain (µe)	36612				
Diametral Strain (µe)	-17524				

Notes/Remarks:

Sample/s supplied by client Tested as received

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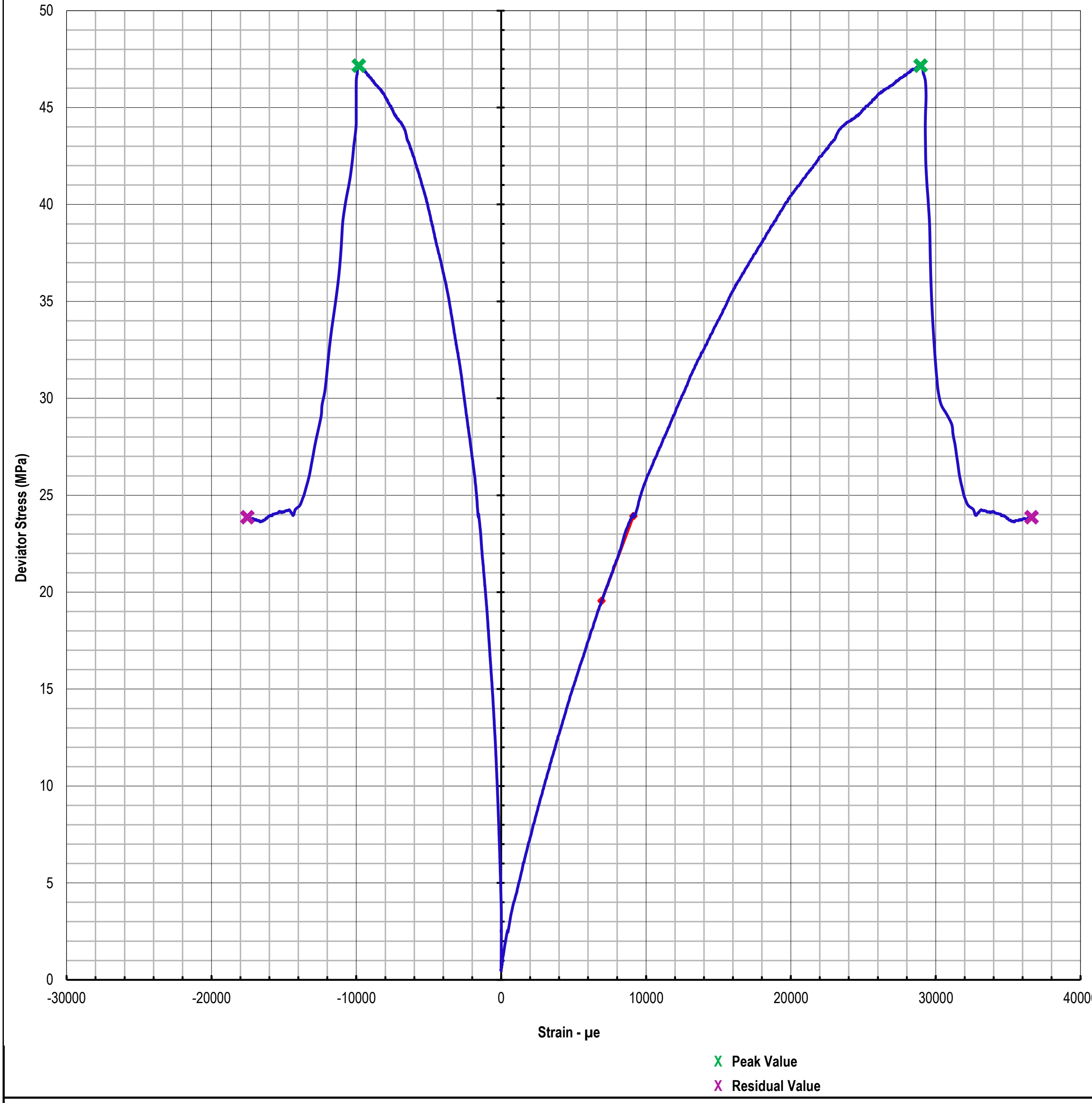
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110055-RTX

Deviator Stress vs Axial Strain Plots



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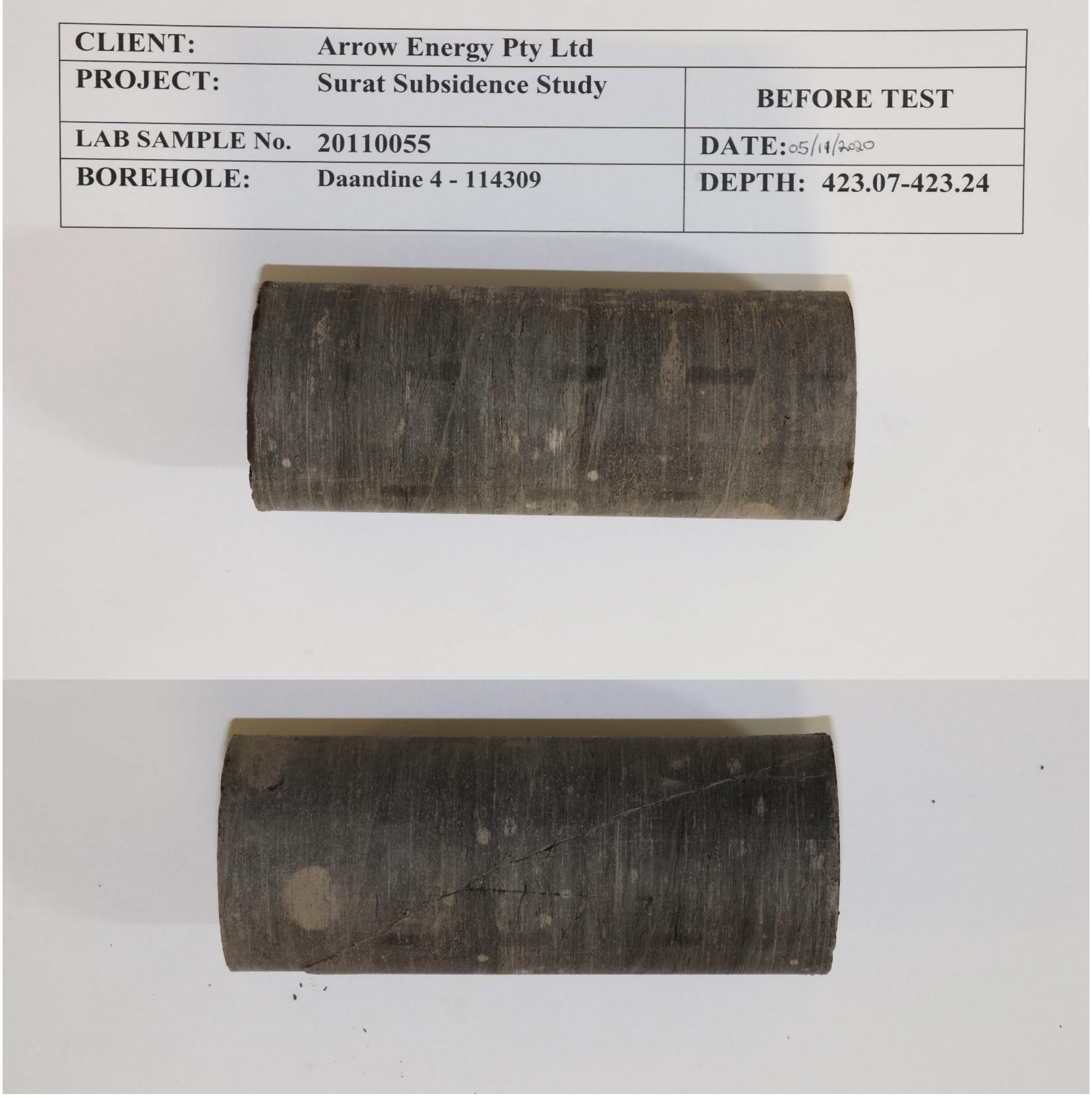
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110055-RTX

Before and After Test Photos



CLIENT:	Arrow Energy Pty Ltd	
PROJECT:	Surat Subsidence Study	BEFORE TEST
LAB SAMPLE No.	20110055	DATE:05/11/2020
BOREHOLE:	Daandine 4 - 114309	DEPTH: 423.07-423.24

Notes/Remarks:

Photo not to scale

Sample/s supplied by client

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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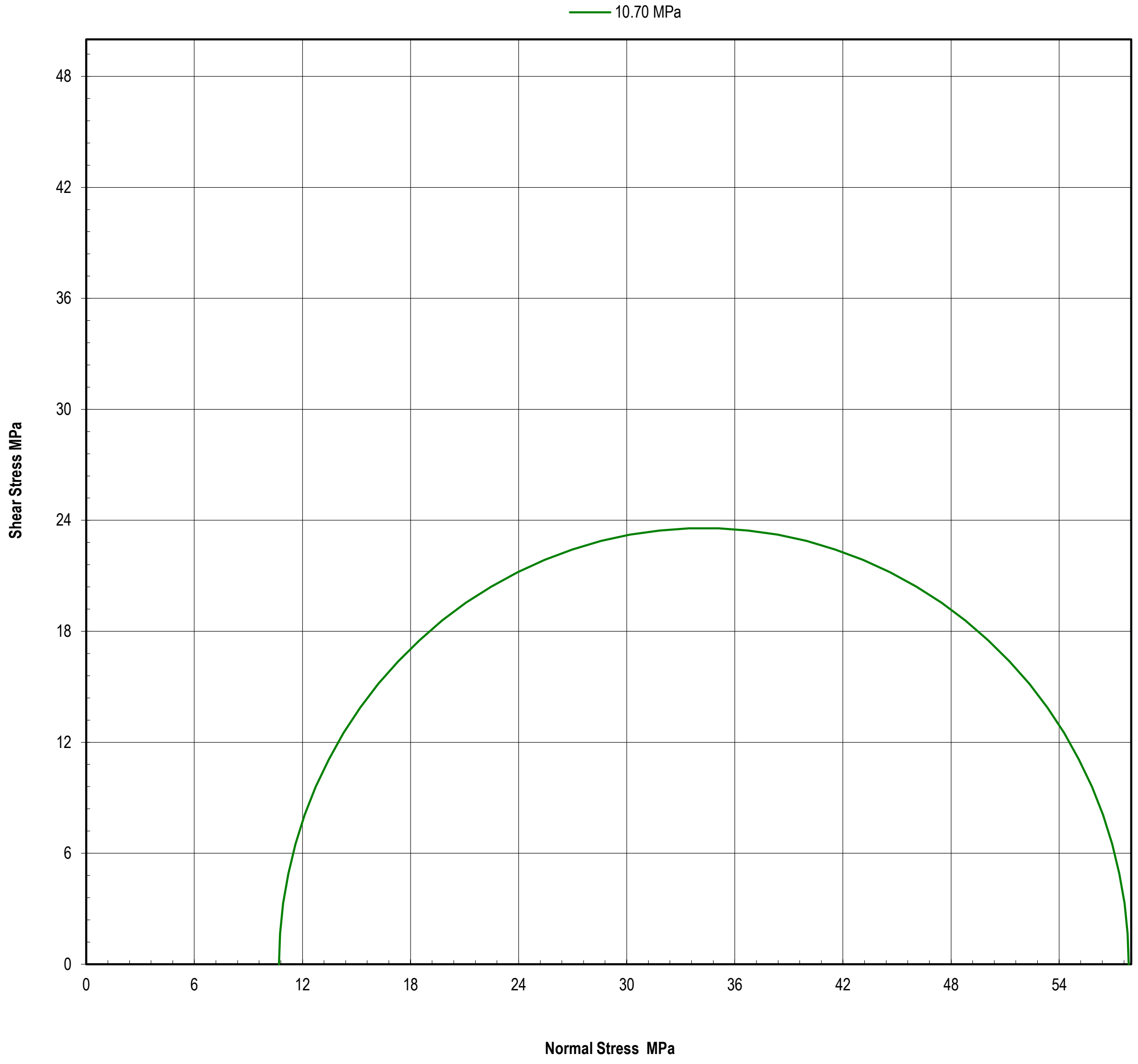
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110055-RTX

Peak Stress Mohr Circle Plot



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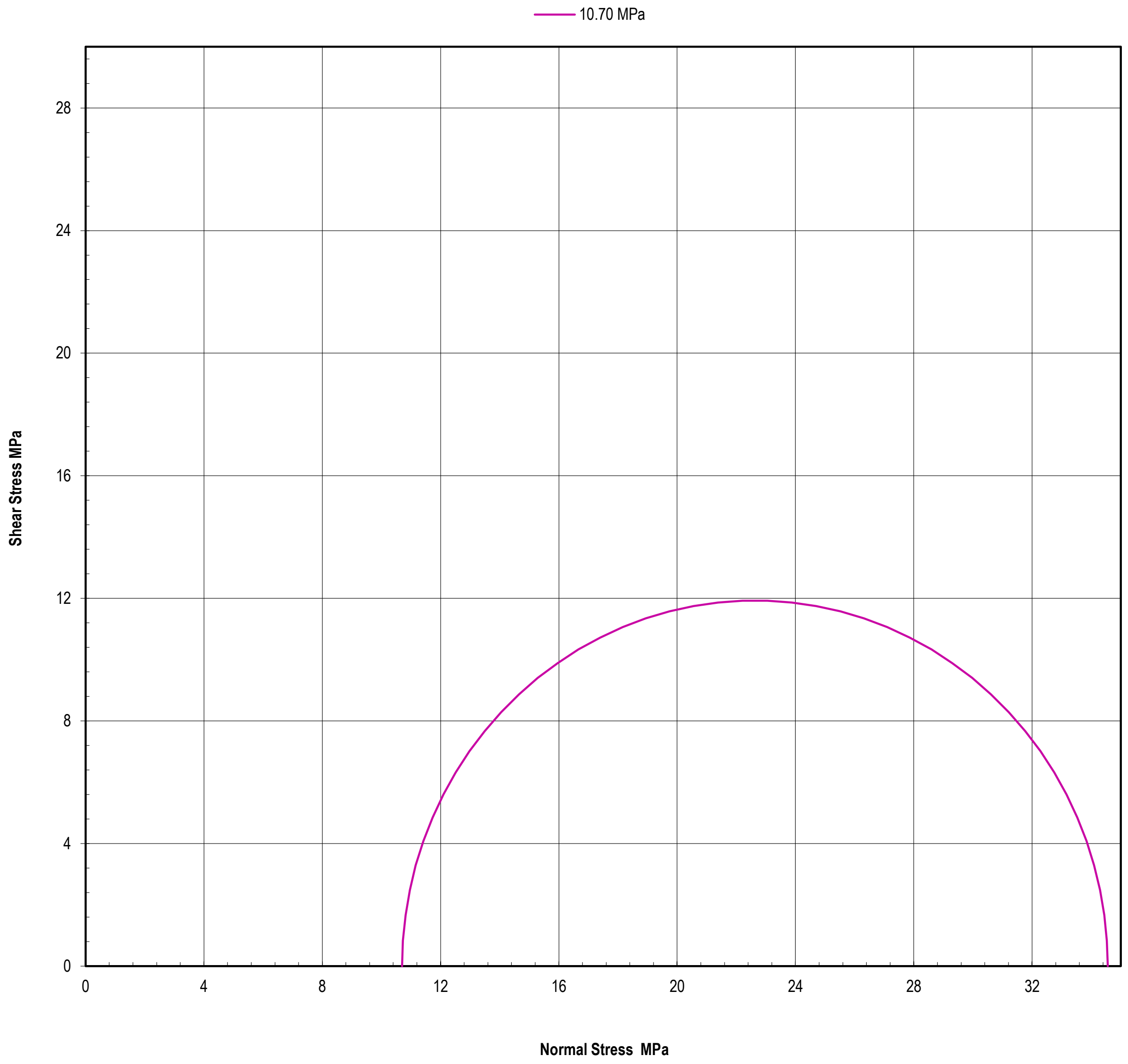
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110055-RTX

Residual Stress Mohr Circle Plot



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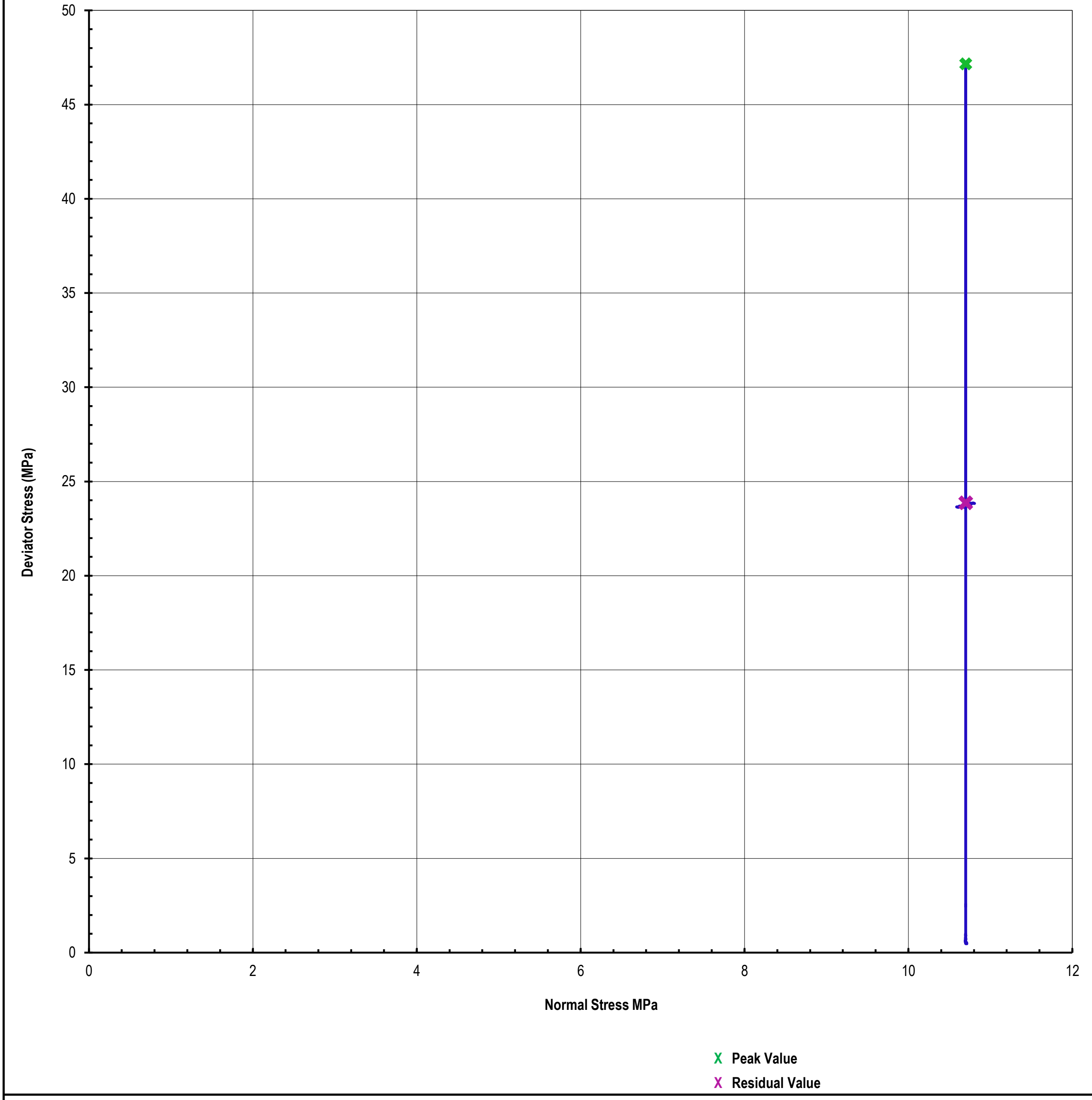
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110055-RTX

Deviator Stress vs Normal Stress Plot



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Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110056-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	6/11/2020
		Report Date	10/11/2020
Project	Surat Subsidence Study		
Client ID	Daandine 4 - 114310	**Depth (m)**	451.11-451.31
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.7	Moisture Content (%)	2.9
Sample Height (mm)	146.7	Wet Density (t/m^3)	2.29
Duration of Test (min)	25:50	Dry Density (t/m^3)	2.23
Rate of Strain (%/min)	0.05	Bedding (^{o})	Nil
Mode of Failure	End Splitting	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	30		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	11.21				
Deviator Stress (MPa)	49.0				
Axial Strain (µe)	17653				
Diametral Strain (µe)	-9353				
Tangent Modulus (GPa)	2.99				
Poisson's Ratio	0.445				

Residual Test Results

Confining Pressure (MPa)	11.28				
Residual Deviator Stress (MPa)	34.2				
Axial Strain (µe)	15878				
Diametral Strain (µe)	-7092				

Notes/Remarks:

Sample/s supplied by client   Tested as received

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

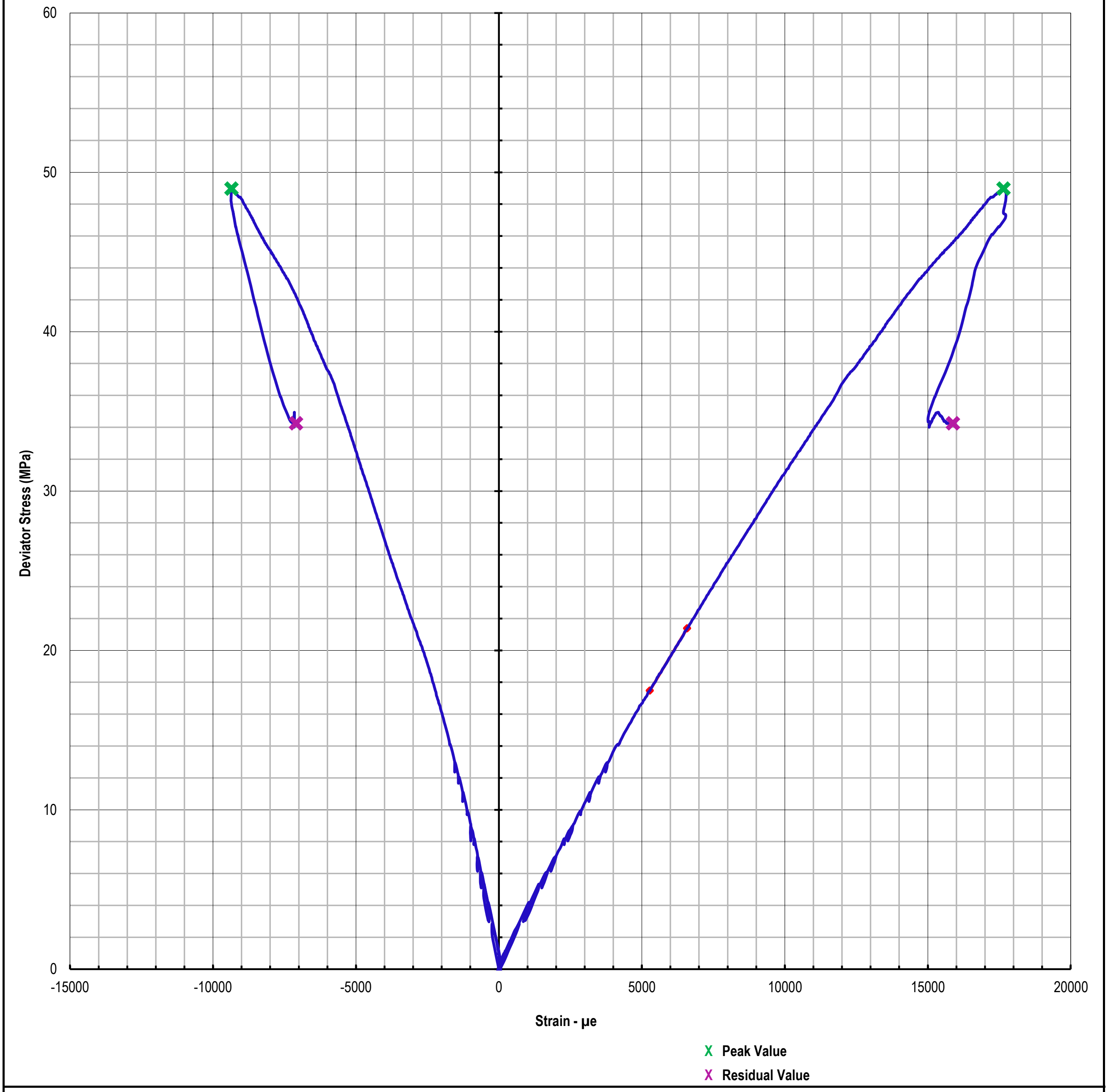
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110056-RTX

Deviator Stress vs Axial Strain Plots



Notes/Remarks:

Graph not to scale

Sample/s supplied by client

Tested as received

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Tested at Trilab Brisbane Laboratory

Authorised Signatory

C. Purvis

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

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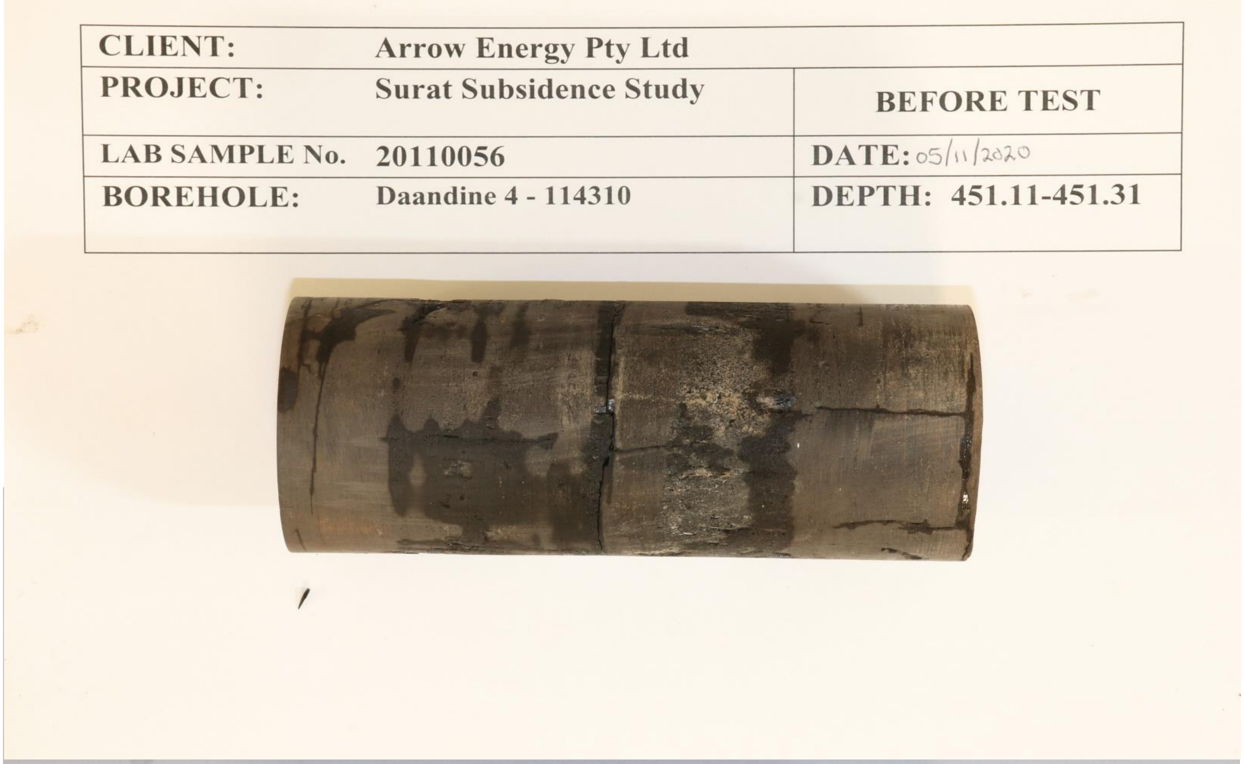
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110056-RTX

Before and After Test Photos



CLIENT:	Arrow Energy Pty Ltd		
PROJECT:	Surat Subsidence Study	BEFORE TEST	
LAB SAMPLE No.	20110056	DATE:	05/11/2020
BOREHOLE:	Daandine 4 - 114310	DEPTH:	451.11-451.31

Notes/Remarks:

Photo not to scale

Sample/s supplied by client

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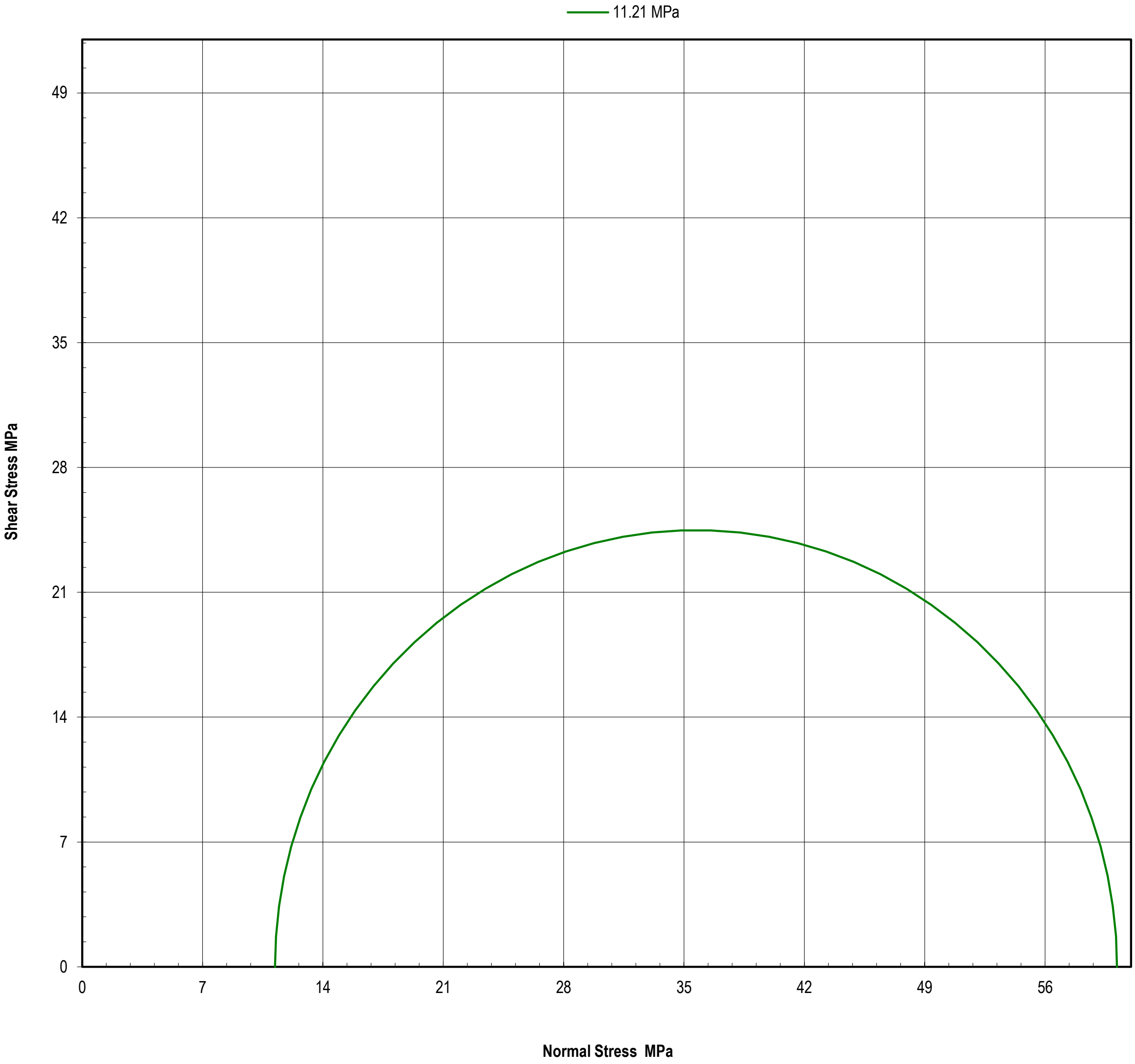
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110056-RTX

Peak Stress Mohr Circle Plot



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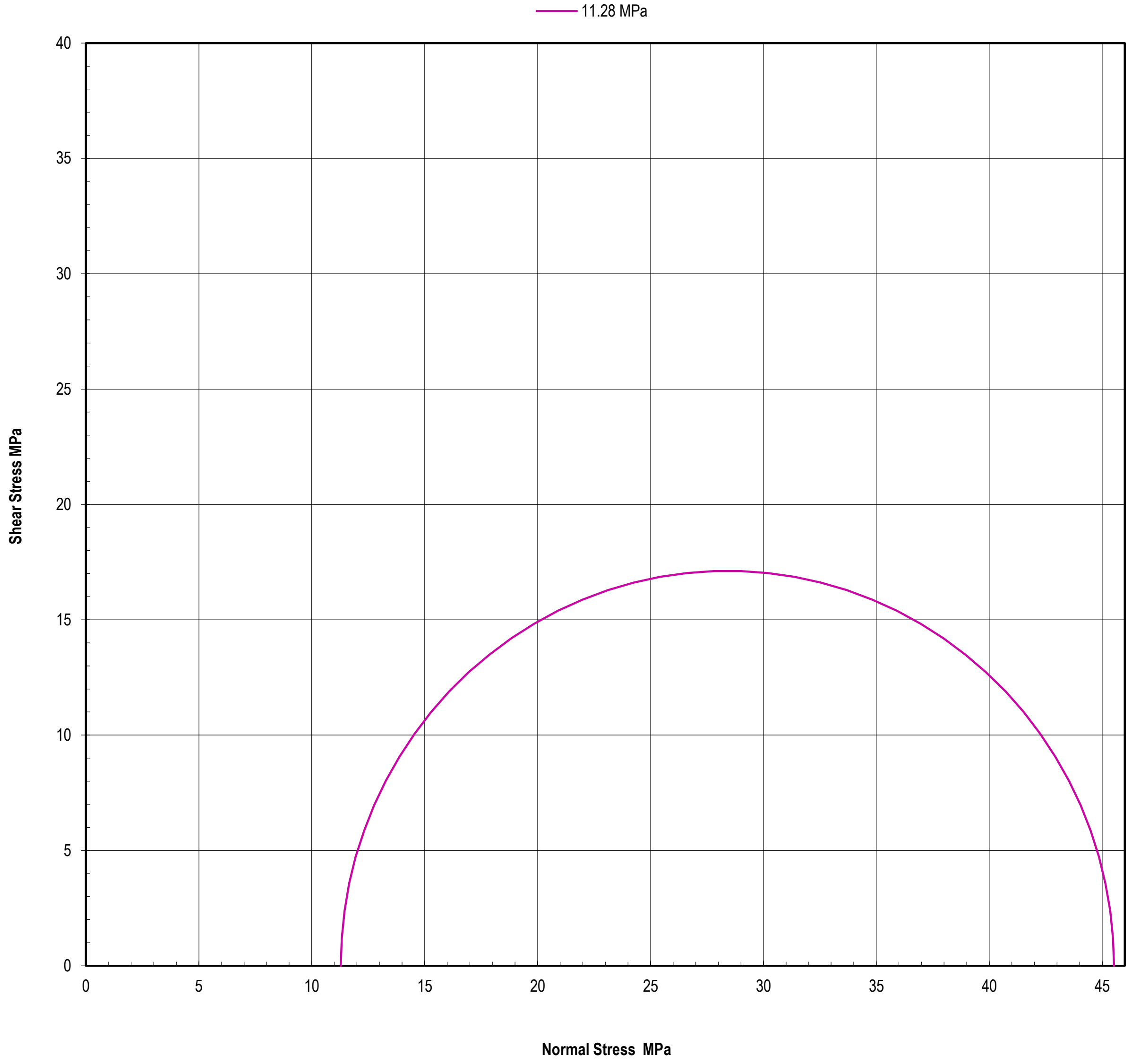
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110056-RTX

Residual Stress Mohr Circle Plot



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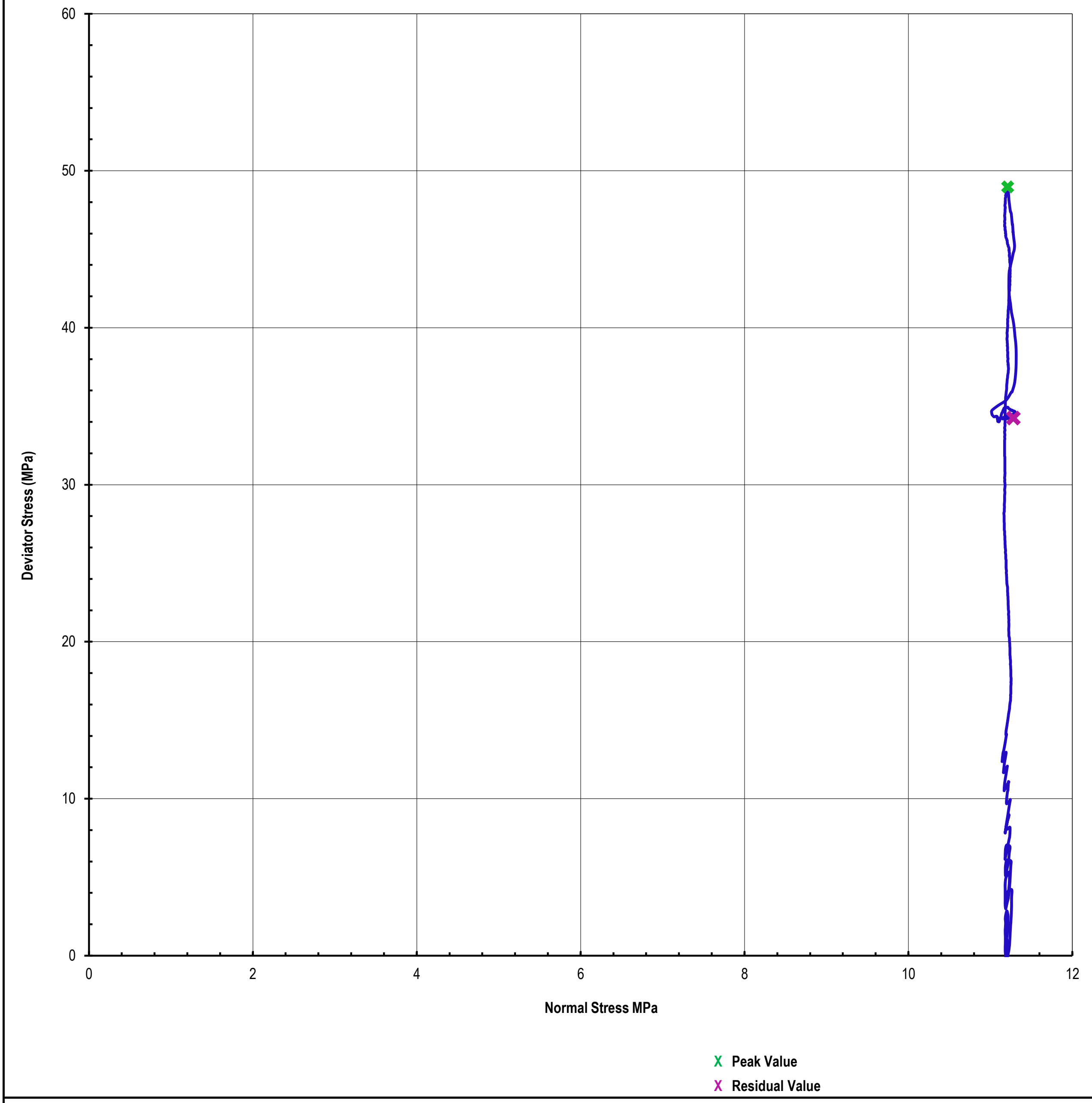
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110056-RTX

Deviator Stress vs Normal Stress Plot



Notes/Remarks:

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Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110057-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	6/11/2020
		Report Date	10/11/2020
Project	Surat Subsidence Study		
Client ID	Kogan North 76 - 114311	**Depth (m)**	200.04-200.06
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.7	Moisture Content (%)	7.5
Sample Height (mm)	142.6	Wet Density (t/m^3)	2.37
Duration of Test (min)	17:45	Dry Density (t/m^3)	2.20
Rate of Strain (%/min)	0.05	Bedding (^{o})	25
Mode of Failure	Shear	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	70		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	5.01				
Deviator Stress (MPa)	45.0				
Axial Strain (µe)	12008				
Diametral Strain (µe)	-4551				
Tangent Modulus (GPa)	4.84				
Poisson's Ratio	0.119				

Residual Test Results

Confining Pressure (MPa)	4.95				
Residual Deviator Stress (MPa)	21.7				
Axial Strain (µe)	17320				
Diametral Strain (µe)	-10780				

Notes/Remarks:

Sample/s supplied by client Tested as received

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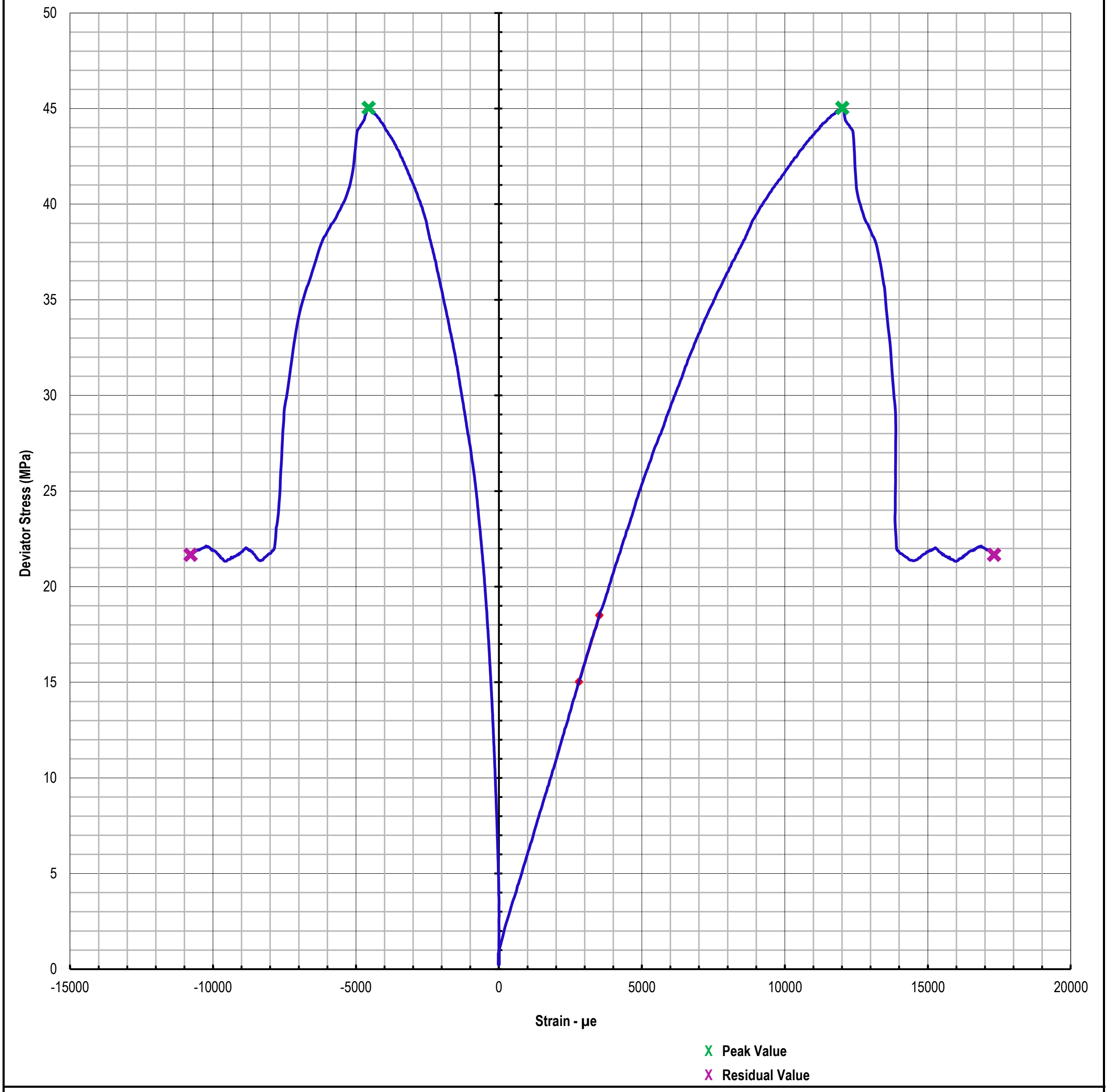
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110057-RTX

Deviator Stress vs Axial Strain Plots



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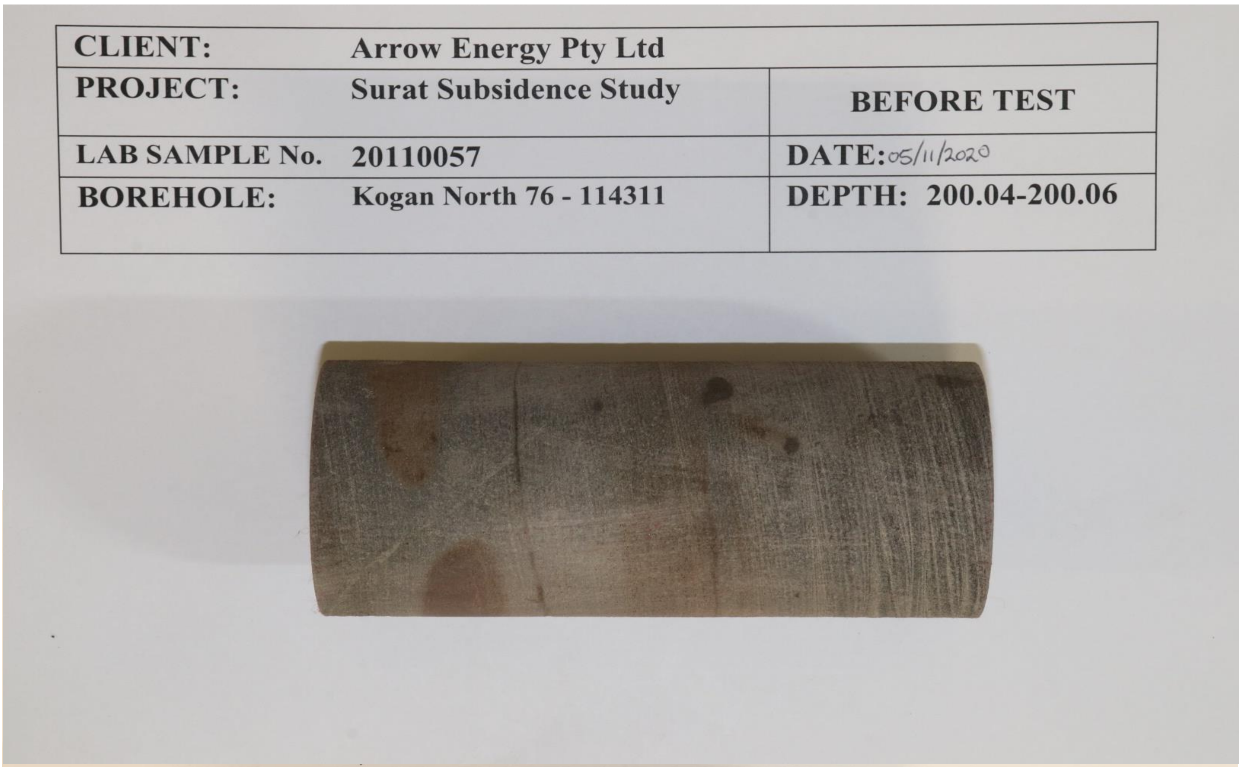
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110057-RTX

Before and After Test Photos



CLIENT:	Arrow Energy Pty Ltd	
PROJECT:	Surat Subsidence Study	BEFORE TEST
LAB SAMPLE No.	20110057	DATE: 05/11/2020
BOREHOLE:	Kogan North 76 - 114311	DEPTH: 200.04-200.06

Notes/Remarks:

Photo not to scale

Sample/s supplied by client

Tested as received

STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

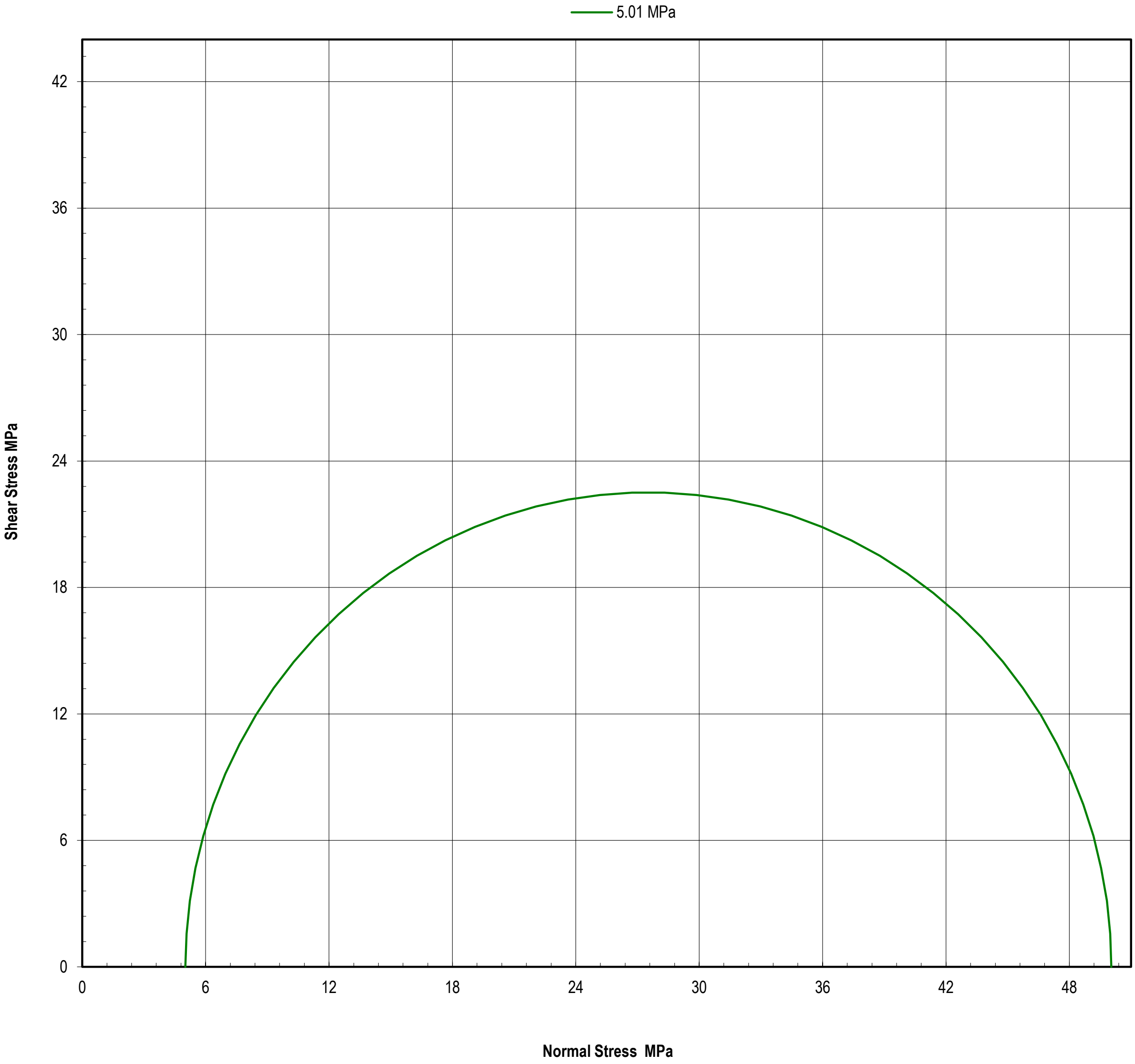
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110057-RTX

Peak Stress Mohr Circle Plot



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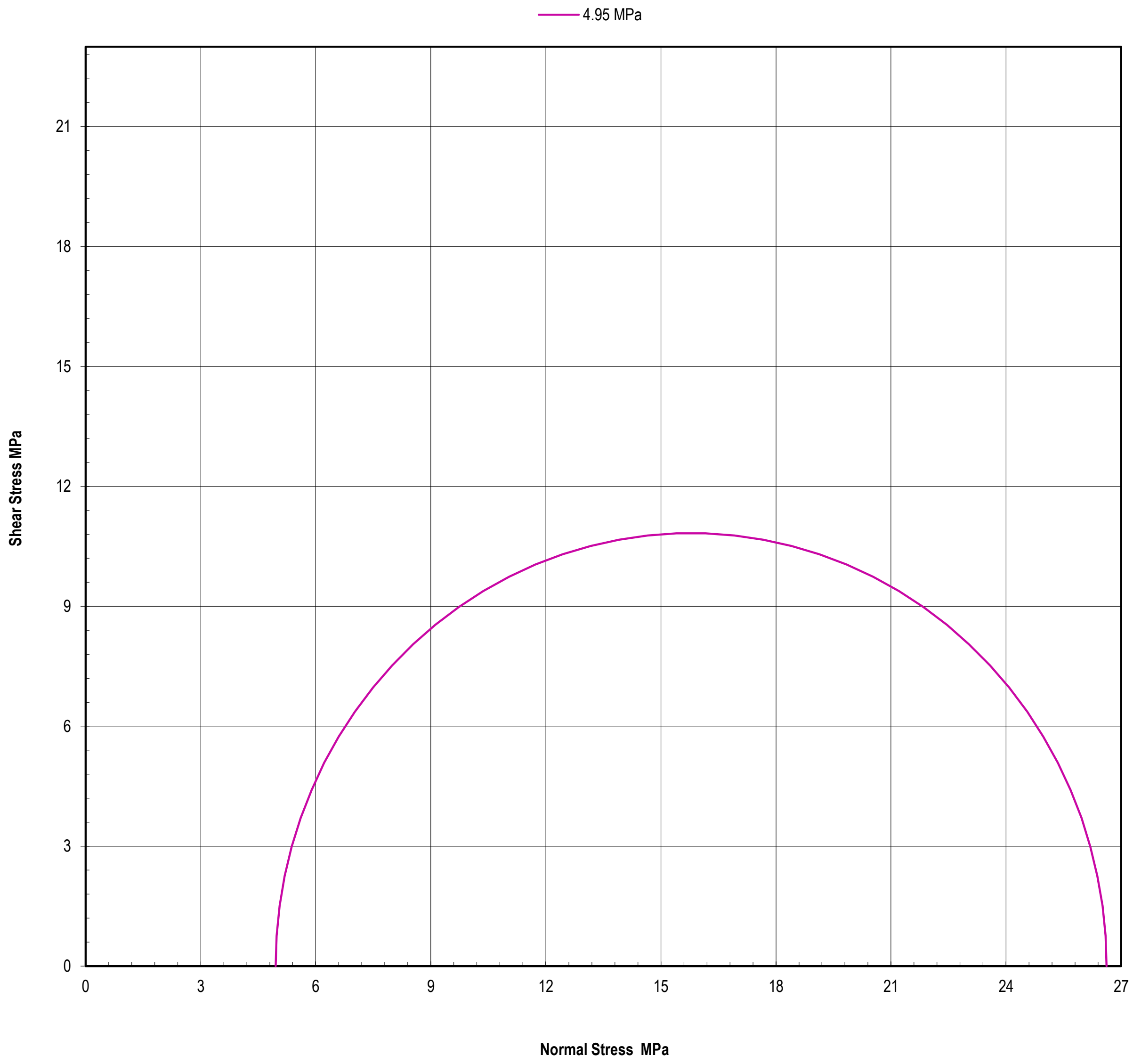
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110057-RTX

Residual Stress Mohr Circle Plot



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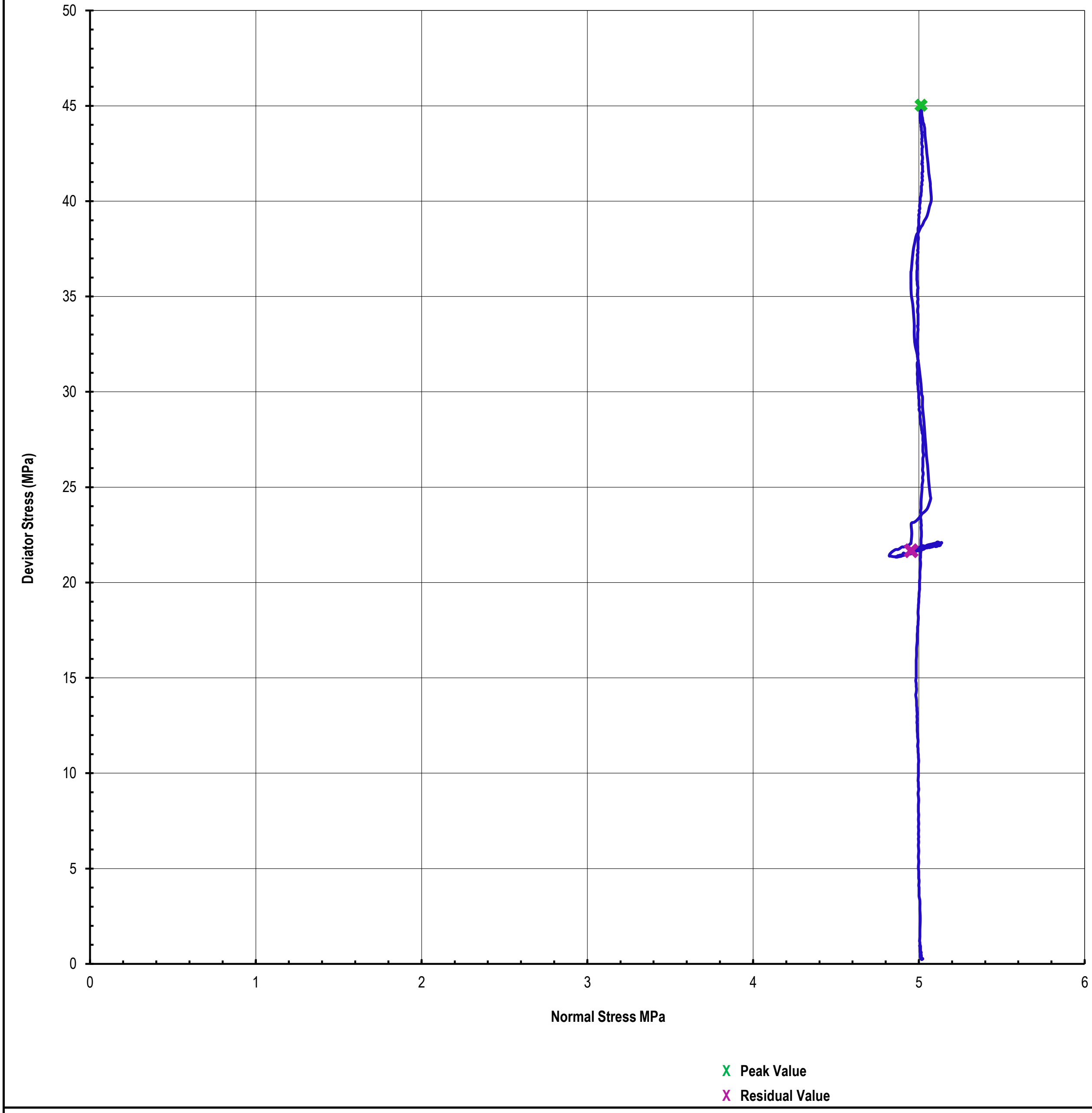
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110057-RTX

Deviator Stress vs Normal Stress Plot



Notes/Remarks:

Graph not to scale

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Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110058-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	6/11/2020
		Report Date	10/11/2020
Project	Surat Subsidence Study		
Client ID	Kogan North 76 - 114312	**Depth (m)**	271.50-271.79
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.6	Moisture Content (%)	1.6
Sample Height (mm)	143.3	Wet Density (t/m^3)	2.15
Duration of Test (min)	11:57	Dry Density (t/m^3)	2.12
Rate of Strain (%/min)	0.05	Bedding (^{o})	20
Mode of Failure	Shear	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	55		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	6.70				
Deviator Stress (MPa)	49.9				
Axial Strain (µe)	8743				
Diametral Strain (µe)	-4815				
Tangent Modulus (GPa)	8.98				
Poisson's Ratio	0.131				

Residual Test Results

Confining Pressure (MPa)	6.72				
Residual Deviator Stress (MPa)	25.6				
Axial Strain (µe)	14166				
Diametral Strain (µe)	-11889				

Notes/Remarks:

Sample/s supplied by client

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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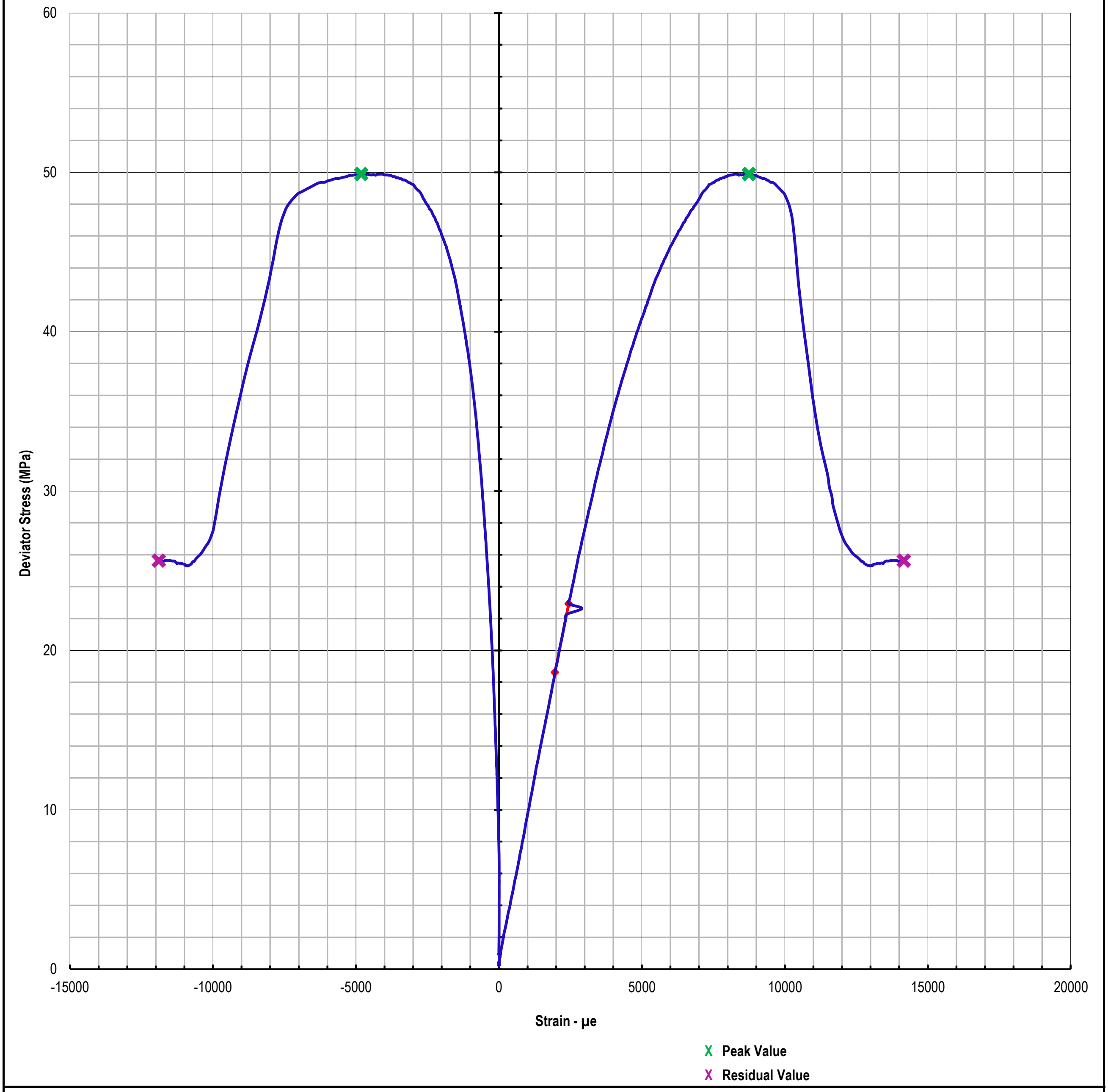
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110058-RTX

Deviator Stress vs Axial Strain Plots



Notes/Remarks:

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

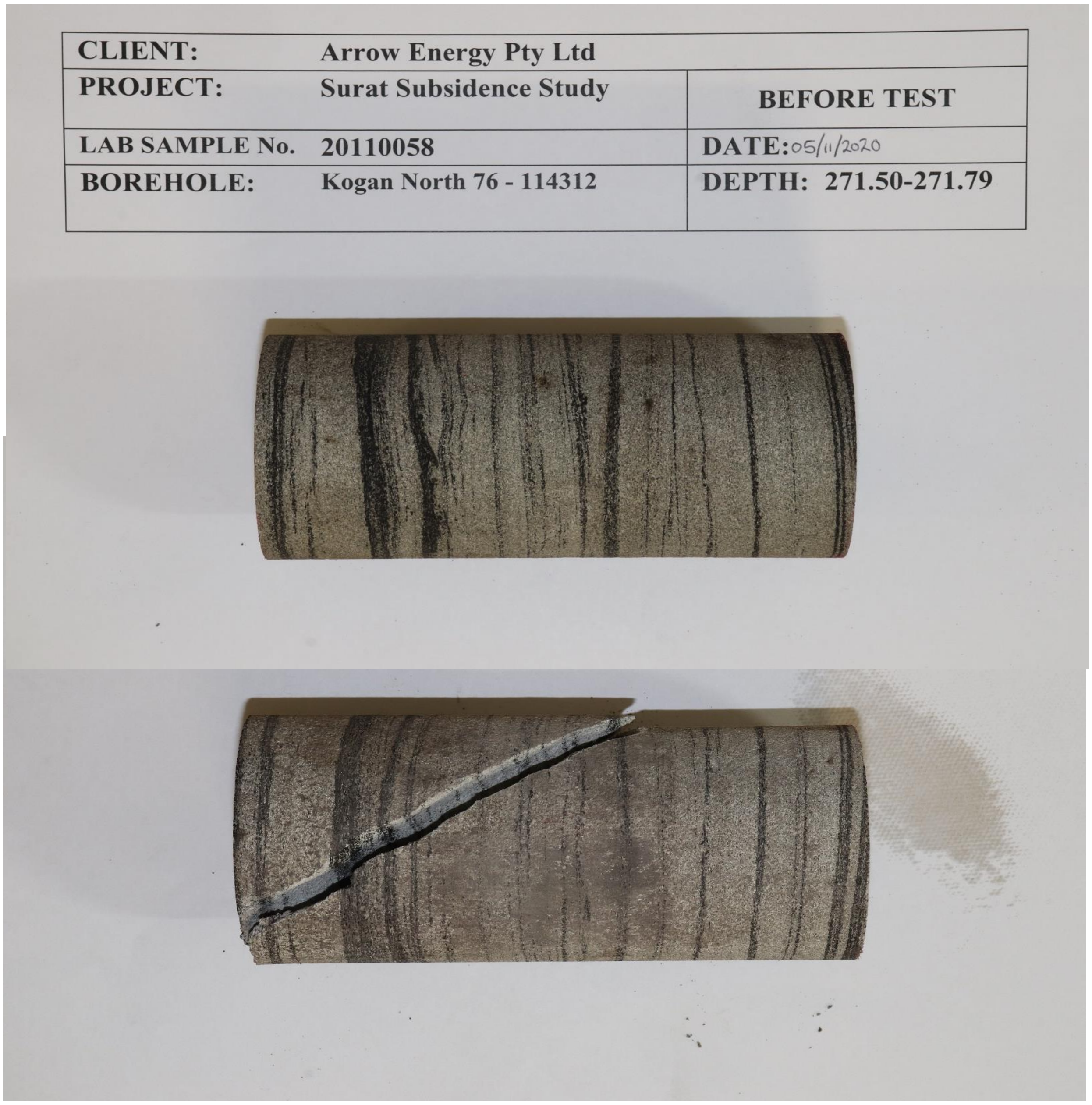
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110058-RTX

Before and After Test Photos



CLIENT:	Arrow Energy Pty Ltd		
PROJECT:	Surat Subsidence Study	**BEFORE TEST**	
LAB SAMPLE No.	20110058	**DATE:** 05/11/2020	
BOREHOLE:	Kogan North 76 - 114312	**DEPTH:**	271.50-271.79

Notes/Remarks:

Photo not to scale

Sample/s supplied by client

Tested as received

STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

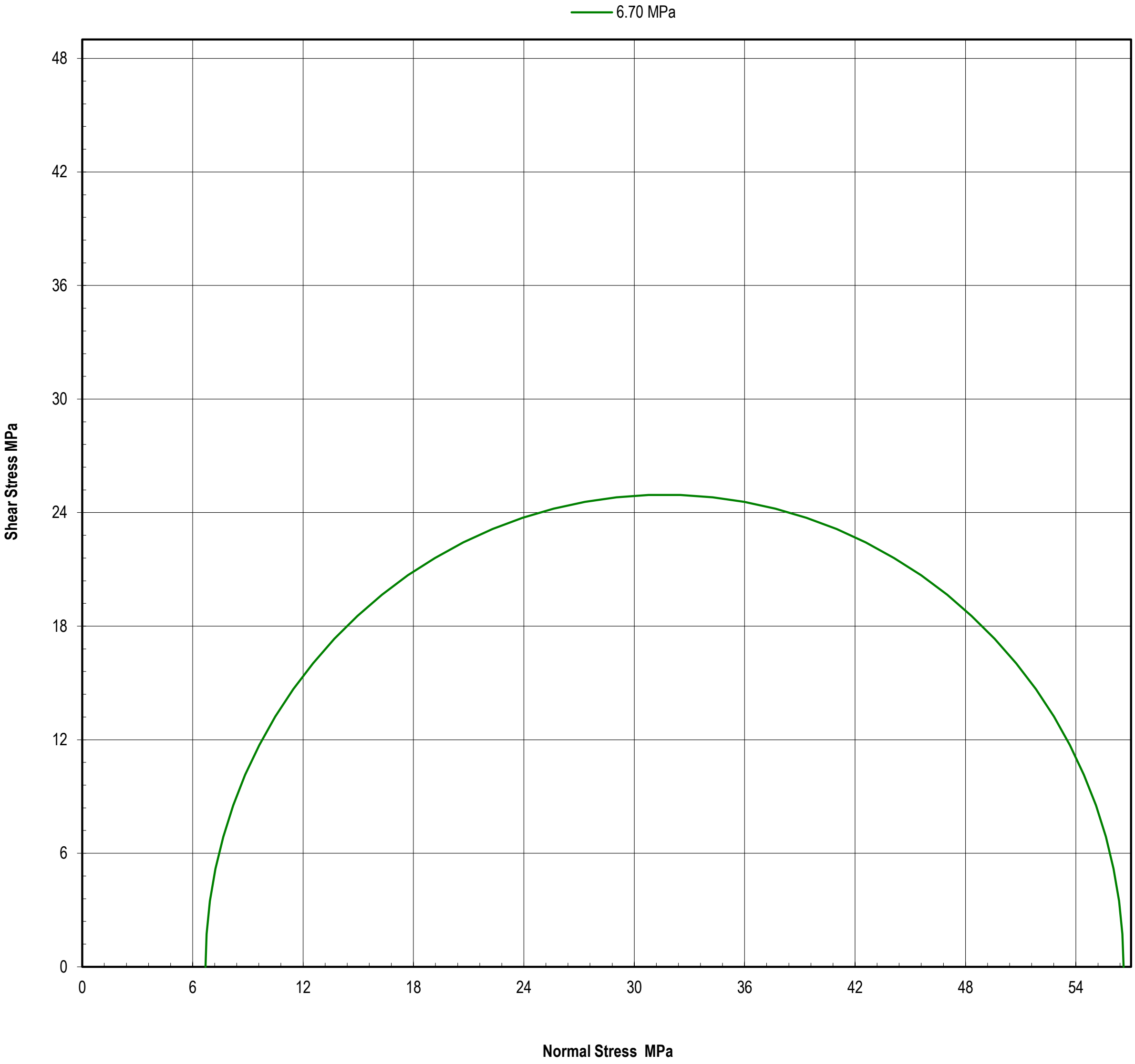
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110058-RTX

Peak Stress Mohr Circle Plot



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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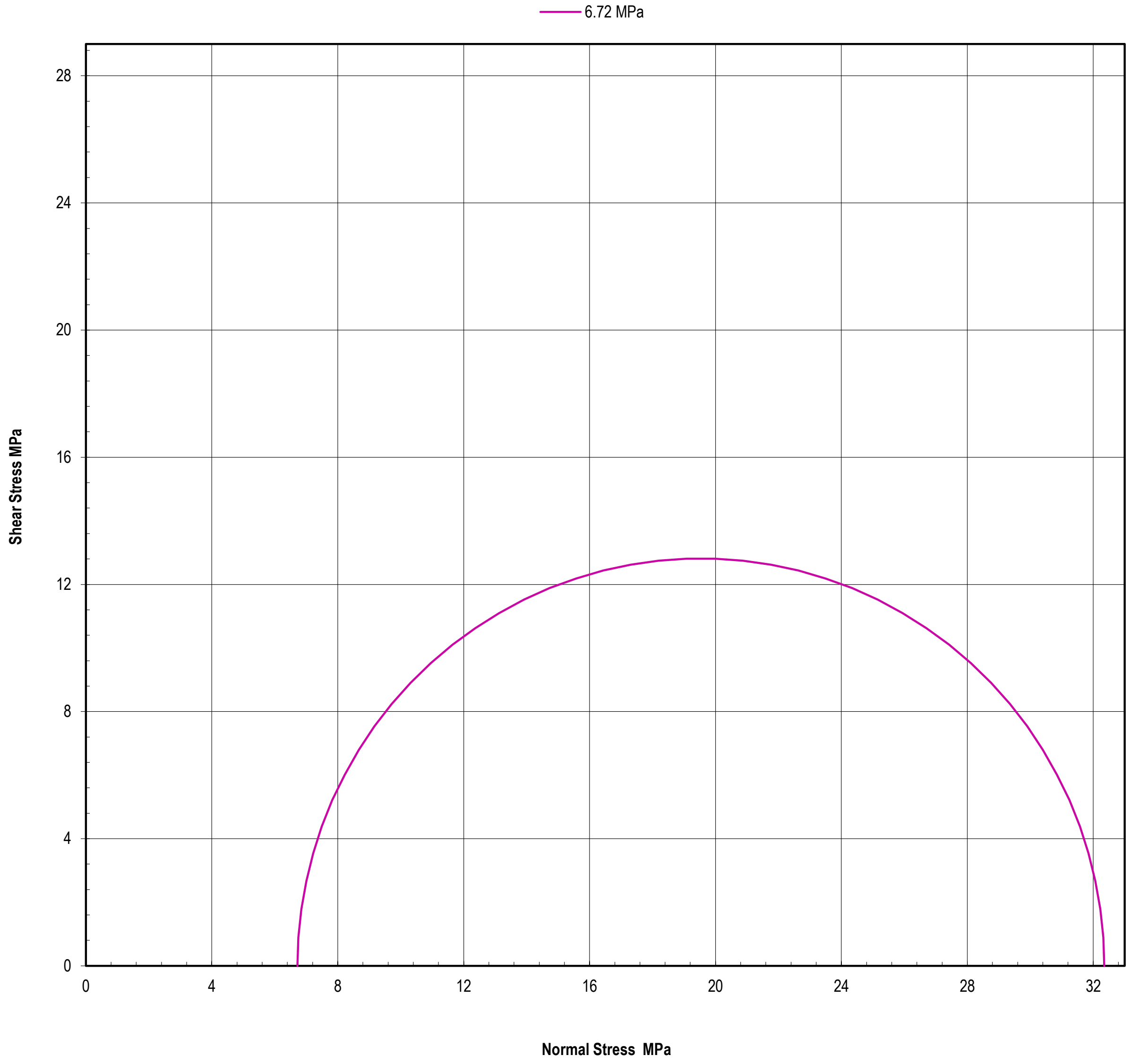
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110058-RTX

Residual Stress Mohr Circle Plot



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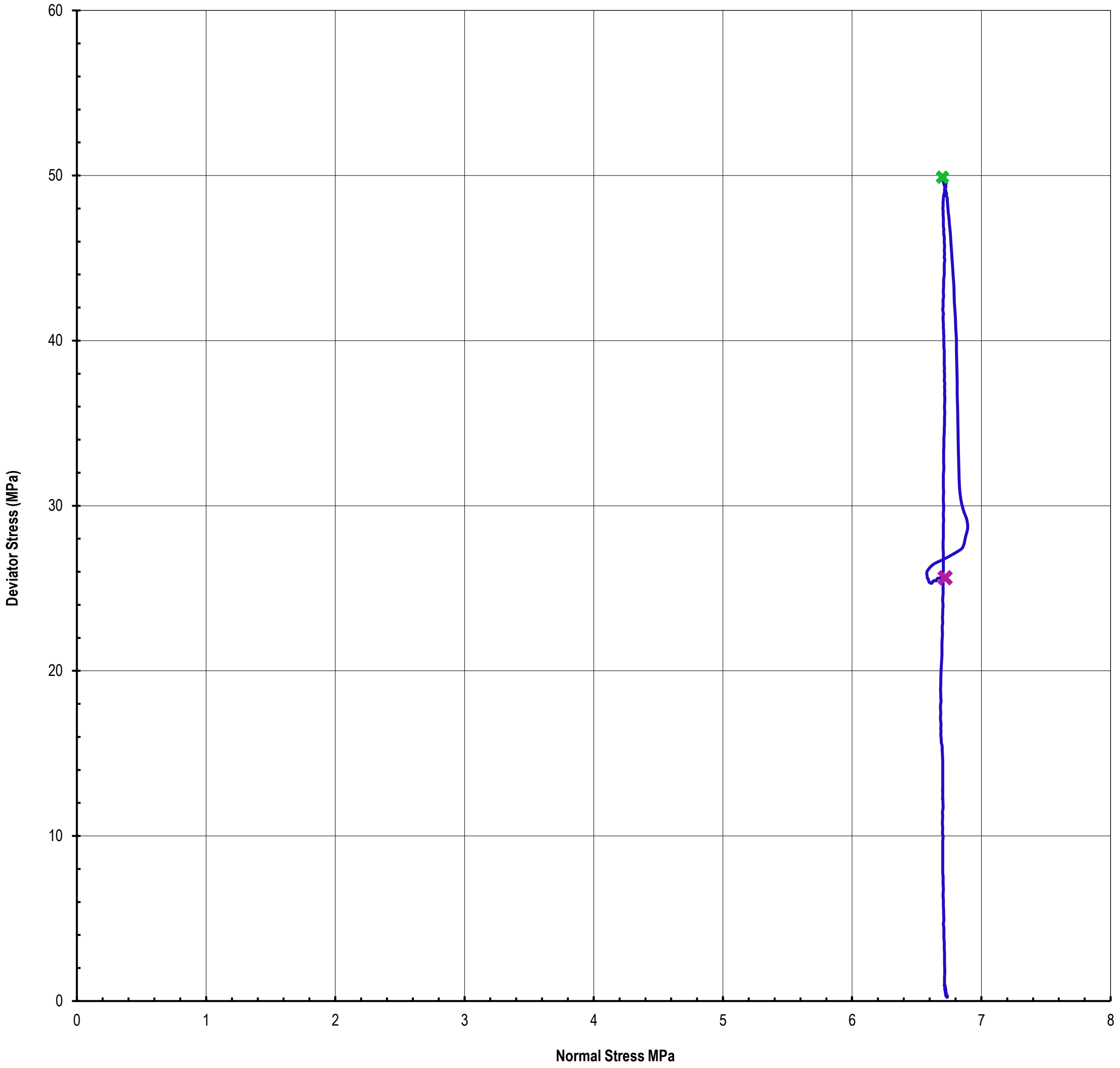
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110058-RTX

Deviator Stress vs Normal Stress Plot



X Peak Value
X Residual Value

Notes/Remarks:

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Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110059-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	9/11/2020
		Report Date	10/11/2020
Project	Surat Subsidence Study		
Client ID	Kogan North 76 - 114,313	**Depth (m)**	298.25-298.43
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.3	Moisture Content (%)	1.8
Sample Height (mm)	145.4	Wet Density (t/m^3)	2.42
Duration of Test (min)	15:06	Dry Density (t/m^3)	2.37
Rate of Strain (%/min)	0.05	Bedding (^{o})	10
Mode of Failure	Shear	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	70		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	7.40				
Deviator Stress (MPa)	56.0				
Axial Strain (µe)	15008				
Diametral Strain (µe)	-5276				
Tangent Modulus (GPa)	4.54				
Poisson's Ratio	0.050				

Residual Test Results

Confining Pressure (MPa)	7.39				
Residual Deviator Stress (MPa)	27.6				
Axial Strain (µe)	15300				
Diametral Strain (µe)	-9449				

Notes/Remarks:

Sample/s supplied by client Tested as received

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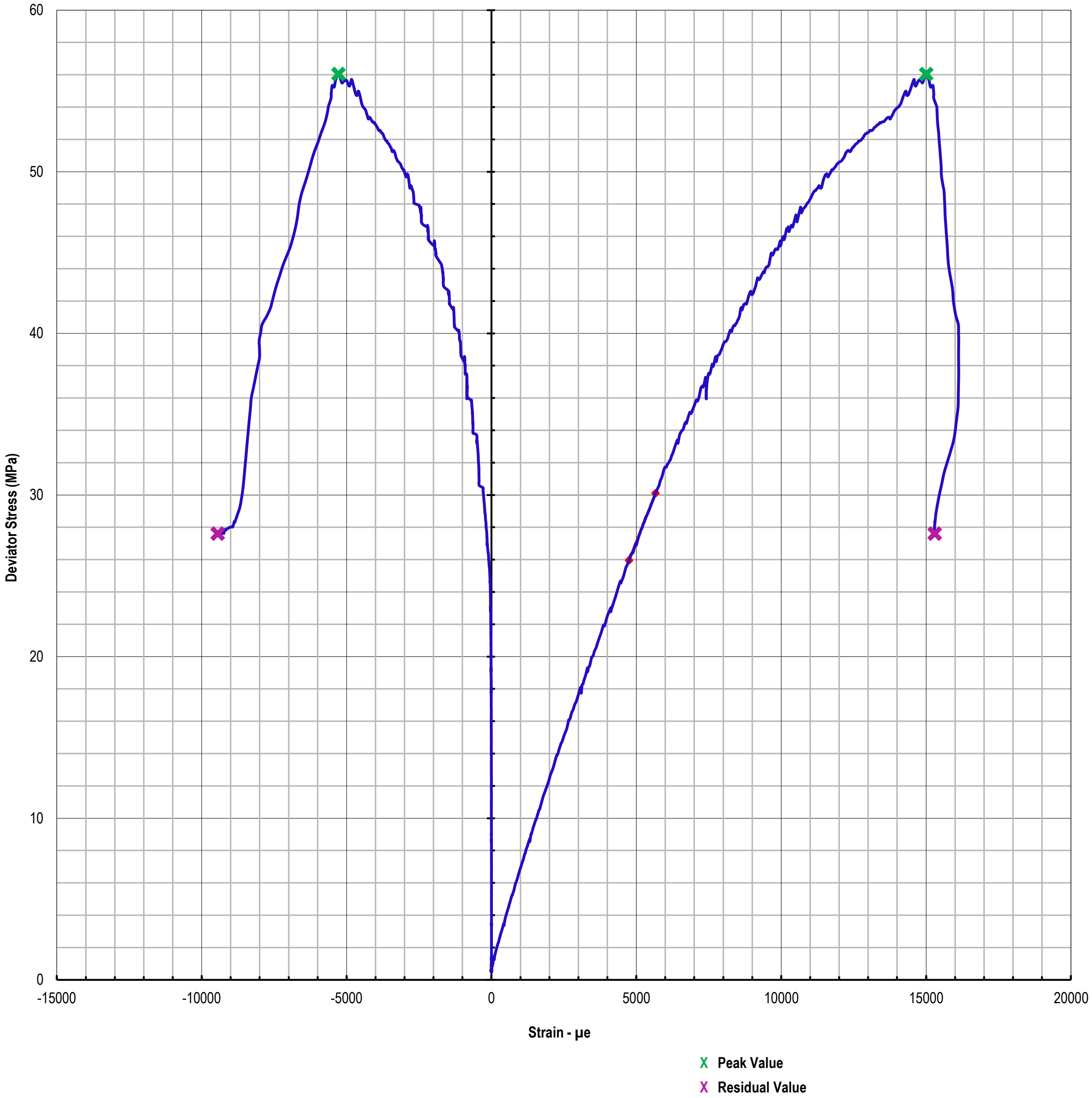
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110059-RTX

Deviator Stress vs Axial Strain Plots



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Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110059-RTX

Before and After Test Photos

CLIENT:	**Arrow Energy Pty Ltd**		
PROJECT:	**Surat Subsidence Study**	**BEFORE TEST**	
LAB SAMPLE No.	**20110059**	**DATE:** 05/11/2020	
BOREHOLE:	**Kogan North 76 - 114,313**	**DEPTH:**	**298.25-298.43**

Notes/Remarks:

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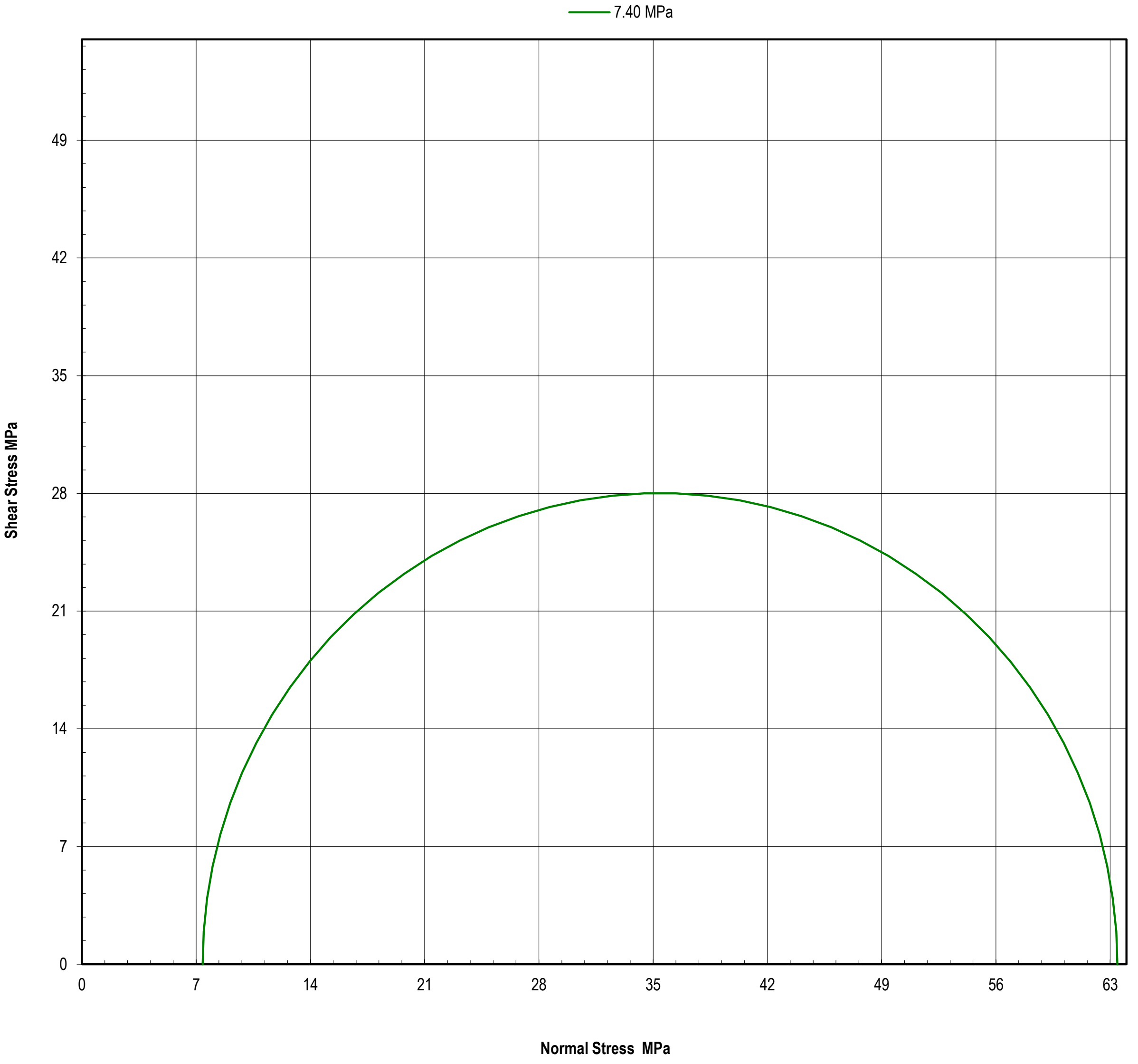
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110059-RTX

Peak Stress Mohr Circle Plot



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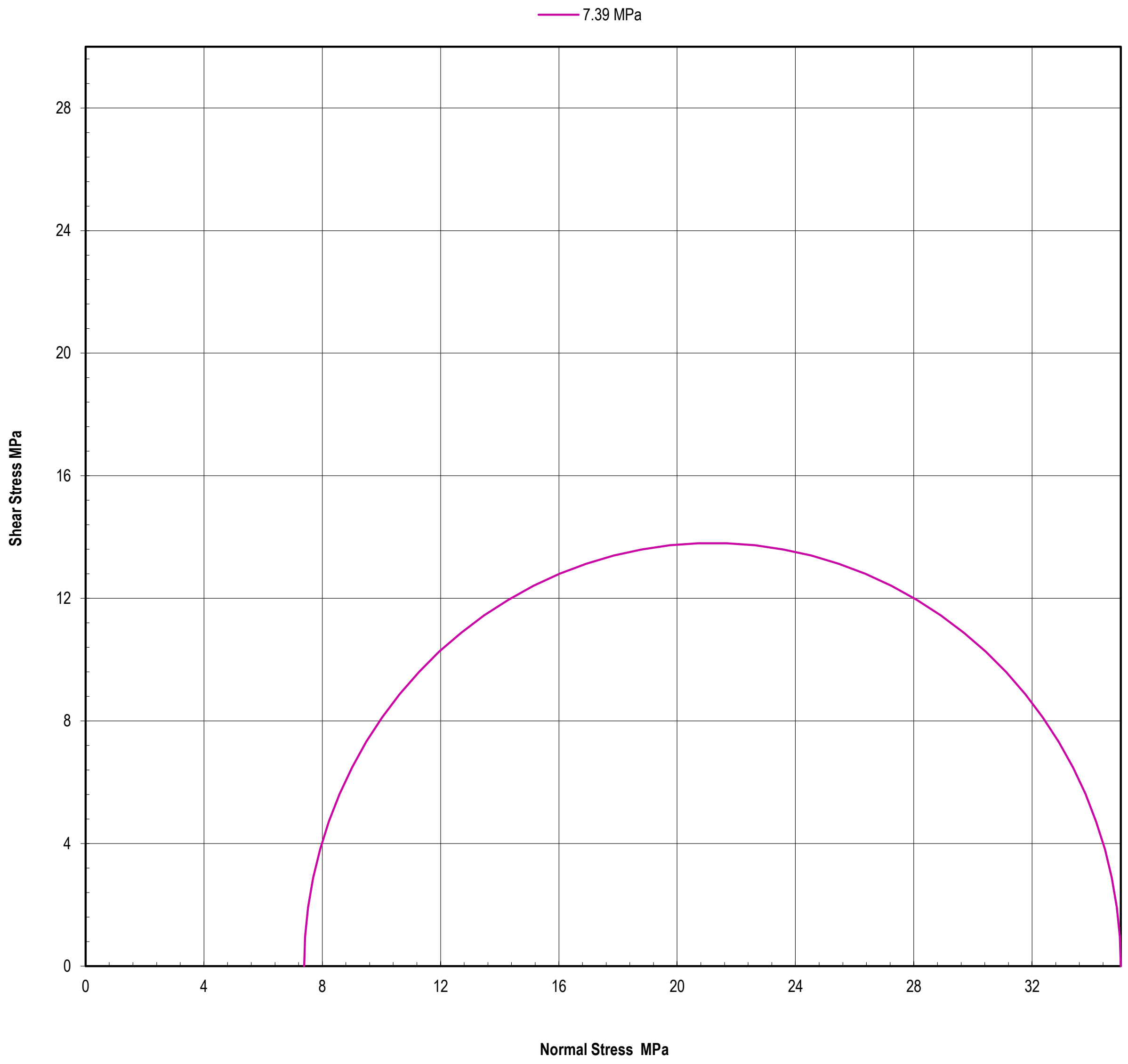
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110059-RTX

Residual Stress Mohr Circle Plot



Notes/Remarks:

Graph not to scale

Sample/s supplied by client

Tested as received

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

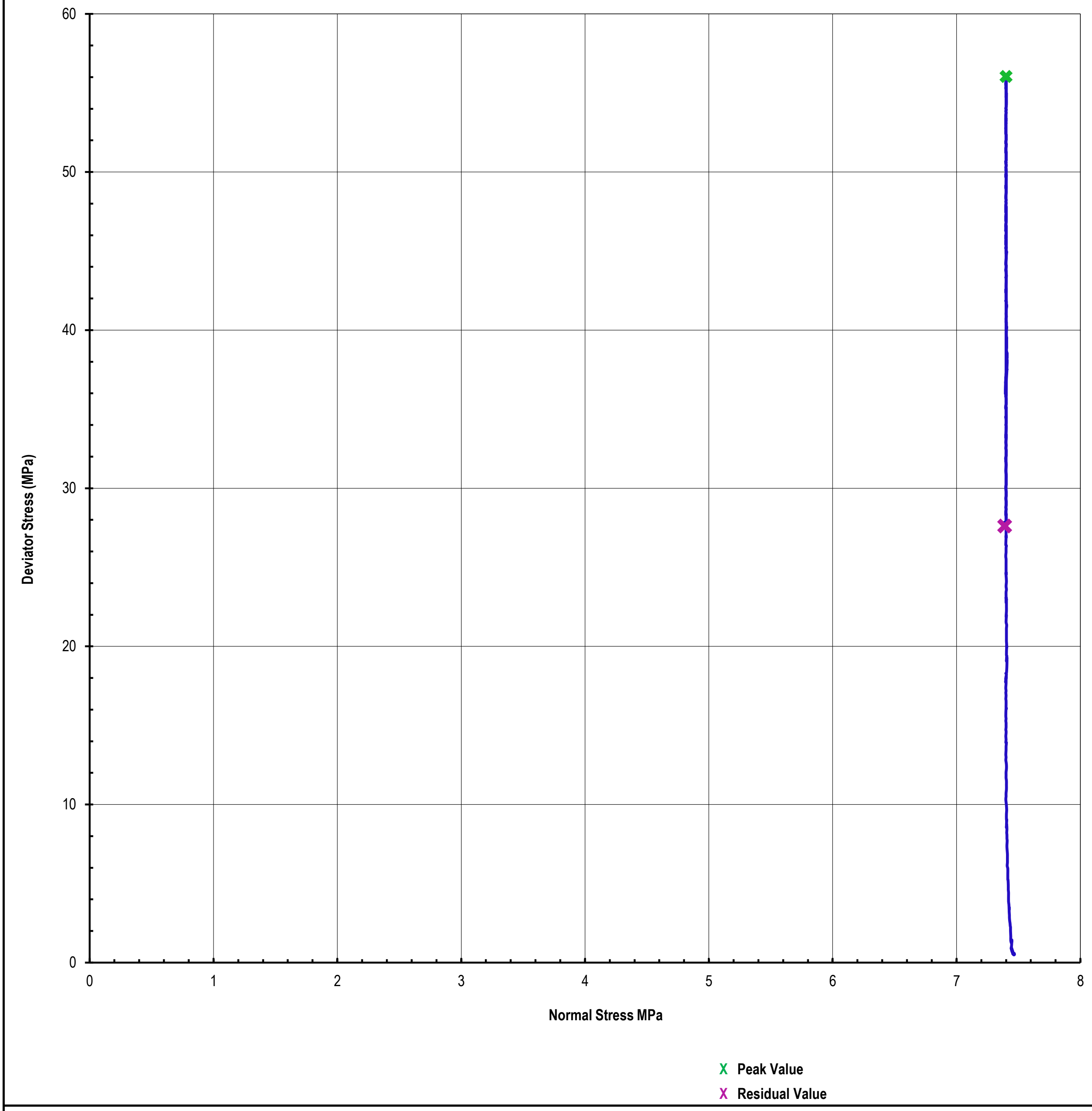
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110059-RTX

Deviator Stress vs Normal Stress Plot



Notes/Remarks:

Graph not to scale

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110060-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	9/11/2020
		Report Date	10/11/2020
Project	Surat Subsidence Study		
Client ID	Tipton 26A - 114314	**Depth (m)**	282.66-282.90
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.5	Moisture Content (%)	1.7
Sample Height (mm)	146.7	Wet Density (t/m^3)	2.37
Duration of Test (min)	17:35	Dry Density (t/m^3)	2.34
Rate of Strain (%/min)	0.05	Bedding (^{o})	10
Mode of Failure	Shear	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	75		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	7.04				
Deviator Stress (MPa)	49.6				
Axial Strain (µe)	12019				
Diametral Strain (µe)	-4548				
Tangent Modulus (GPa)	5.15				
Poisson's Ratio	0.060				

Residual Test Results

Confining Pressure (MPa)	6.93				
Residual Deviator Stress (MPa)	26.5				
Axial Strain (µe)	16668				
Diametral Strain (µe)	-9823				

Notes/Remarks:

Sample/s supplied by client Tested as received

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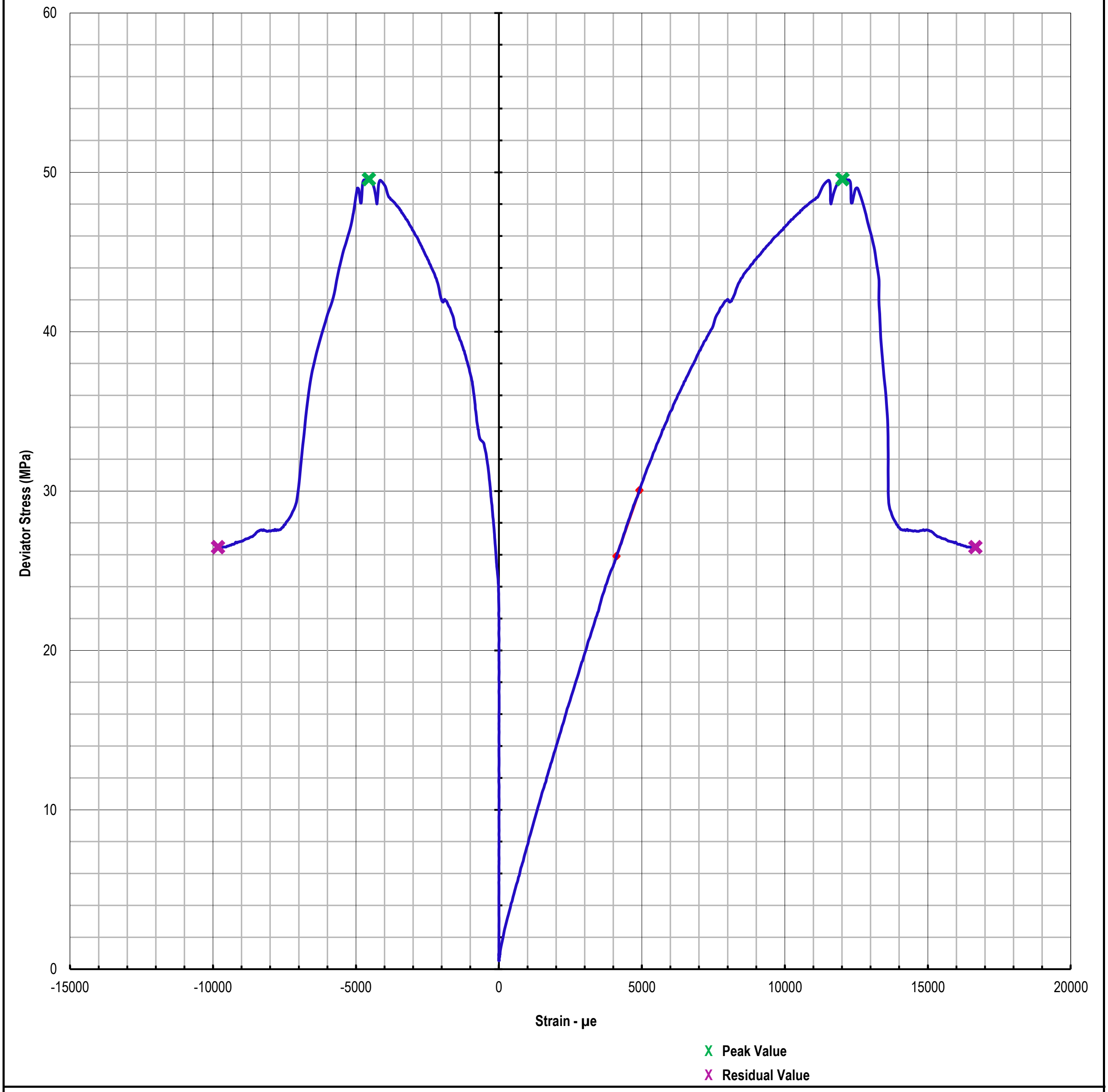
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110060-RTX

Deviator Stress vs Axial Strain Plots



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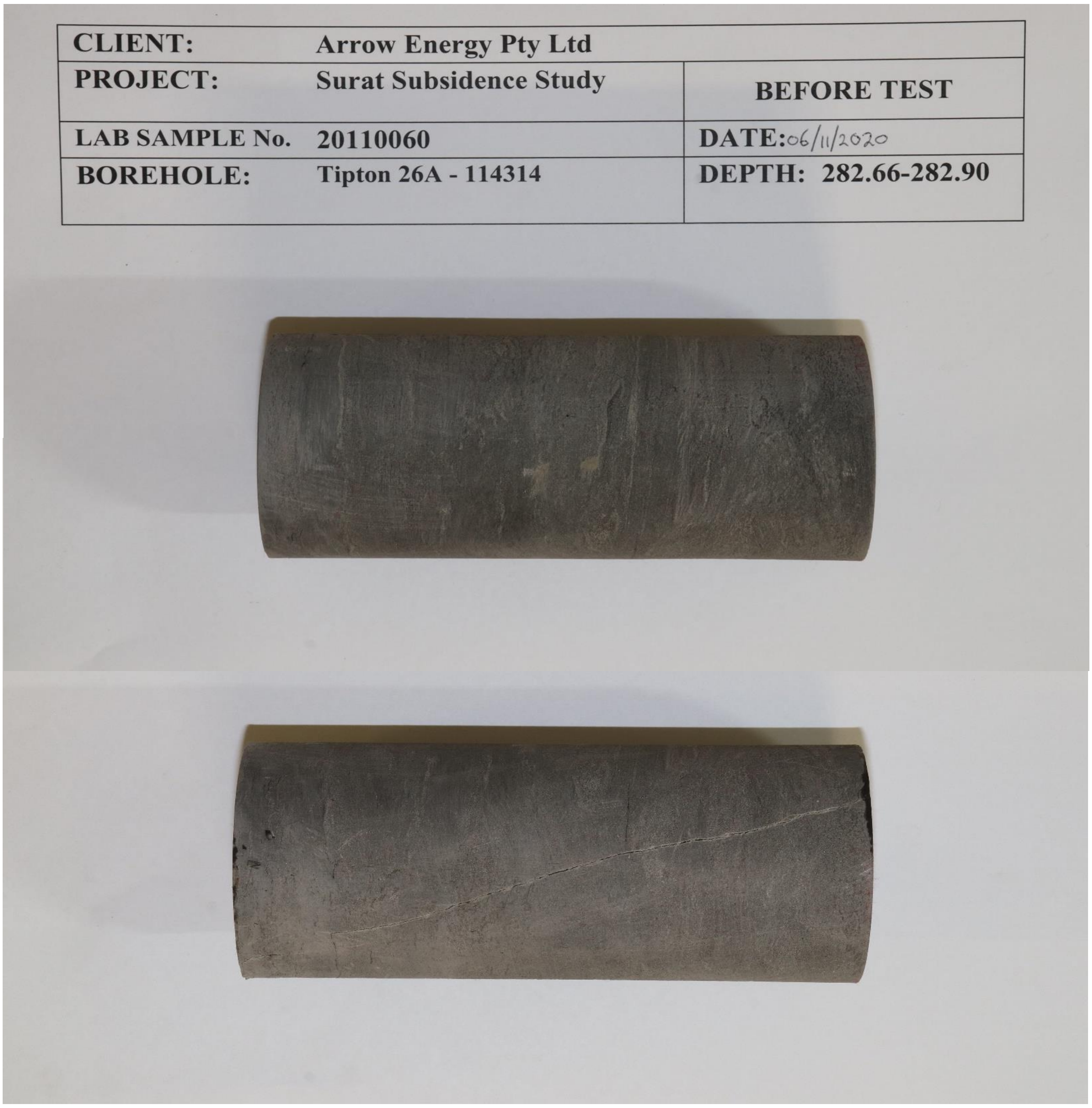
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110060-RTX

Before and After Test Photos



CLIENT:	Arrow Energy Pty Ltd		
PROJECT:	Surat Subsidence Study	BEFORE TEST	
LAB SAMPLE No.	20110060	DATE:	06/11/2020
BOREHOLE:	Tipton 26A - 114314	DEPTH:	282.66-282.90

Notes/Remarks:

Photo not to scale

Sample/s supplied by client

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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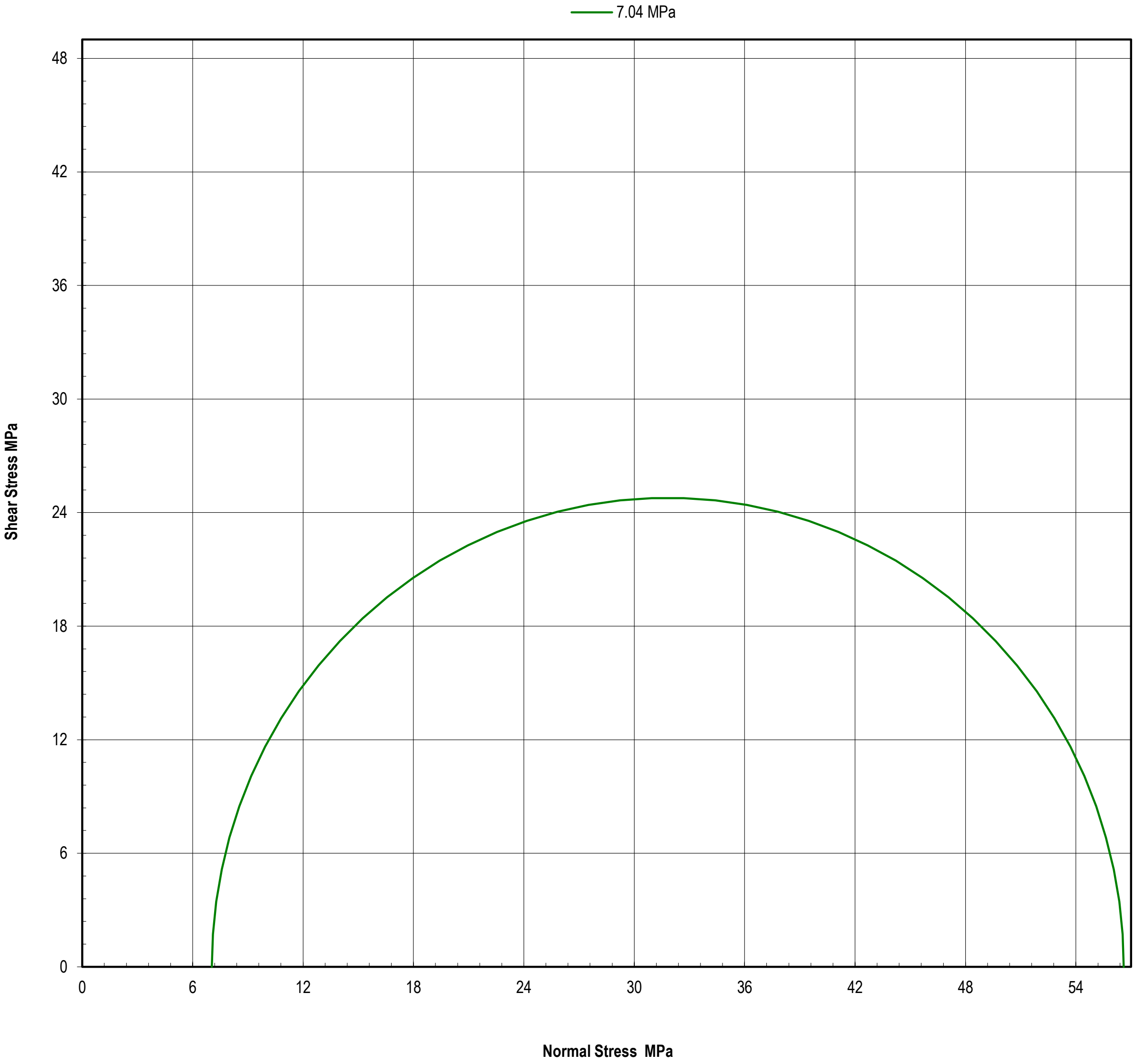
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110060-RTX

Peak Stress Mohr Circle Plot



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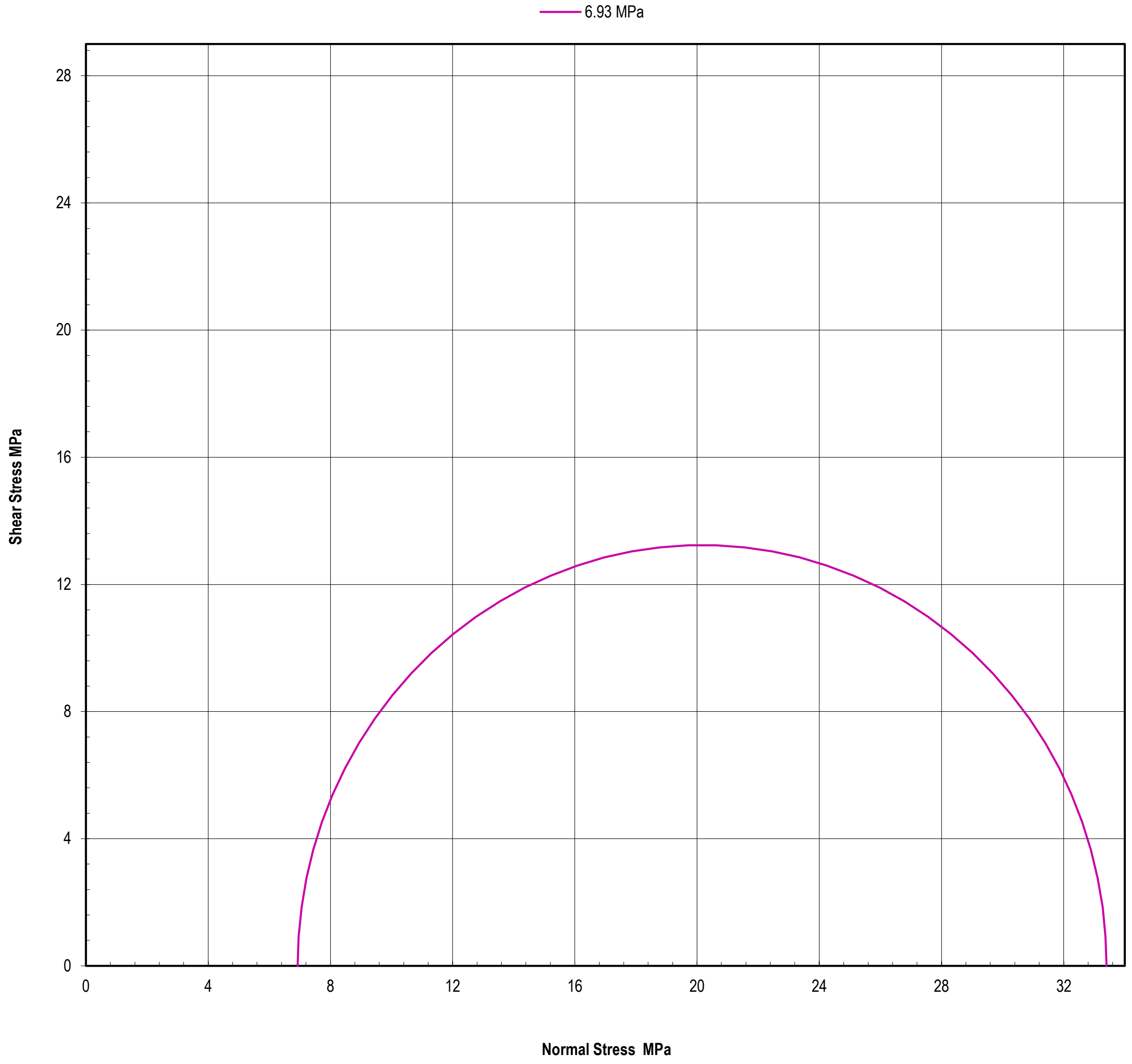
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110060-RTX

Residual Stress Mohr Circle Plot



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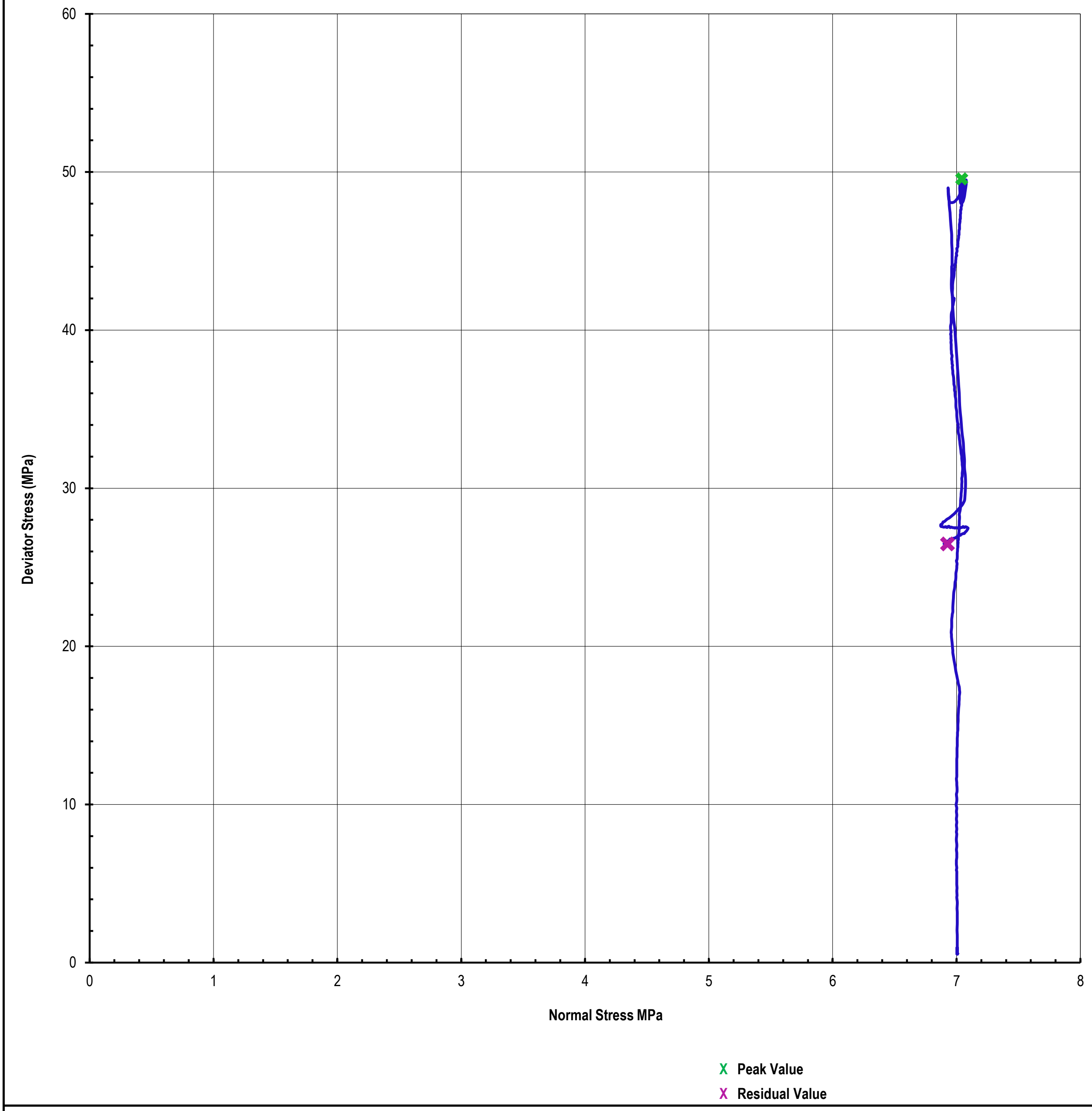
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110060-RTX

Deviator Stress vs Normal Stress Plot



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Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110061-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	9/11/2020
		Report Date	10/11/2020
Project	Surat Subsidence Study		
Client ID	Tipton 26A - 114,315	**Depth (m)**	471.36-471.57
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.8	Moisture Content (%)	2.0
Sample Height (mm)	147.5	Wet Density (t/m^3)	2.39
Duration of Test (min)	21:42	Dry Density (t/m^3)	2.35
Rate of Strain (%/min)	0.05	Bedding (^{o})	Nil
Mode of Failure	Shear	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	75		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	11.74				
Deviator Stress (MPa)	64.2				
Axial Strain (με)	16339				
Diametral Strain (με)	-7958				
Tangent Modulus (GPa)	5.71				
Poisson's Ratio	0.175				

Residual Test Results

Confining Pressure (MPa)	11.67				
Residual Deviator Stress (MPa)	38.7				
Axial Strain (με)	21184				
Diametral Strain (με)	-15171				

Notes/Remarks:

Sample/s supplied by client   Tested as received

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

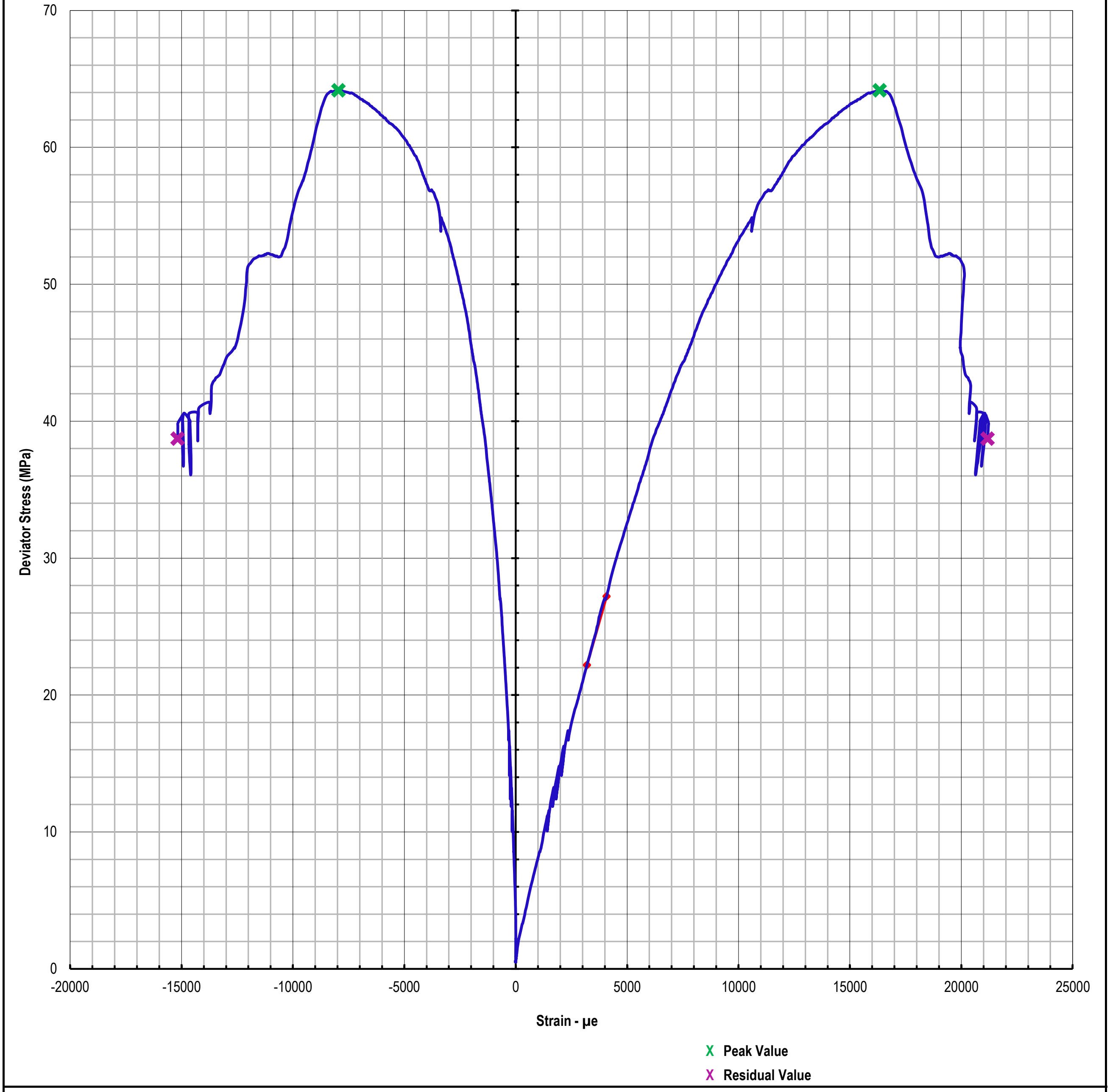
ASTM D7012

Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110061-RTX

Deviator Stress vs Axial Strain Plots



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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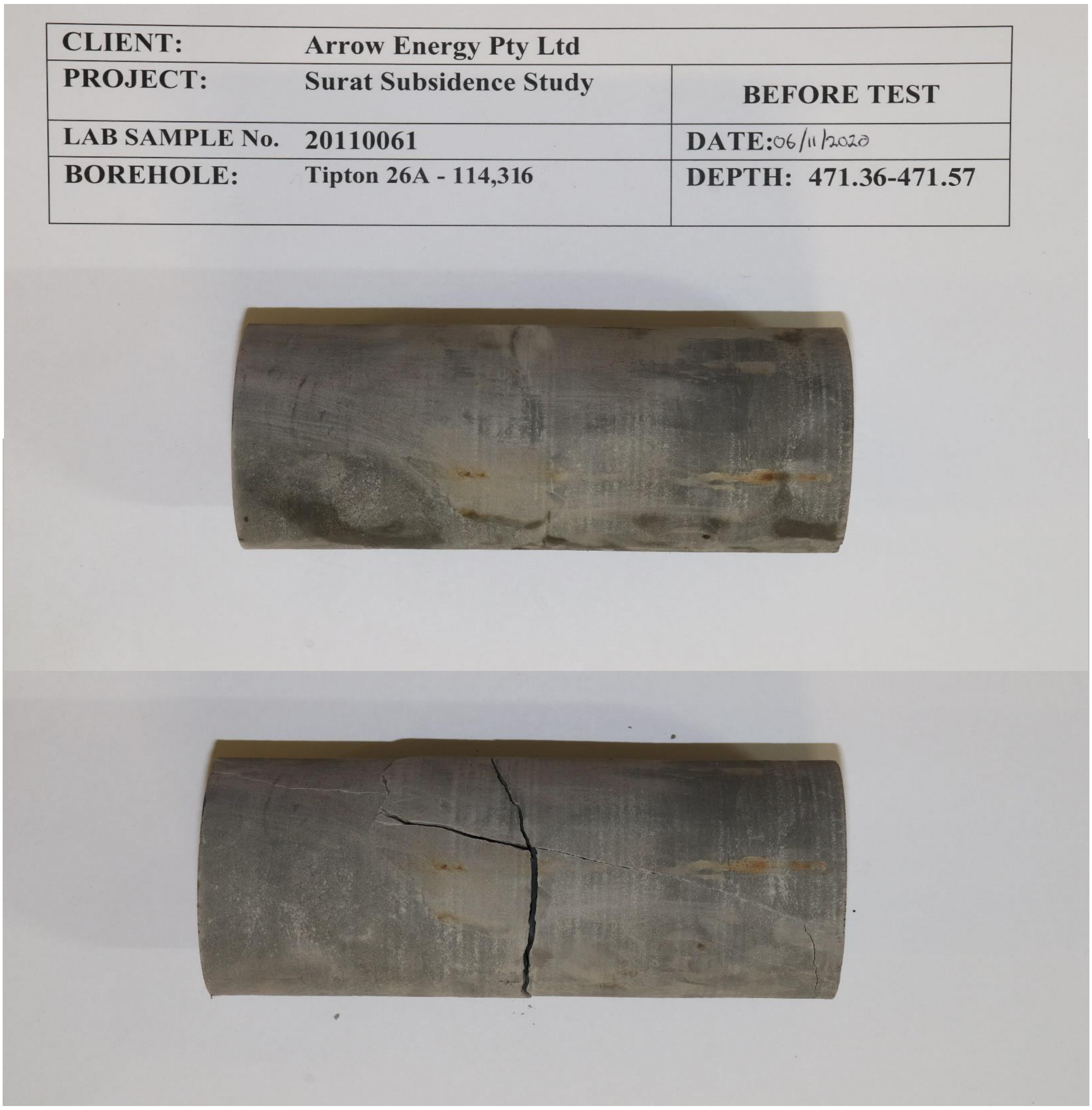
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110061-RTX

Before and After Test Photos



CLIENT: Arrow Energy Pty Ltd
PROJECT: Surat Subsidence Study
BEFORE TEST
LAB SAMPLE No. 20110061
DATE:06/11/2020
BOREHOLE: Tipton 26A - 114,316
DEPTH: 471.36-471.57

Notes/Remarks:

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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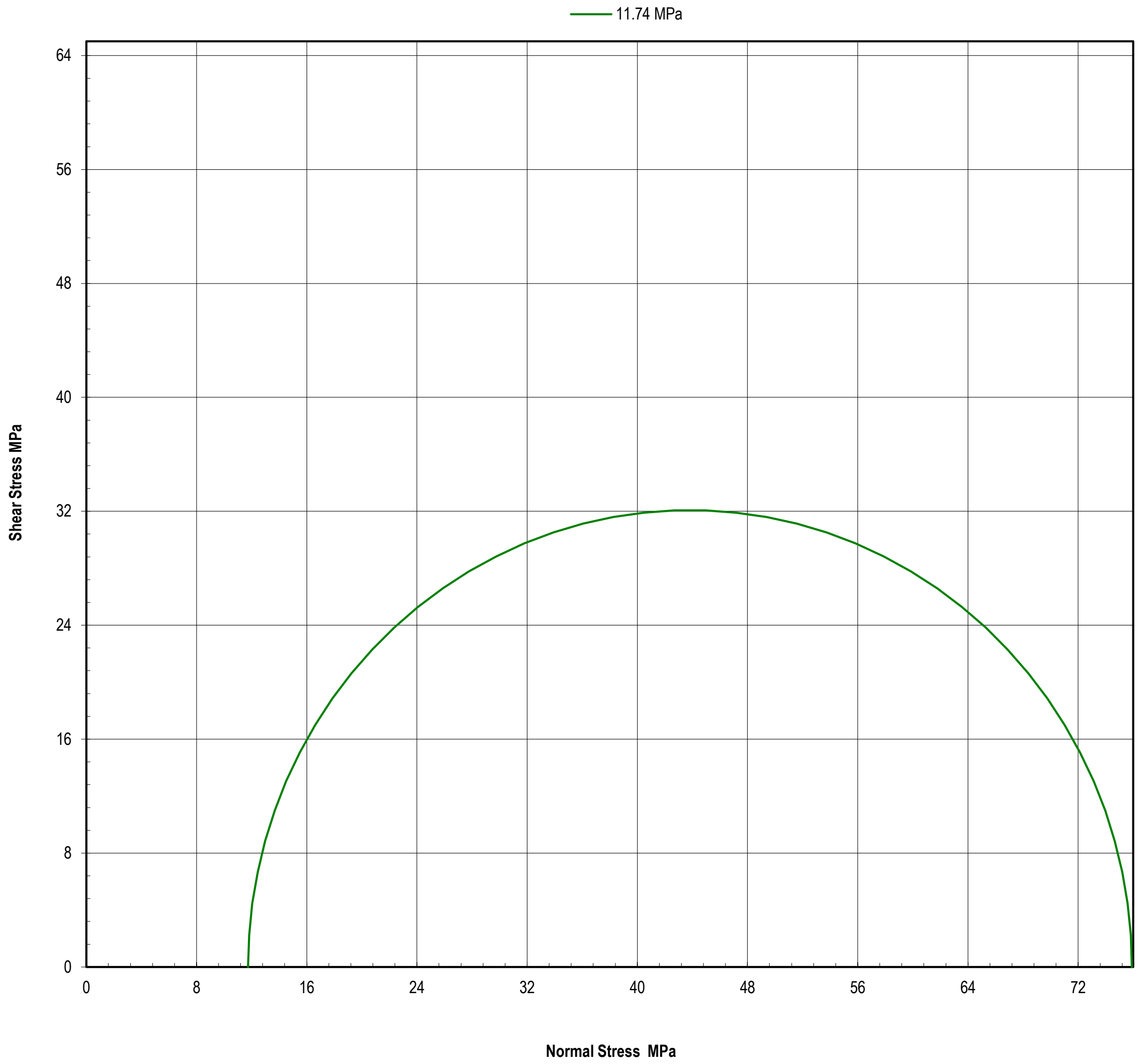
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110061-RTX

Peak Stress Mohr Circle Plot



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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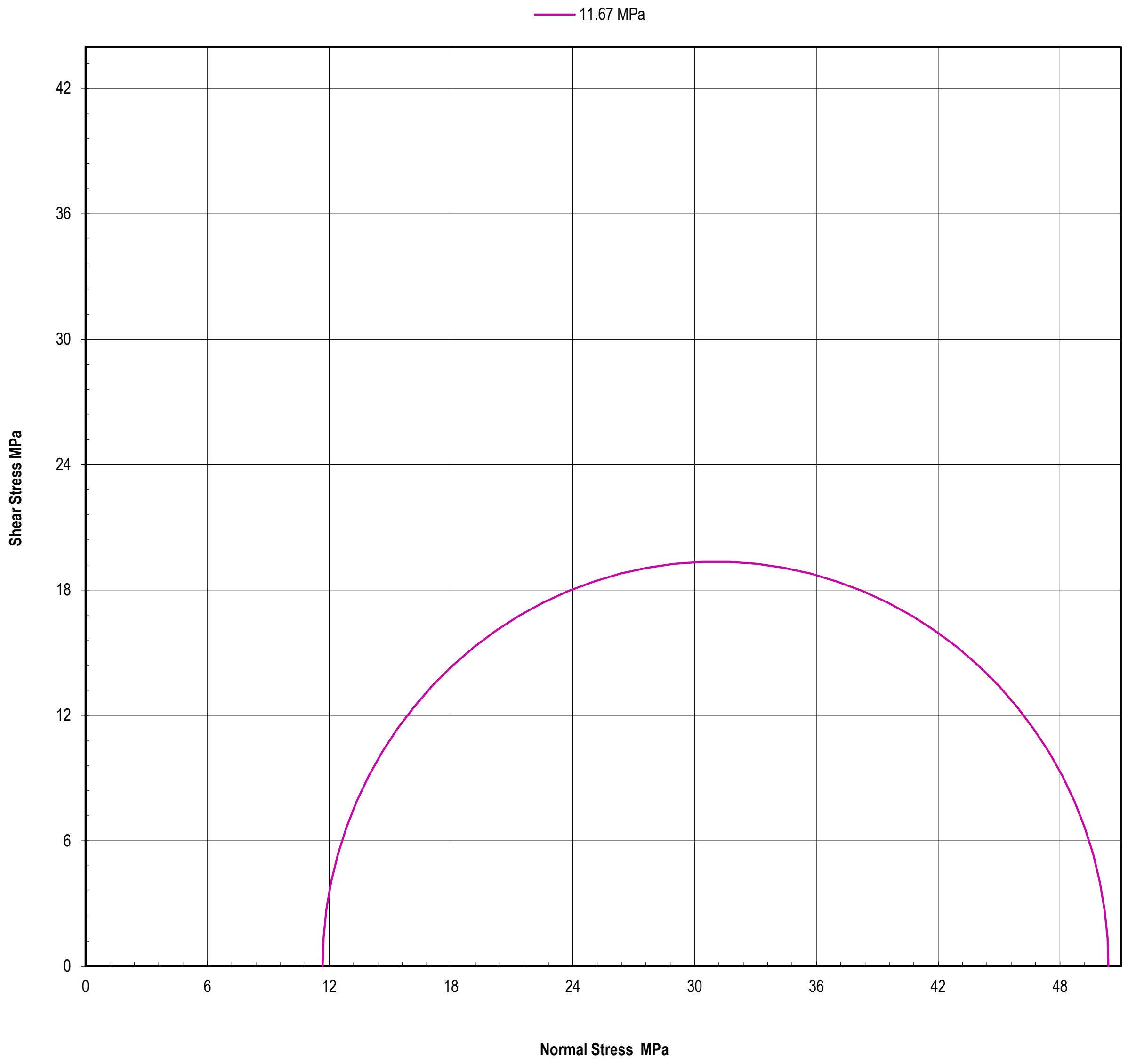
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110061-RTX

Residual Stress Mohr Circle Plot



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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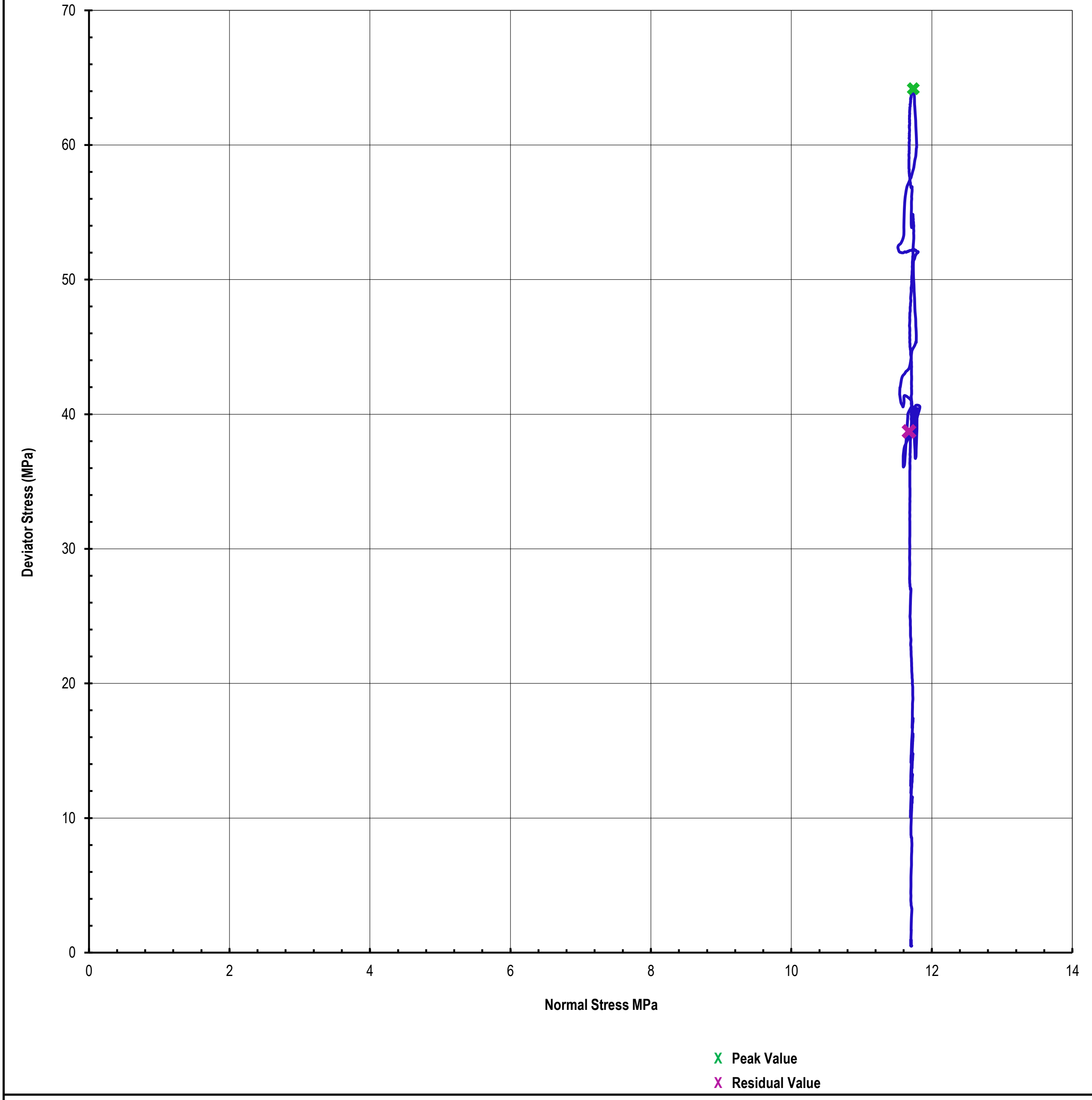
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110061-RTX

Deviator Stress vs Normal Stress Plot



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Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110062-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	9/11/2020
		Report Date	10/11/2020
Project	Surat Subsidence Study		
Client ID	Meenawarra 16 - 114327	**Depth (m)**	203.90-204.09
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.6	Moisture Content (%)	6.8
Sample Height (mm)	149.5	Wet Density (t/m^3)	1.30
Duration of Test (min)	32:47	Dry Density (t/m^3)	1.22
Rate of Strain (%/min)	0.05	Bedding (^{o})	Nil
Mode of Failure	Conical	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	75		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	5.10				
Deviator Stress (MPa)	74.0				
Axial Strain (με)	26440				
Diametral Strain (με)	-9358				
Tangent Modulus (GPa)	3.23				
Poisson's Ratio	0.203				

Residual Test Results

Confining Pressure (MPa)	5.10				
Residual Deviator Stress (MPa)	29.4				
Axial Strain (με)	34616				
Diametral Strain (με)	-7853				

Notes/Remarks:

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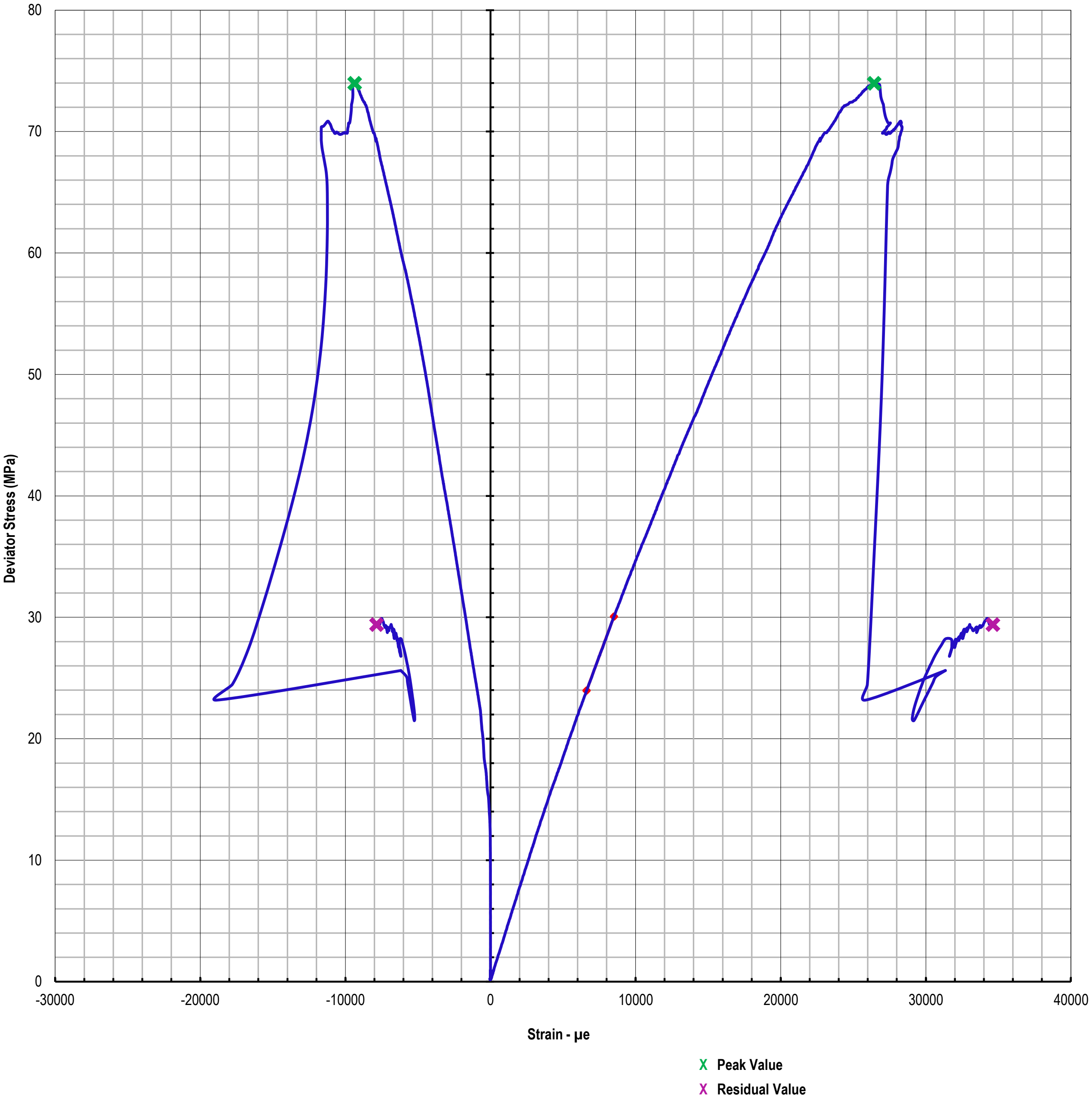
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110062-RTX

Deviator Stress vs Axial Strain Plots



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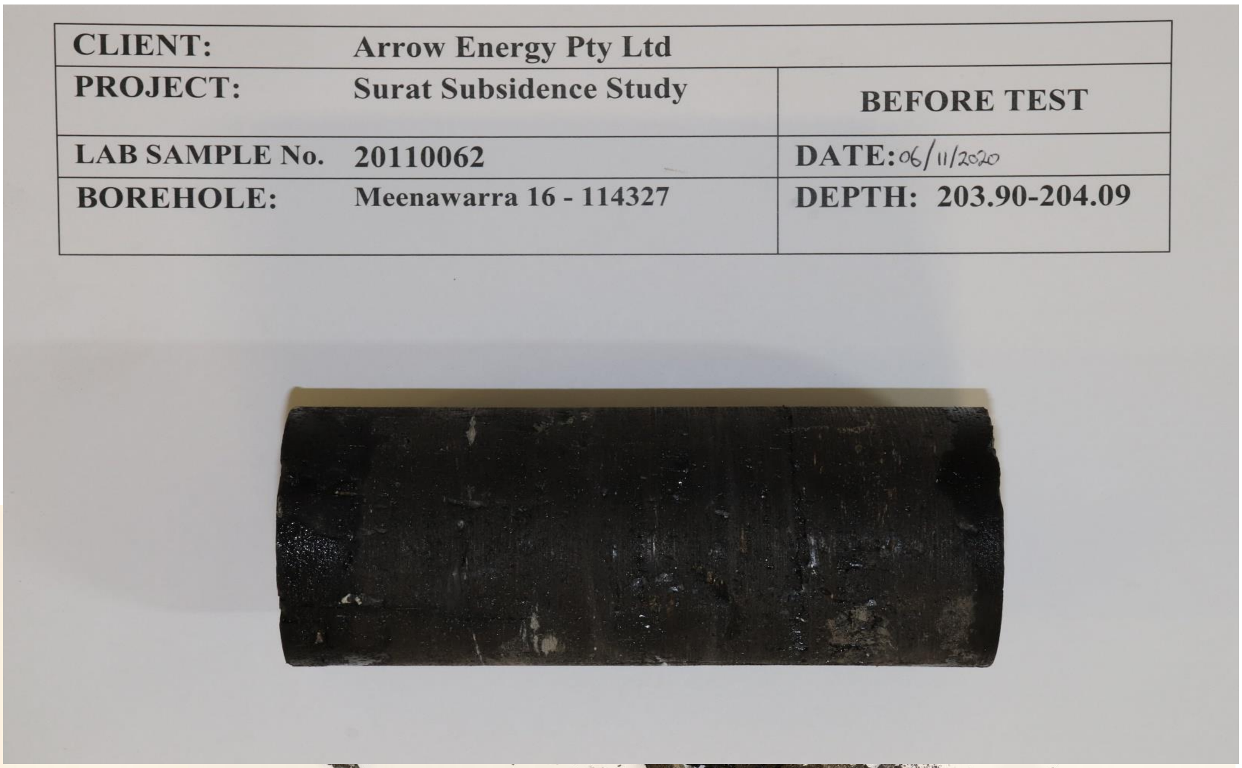
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110062-RTX

Before and After Test Photos



CLIENT:	Arrow Energy Pty Ltd	
PROJECT:	Surat Subsidence Study	BEFORE TEST
LAB SAMPLE No.	20110062	DATE: 06/11/2020
BOREHOLE:	Meenawarra 16 - 114327	DEPTH: 203.90-204.09

Notes/Remarks:

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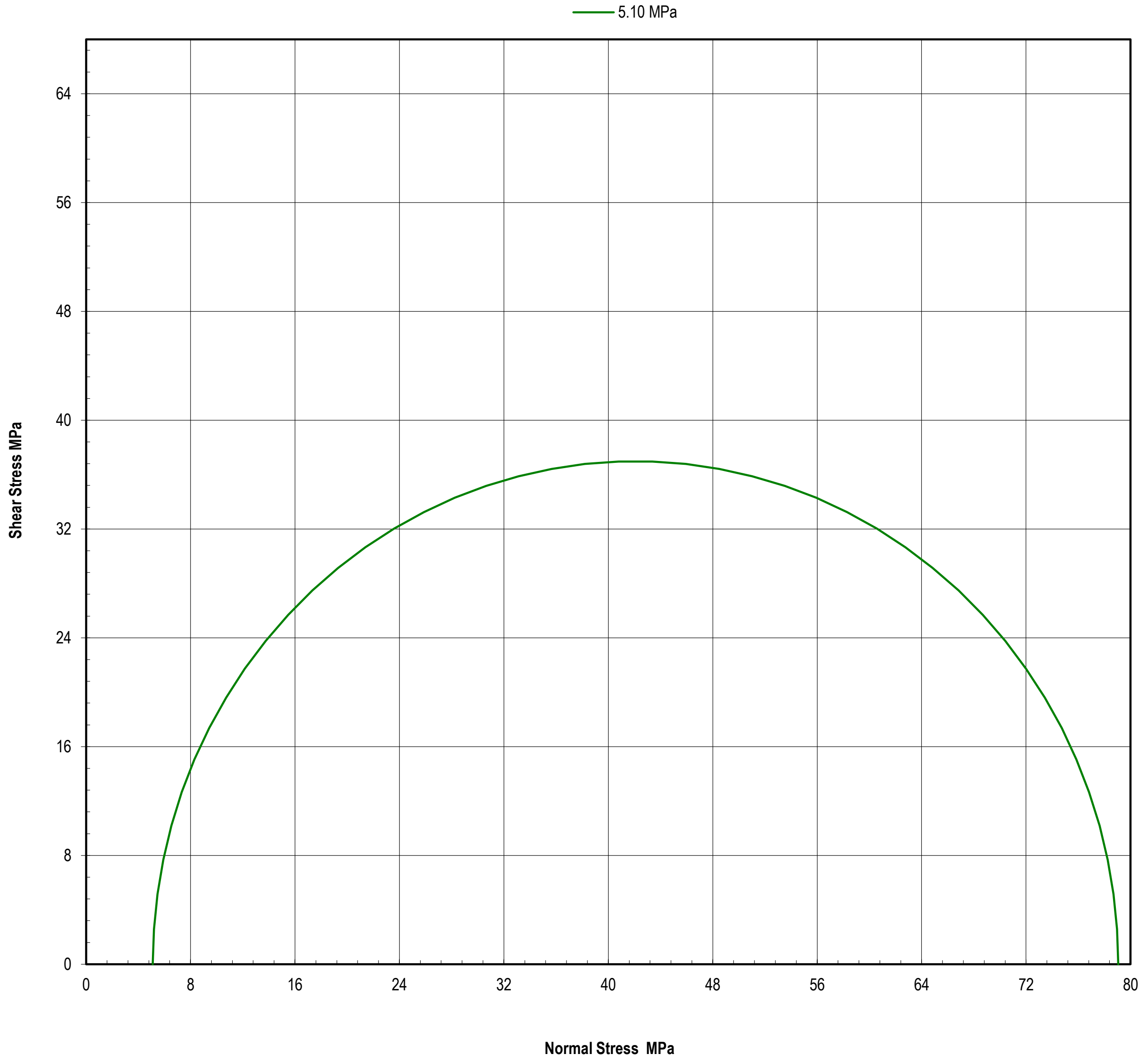
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110062-RTX

Peak Stress Mohr Circle Plot



Notes/Remarks:

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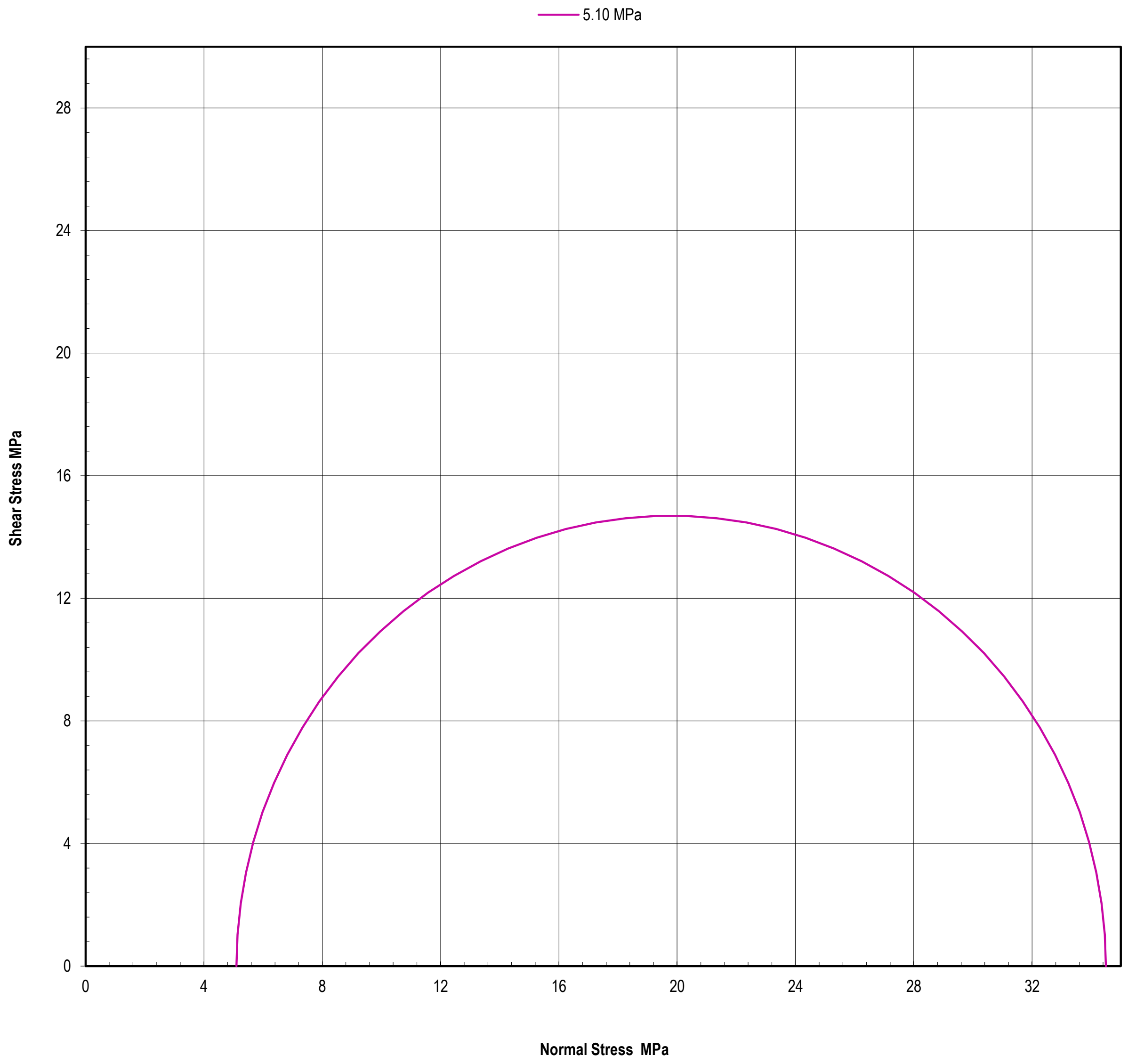
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110062-RTX

Residual Stress Mohr Circle Plot



Notes/Remarks:

Graph not to scale

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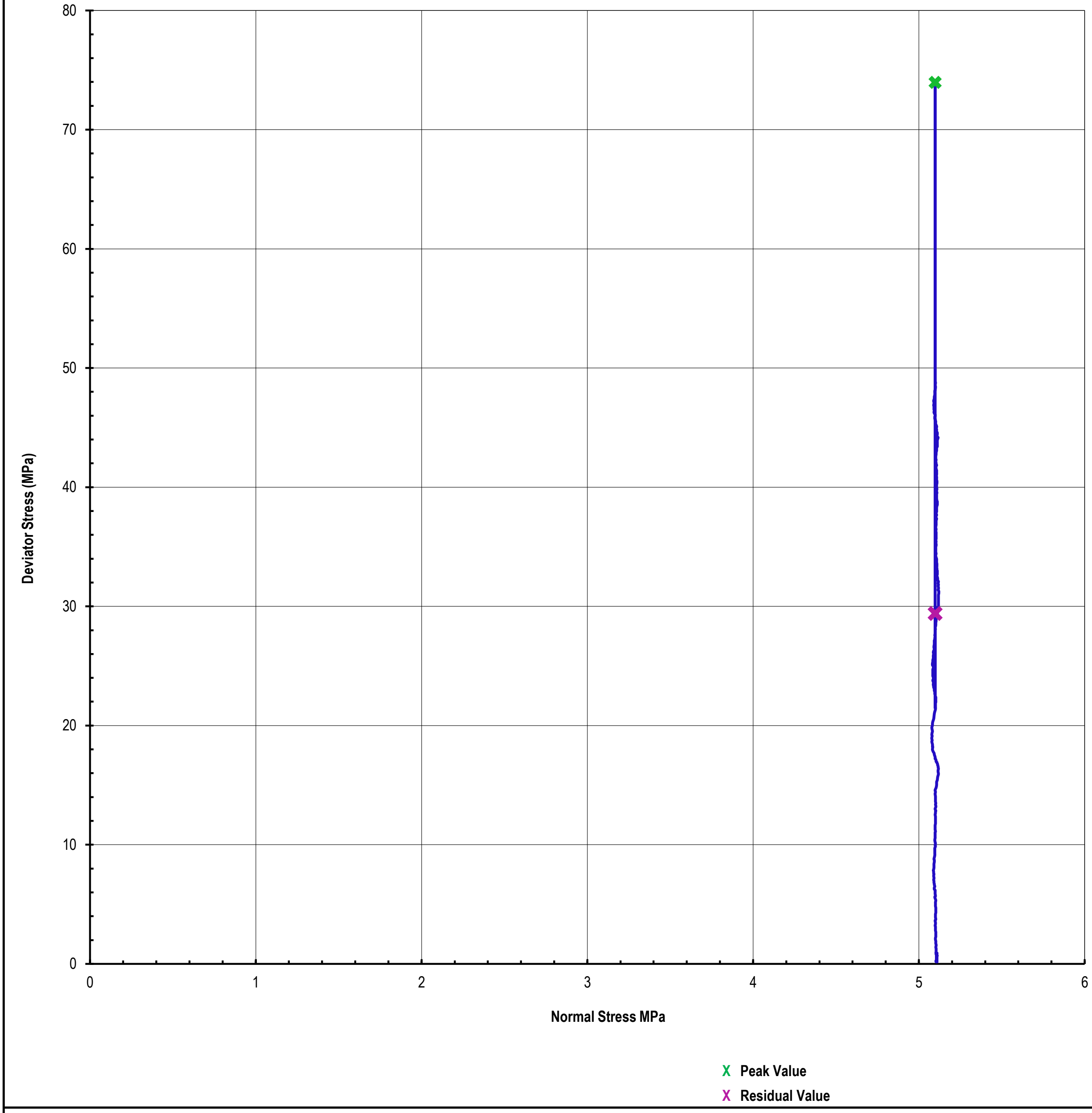
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110062-RTX

Deviator Stress vs Normal Stress Plot



Notes/Remarks:

Graph not to scale

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Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110063-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	9/11/2020
		Report Date	10/11/2020
Project	Surat Subsidence Study		
Client ID	Meenawarra 16 - 114,317	**Depth (m)**	263.62-263.87
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.6	Moisture Content (%)	4.2
Sample Height (mm)	144.6	Wet Density (t/m^3)	2.33
Duration of Test (min)	18:03	Dry Density (t/m^3)	2.23
Rate of Strain (%/min)	0.05	Bedding (^{o})	35
Mode of Failure	Shear	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	60		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	6.61				
Deviator Stress (MPa)	32.6				
Axial Strain (µe)	11201				
Diametral Strain (µe)	-207				
Tangent Modulus (GPa)	3.99				
Poisson's Ratio	0.000				

Residual Test Results

Confining Pressure (MPa)	6.50				
Residual Deviator Stress (MPa)	18.3				
Axial Strain (µe)	17617				
Diametral Strain (µe)	-4814				

Notes/Remarks:

Sample/s supplied by client Tested as received

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Tested at Trilab Brisbane Laboratory

Authorised Signatory

C. Purvis

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Laboratory No. 9926

STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

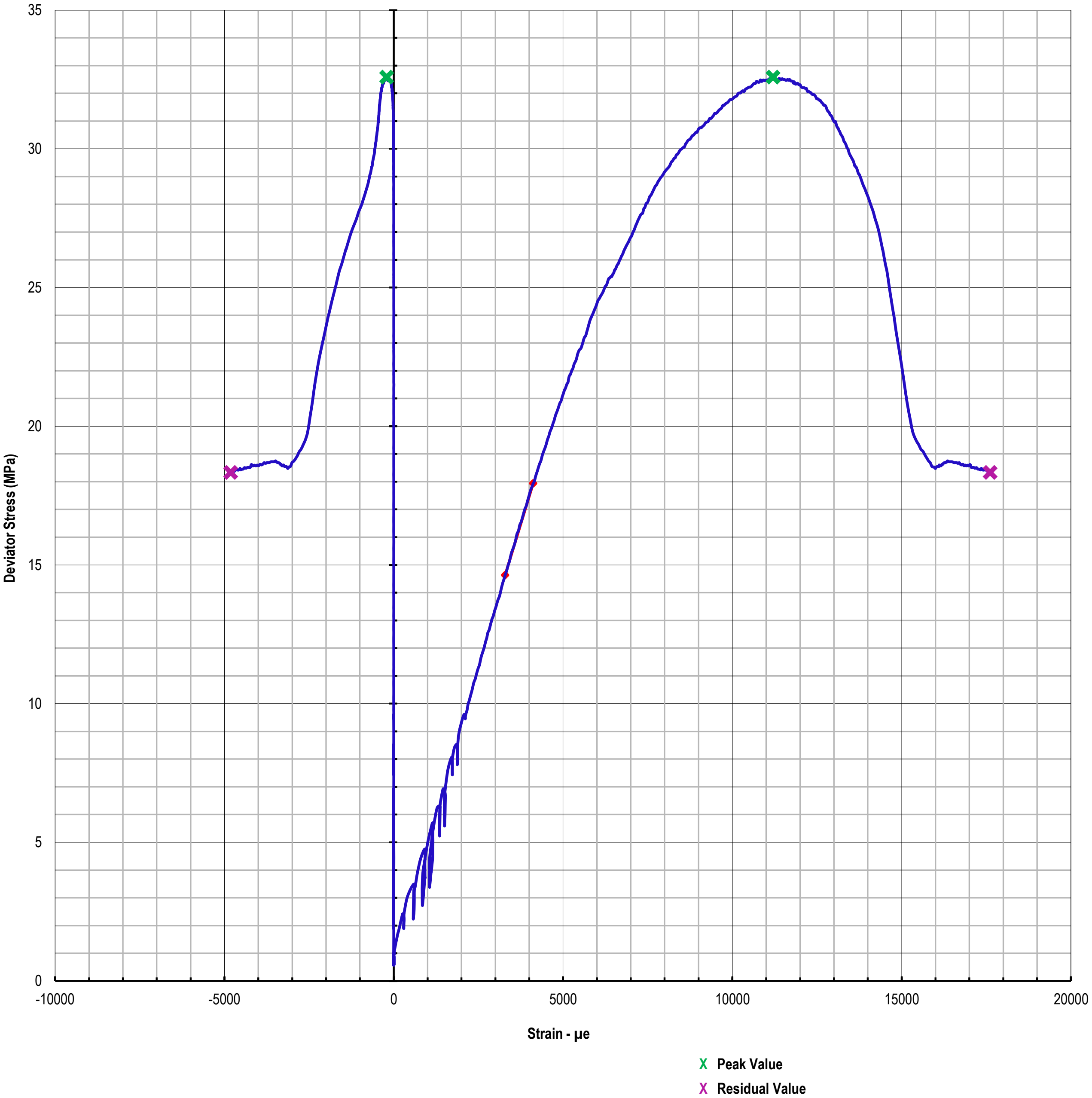
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110063-RTX

Deviator Stress vs Axial Strain Plots



Notes/Remarks:

Graph not to scale

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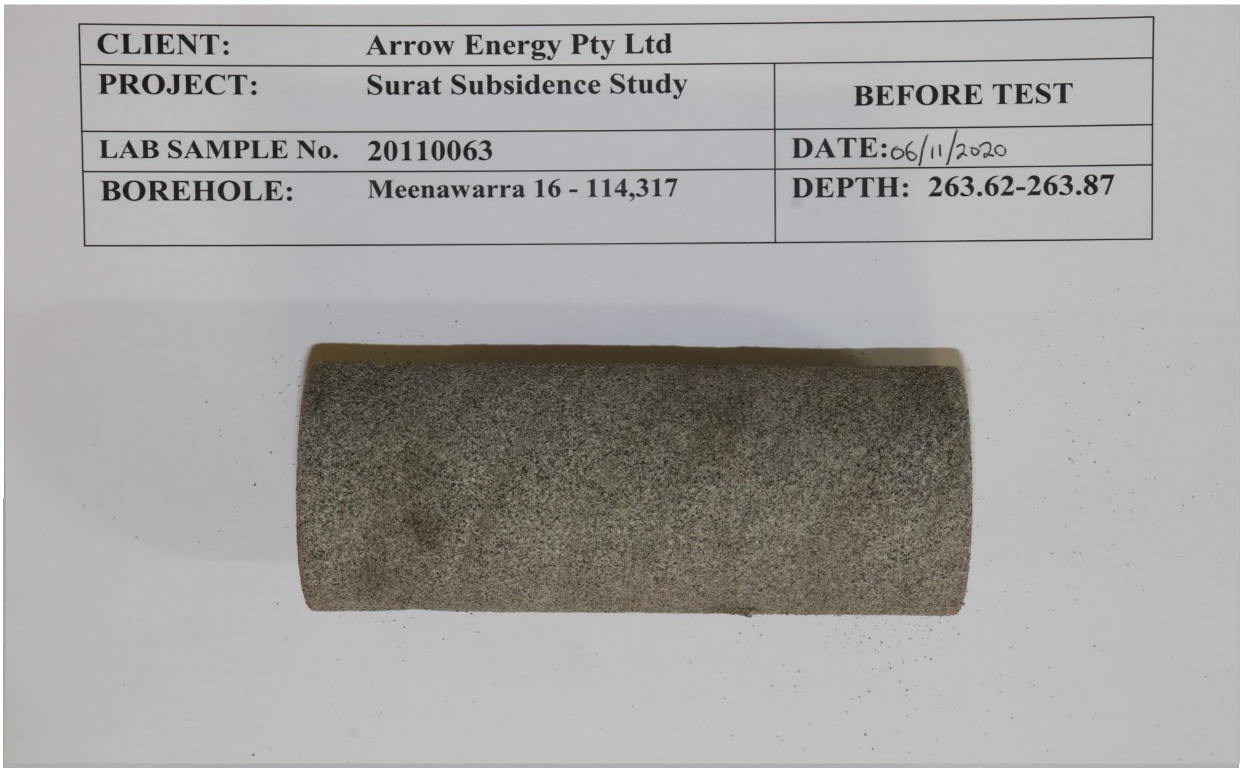
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

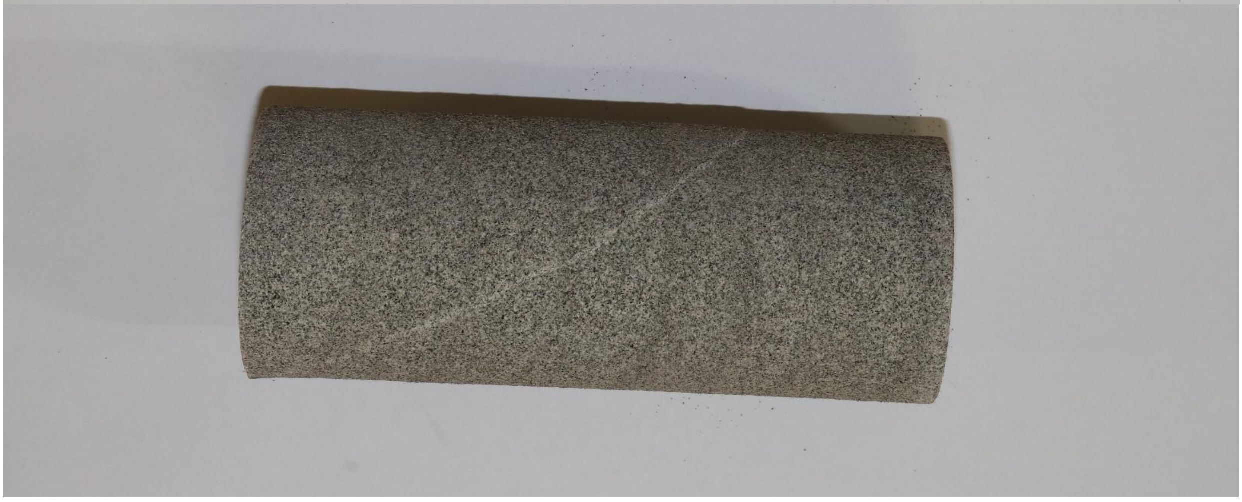
Client Arrow Energy Pty Ltd

Report No. 20110063-RTX

Before and After Test Photos



CLIENT:	Arrow Energy Pty Ltd		
PROJECT:	Surat Subsidence Study	**BEFORE TEST**	
LAB SAMPLE No.	20110063	**DATE:**	06/11/2020
BOREHOLE:	Meenawarra 16 - 114,317	**DEPTH:**	263.62-263.87



Notes/Remarks:

Photo not to scale

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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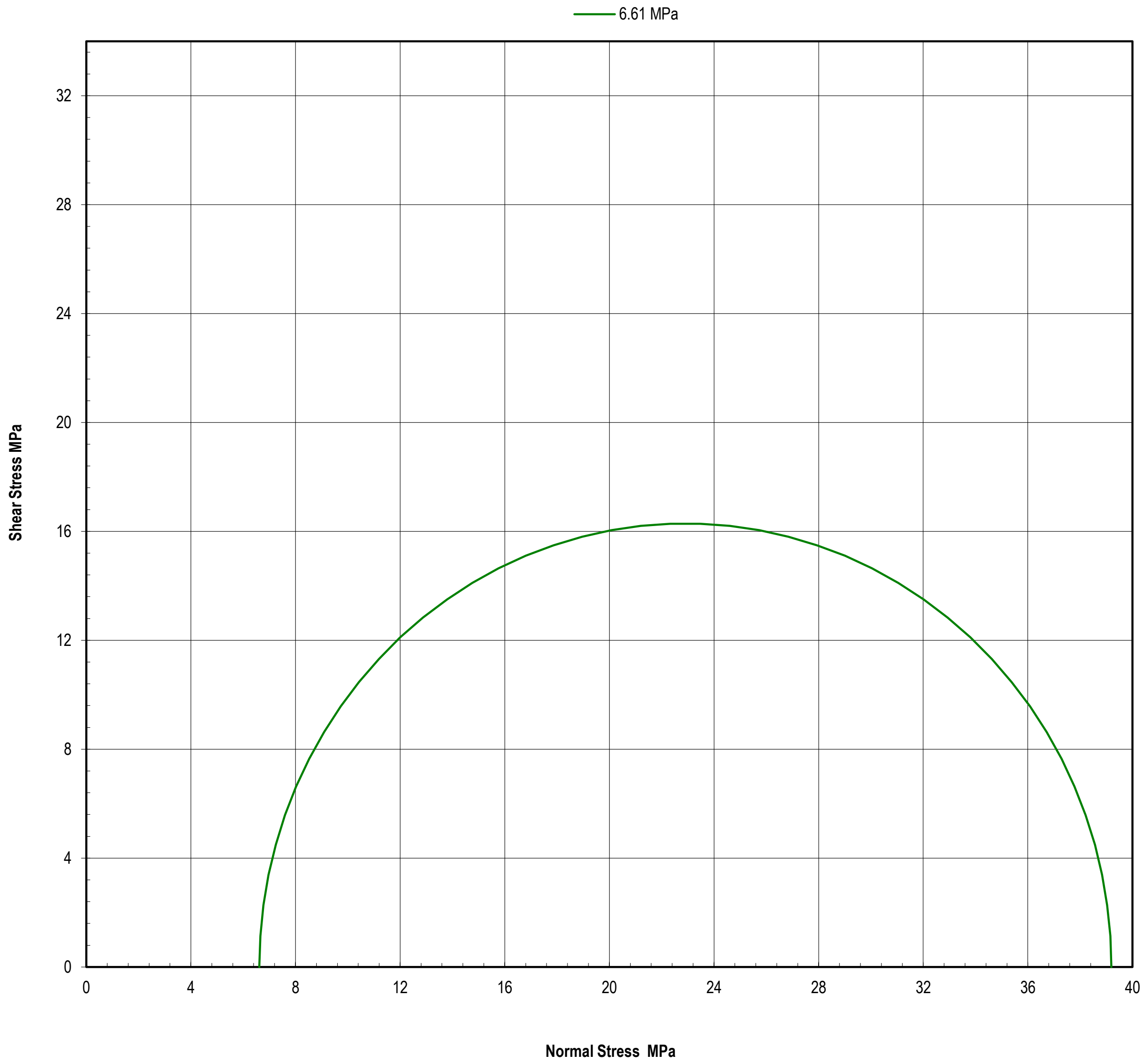
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110063-RTX

Peak Stress Mohr Circle Plot



Notes/Remarks:

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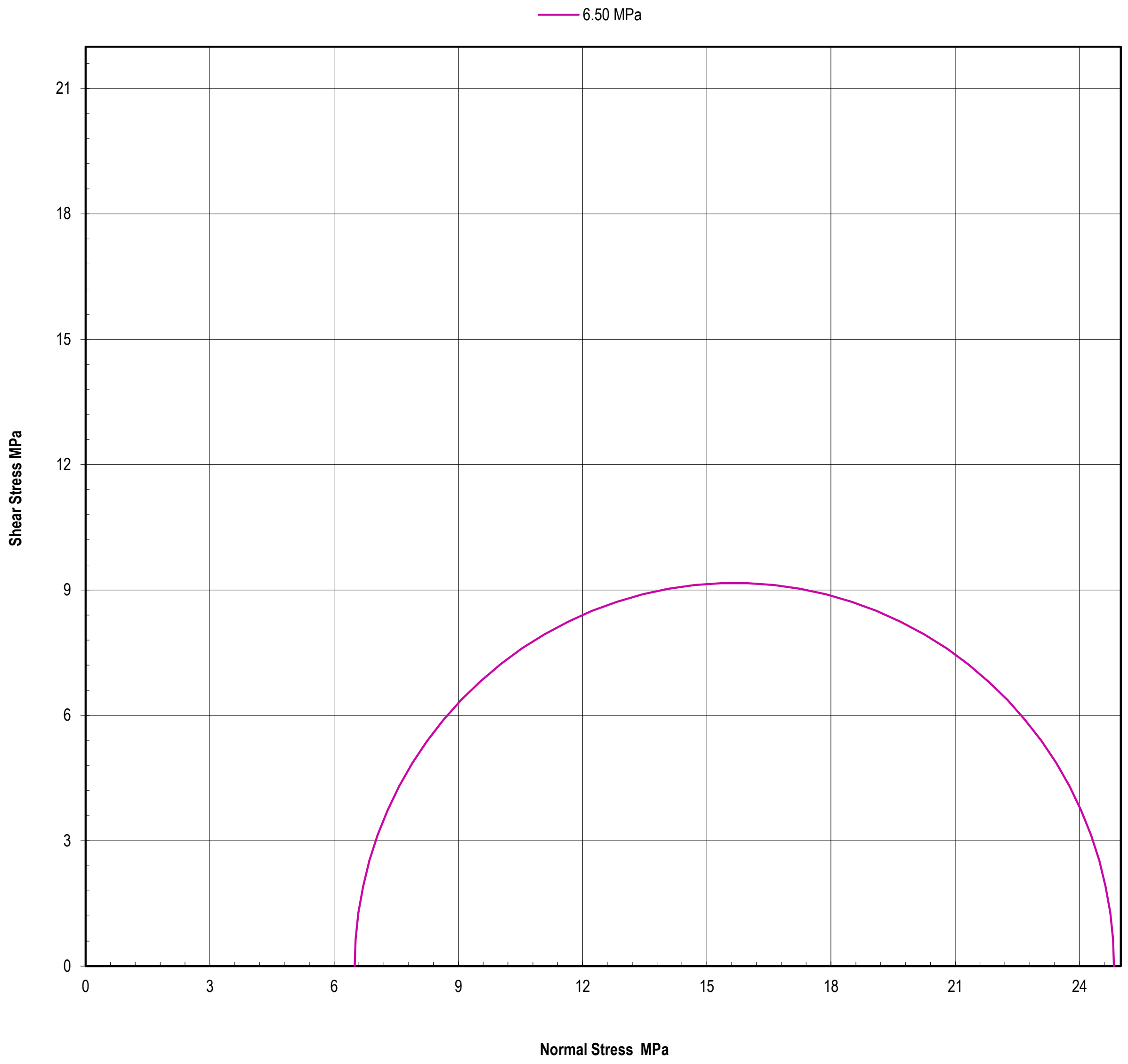
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110063-RTX

Residual Stress Mohr Circle Plot



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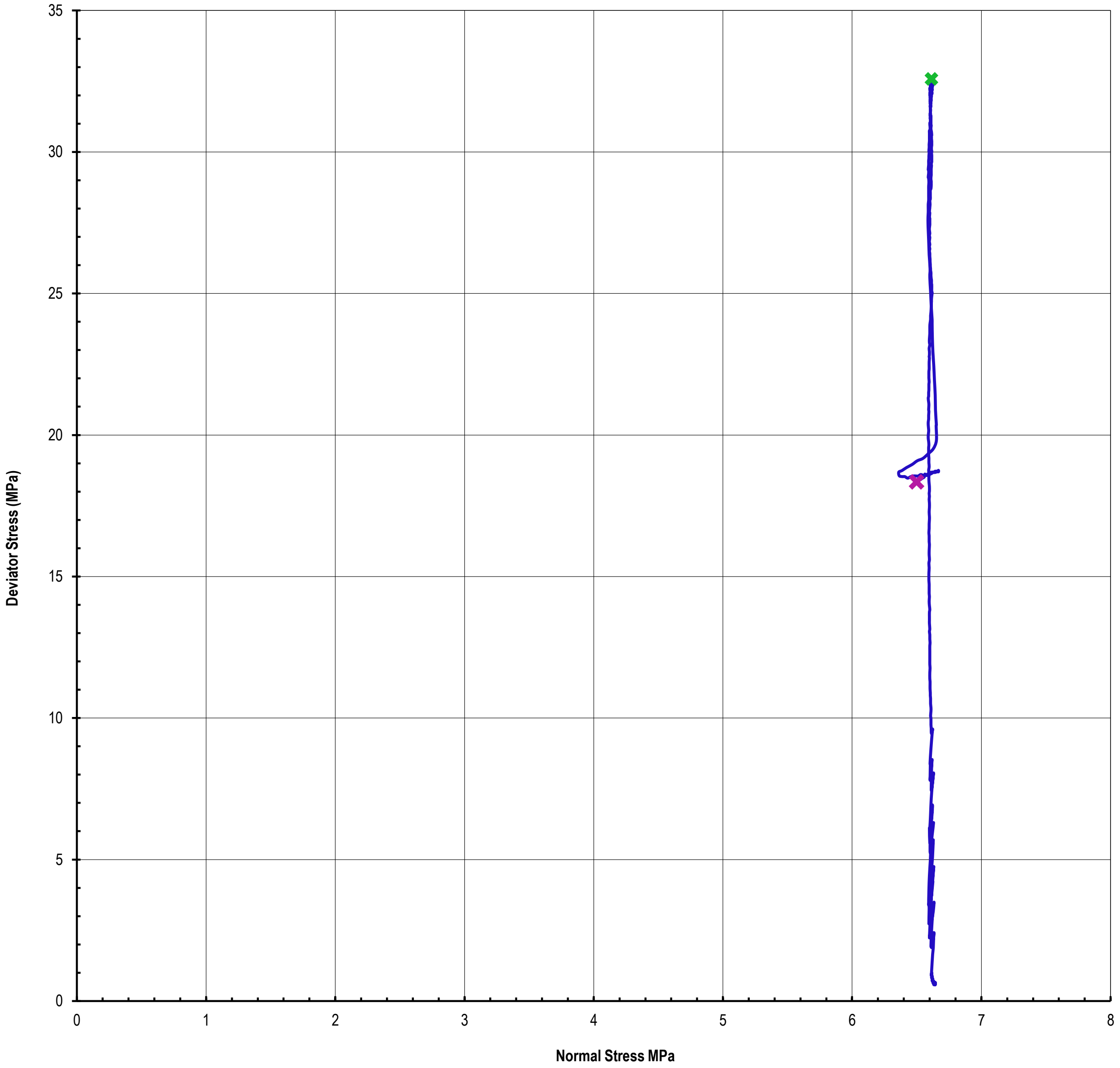
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110063-RTX

Deviator Stress vs Normal Stress Plot



X Peak Value
X Residual Value

Notes/Remarks:

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Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110064-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	9/11/2020
		Report Date	10/01/2020
Project	Surat Subsidence Study		
Client ID	Meenawarra 16 - 114318	**Depth (m)**	267.26-267.47
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.4	Moisture Content (%)	2.4
Sample Height (mm)	145.4	Wet Density (t/m^3)	2.36
Duration of Test (min)	19:50	Dry Density (t/m^3)	2.30
Rate of Strain (%/min)	0.05	Bedding (^{o})	15
Mode of Failure		Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	0		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	6.63				
Deviator Stress (MPa)	40.7				
Axial Strain (µe)	18906				
Diametral Strain (µe)	-8193				
Tangent Modulus (GPa)	2.96				
Poisson's Ratio	0.063				

Residual Test Results

Confining Pressure (MPa)	6.60				
Residual Deviator Stress (MPa)	20.9				
Axial Strain (µe)	21033				
Diametral Strain (µe)	-11922				

Notes/Remarks:

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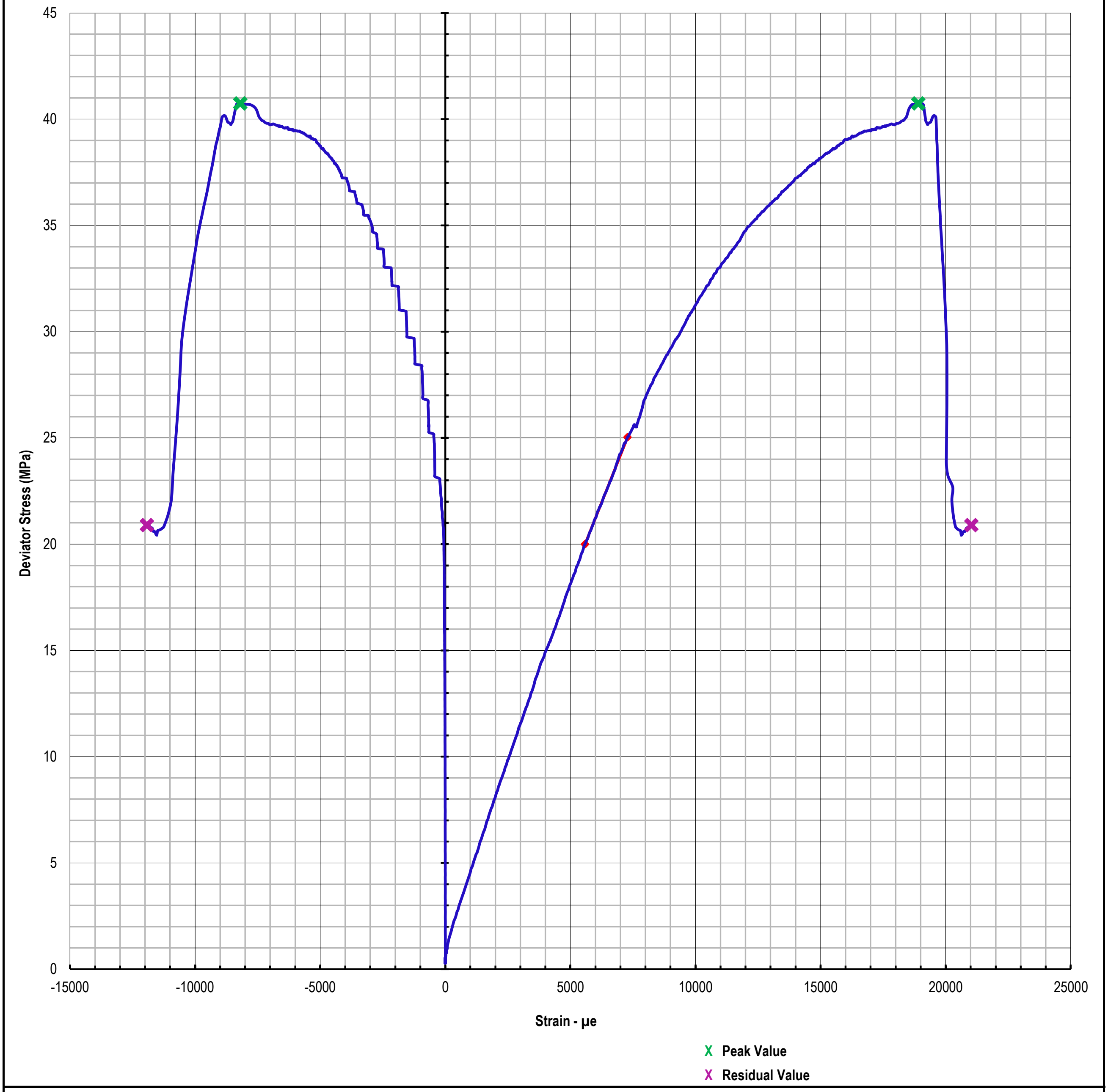
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110064-RTX

Deviator Stress vs Axial Strain Plots



Notes/Remarks:

Graph not to scale

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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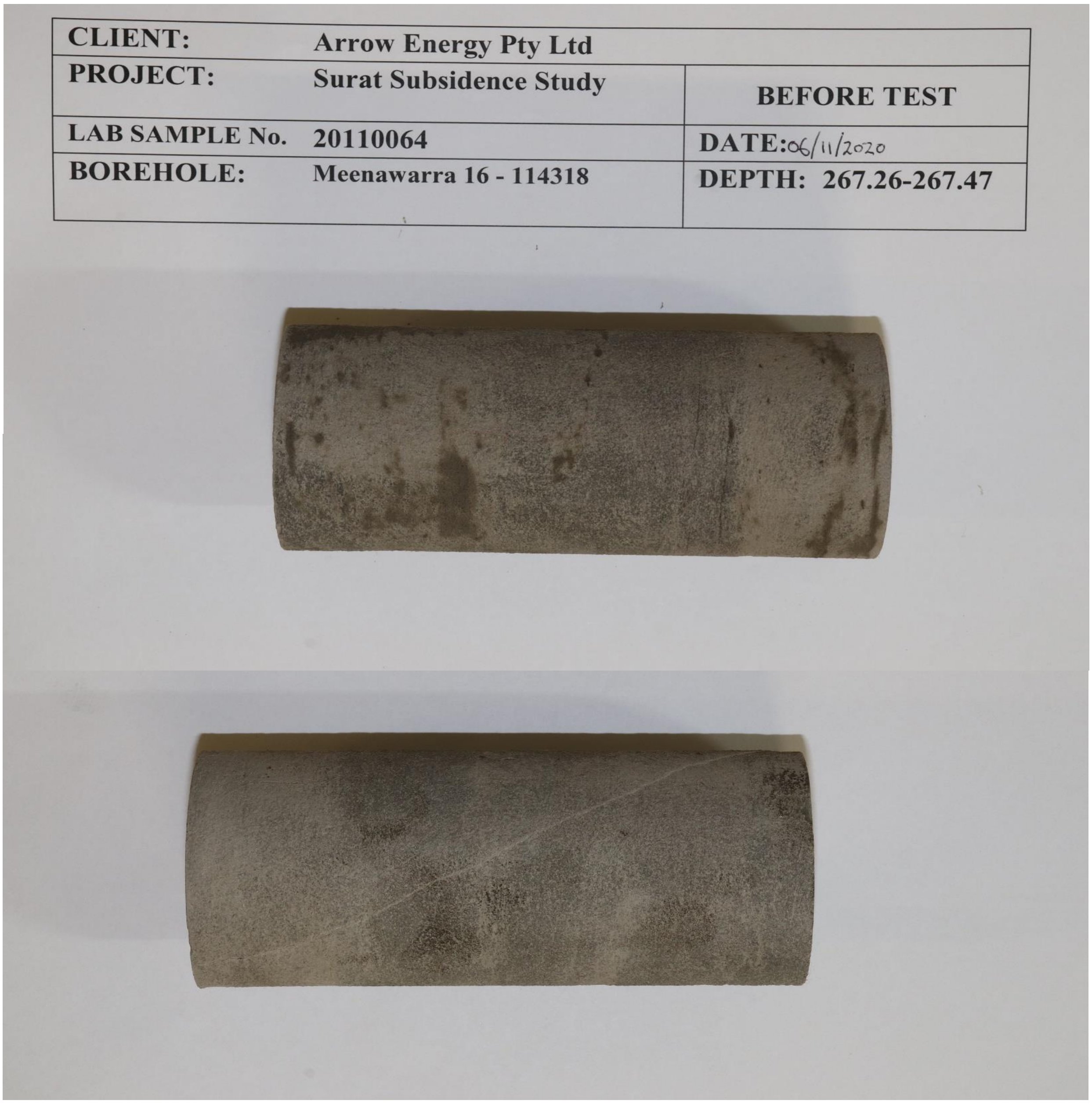
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110064-RTX

Before and After Test Photos



CLIENT: Arrow Energy Pty Ltd
PROJECT: Surat Subsidence Study
BEFORE TEST
LAB SAMPLE No. 20110064
DATE: 06/11/2020
BOREHOLE: Meenawarra 16 - 114318
DEPTH: 267.26-267.47

Notes/Remarks:

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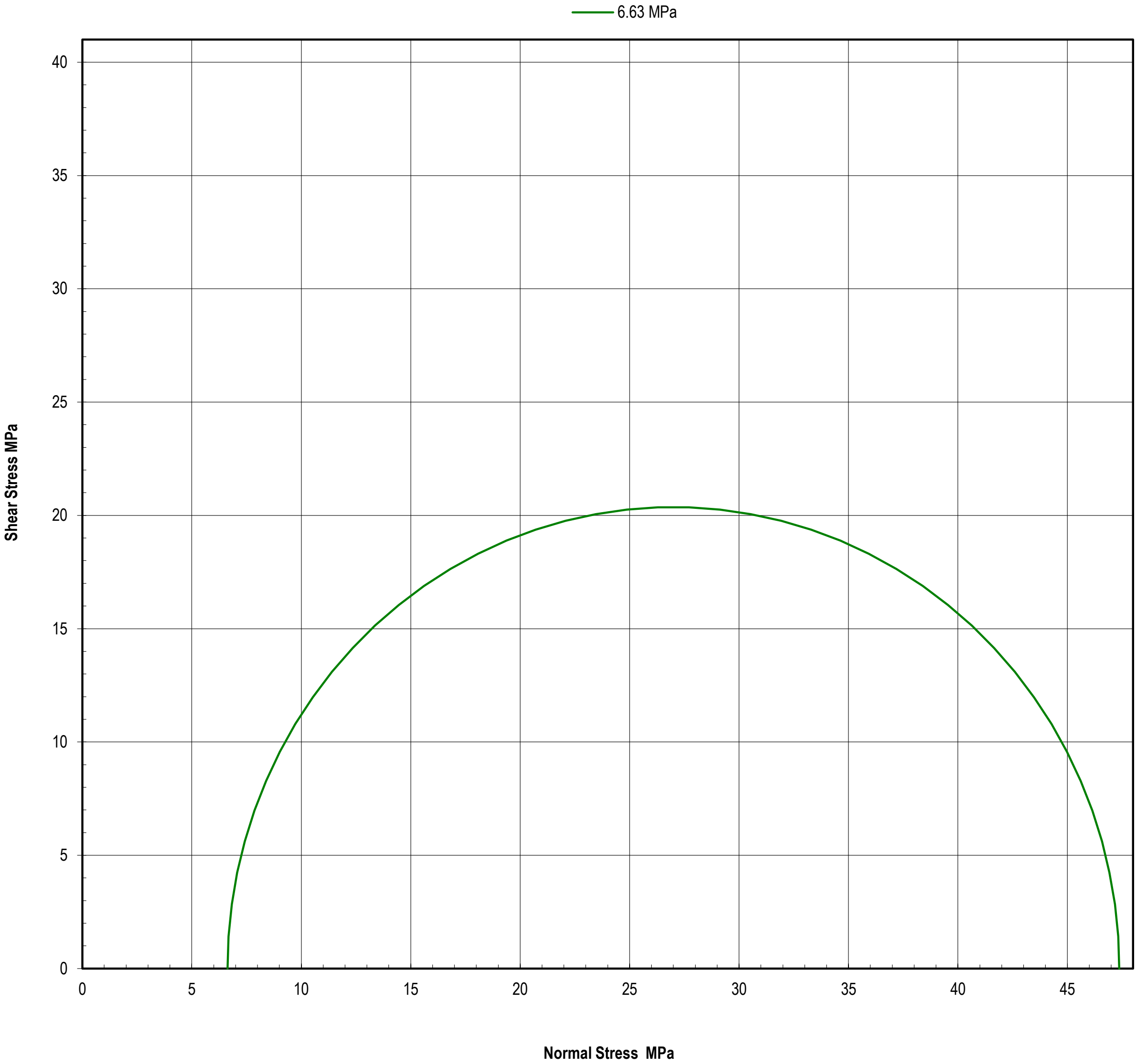
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110064-RTX

Peak Stress Mohr Circle Plot



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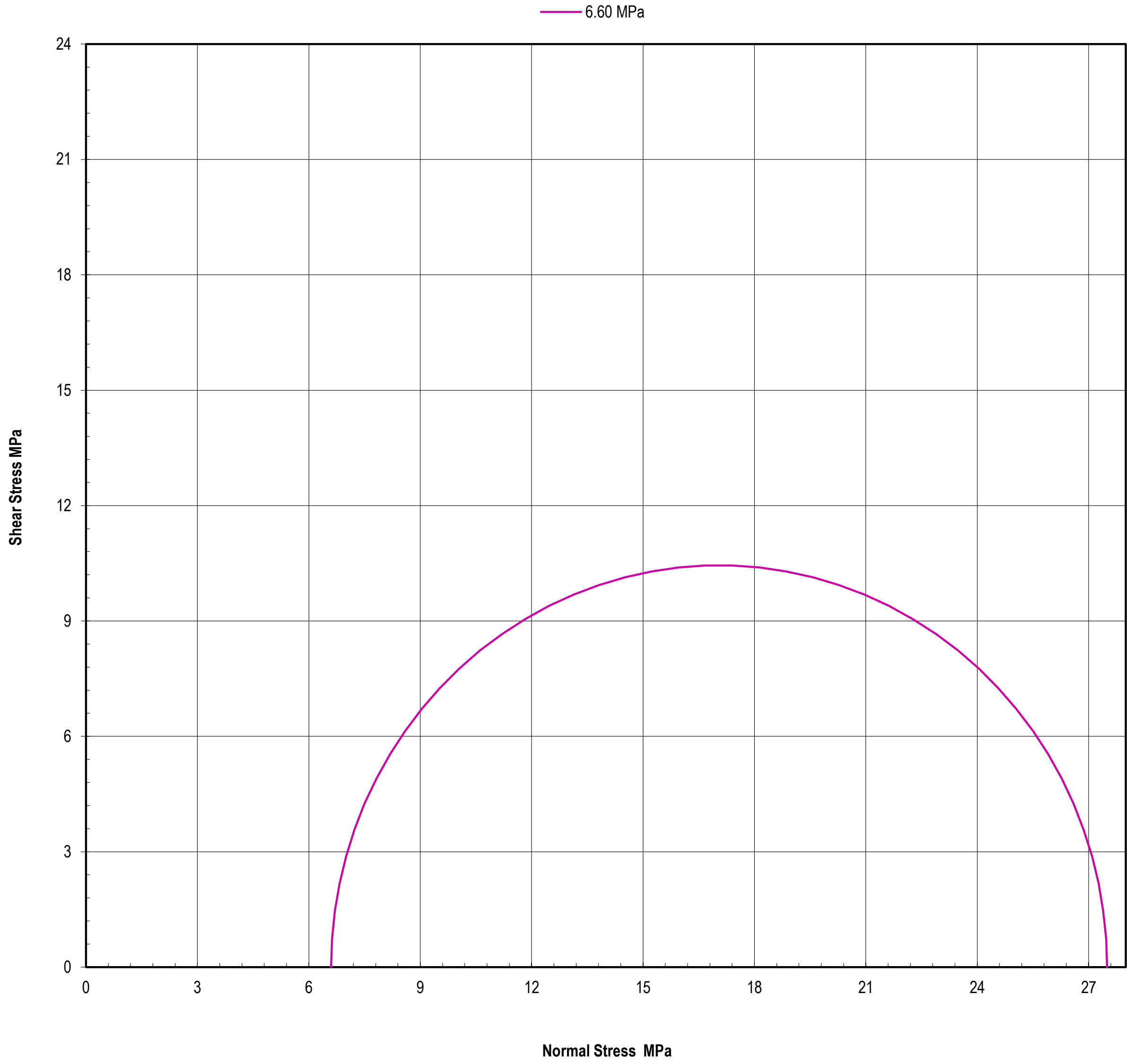
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110064-RTX

Residual Stress Mohr Circle Plot



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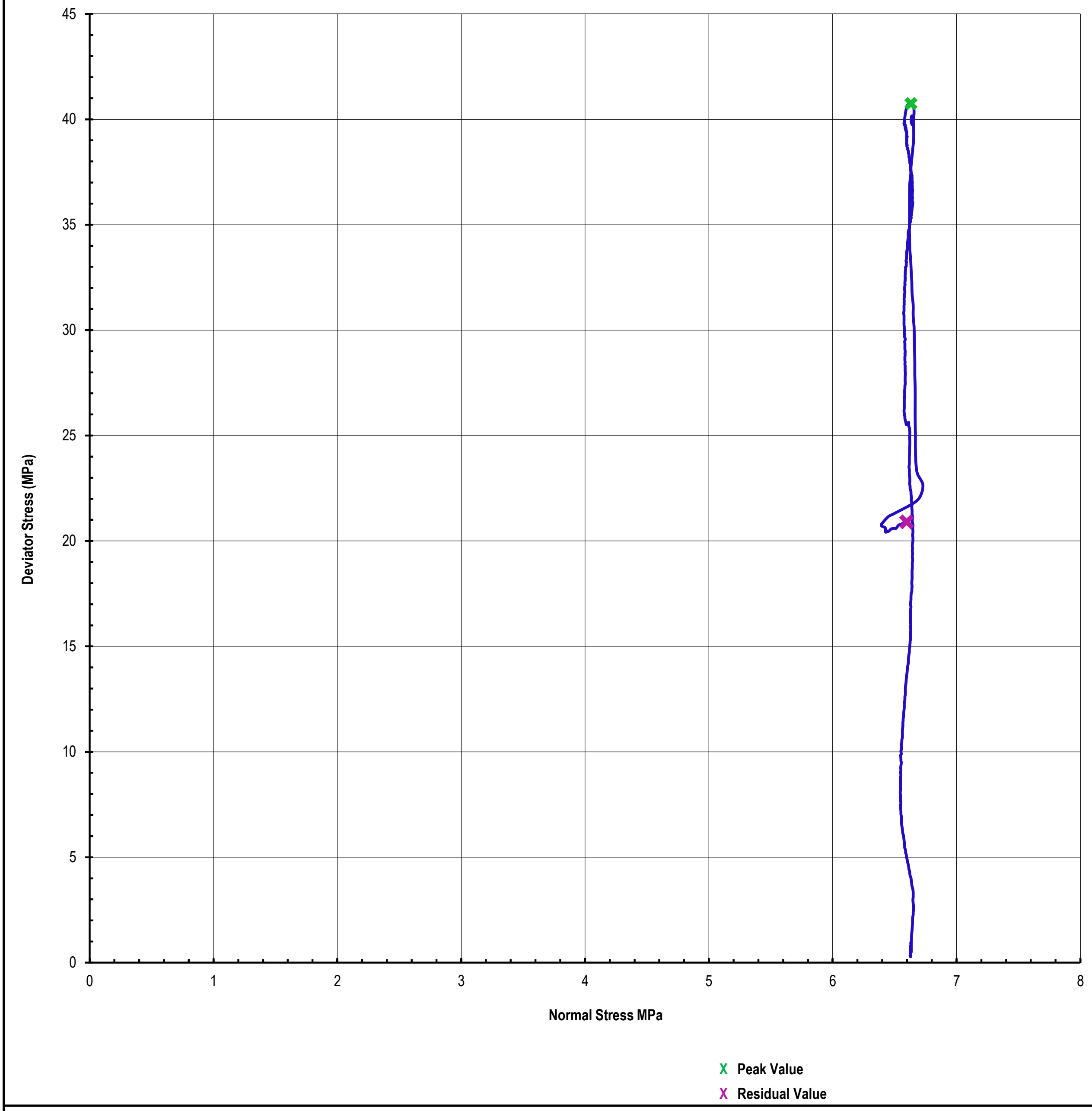
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110064-RTX

Deviator Stress vs Normal Stress Plot



Notes/Remarks:

Graph not to scale

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110065-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	10/11/2020
		Report Date	11/11/2020
Project	Surat Subsidence Study		
Client ID	Meenawarra 16 - 114319	**Depth (m)**	282.36-282.54
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.6	Moisture Content (%)	2.4
Sample Height (mm)	146.3	Wet Density (t/m^3)	2.37
Duration of Test (min)	14:50	Dry Density (t/m^3)	2.31
Rate of Strain (%/min)	0.05	Bedding (^{o})	15
Mode of Failure	Shear	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	75		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	7.02				
Deviator Stress (MPa)	50.3				
Axial Strain (µe)	16186				
Diametral Strain (µe)	-5735				
Tangent Modulus (GPa)	3.95				
Poisson's Ratio	0.073				

Residual Test Results

Confining Pressure (MPa)	7.05				
Residual Deviator Stress (MPa)	28.0				
Axial Strain (µe)	21642				
Diametral Strain (µe)	-10694				

Notes/Remarks:

Sample/s supplied by client

Tested as received

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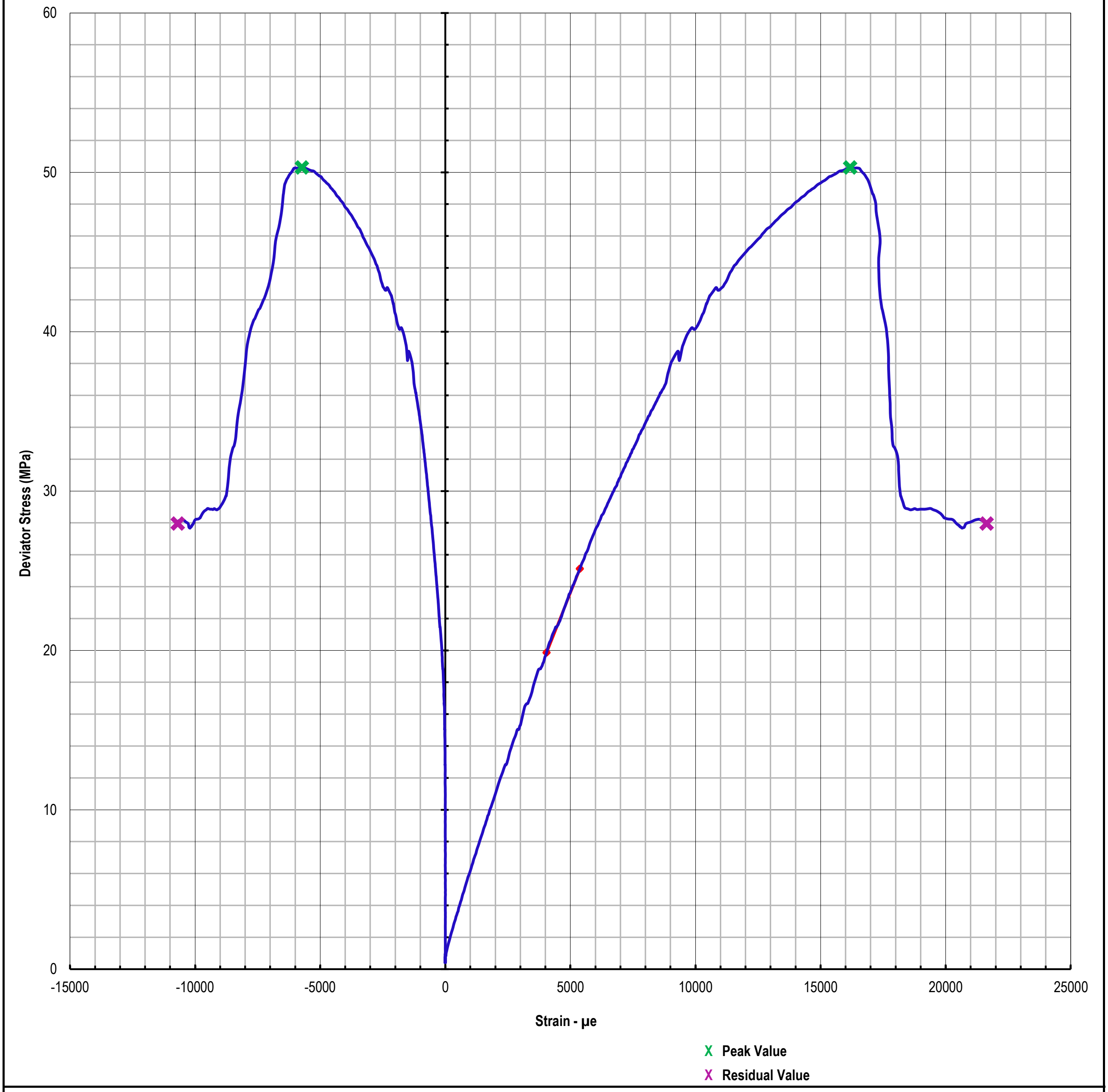
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110065-RTX

Deviator Stress vs Axial Strain Plots



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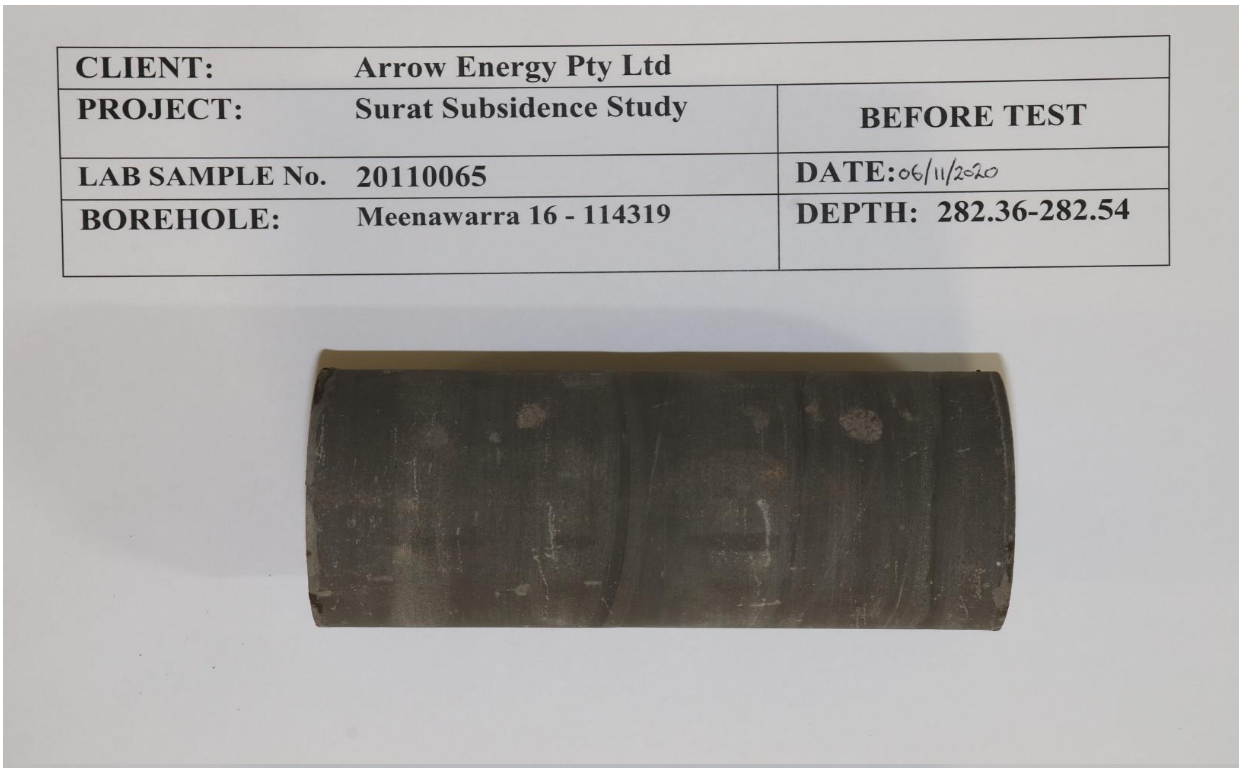
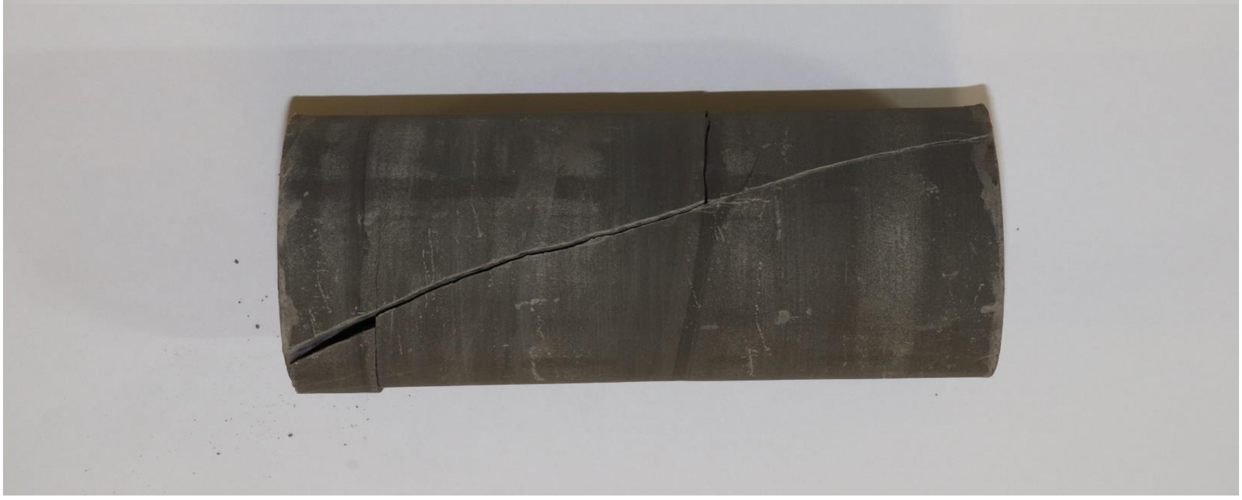
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110065-RTX

Before and After Test Photos



CLIENT:	**Arrow Energy Pty Ltd**	
PROJECT:	**Surat Subsidence Study**	**BEFORE TEST**
LAB SAMPLE No.	**20110065**	**DATE:** 06/11/2020
BOREHOLE:	**Meenawarra 16 - 114319**	**DEPTH: 282.36-282.54**



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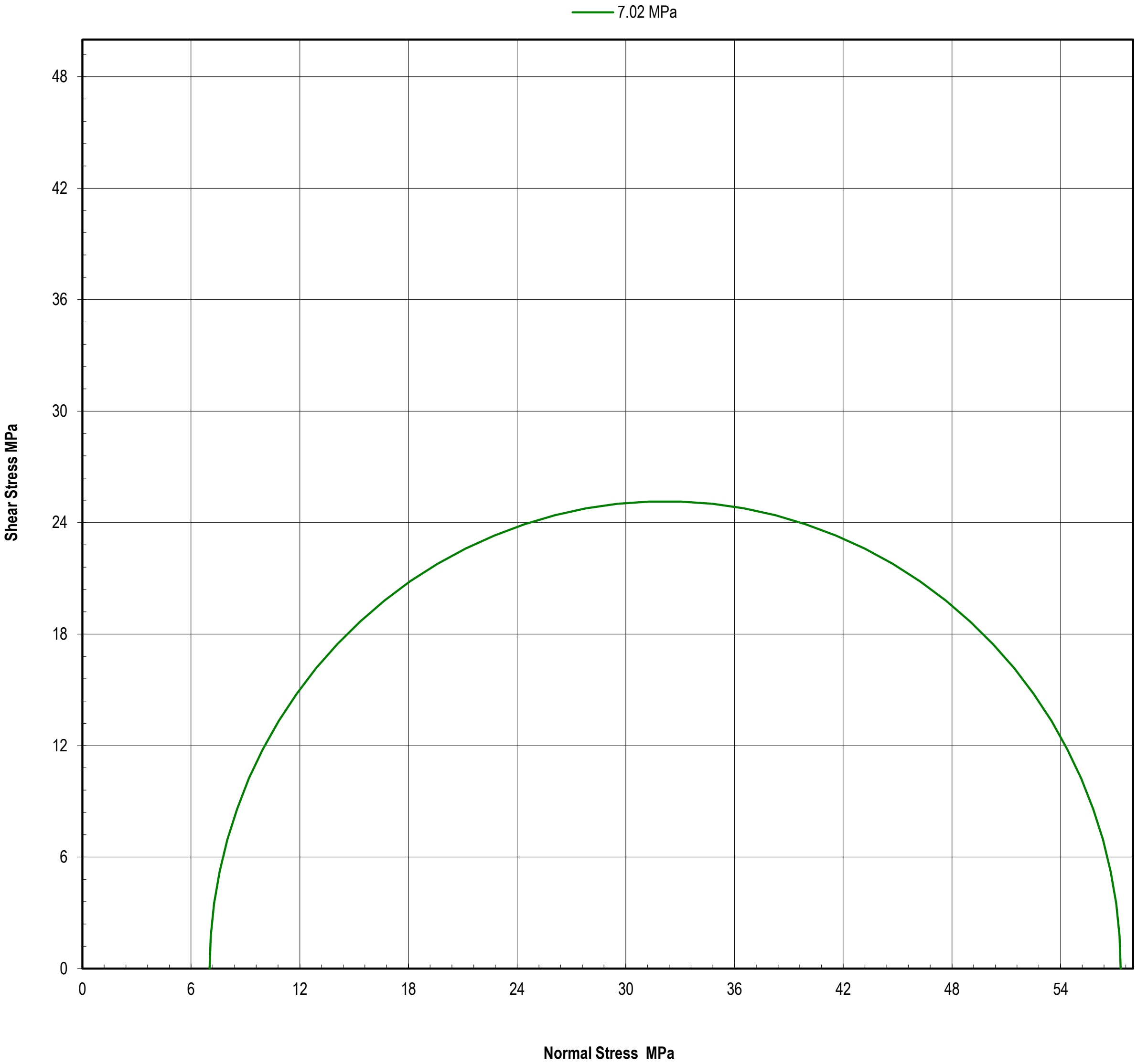
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110065-RTX

Peak Stress Mohr Circle Plot



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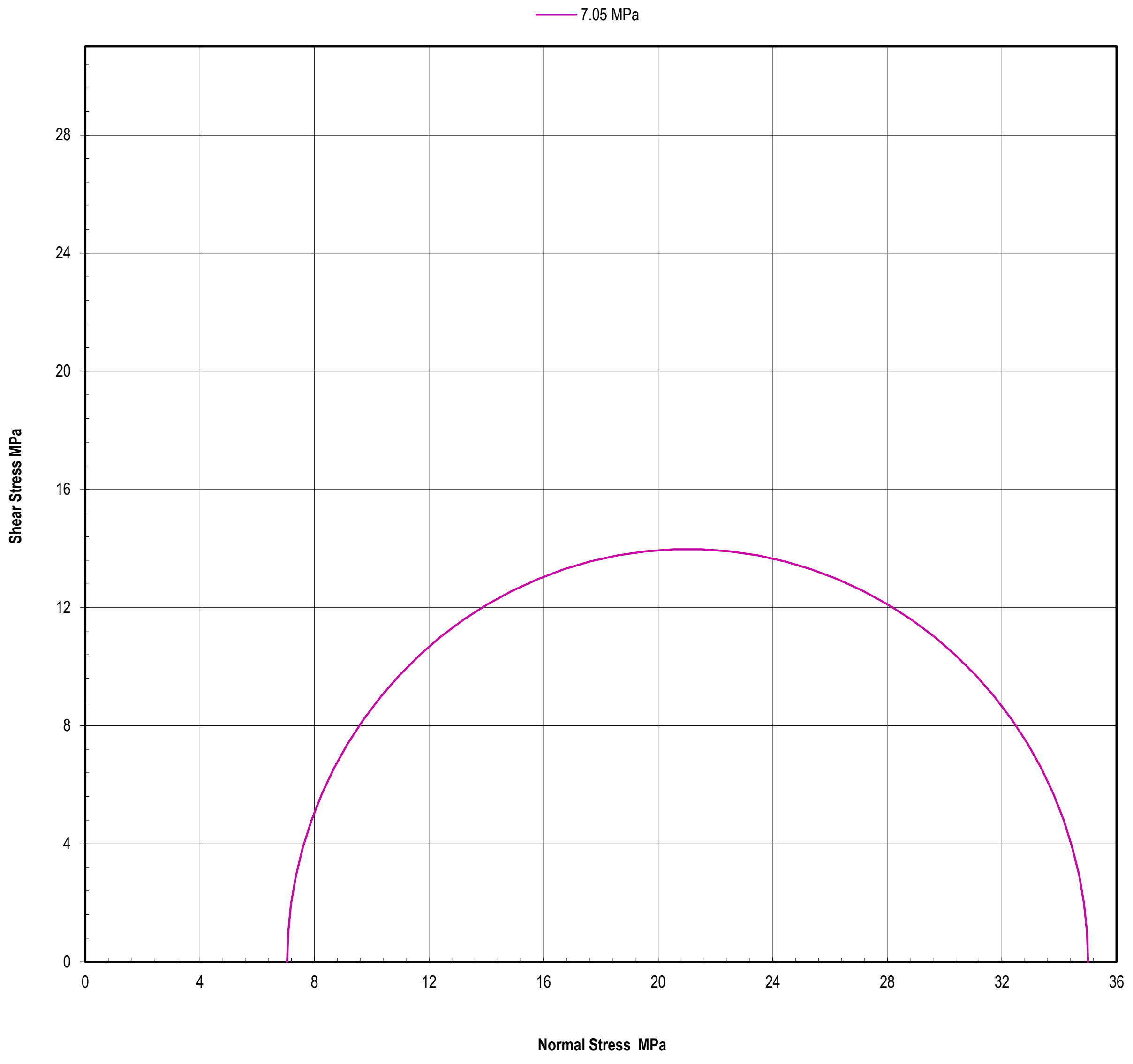
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110065-RTX

Residual Stress Mohr Circle Plot



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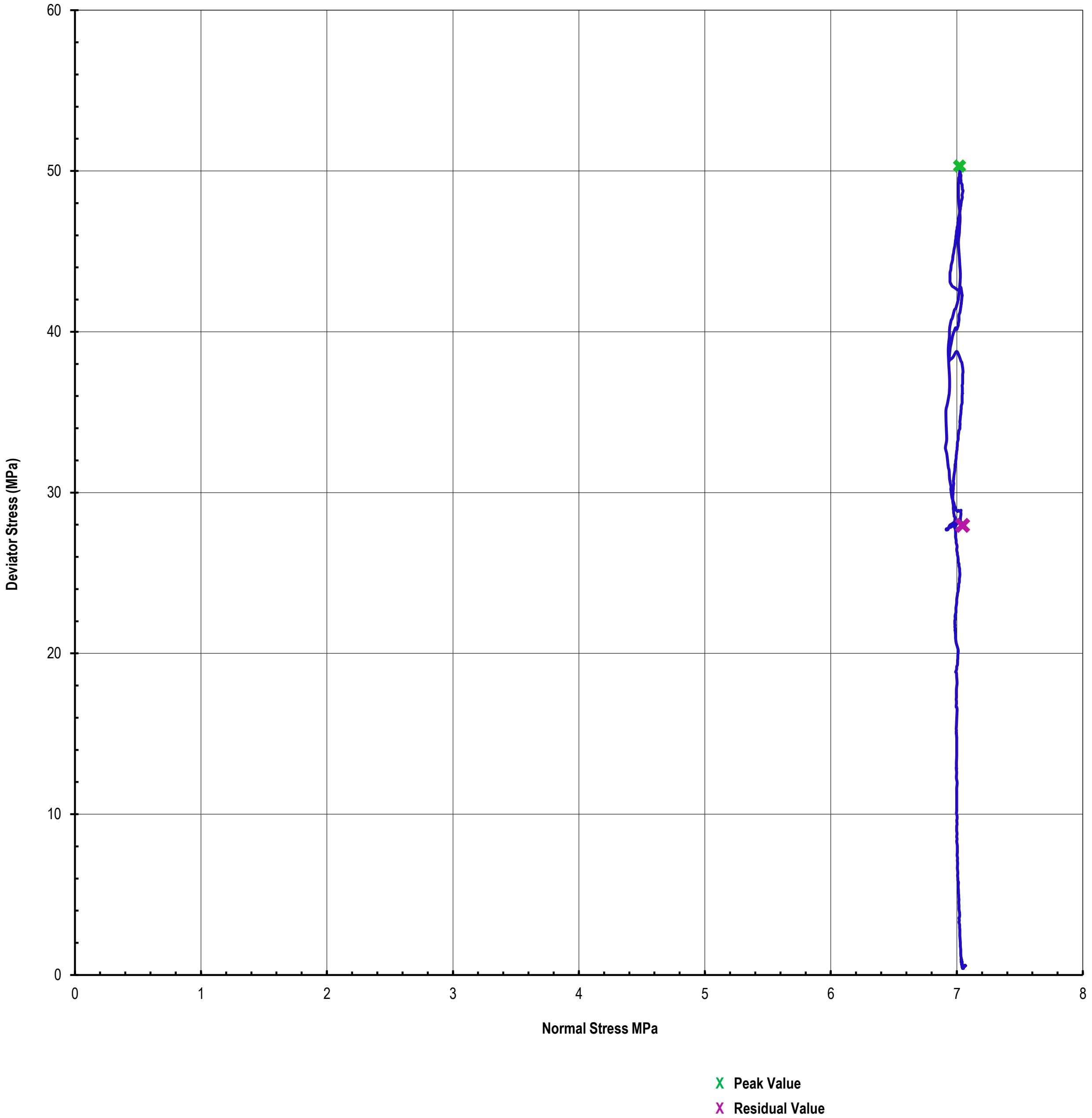
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110065-RTX

Deviator Stress vs Normal Stress Plot



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Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110066-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	10/11/2020
		Report Date	11/11/2020
Project	Surat Subsidence Study		
Client ID	Meenawarra 16 - 114320	**Depth (m)**	363.67-363-85
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.8	Moisture Content (%)	2.2
Sample Height (mm)	125.8	Wet Density (t/m^3)	2.41
Duration of Test (min)	16:25	Dry Density (t/m^3)	2.36
Rate of Strain (%/min)	0.05	Bedding (^{o})	5
Mode of Failure	Shear	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	70		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	9.06				
Deviator Stress (MPa)	55.2				
Axial Strain (με)	10264				
Diametral Strain (με)	-2298				
Tangent Modulus (GPa)	6.62				
Poisson's Ratio	0.096				

Residual Test Results

Confining Pressure (MPa)	8.98				
Residual Deviator Stress (MPa)	35.8				
Axial Strain (με)	17193				
Diametral Strain (με)	-8062				

Notes/Remarks:

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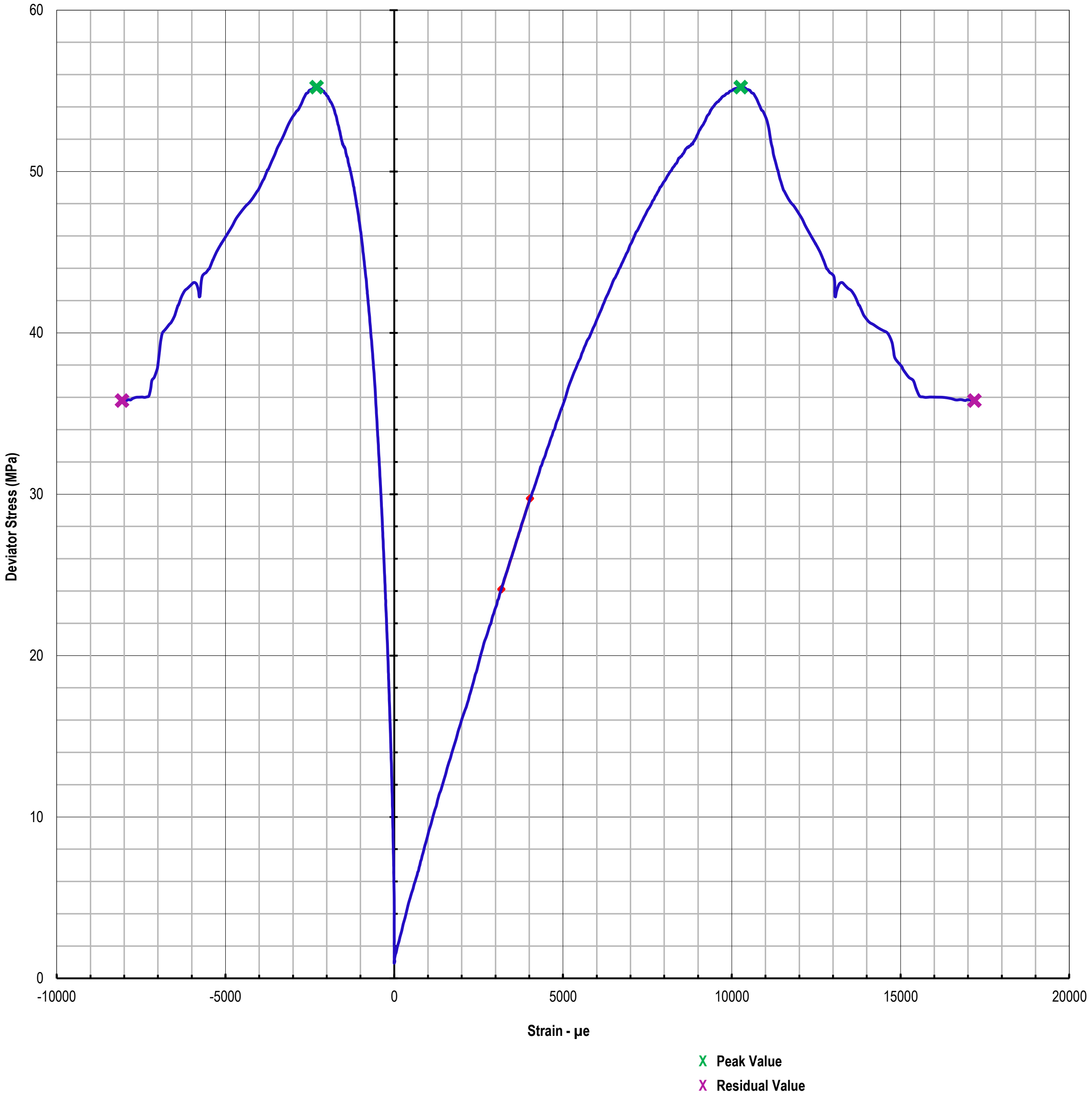
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110066-RTX

Deviator Stress vs Axial Strain Plots



Notes/Remarks:

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Sample/s supplied by client

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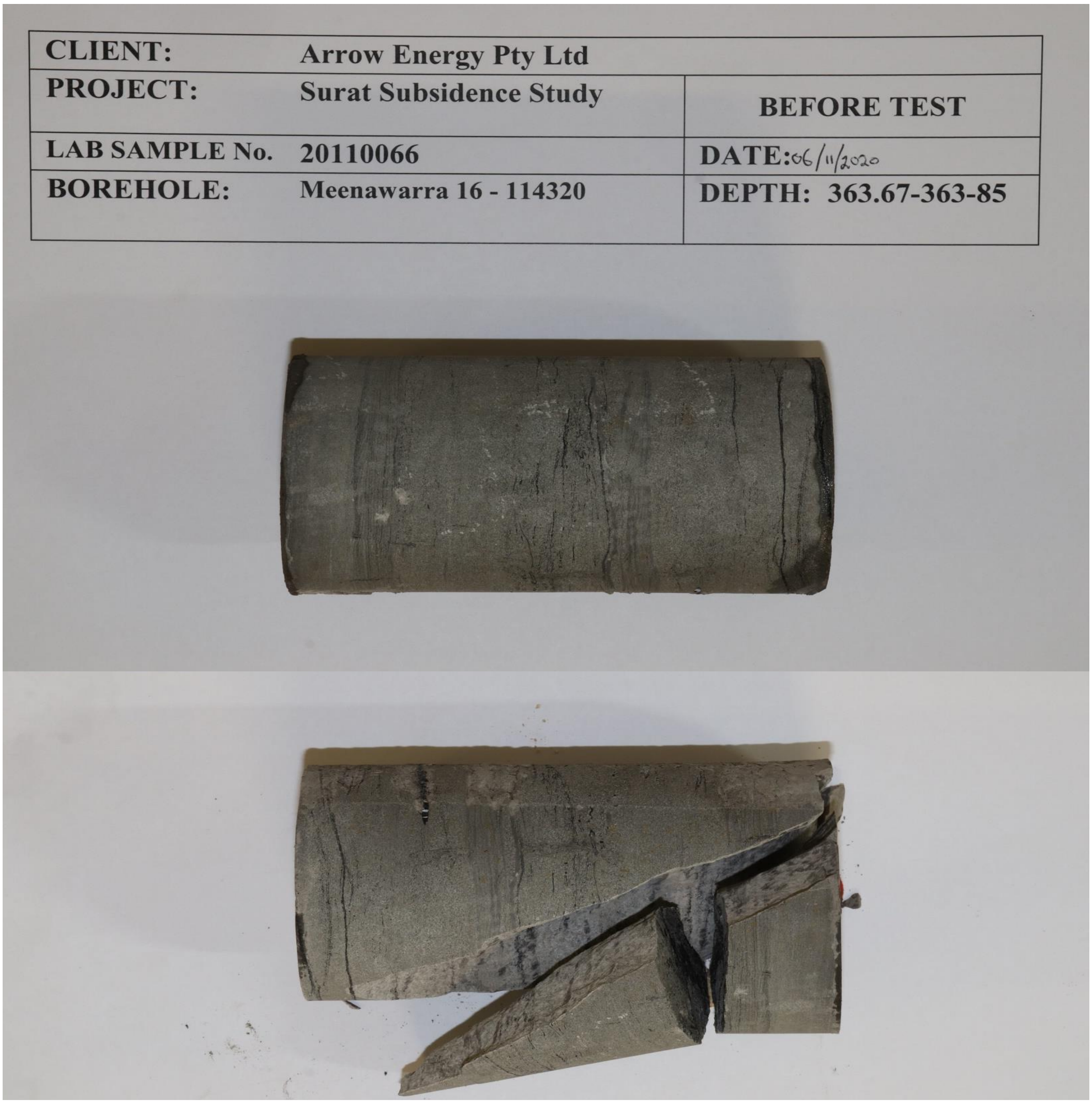
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110066-RTX

Before and After Test Photos



CLIENT: Arrow Energy Pty Ltd
PROJECT: Surat Subsidence Study
BEFORE TEST
LAB SAMPLE No. 20110066
DATE: 06/11/2020
BOREHOLE: Meenawarra 16 - 114320
DEPTH: 363.67-363-85

Notes/Remarks:

Photo not to scale

Sample/s supplied by client

Tested as received

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

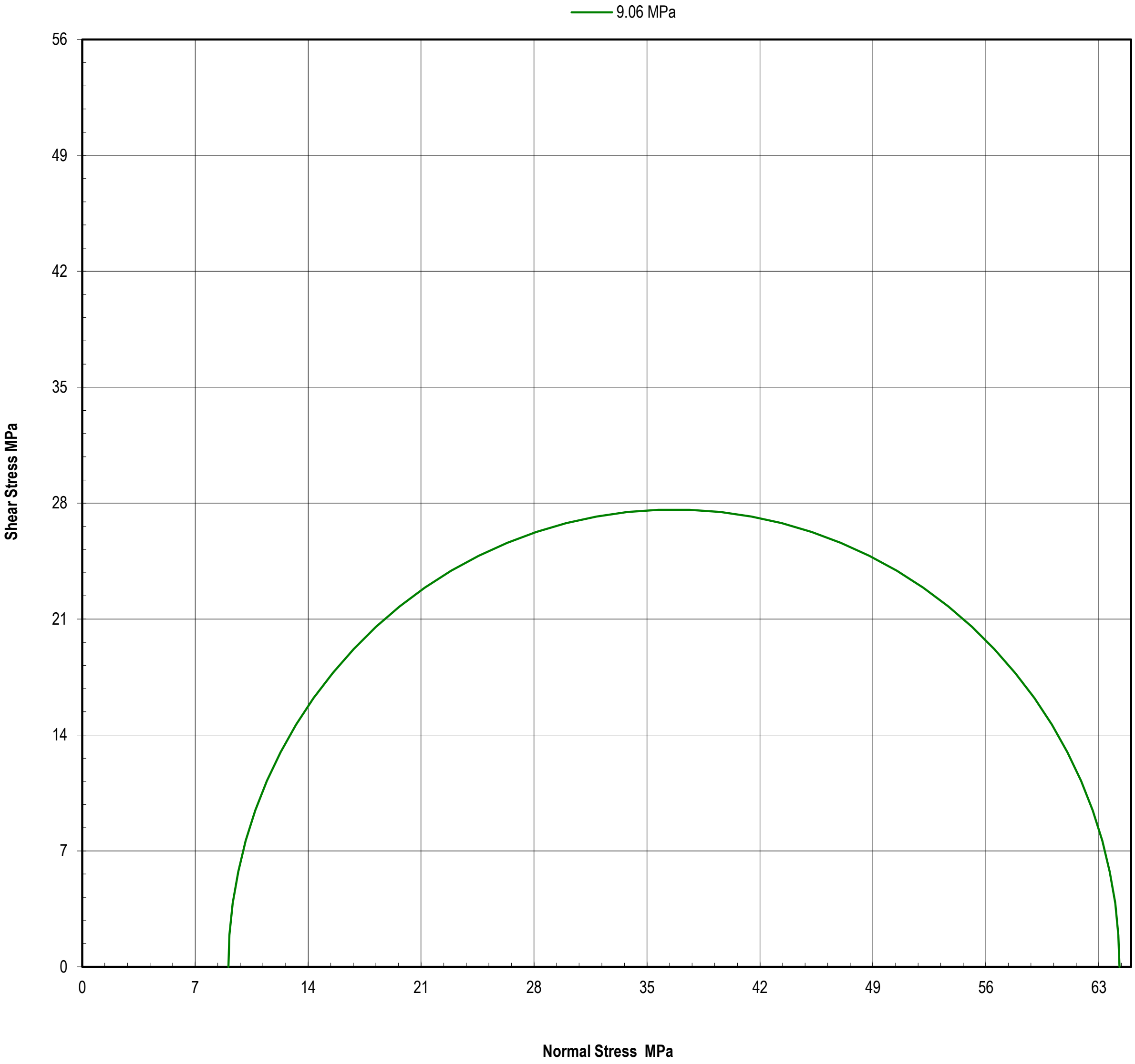
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110066-RTX

Peak Stress Mohr Circle Plot



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Tested at Trilab Brisbane Laboratory

Authorised Signatory

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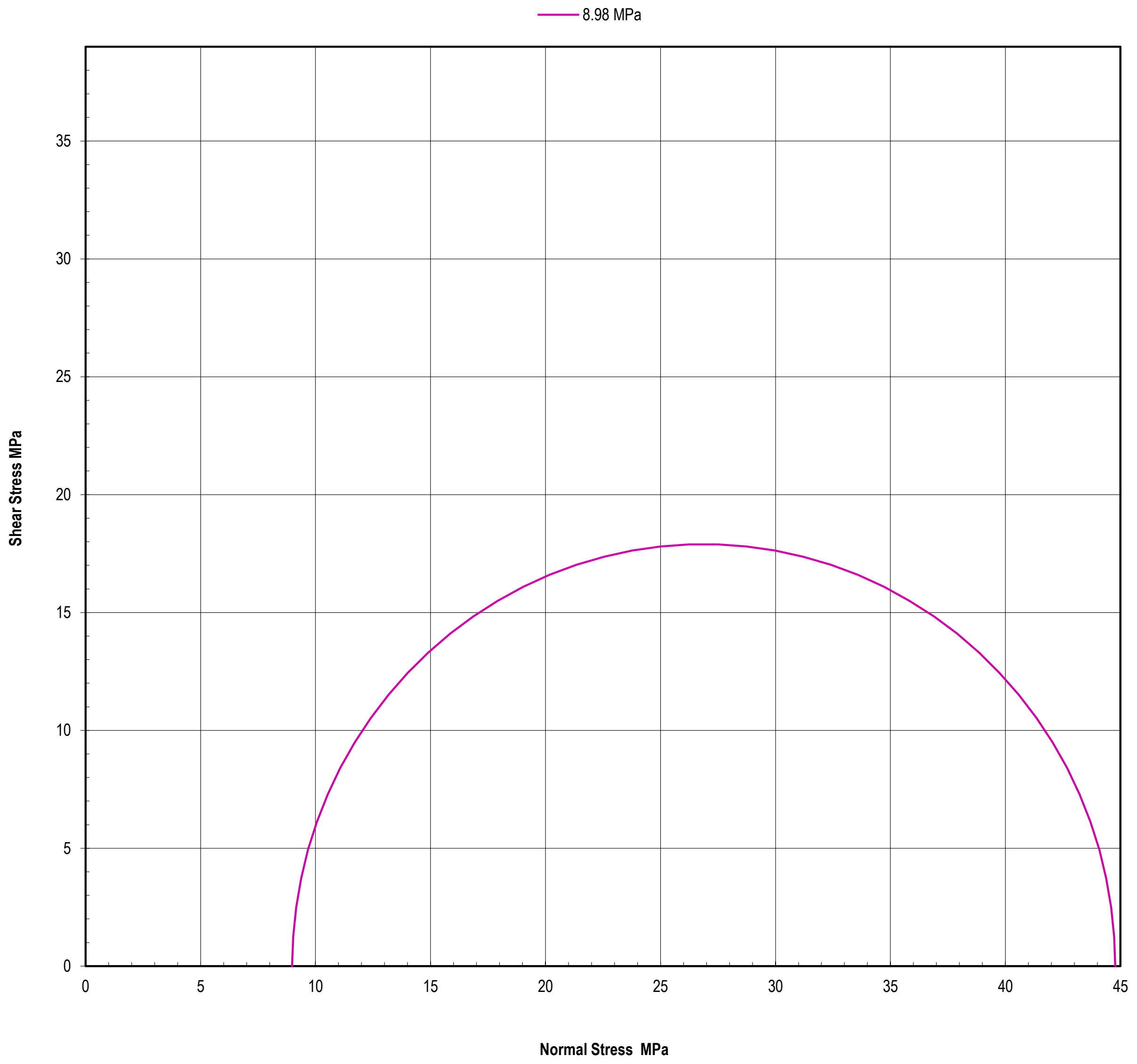
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110066-RTX

Residual Stress Mohr Circle Plot



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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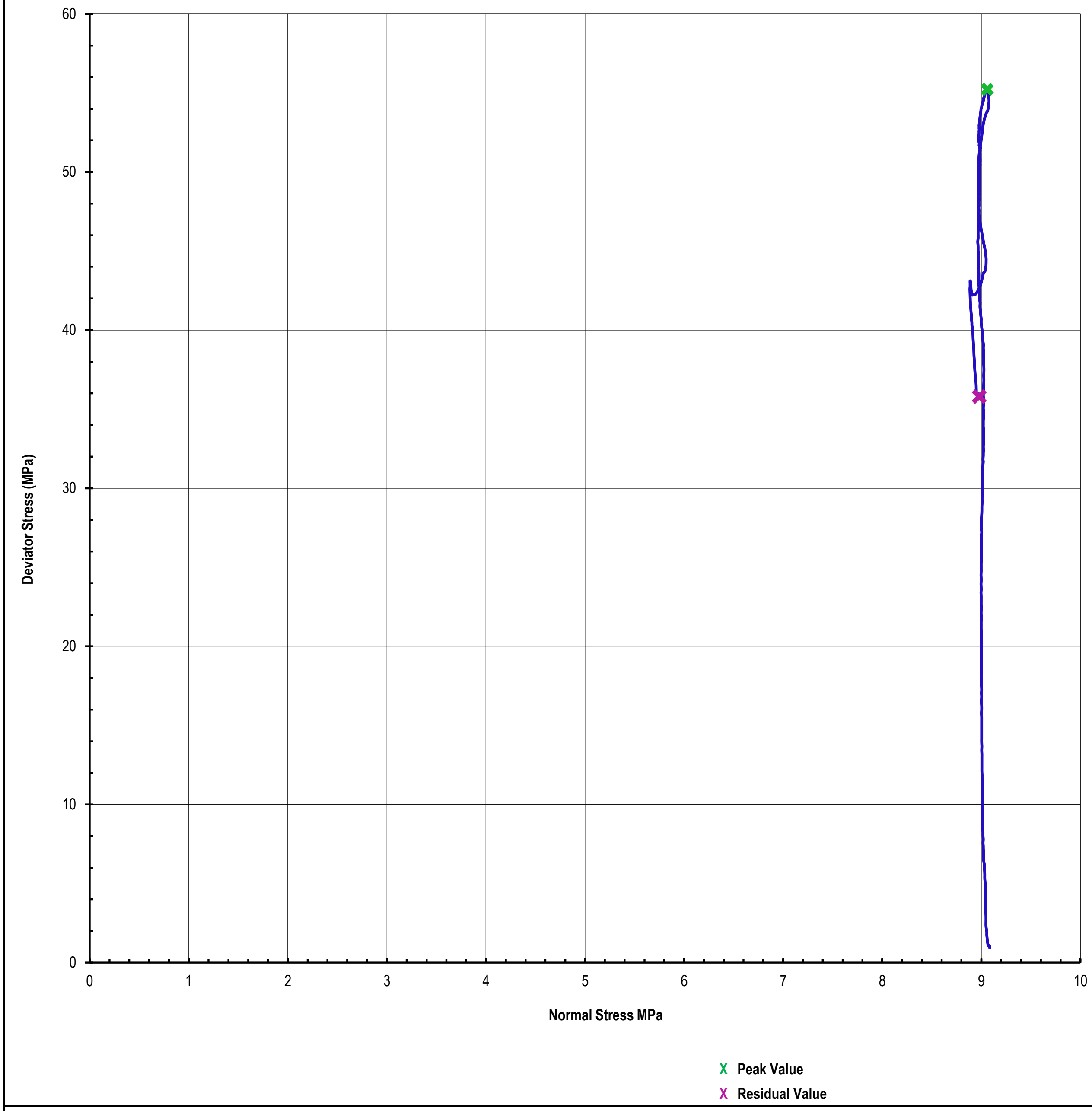
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110066-RTX

Deviator Stress vs Normal Stress Plot



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.** **Workorder No.**	20110067-RTX 0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date** **Report Date**	10/11/2020 11/11/2020
Project	Surat Subsidence Study		
Client ID	Meenawarra 16 - 114,321	**Depth (m)**	419.86-420.00
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.4	Moisture Content (%)	3.4
Sample Height (mm)	127.6	Wet Density (t/m^3)	1.62
Duration of Test (min)	18:09	Dry Density (t/m^3)	1.57
Rate of Strain (%/min)	0.05	Bedding (^{o})	15
Mode of Failure	Shear and Defect	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	65		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	10.36				
Deviator Stress (MPa)	52.8				
Axial Strain (µe)	25462				
Diametral Strain (µe)	-11338				
Tangent Modulus (GPa)	2.64				
Poisson's Ratio	0.158				

Residual Test Results

Confining Pressure (MPa)	10.47				
Residual Deviator Stress (MPa)	33.6				
Axial Strain (µe)	33629				
Diametral Strain (µe)	-18558				

Notes/Remarks:

Sample/s supplied by client Tested as received

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Authorised Signatory
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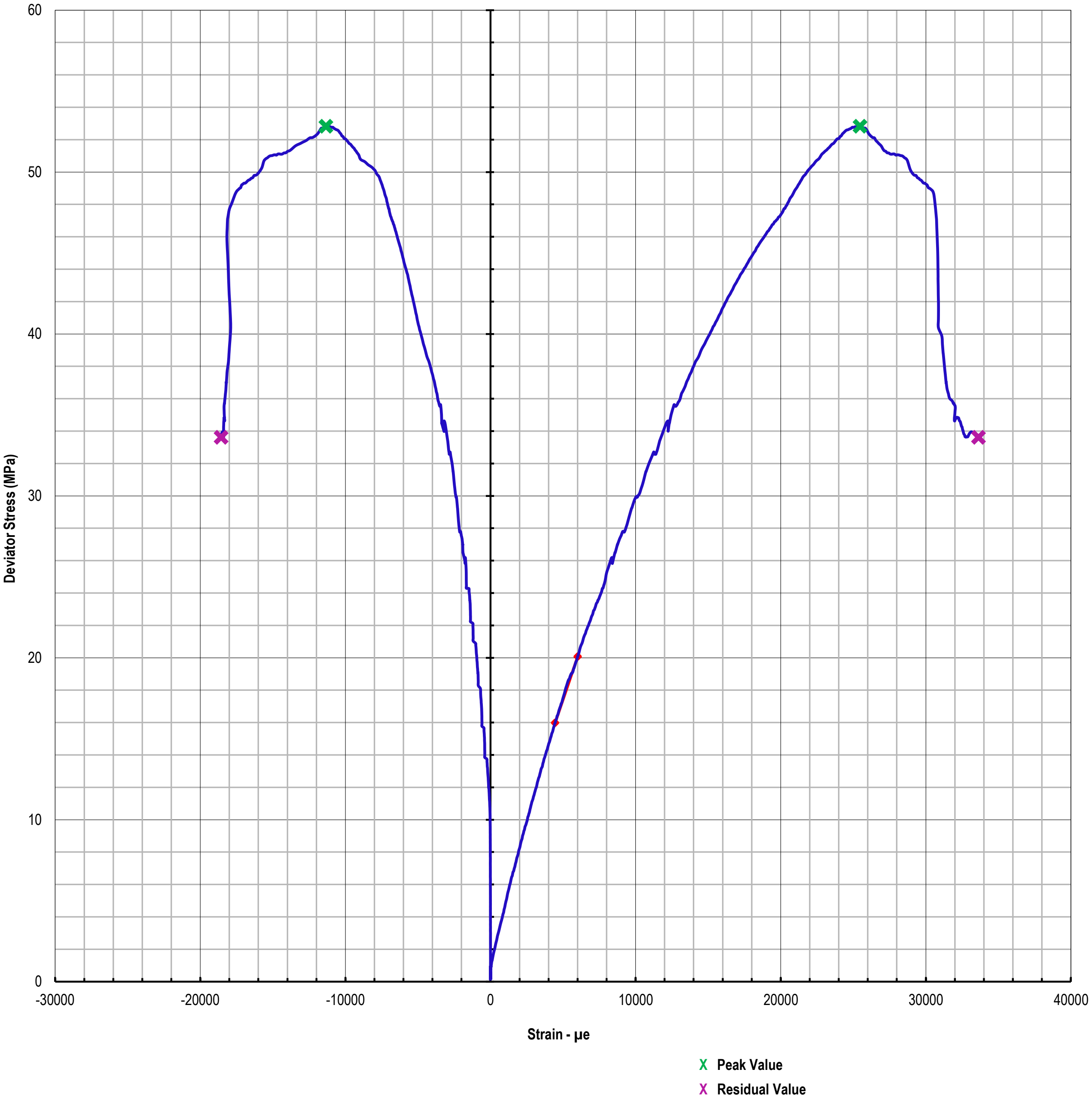
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110067-RTX

Deviator Stress vs Axial Strain Plots



Notes/Remarks:

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110067-RTX

Before and After Test Photos

CLIENT:	Arrow Energy Pty Ltd	
PROJECT:	Surat Subsidence Study	**BEFORE TEST**
LAB SAMPLE No.	20110067	**DATE:** 06/11/2020
BOREHOLE:	Meenawarra 16 - 114,321	**DEPTH:** 419.86-420.00

Notes/Remarks:

Photo not to scale

Sample/s supplied by client

Tested as received

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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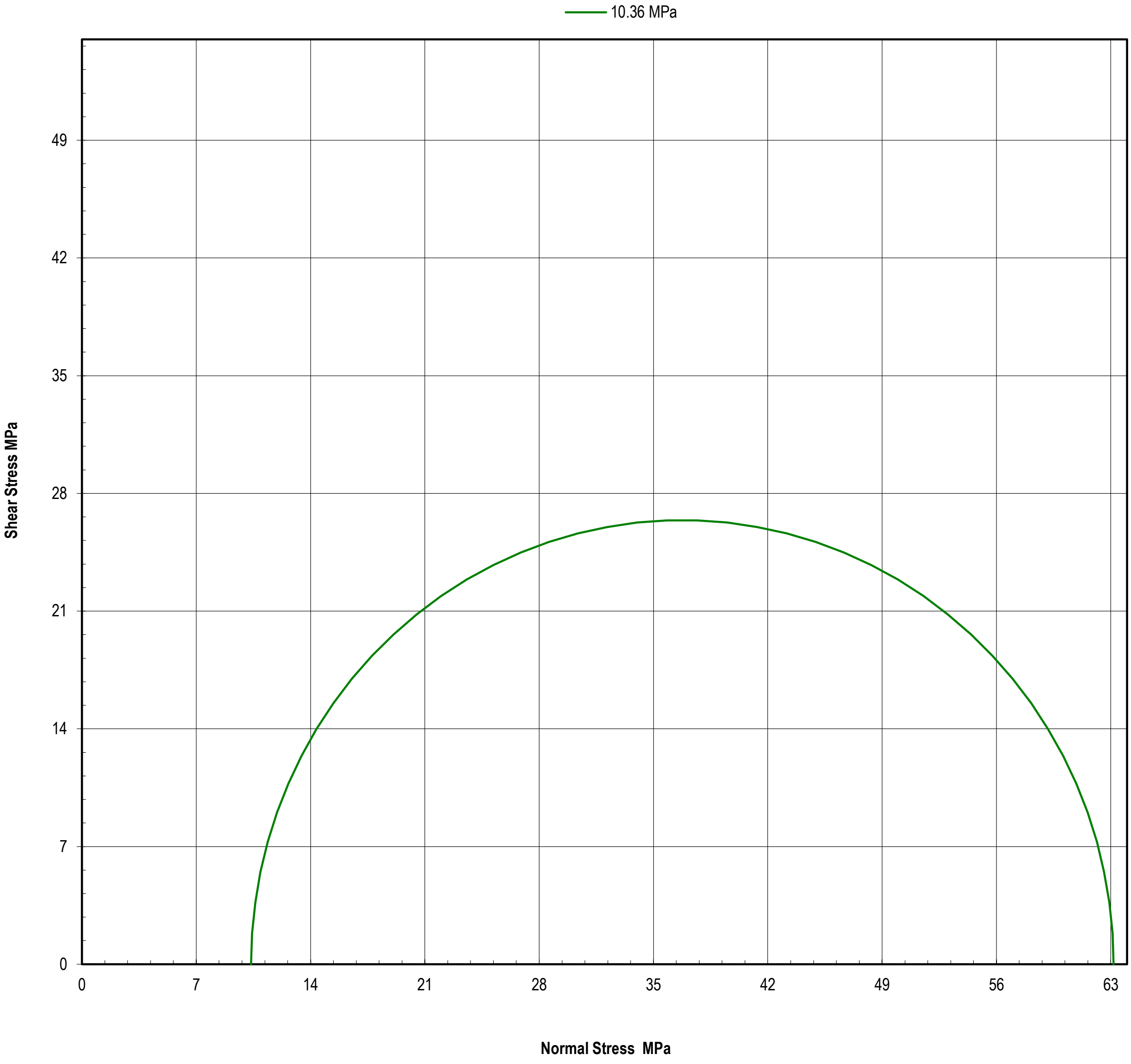
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110067-RTX

Peak Stress Mohr Circle Plot



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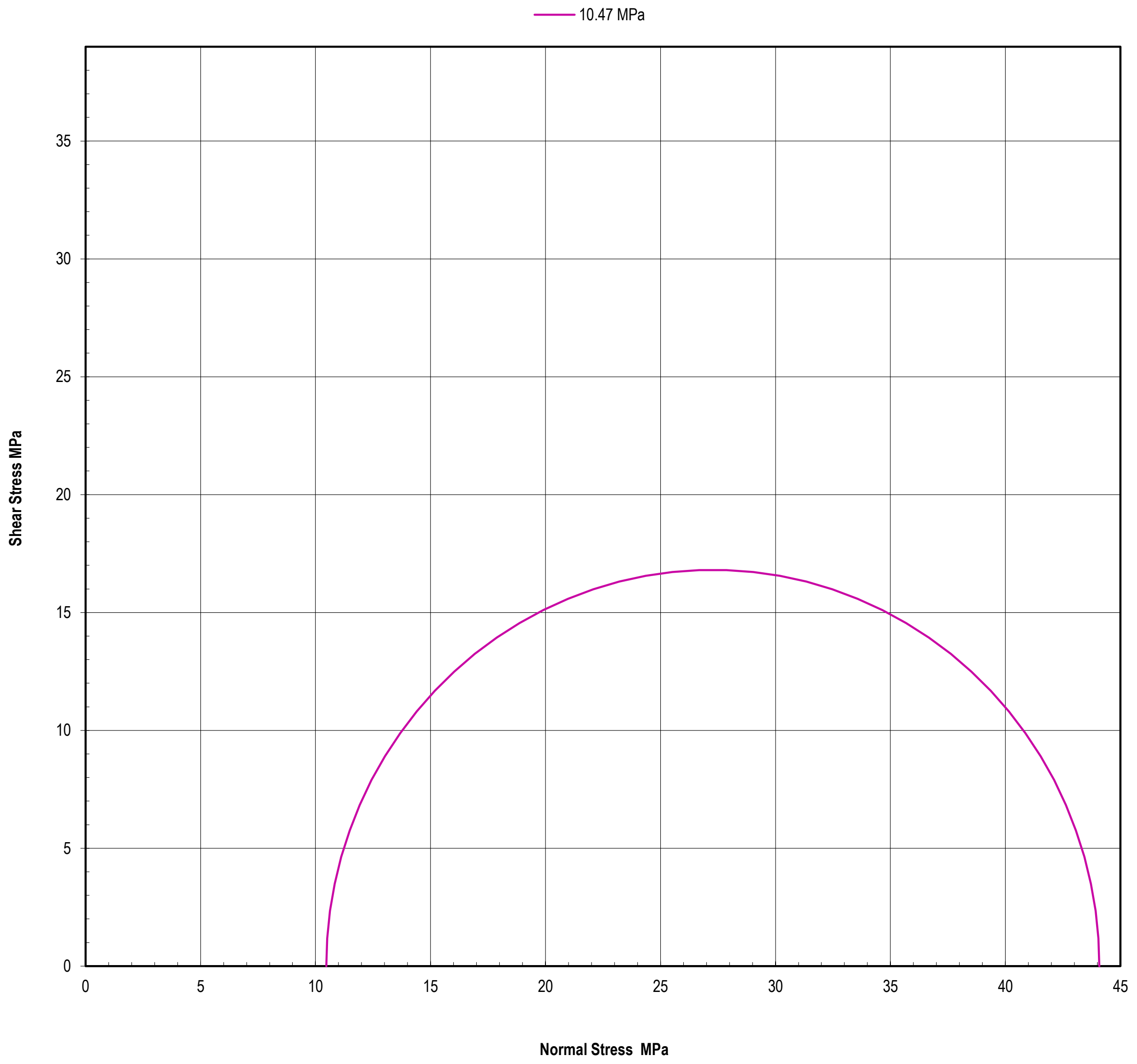
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110067-RTX

Residual Stress Mohr Circle Plot



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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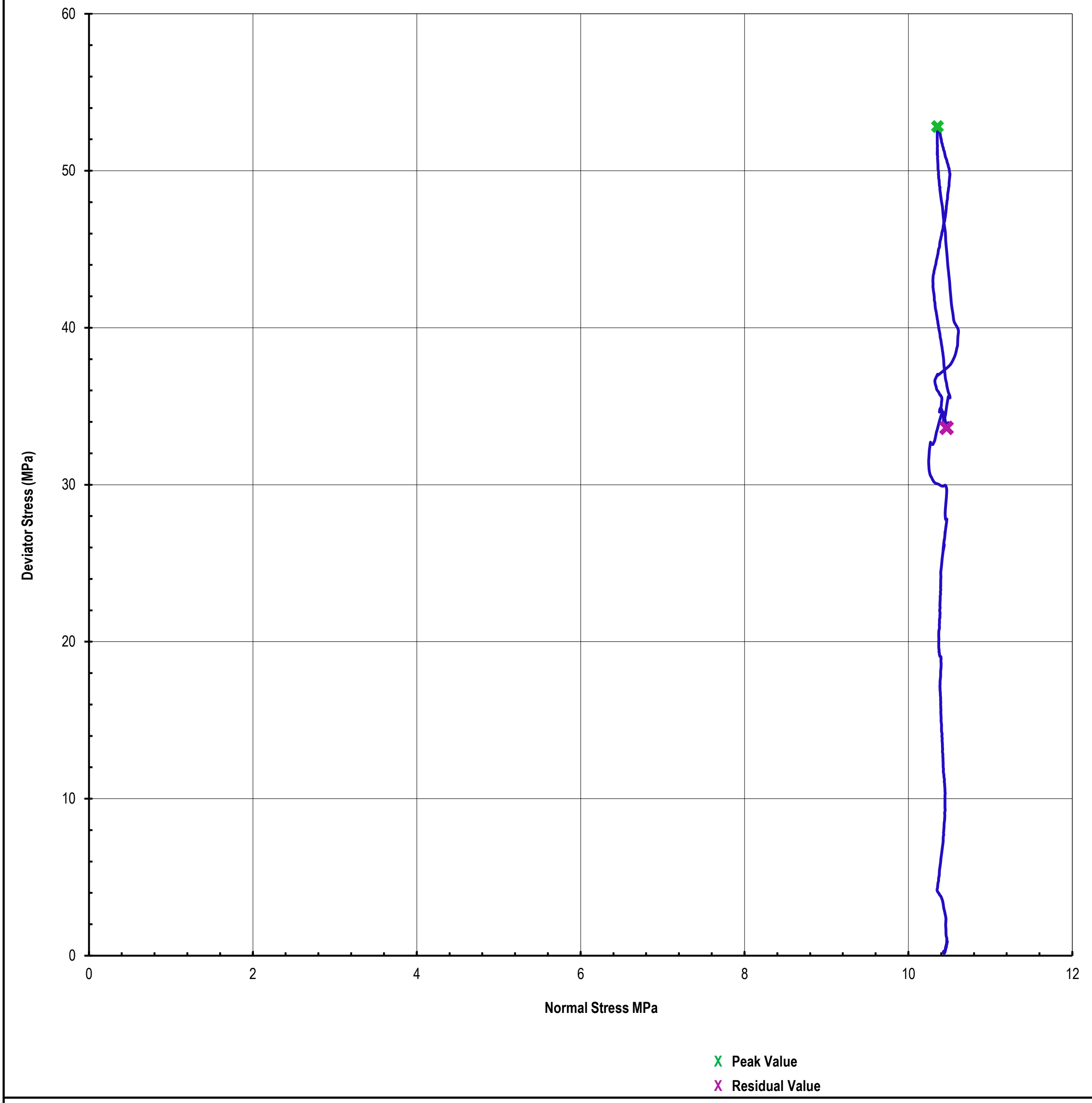
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110067-RTX

Deviator Stress vs Normal Stress Plot



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110068-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	10/11/2020
		Report Date	11/11/2020
Project	Surat Subsidence Study		
Client ID	Meenawarra 16 - 114323	**Depth (m)**	435.72-435.86
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.3	Moisture Content (%)	2.7
Sample Height (mm)	124.1	Wet Density (t/m^3)	1.85
Duration of Test (min)	18:11	Dry Density (t/m^3)	1.80
Rate of Strain (%/min)	0.05	Bedding (^{o})	10
Mode of Failure	Shear	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	60		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	10.70				
Deviator Stress (MPa)	64.4				
Axial Strain (µe)	25950				
Diametral Strain (µe)	-10972				
Tangent Modulus (GPa)	3.54				
Poisson's Ratio	0.141				

Residual Test Results

Confining Pressure (MPa)	10.76				
Residual Deviator Stress (MPa)	24.5				
Axial Strain (µe)	32932				
Diametral Strain (µe)	-29167				

Notes/Remarks:

Sample/s supplied by client Tested as received

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

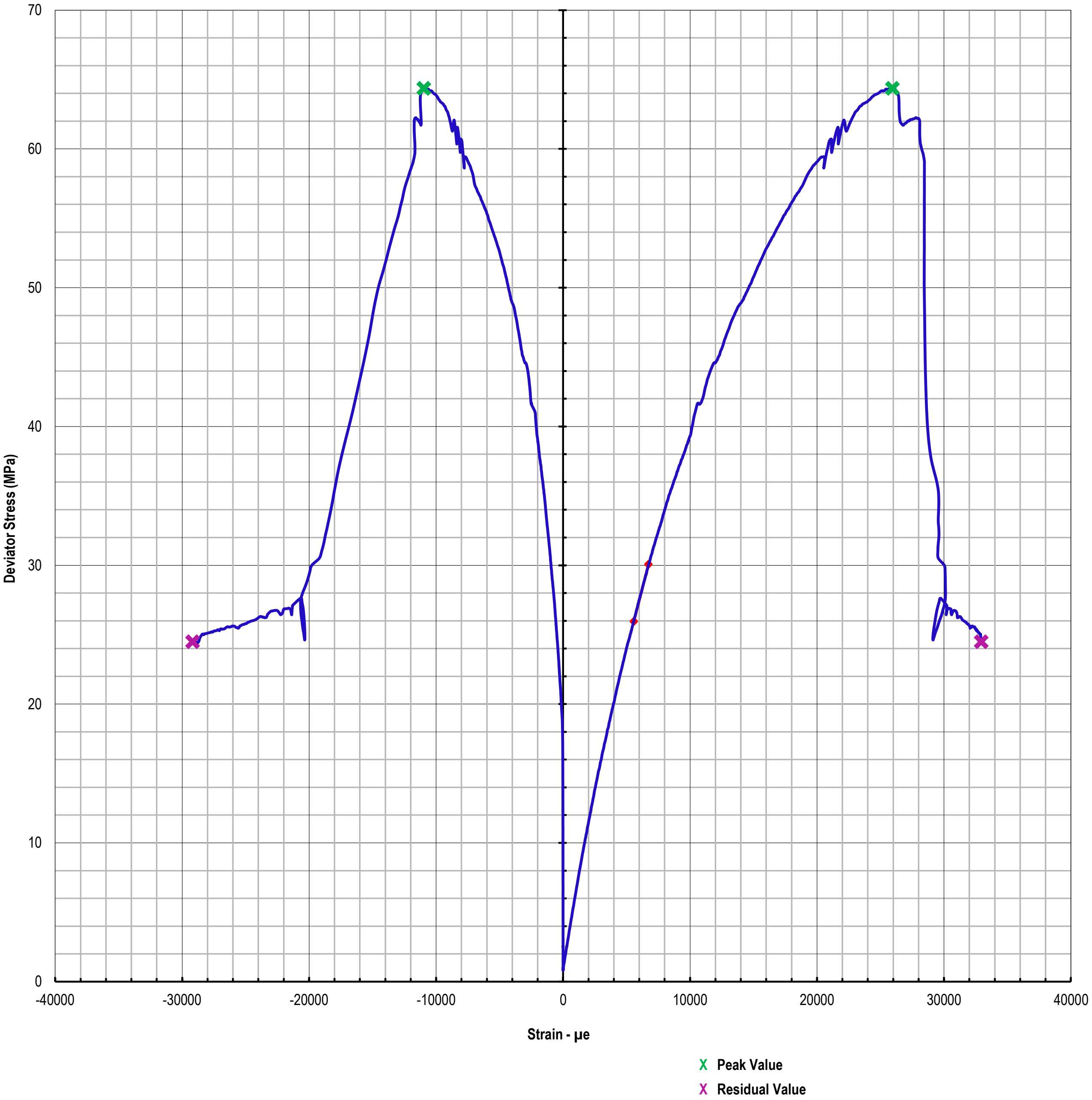
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110068-RTX

Deviator Stress vs Axial Strain Plots



Notes/Remarks:

Graph not to scale

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

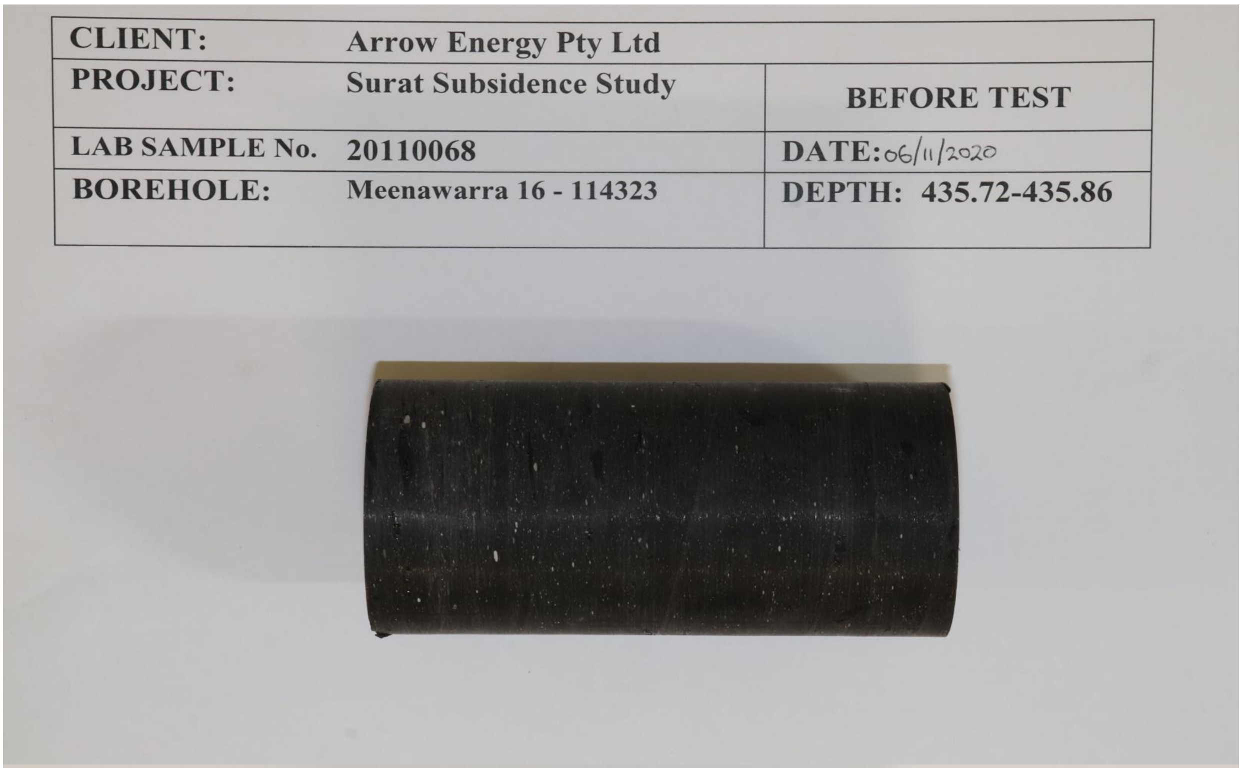
ASTM D7012

Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110068-RTX

Before and After Test Photos



CLIENT:	Arrow Energy Pty Ltd	
PROJECT:	Surat Subsidence Study	BEFORE TEST
LAB SAMPLE No.	20110068	DATE: 06/11/2020
BOREHOLE:	Meenawarra 16 - 114323	DEPTH: 435.72-435.86

Notes/Remarks:

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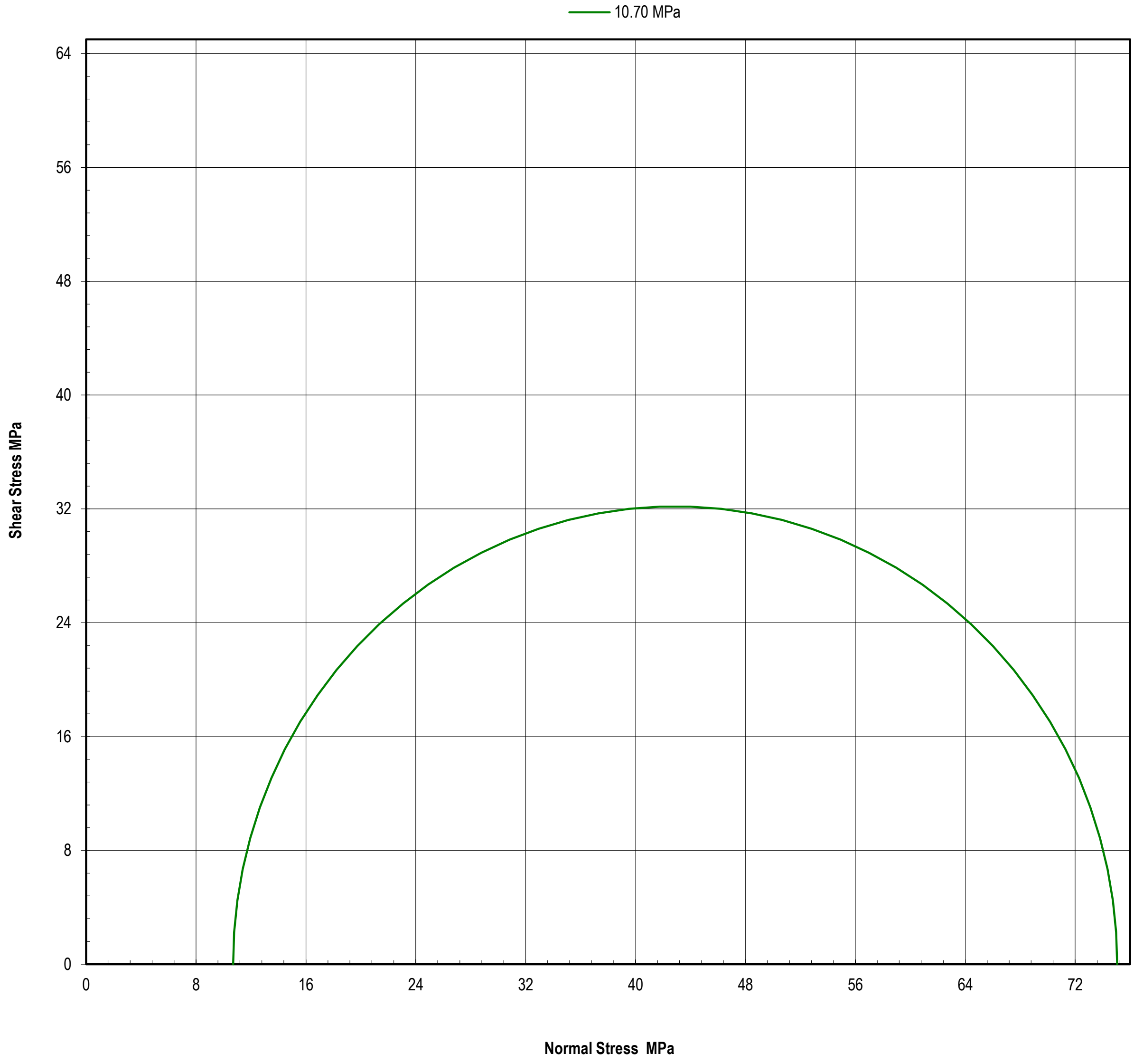
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110068-RTX

Peak Stress Mohr Circle Plot



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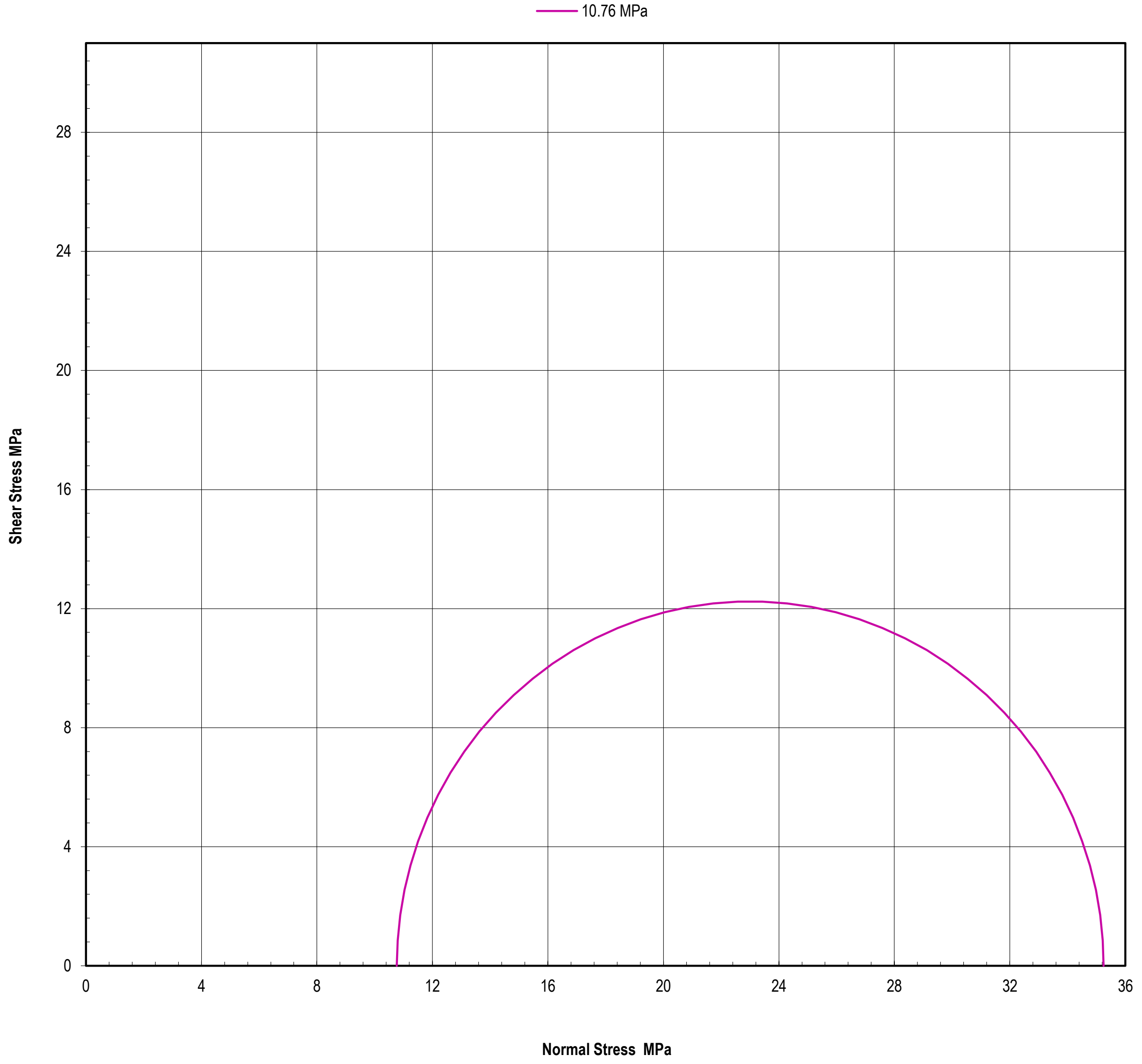
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110068-RTX

Residual Stress Mohr Circle Plot



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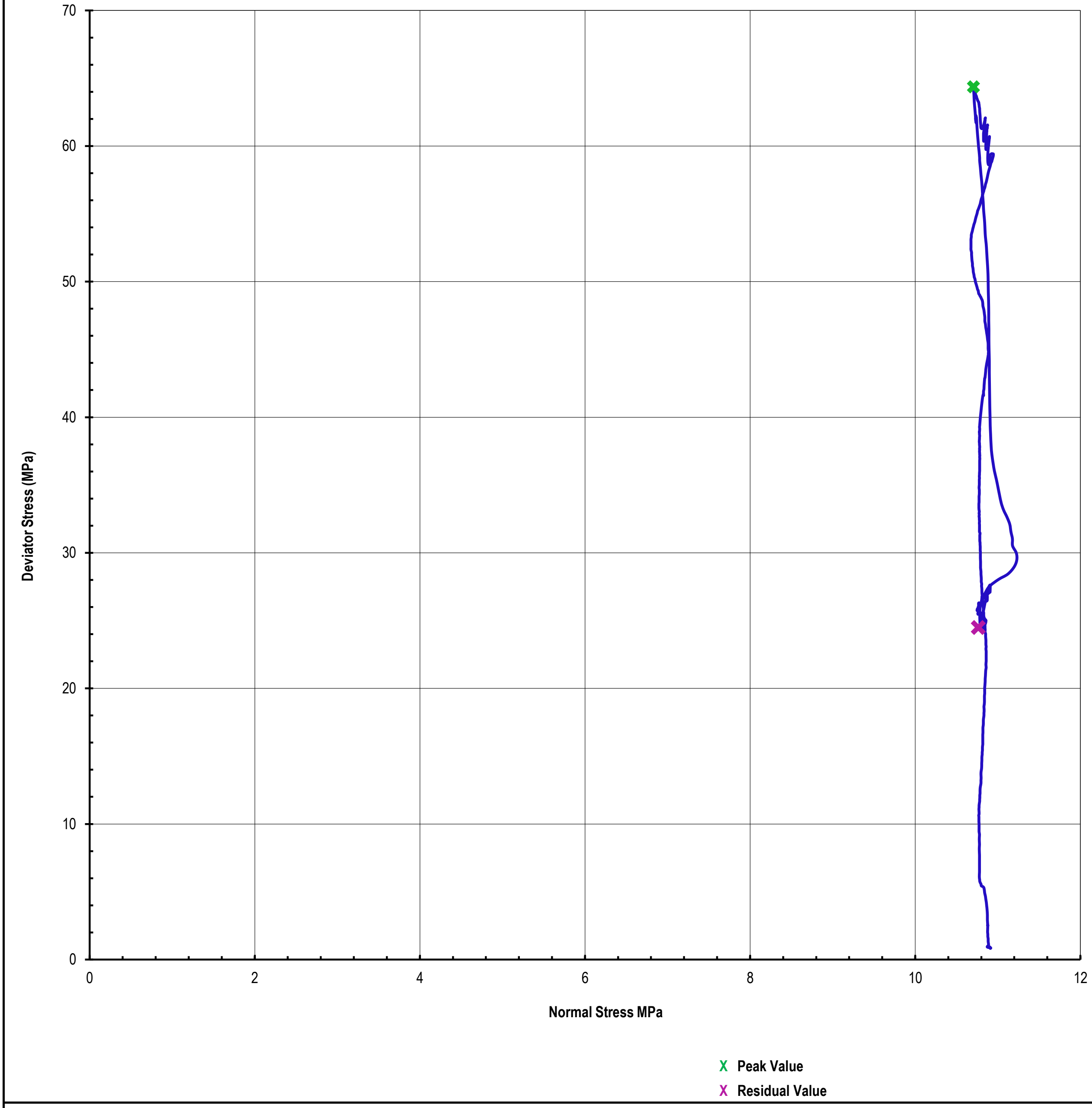
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110068-RTX

Deviator Stress vs Normal Stress Plot



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Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110069-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	10/11/2020
		Report Date	11/11/2020
Project	Surat Subsidence Study		
Client ID	Meenawarra 16 - 114324	**Depth (m)**	470.07-470.30
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.6	Moisture Content (%)	2.1
Sample Height (mm)	145.7	Wet Density (t/m^3)	2.45
Duration of Test (min)	19:27	Dry Density (t/m^3)	2.40
Rate of Strain (%/min)	0.05	Bedding (^{o})	Nil
Mode of Failure	Conical	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	65		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	11.49				
Deviator Stress (MPa)	60.7				
Axial Strain (με)	11095				
Diametral Strain (με)	-3003				
Tangent Modulus (GPa)	6.14				
Poisson's Ratio	0.088				

Residual Test Results

Confining Pressure (MPa)	11.50				
Residual Deviator Stress (MPa)	42.5				
Axial Strain (με)	14198				
Diametral Strain (με)	-8262				

Notes/Remarks:

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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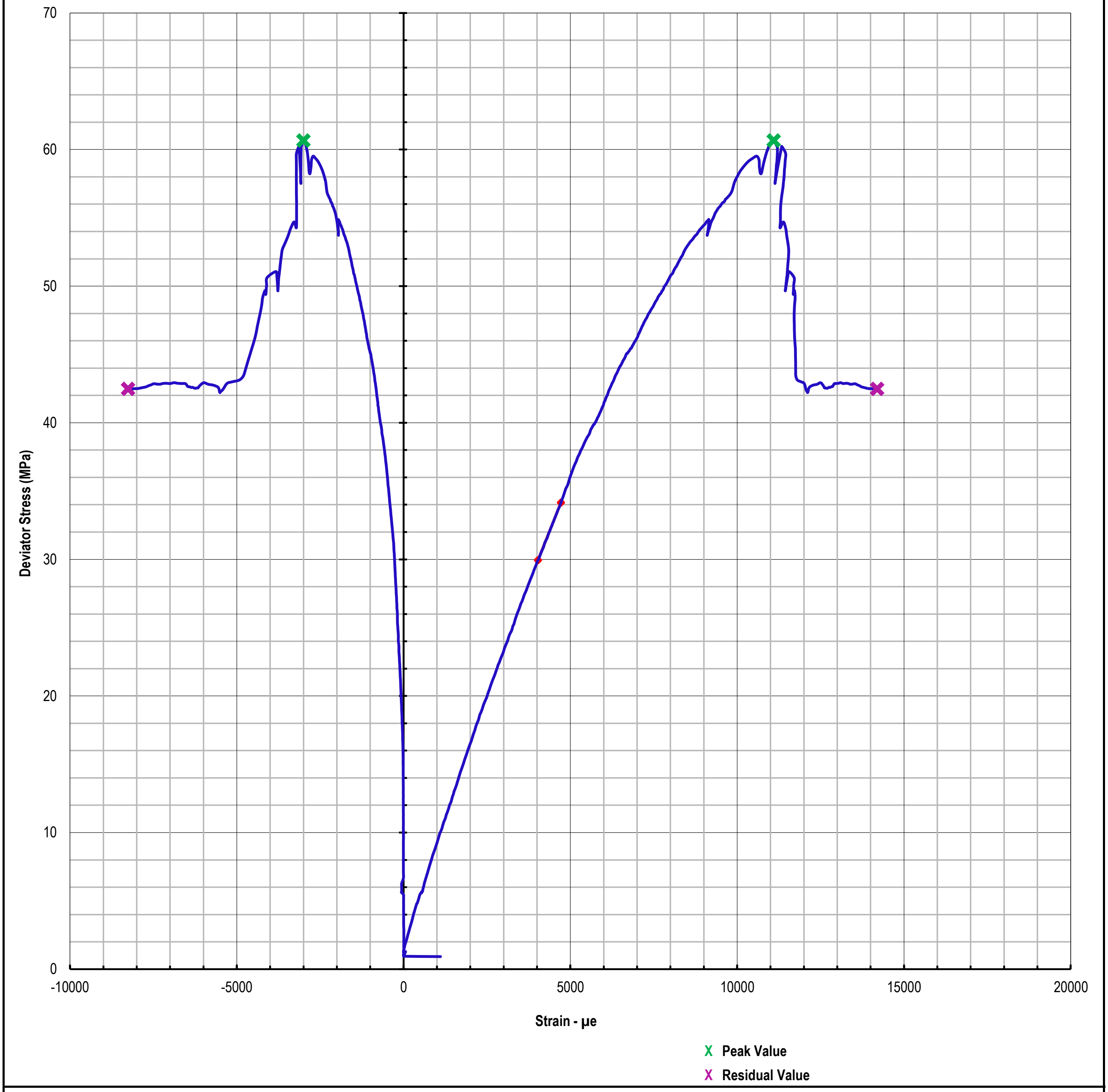
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110069-RTX

Deviator Stress vs Axial Strain Plots



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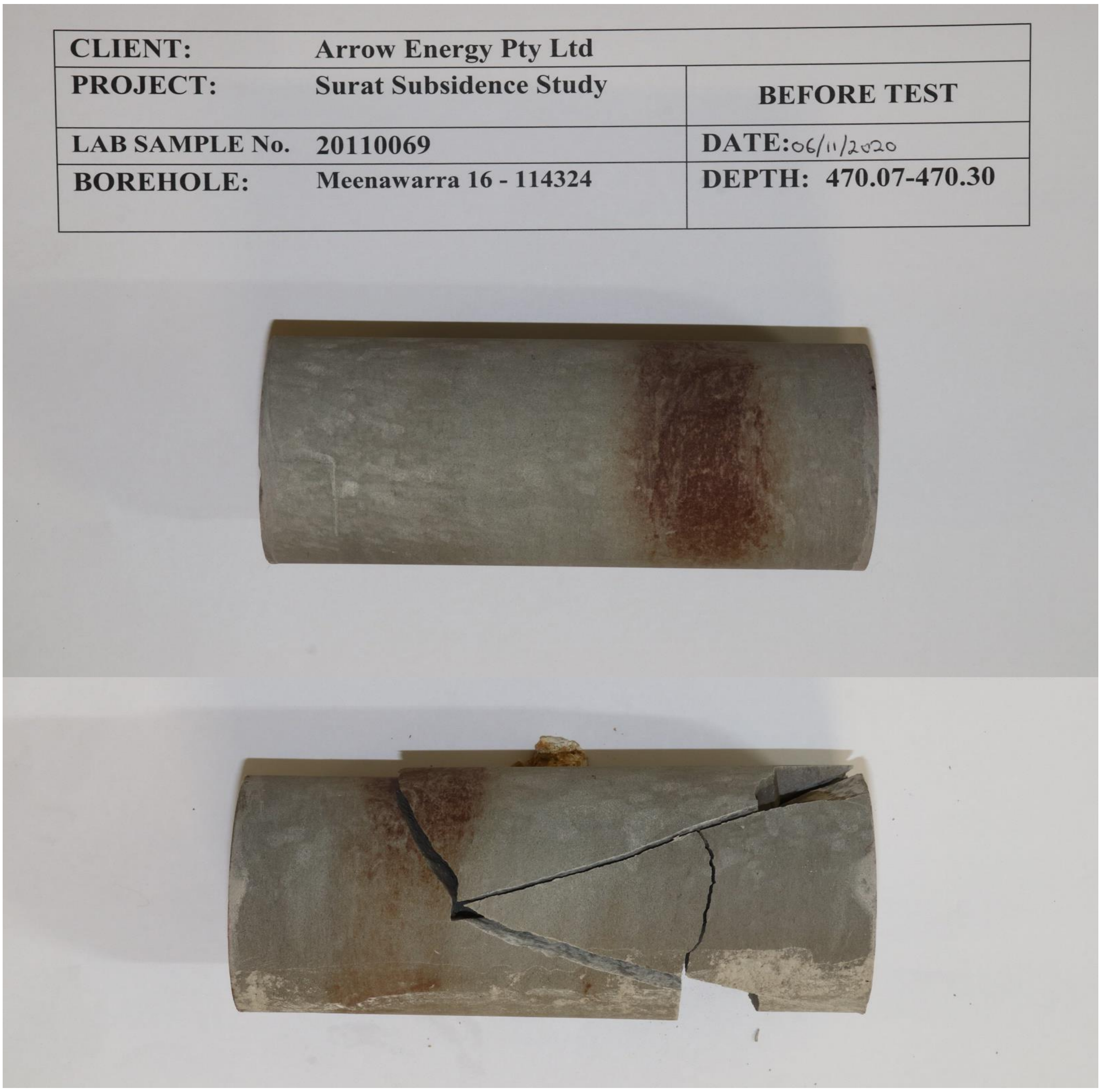
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110069-RTX

Before and After Test Photos



CLIENT:	Arrow Energy Pty Ltd	
PROJECT:	Surat Subsidence Study	BEFORE TEST
LAB SAMPLE No.	20110069	DATE: 06/11/2020
BOREHOLE:	Meenawarra 16 - 114324	DEPTH: 470.07-470.30

Notes/Remarks:

Photo not to scale

Sample/s supplied by client

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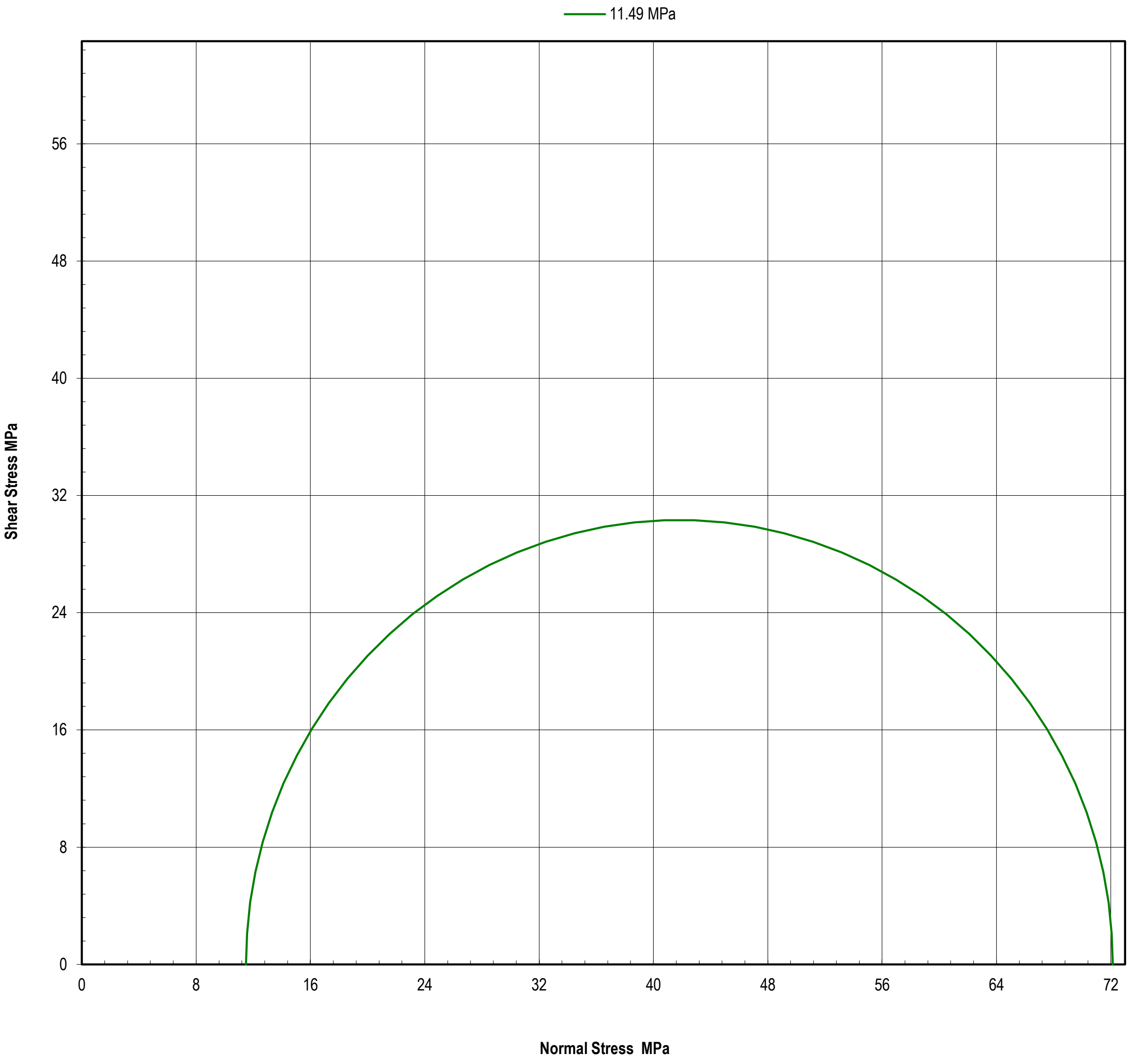
Client Arrow Energy Pty Ltd

Report No. 20110069-RTX

Peak Stress Mohr Circle Plot



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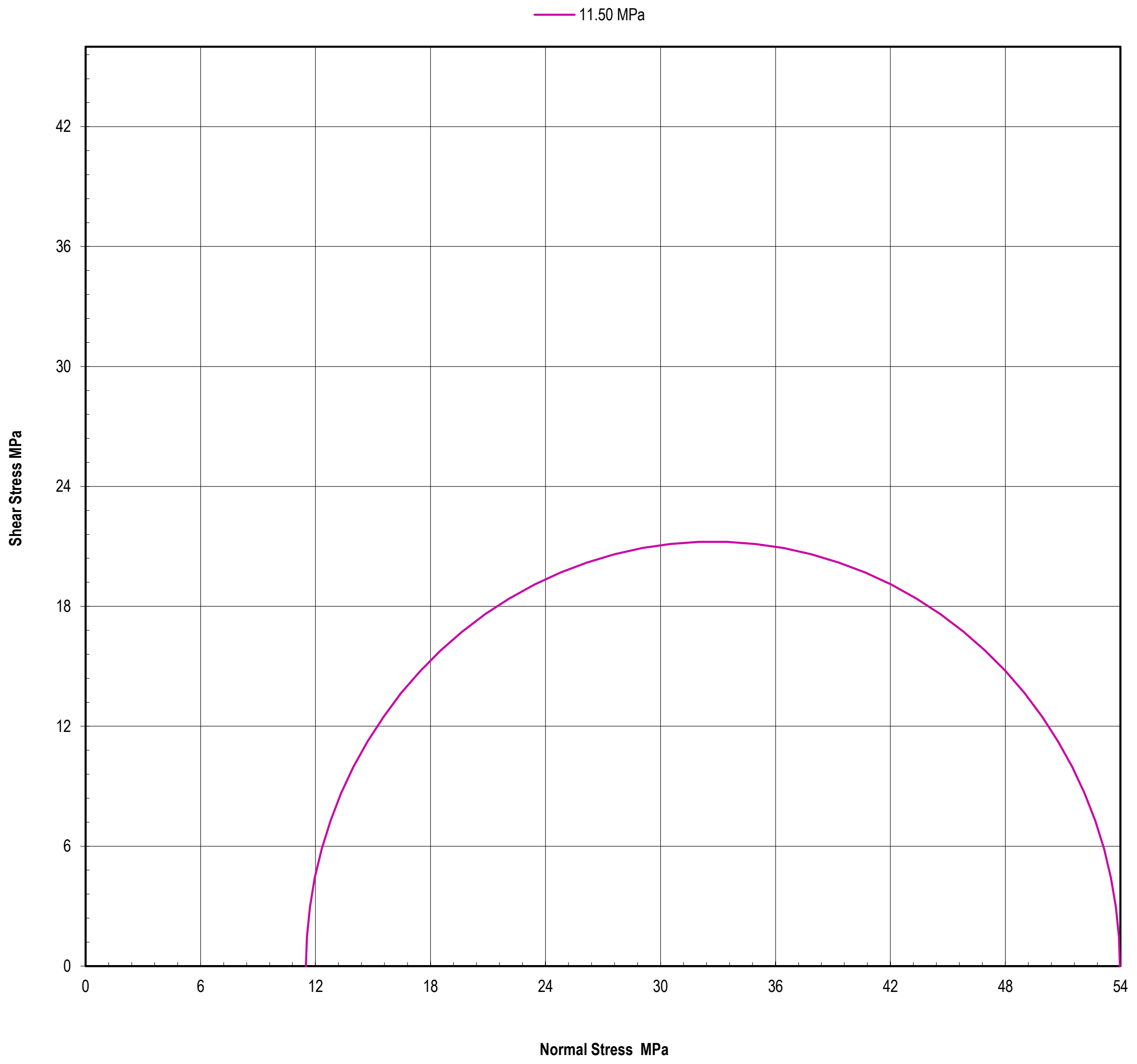
ASTM D7012

Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110069-RTX

Residual Stress Mohr Circle Plot



Notes/Remarks:

Graph not to scale

Sample/s supplied by client

Tested as received

Tested at Trilab Brisbane Laboratory

Authorised Signatory

C. Purvis

NATA
ACCREDITED FOR TECHNICAL COMPETENCE

Laboratory No. 9926

STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

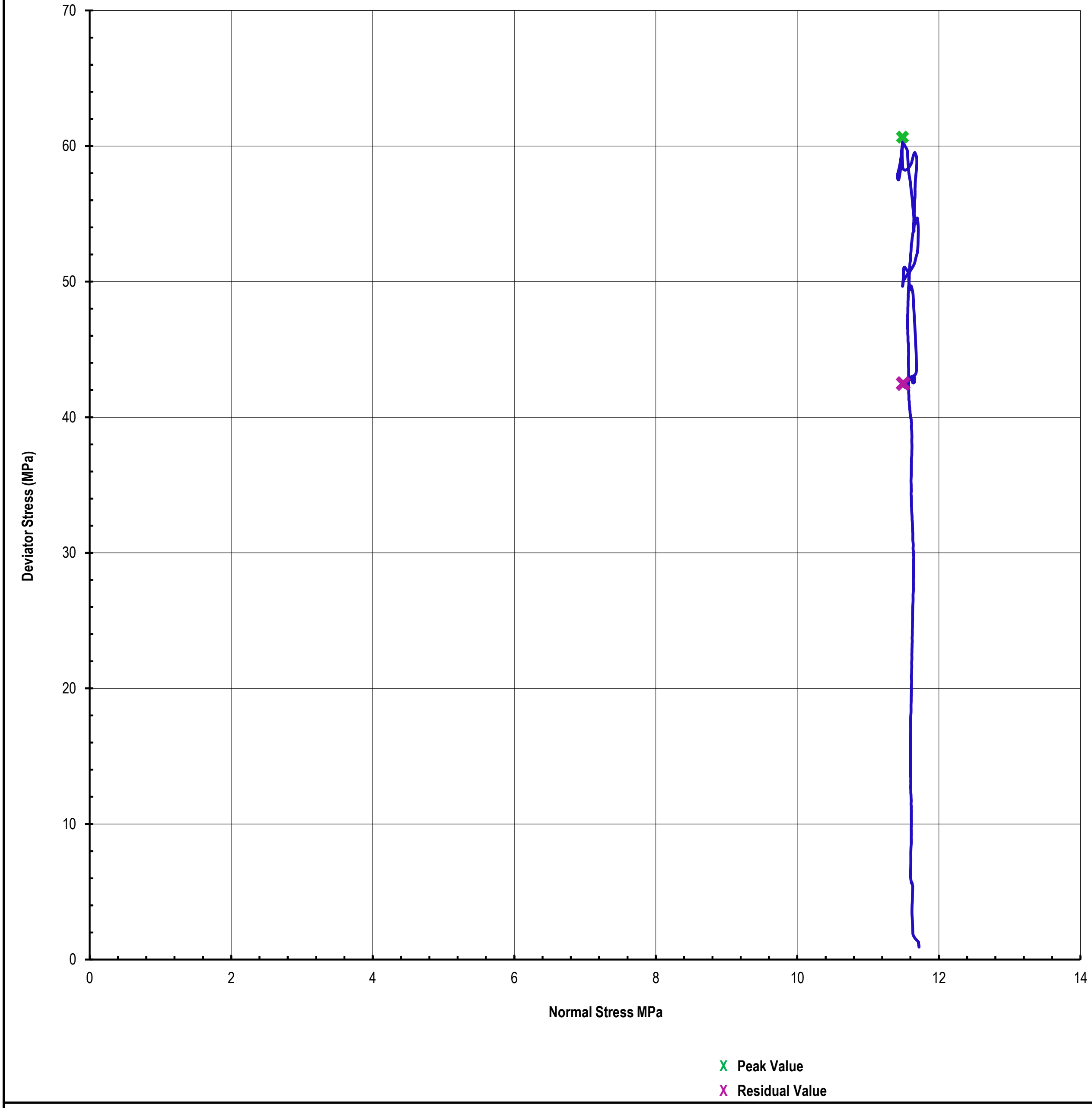
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110069-RTX

Deviator Stress vs Normal Stress Plot



Notes/Remarks:

Graph not to scale

Sample/s supplied by client

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Laboratory No. 9926

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WA 6107
Ph: +61 8 9258 8323

STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110070-RTX
		Workorder No.	0007965
Address	GPO Box 5262, Brisbane QLD 4001	**Test Date**	10/11/2020
		Report Date	11/11/2020
Project	Surat Subsidence Study		
Client ID	Meenawarra 16 - 114325	**Depth (m)**	478.49-478.64
Description	-		
Sample Type	Single Individual Rock Core Specimen		

Sample Details

Average Sample Diameter (mm)	60.5	Moisture Content (%)	2.2
Sample Height (mm)	144.9	Wet Density (t/m^3)	1.39
Duration of Test (min)	29:22	Dry Density (t/m^3)	1.36
Rate of Strain (%/min)	0.05	Bedding (^{o})	20
Mode of Failure	Shear	Test Apparatus	RTR2500 Triaxial Machine
Rupture Angle (°)	60		

Intact Test Results

	Peak Value				
Confining Pressure (MPa)	11.86				
Deviator Stress (MPa)	69.4				
Axial Strain (µe)	29226				
Diametral Strain (µe)	-15906				
Tangent Modulus (GPa)	3.40				
Poisson's Ratio	0.280				

Residual Test Results

Confining Pressure (MPa)	11.89				
Residual Deviator Stress (MPa)	66.2				
Axial Strain (µe)	35969				
Diametral Strain (µe)	-25946				

Notes/Remarks:

Sample/s supplied by client

Tested as received

Accredited for compliance with ISO/IES 17025 - Testing.
The results of the tests, calibrations, and/or measurements included in this document are traceable to Australian/National Standards.

Tested at Trilab Brisbane Laboratory

Authorised Signatory
C. Purvis

NATA
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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

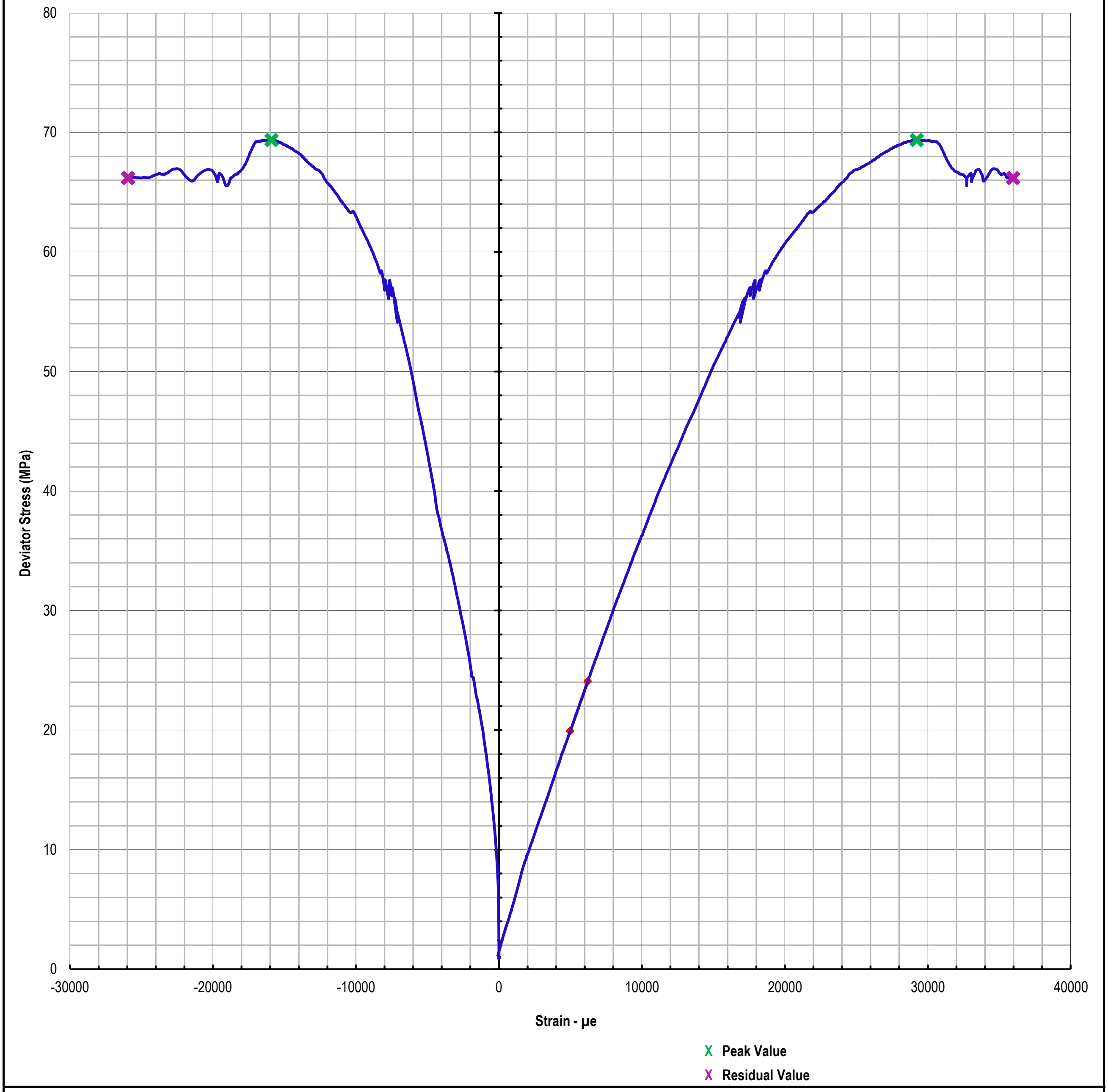
ASTM D7012

Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110070-RTX

Deviator Stress vs Axial Strain Plots



Notes/Remarks:

Graph not to scale

Sample/s supplied by client

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110070-RTX

Before and After Test Photos

CLIENT:	Arrow Energy Pty Ltd	
PROJECT:	Surat Subsidence Study	BEFORE TEST
LAB SAMPLE No.	20110070	DATE: 06/11/2020
BOREHOLE:	Meenawarra 16 - 114325	DEPTH: 478.49-478.64

Notes/Remarks:

Photo not to scale

Sample/s supplied by client

Tested as received

STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

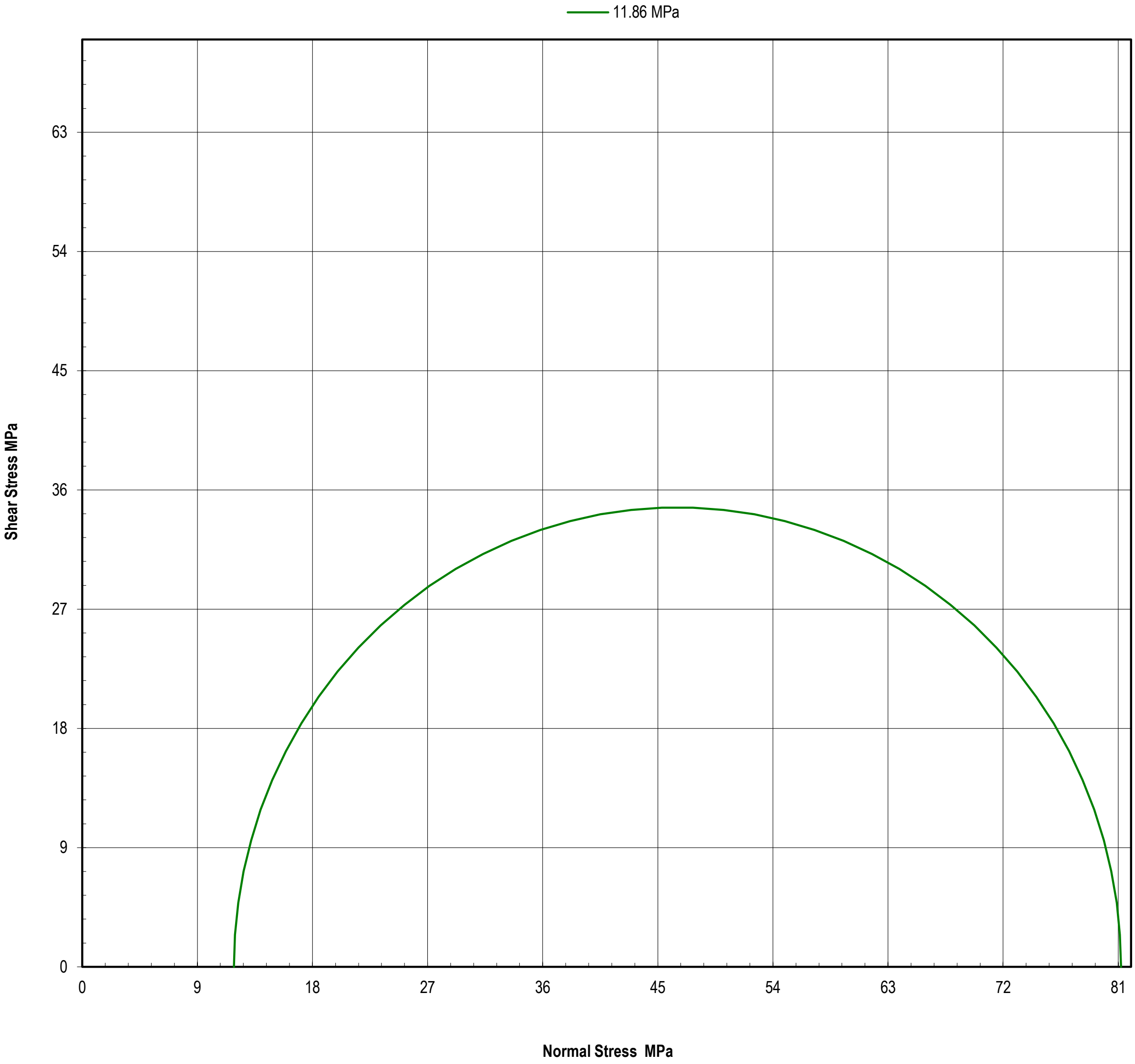
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110070-RTX

Peak Stress Mohr Circle Plot



Notes/Remarks:

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Sample/s supplied by client

Tested as received

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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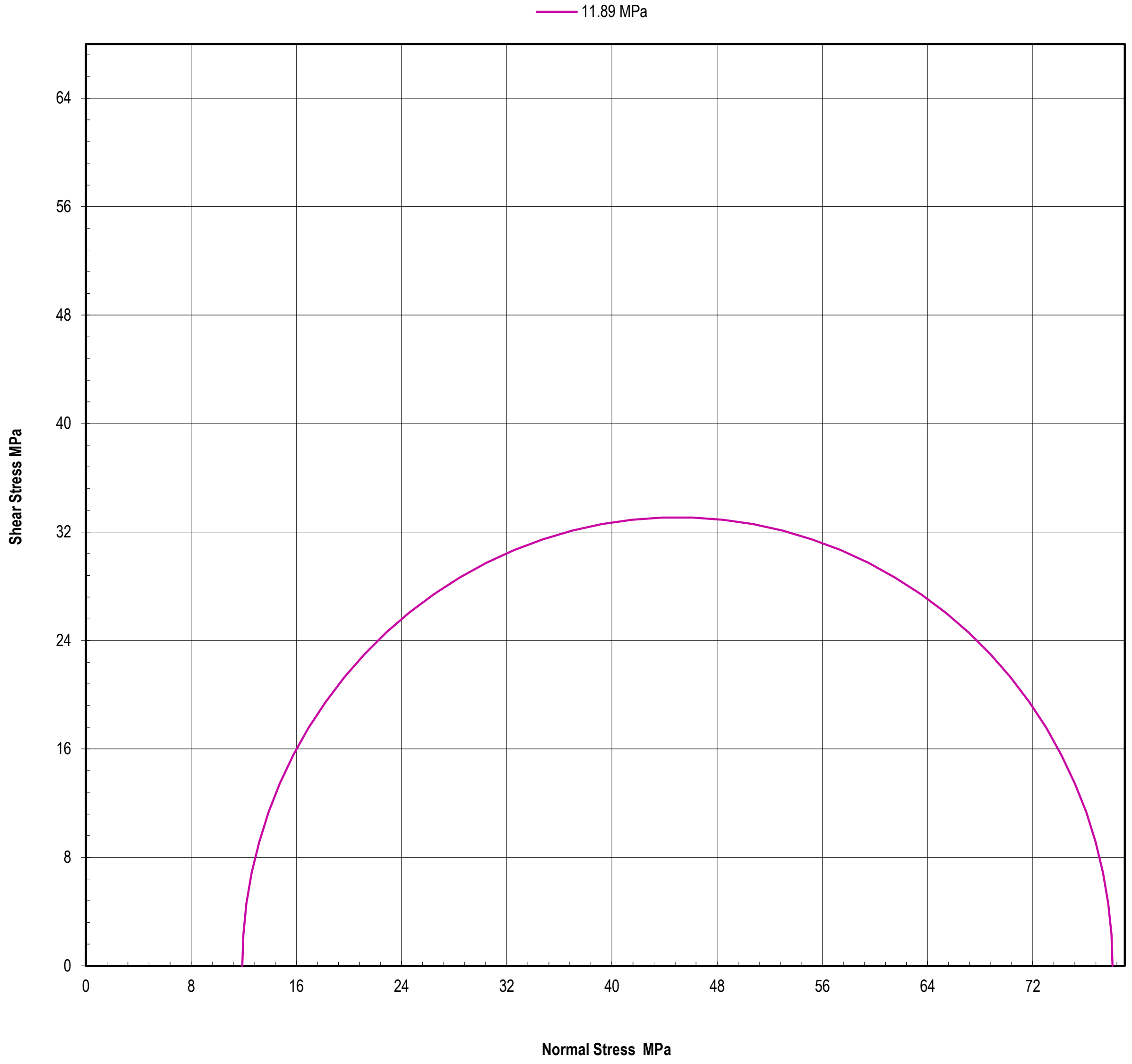
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110070-RTX

Residual Stress Mohr Circle Plot



Notes/Remarks:

Graph not to scale

Sample/s supplied by client

Tested as received

Tested at Trilab Brisbane Laboratory

Authorised Signatory
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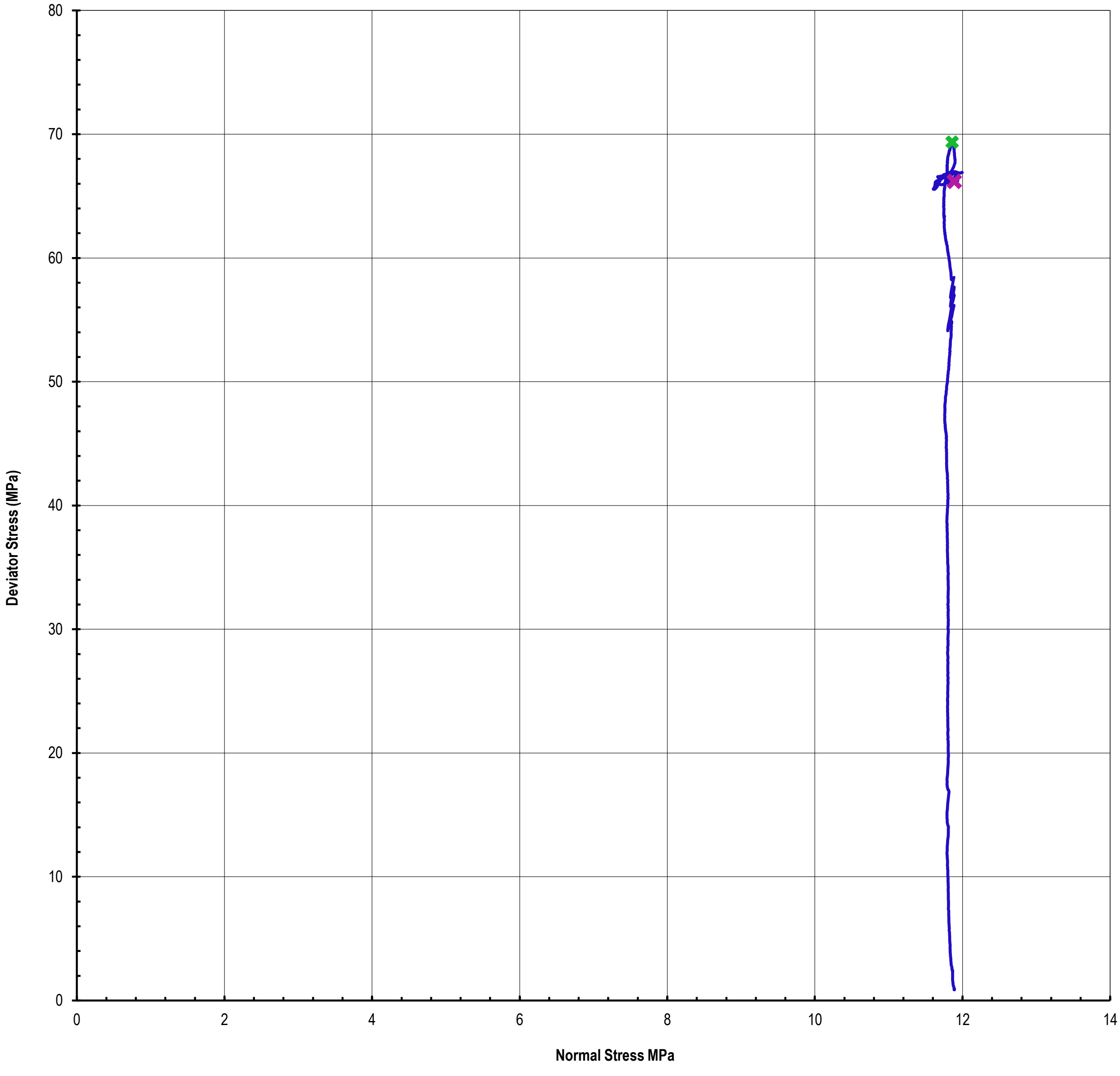
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110070-RTX

Deviator Stress vs Normal Stress Plot



X Peak Value
X Residual Value

Notes/Remarks:

Graph not to scale

Sample/s supplied by client

Tested as received

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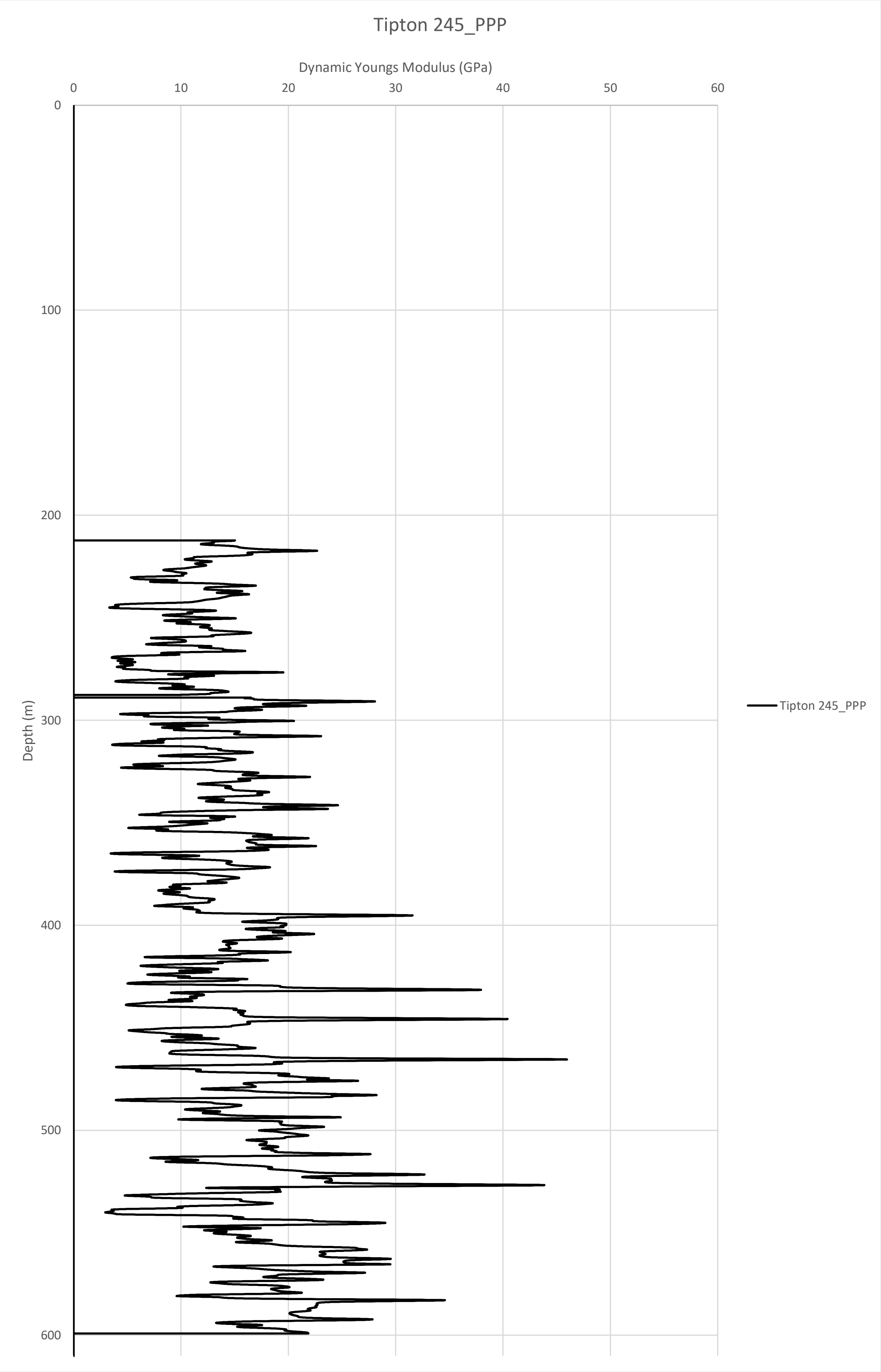
Appendix B – Wireline modulus results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30
40
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Depth (m)
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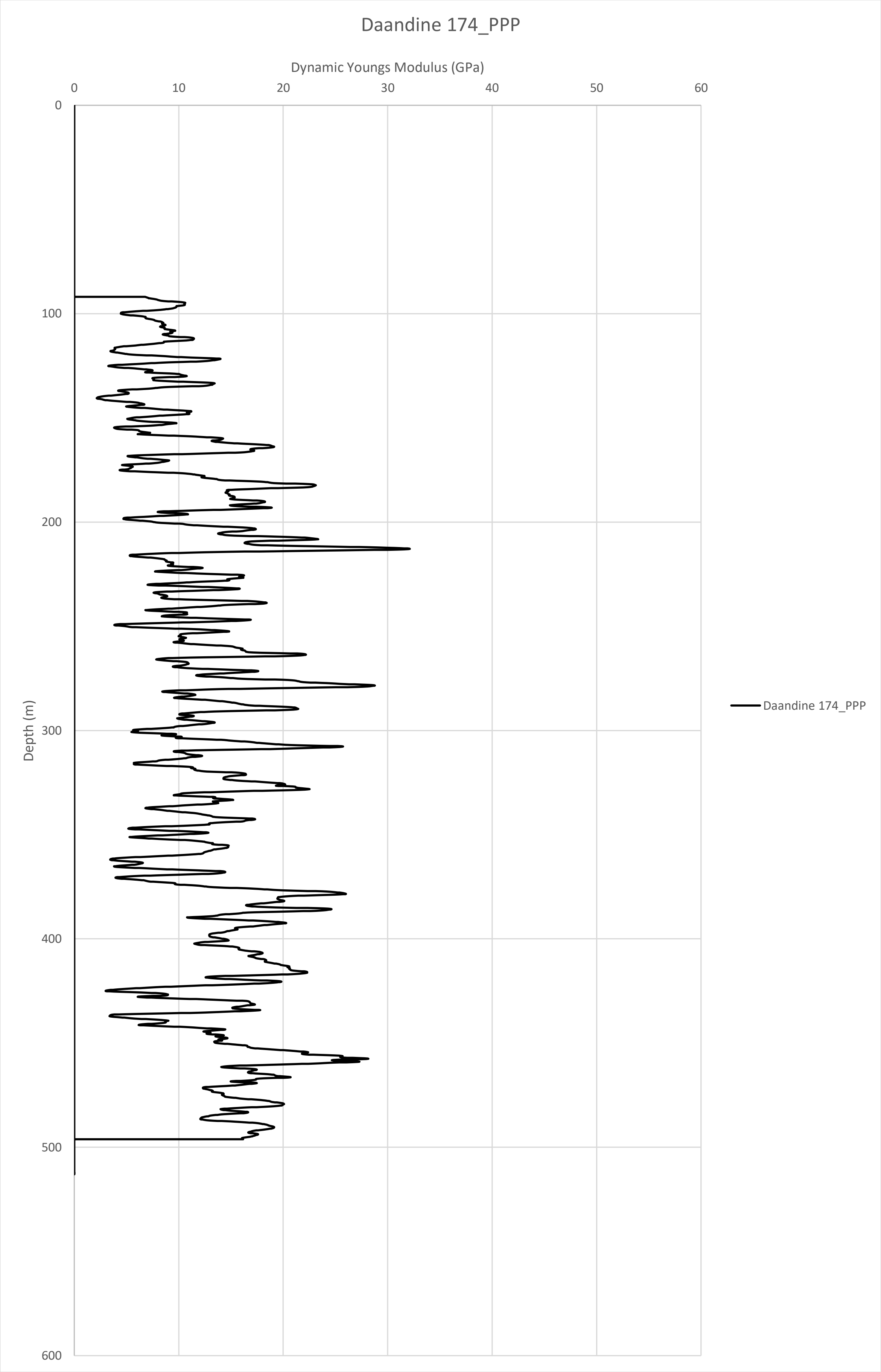
400
500
600
Tipton 245_PPP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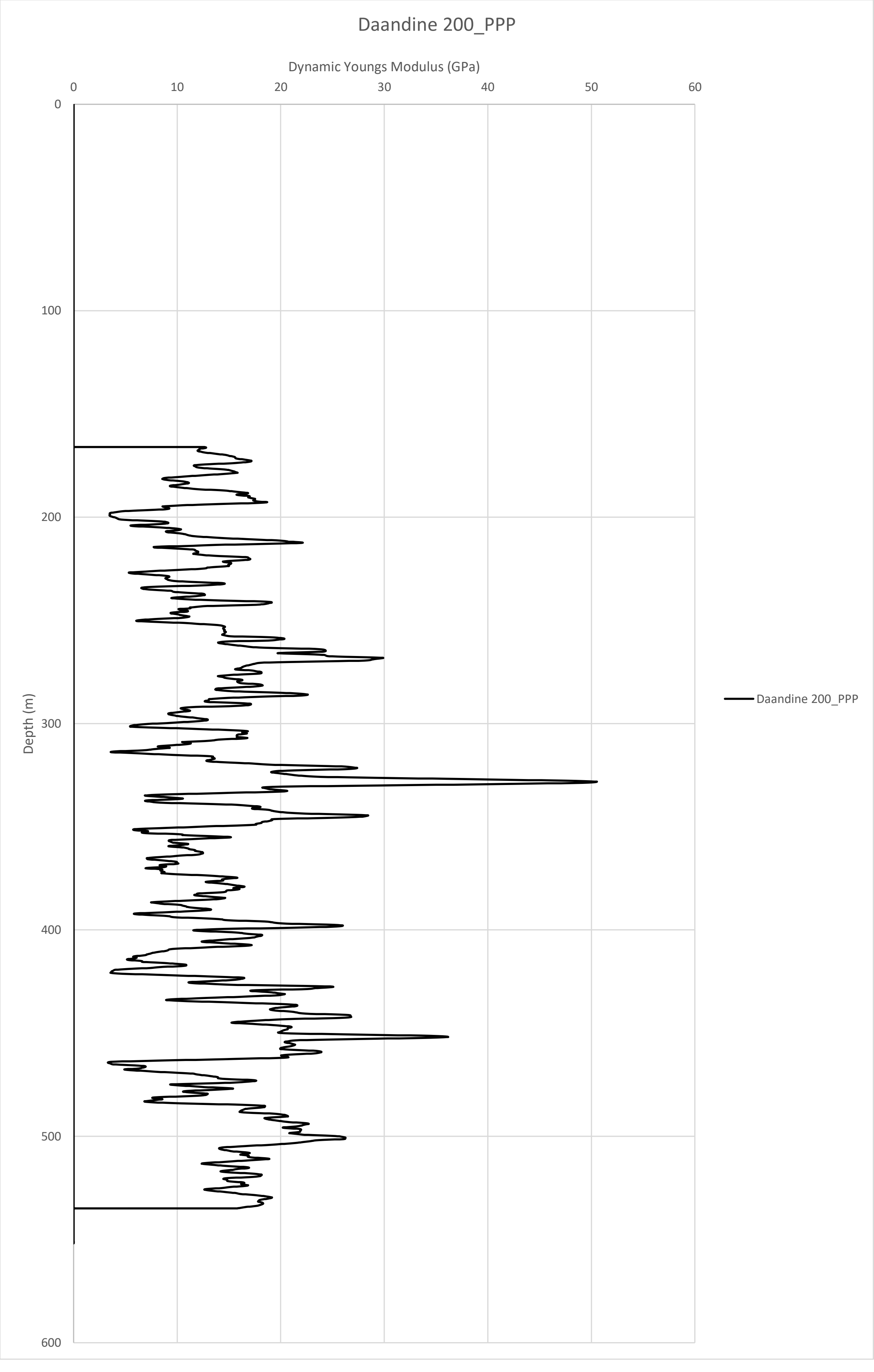
Daandine 174_PPP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Depth (m)
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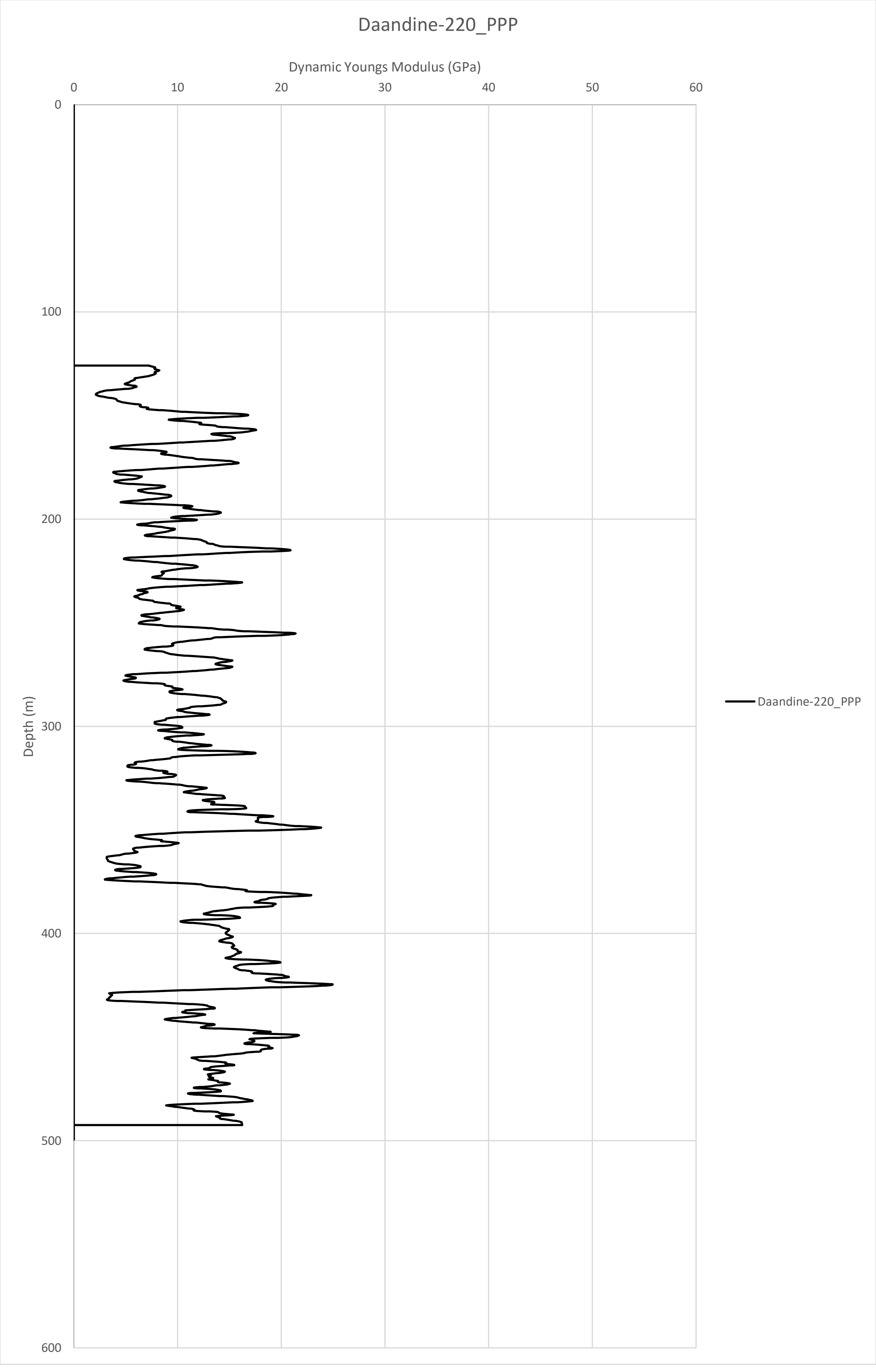
600
Daandine 200_PPP

Daandine-220_PPP
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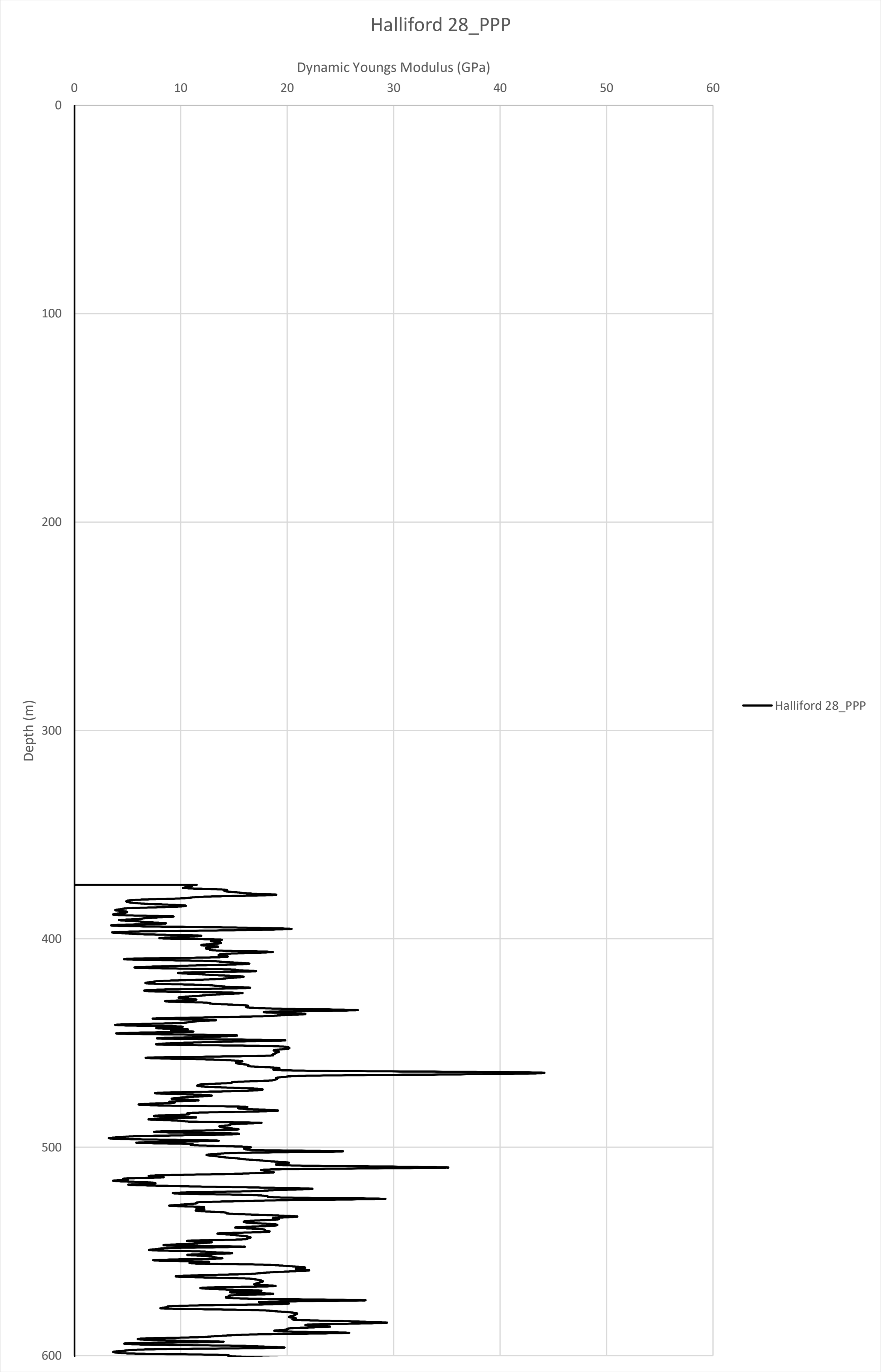
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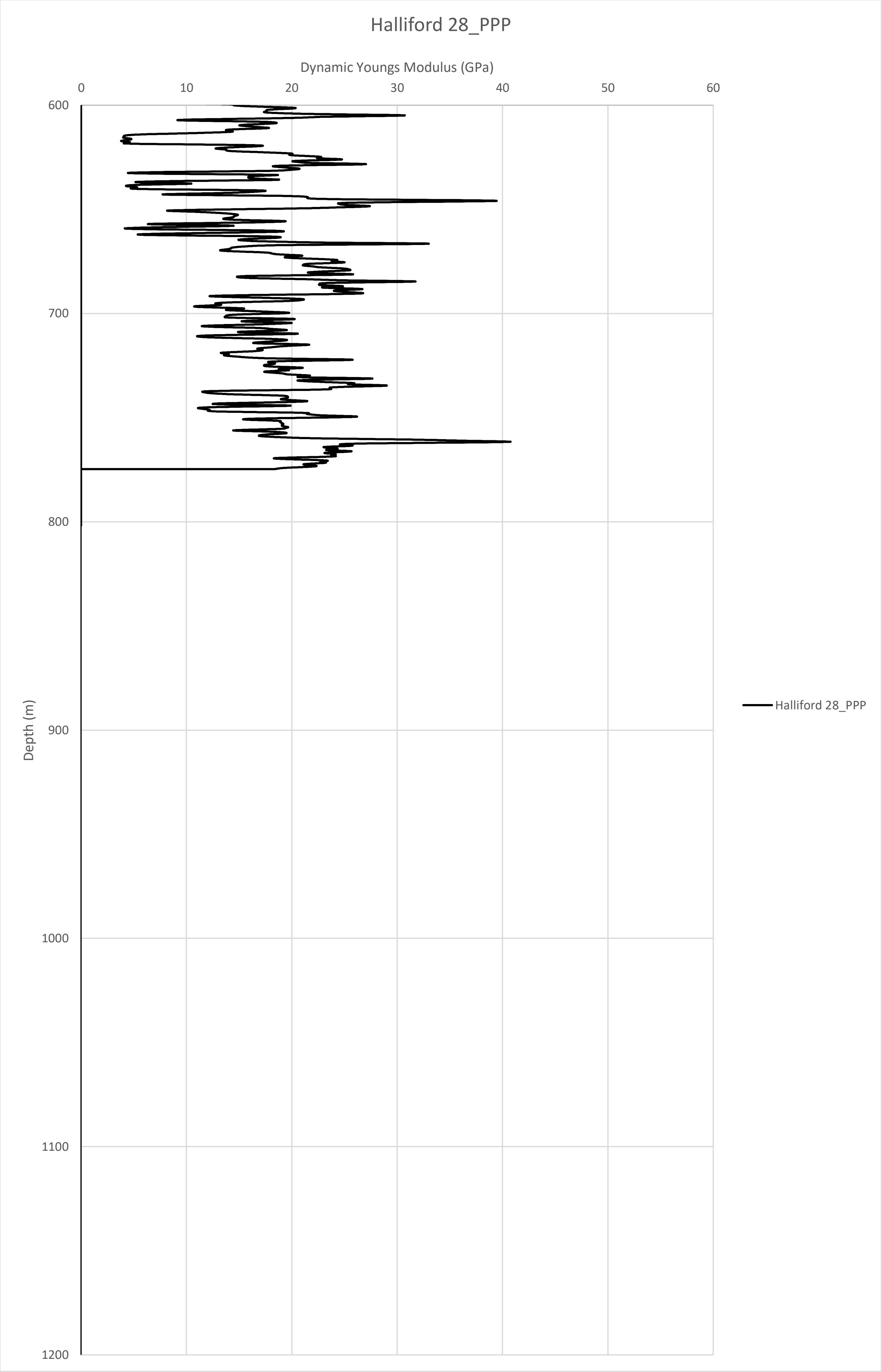
600
Halliford 28_PPP


Halliford 28_PPP
Dynamic Youngs Modulus (GPa)
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40
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600
700
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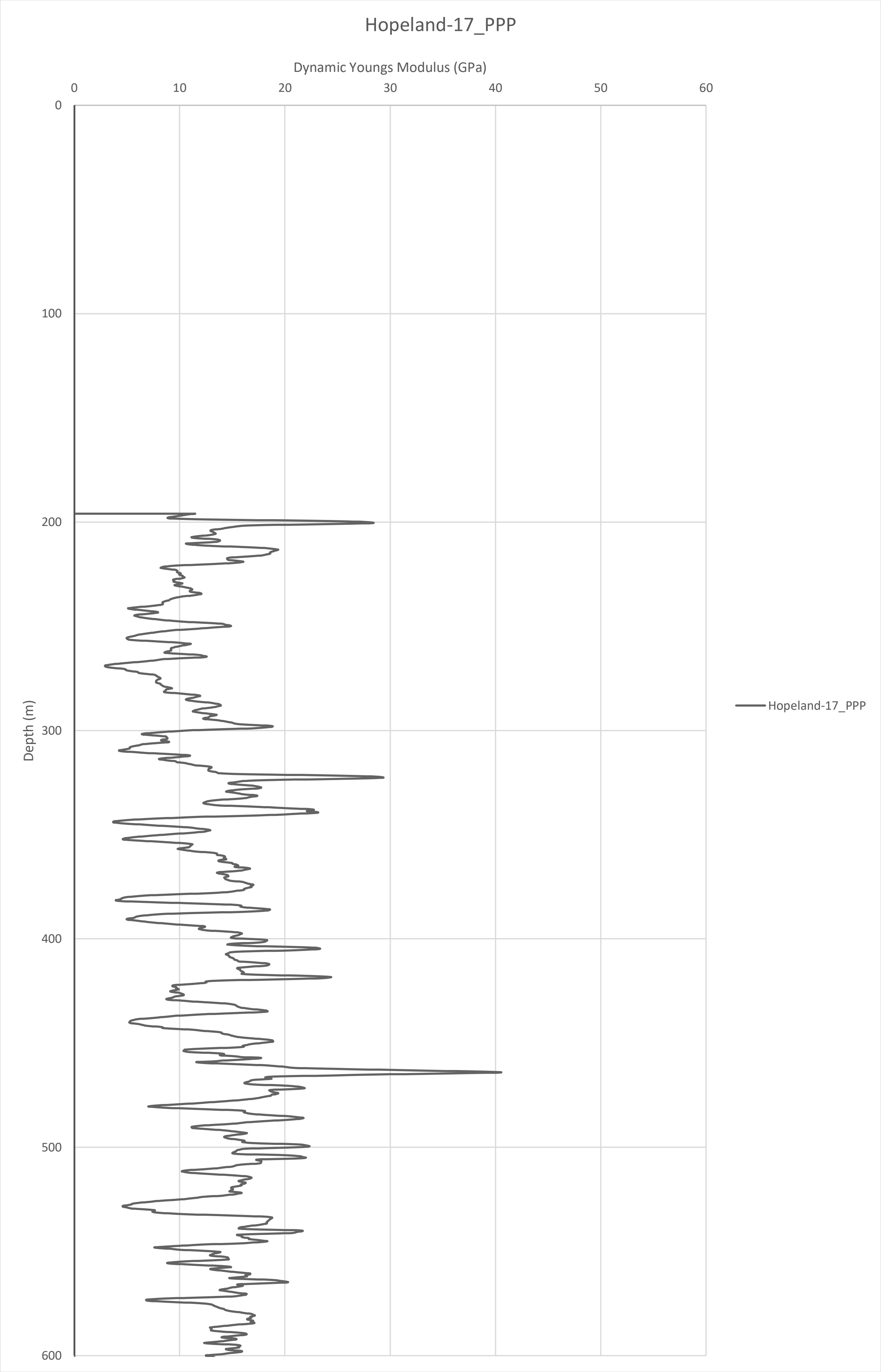
1100
1200
Depth (m)
Halliford 28_PPP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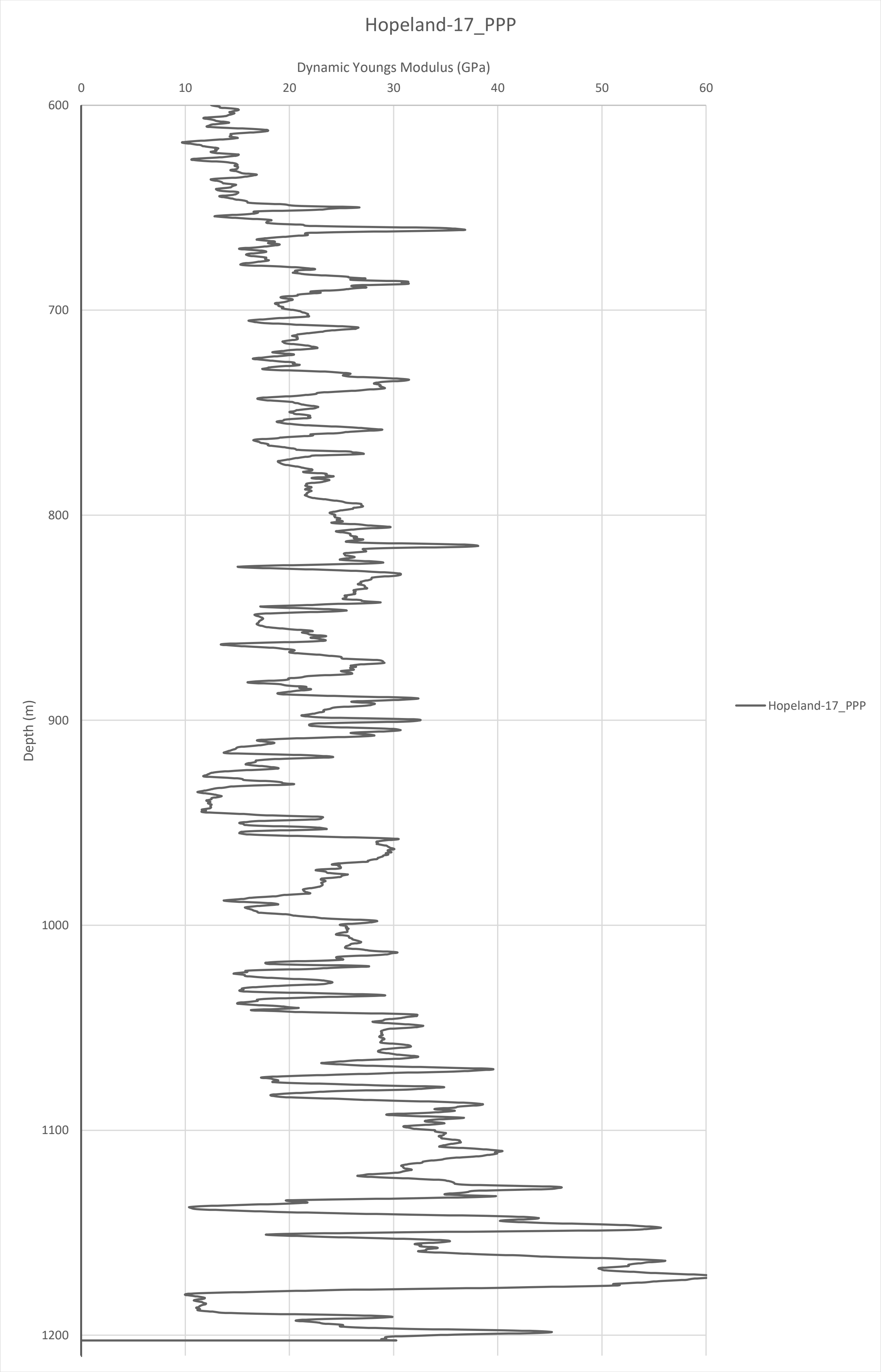
Depth (m)
Hopeland-17_PPP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Depth (m)
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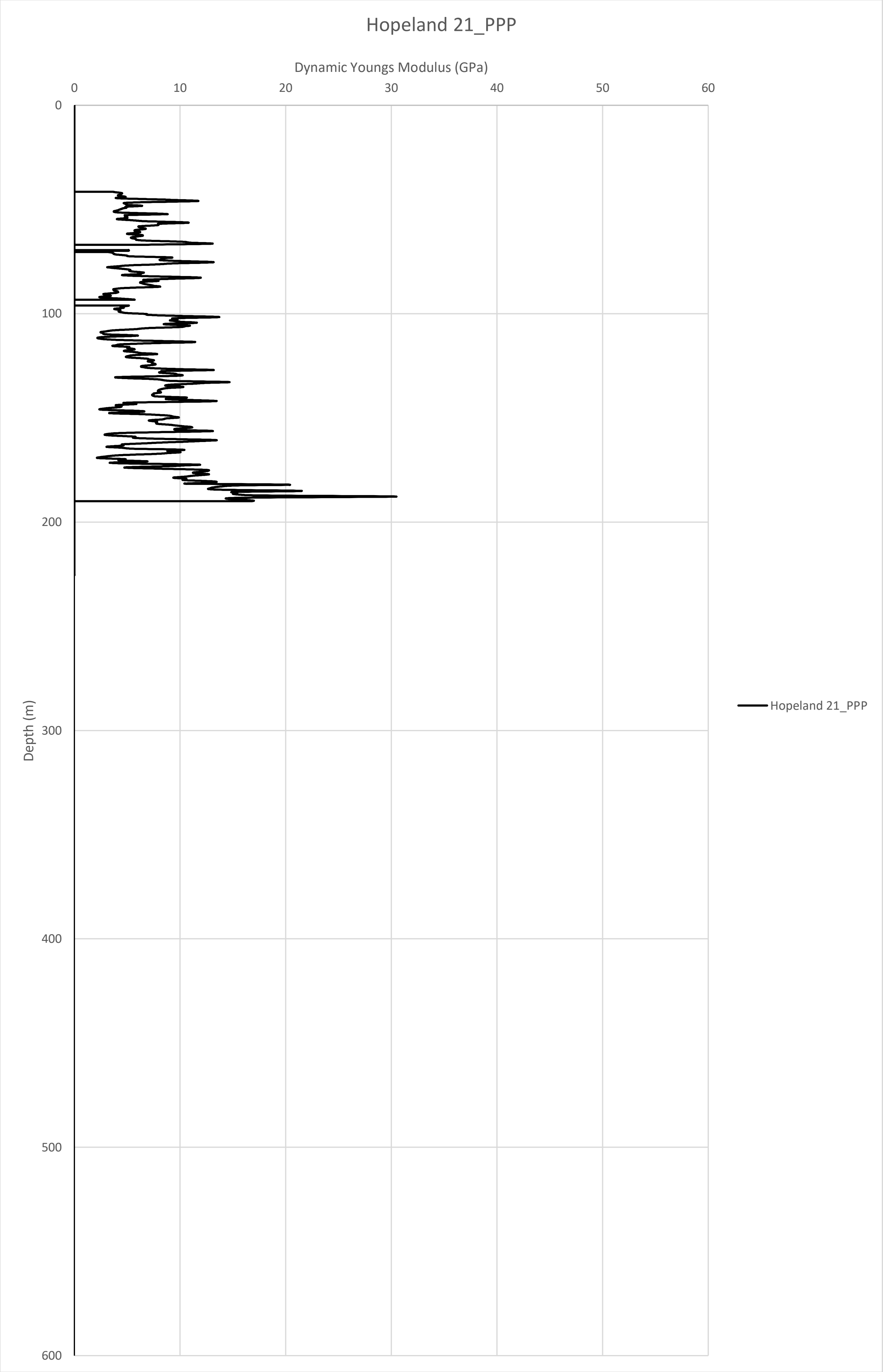
Hopeland-17_PPP


Hopeland 21_PPP
Dynamic Youngs Modulus (GPa)
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Depth (m)
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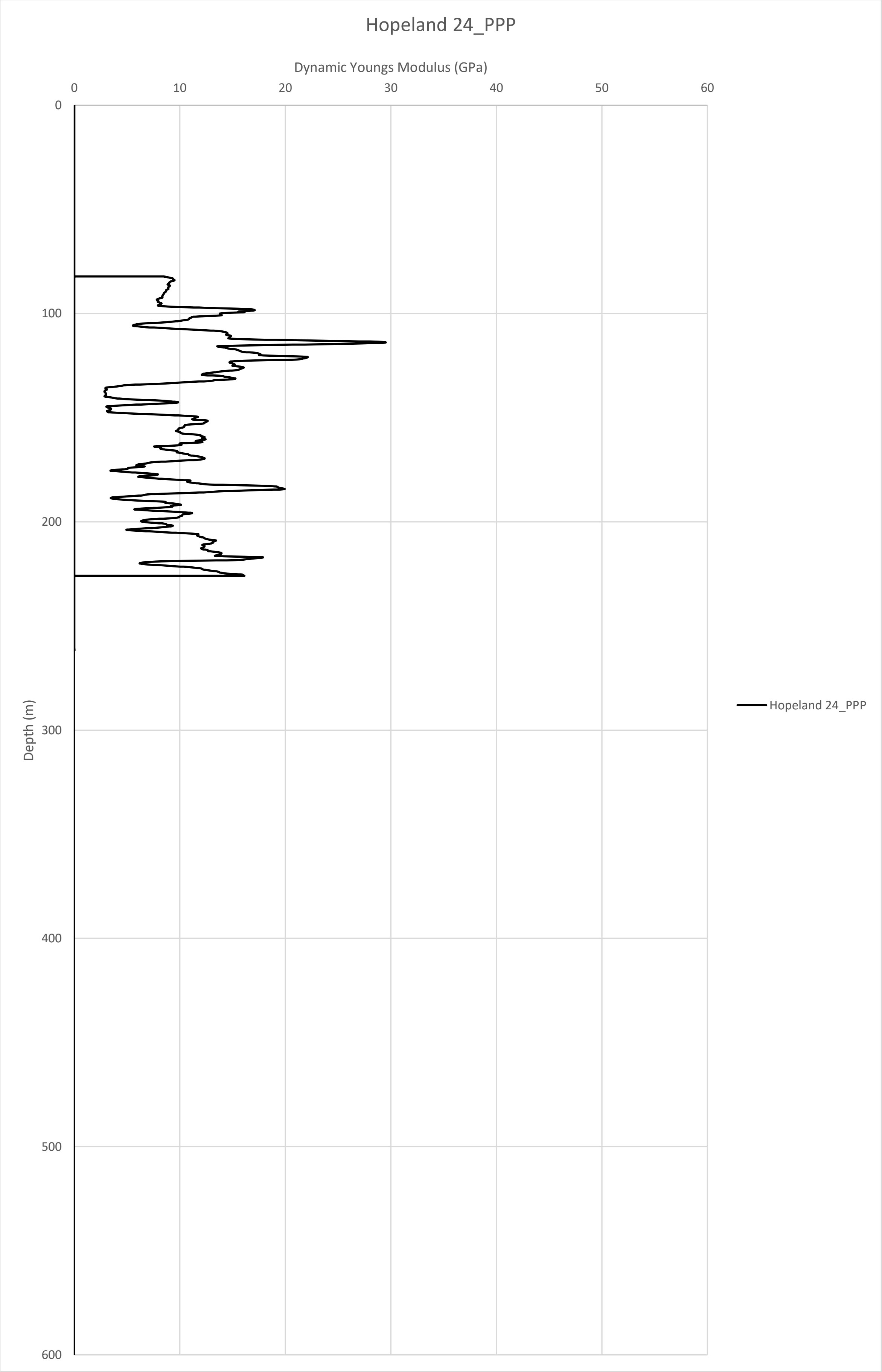
500
600
Hopeland 21_PPP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Depth (m)
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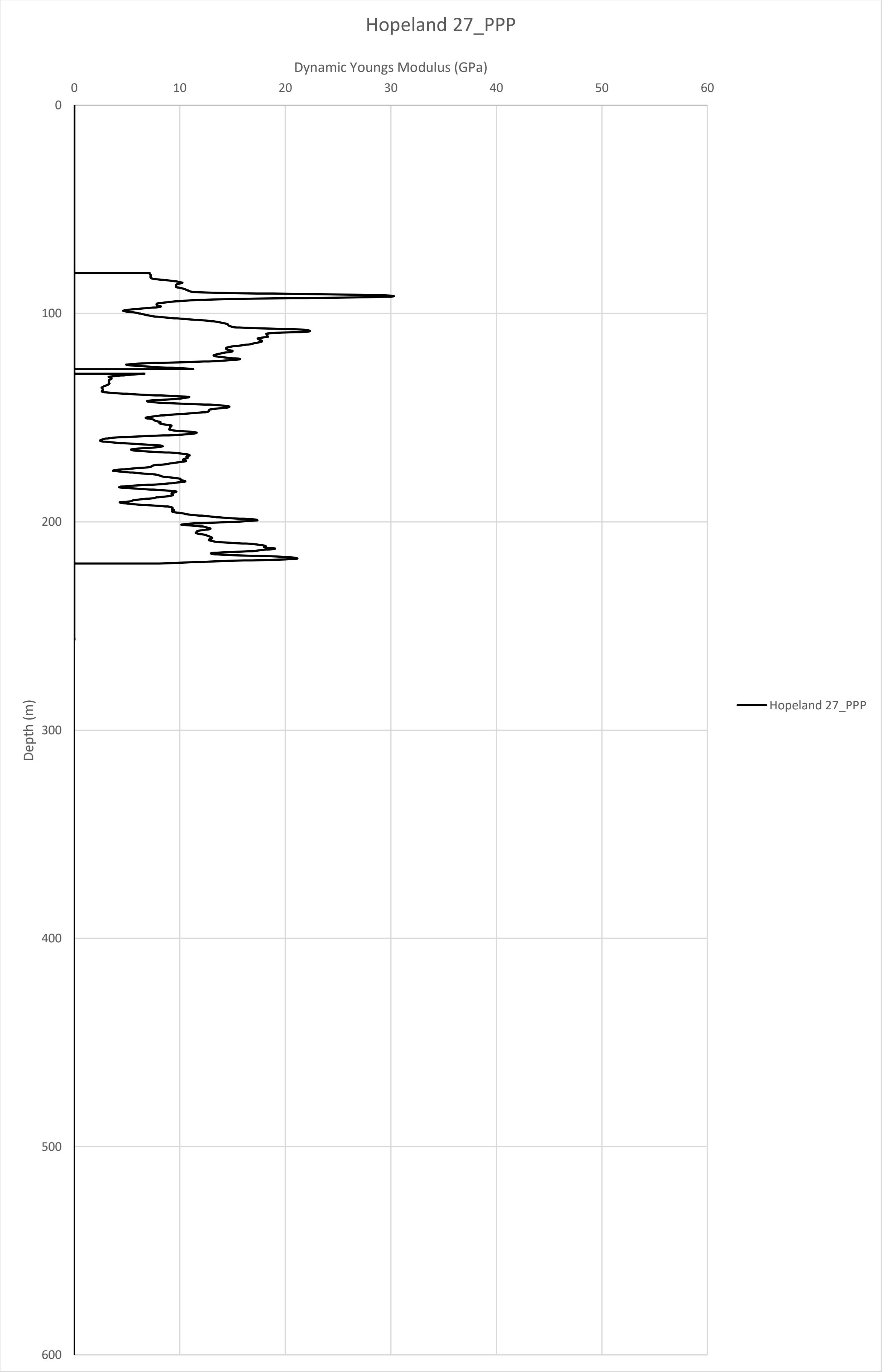
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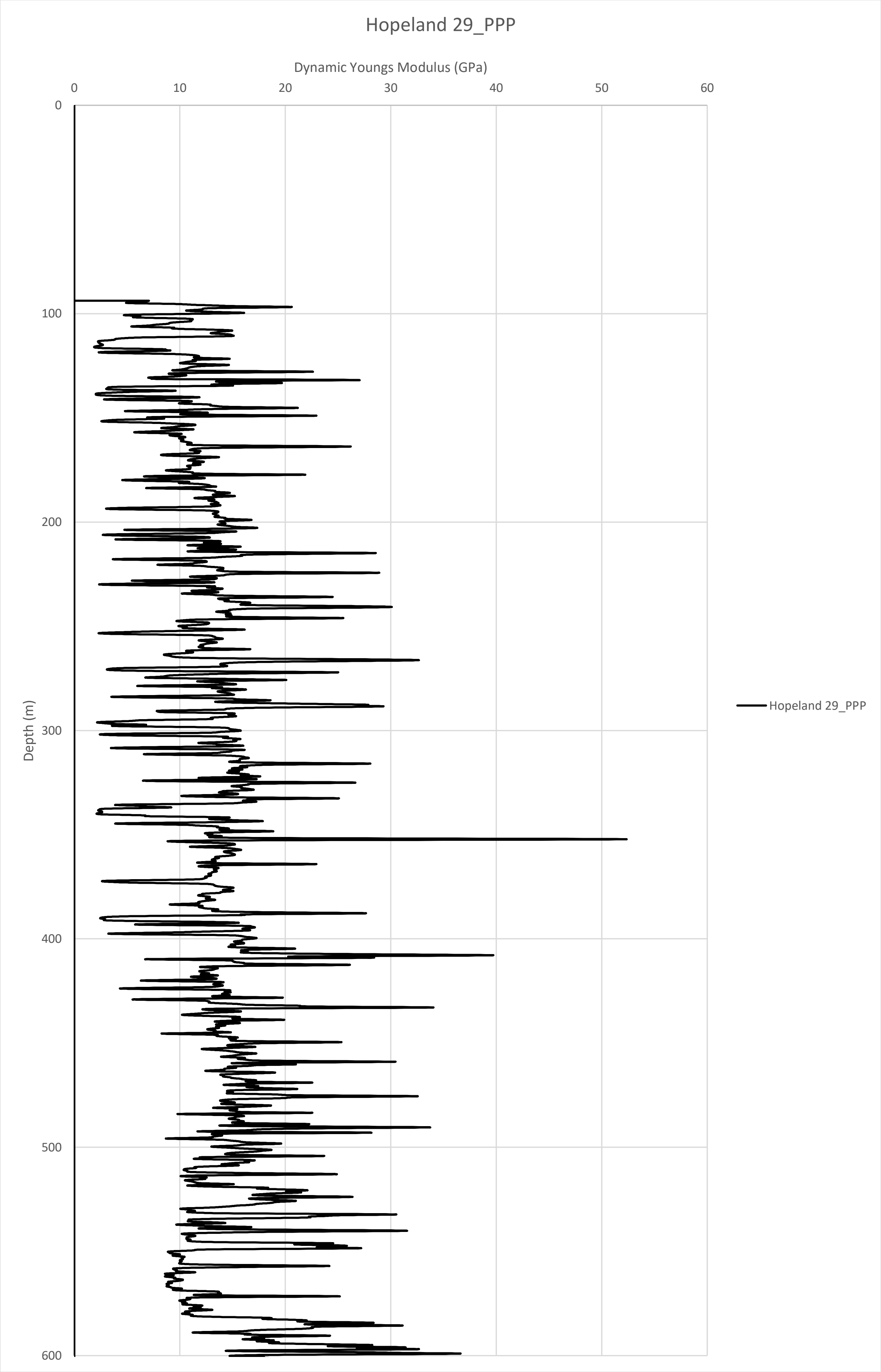
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Depth (m)
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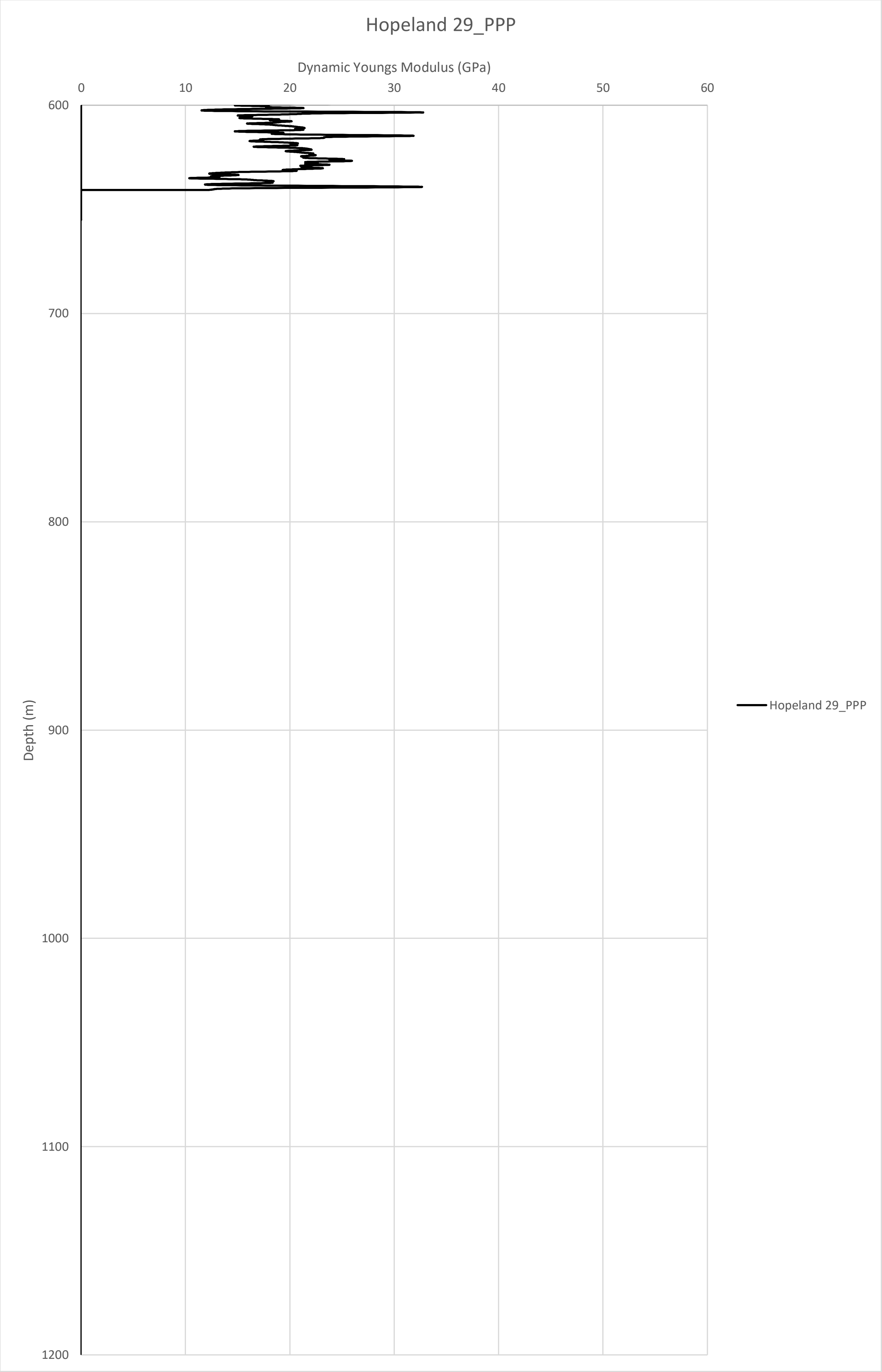

Hopeland 29_PPP
Dynamic Youngs Modulus (GPa)
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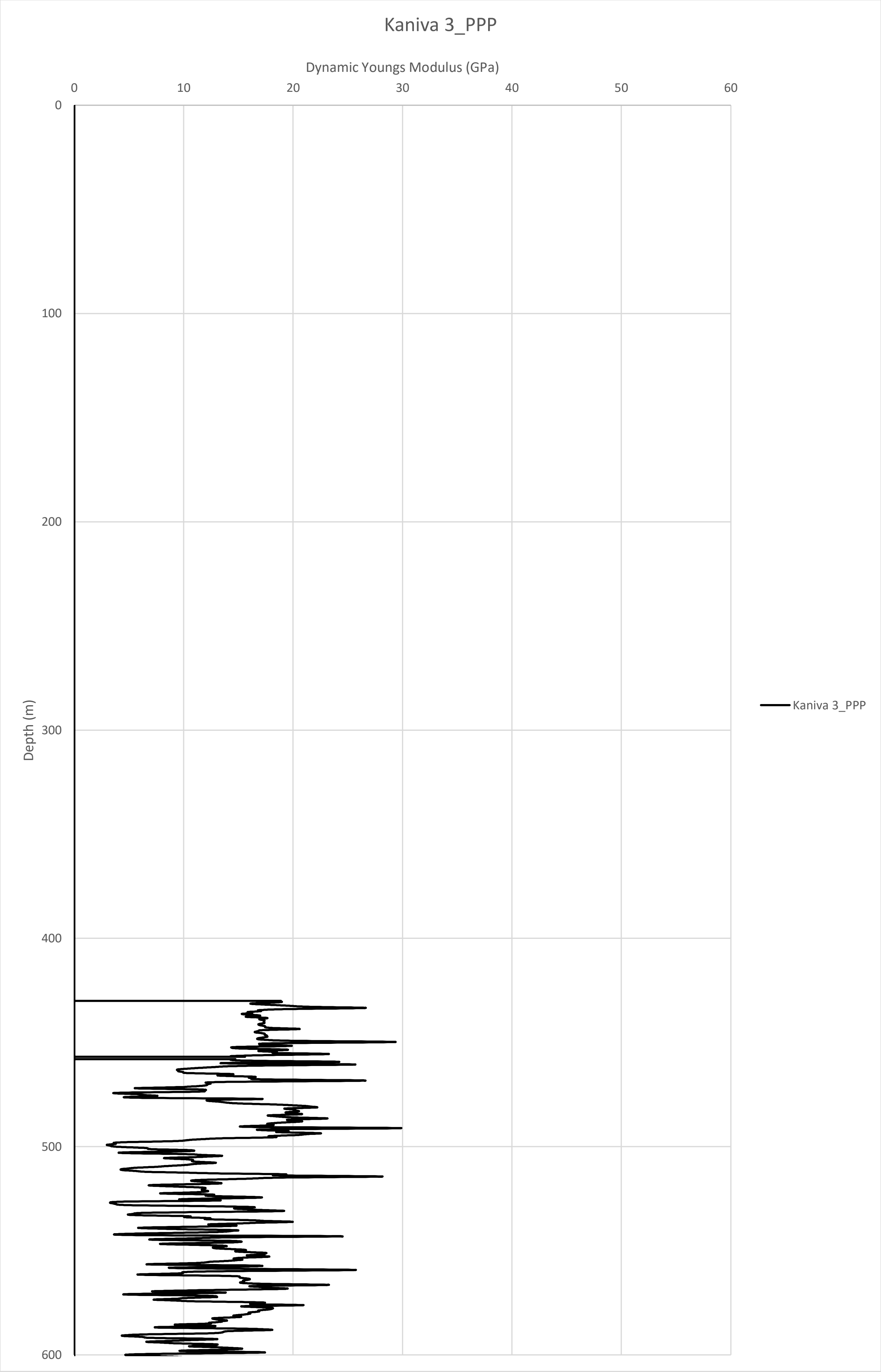
Depth (m)
Hopeland 29_PPP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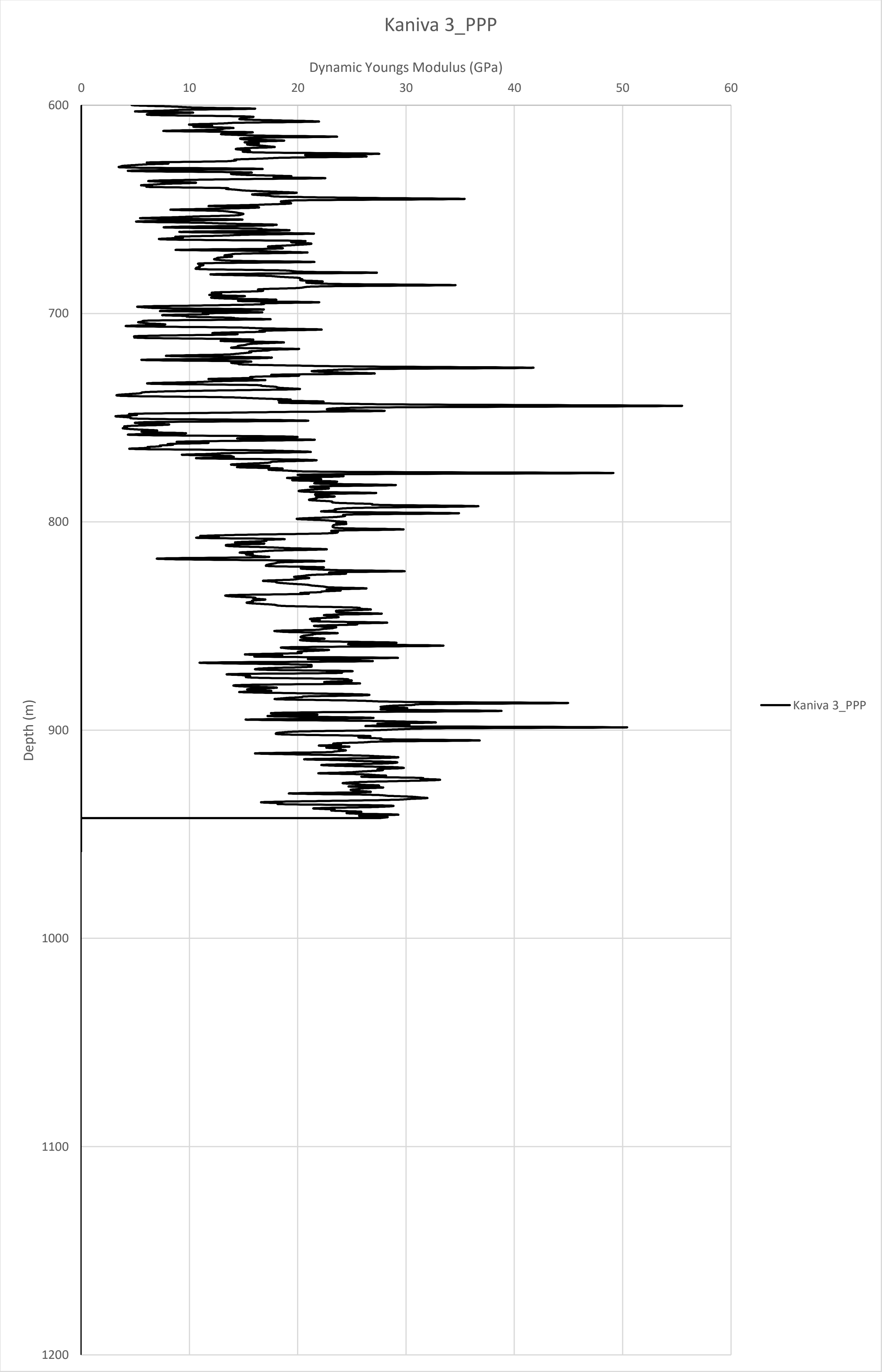
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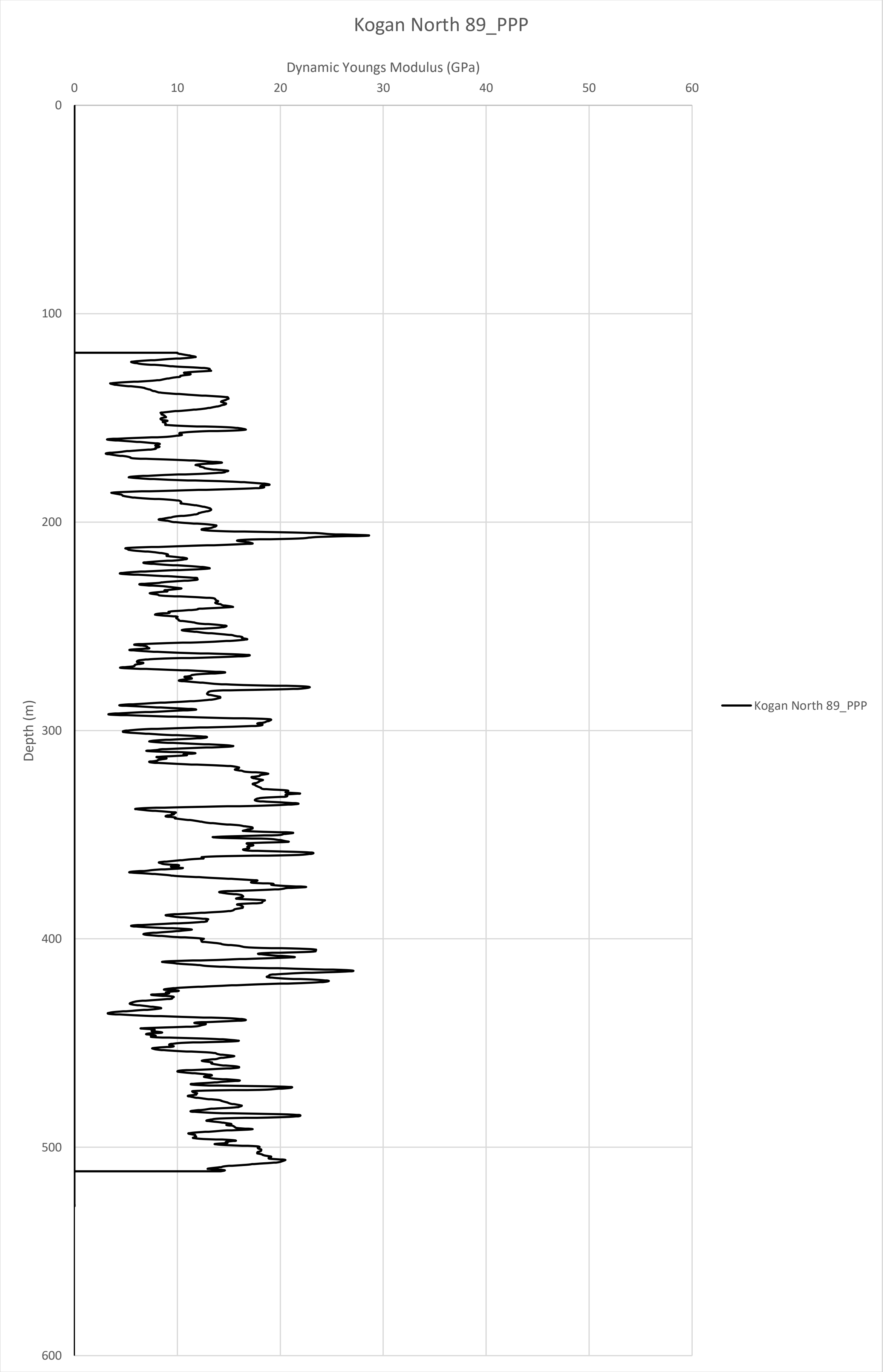
Depth (m)
Kaniva 3_PPP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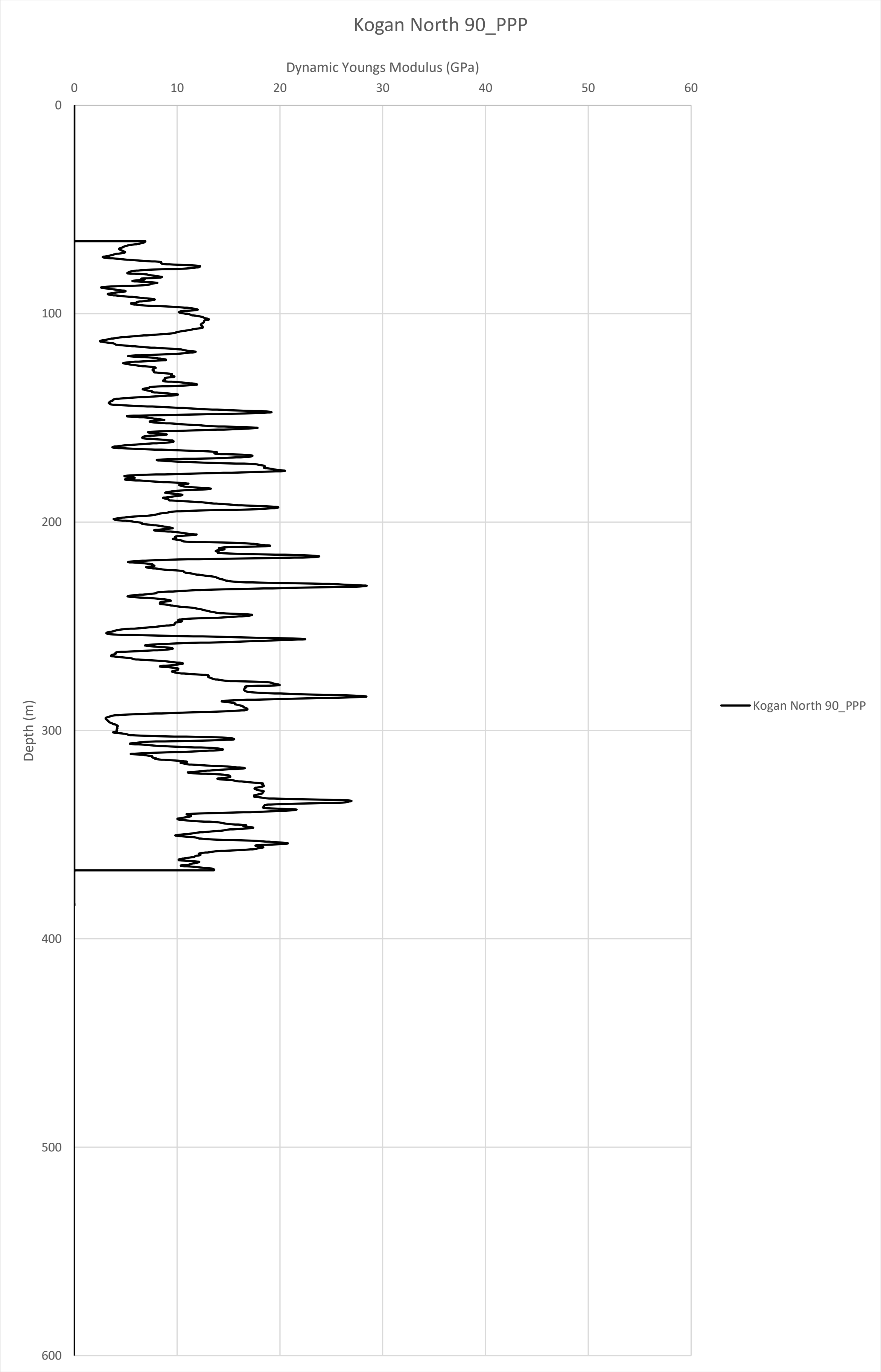
Depth (m)
Kogan North 89_PPP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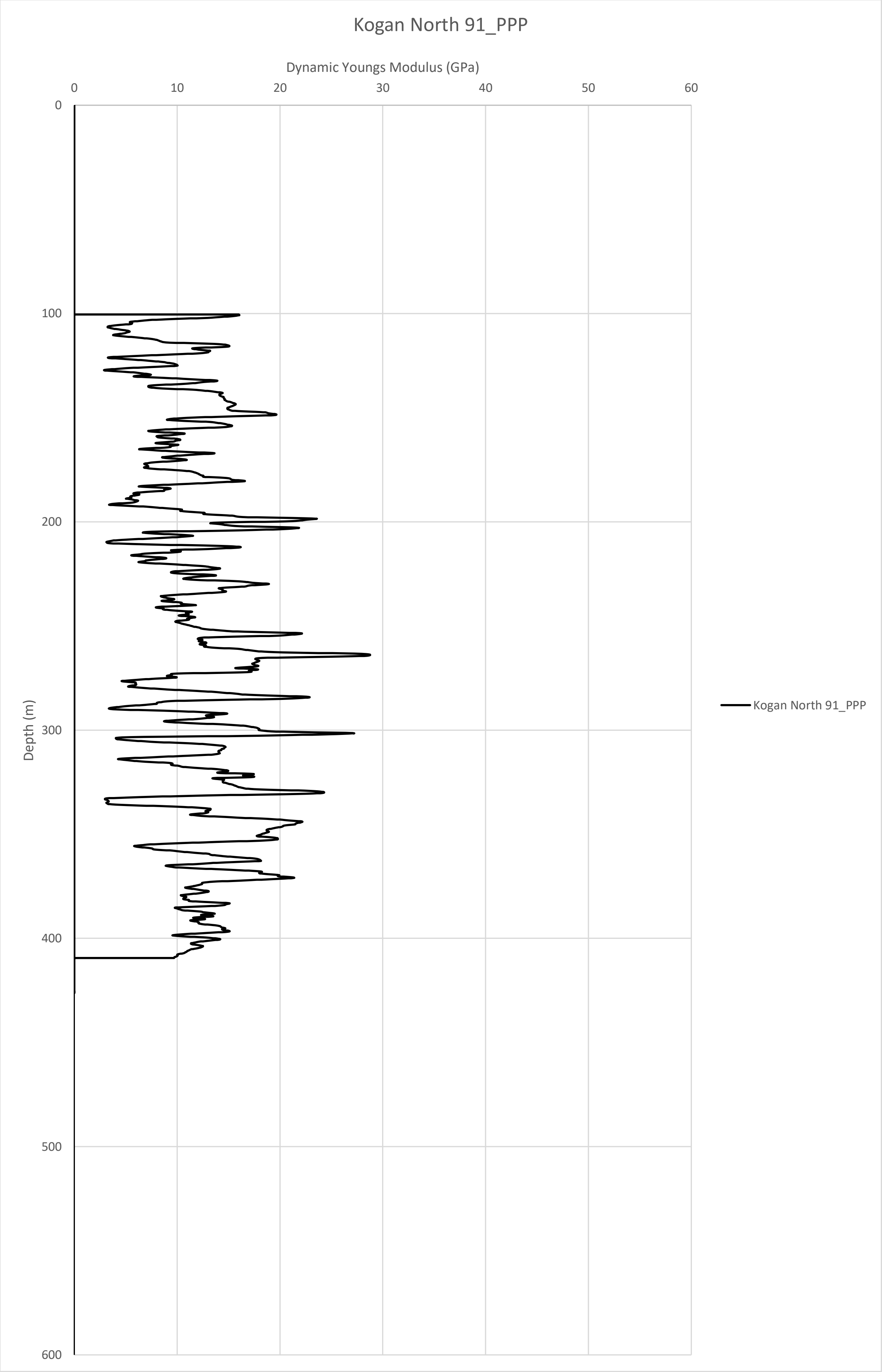
Kogan North 90_PPP


Kogan North 91_PPP
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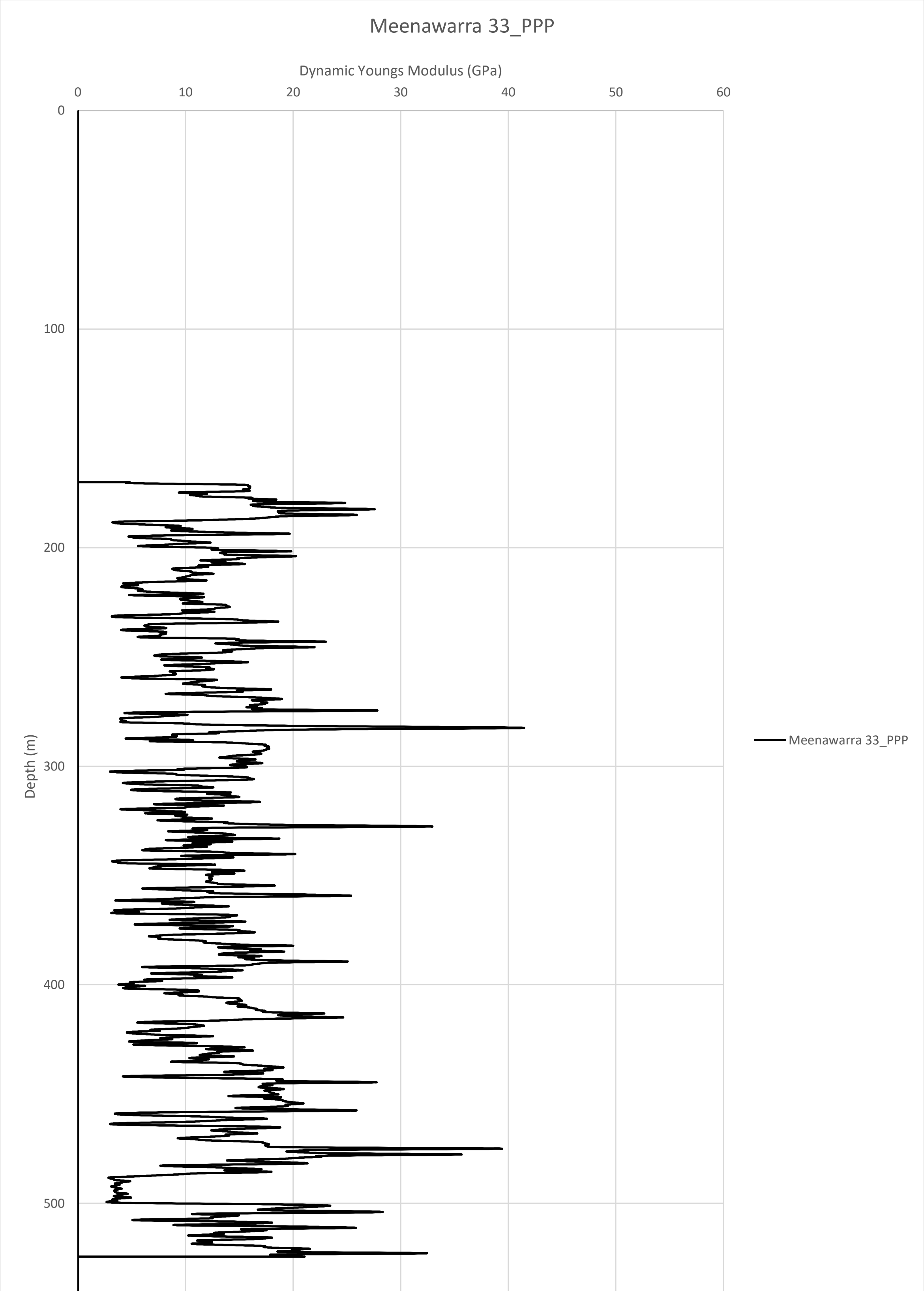
Kogan North 91_PPP


Meenawarra 33_PPP
Dynamic Youngs Modulus (GPa)
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Depth (m)
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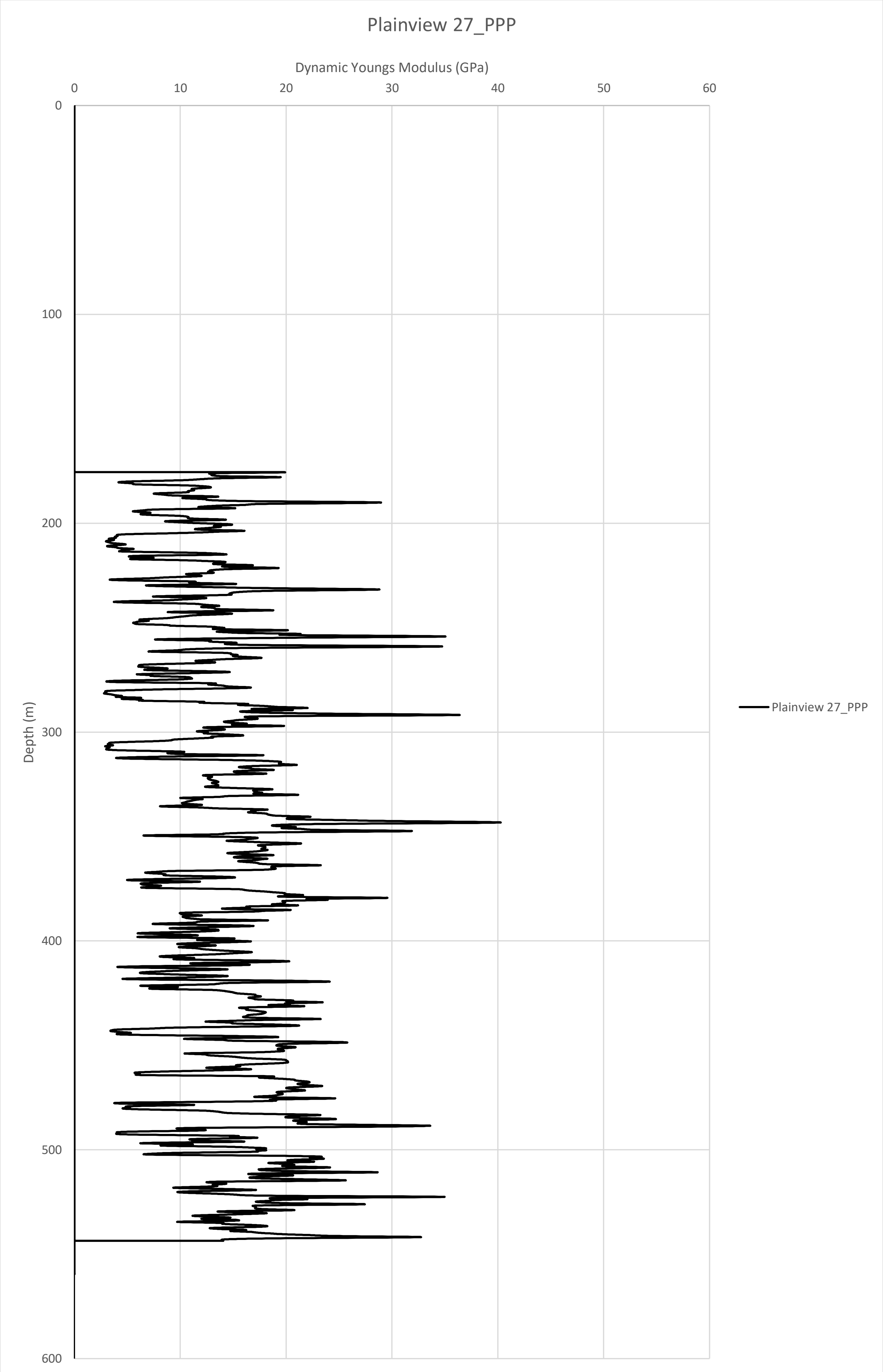
Meenawarra 33_PPP


Plainview 27_PPP
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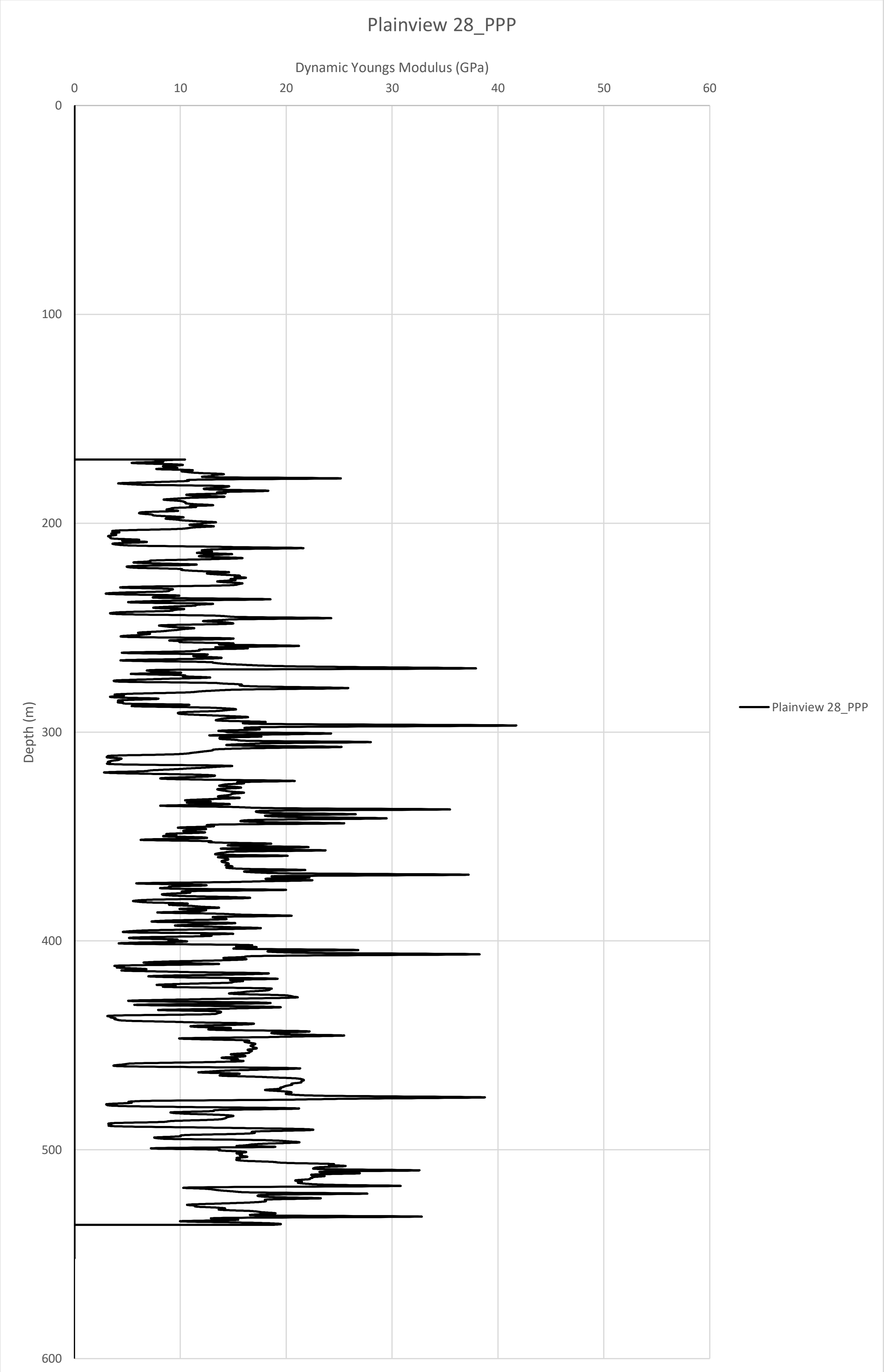
Depth (m)
Plainview 27_PPP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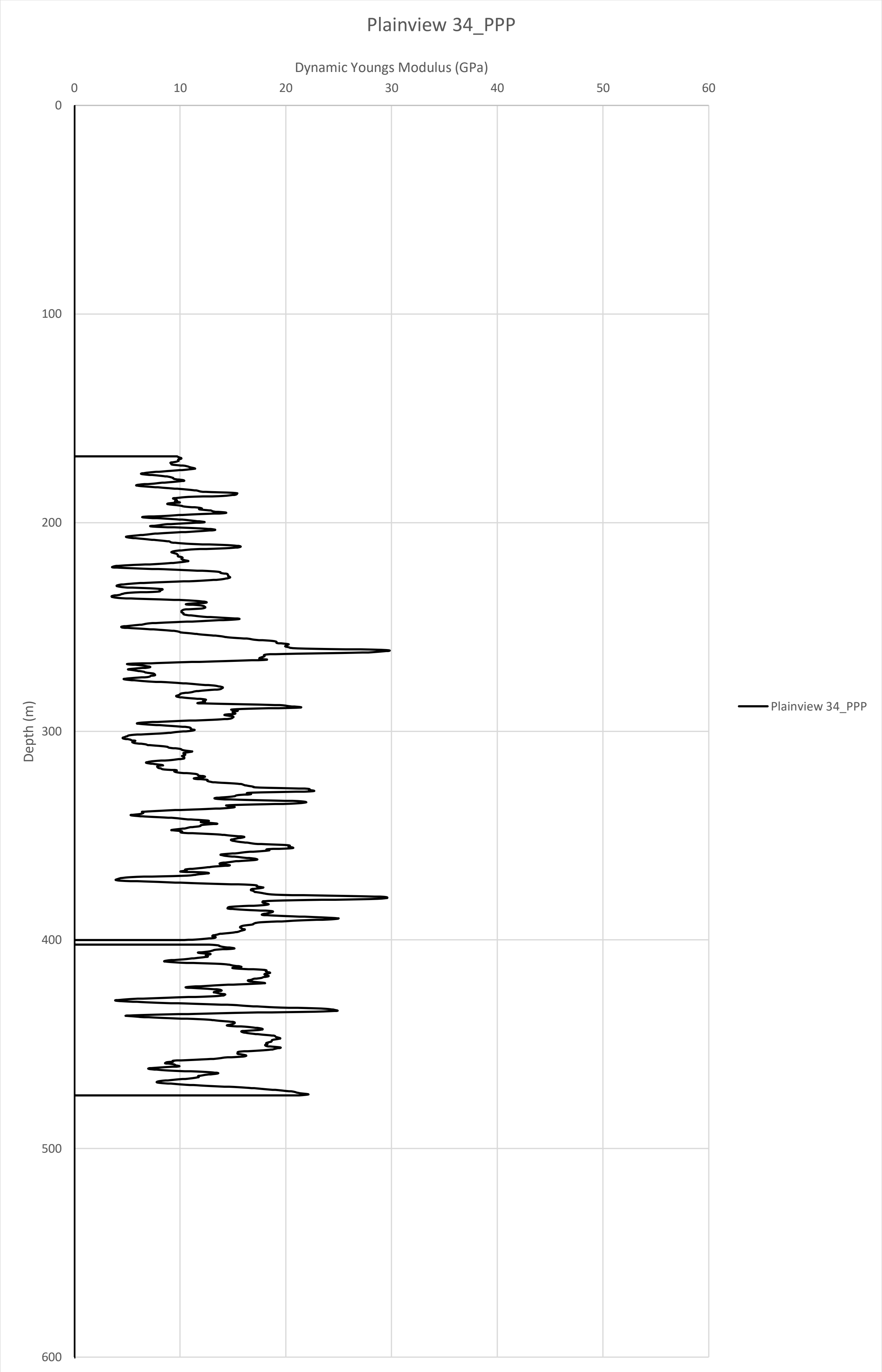
Depth (m)
Plainview 28_PPP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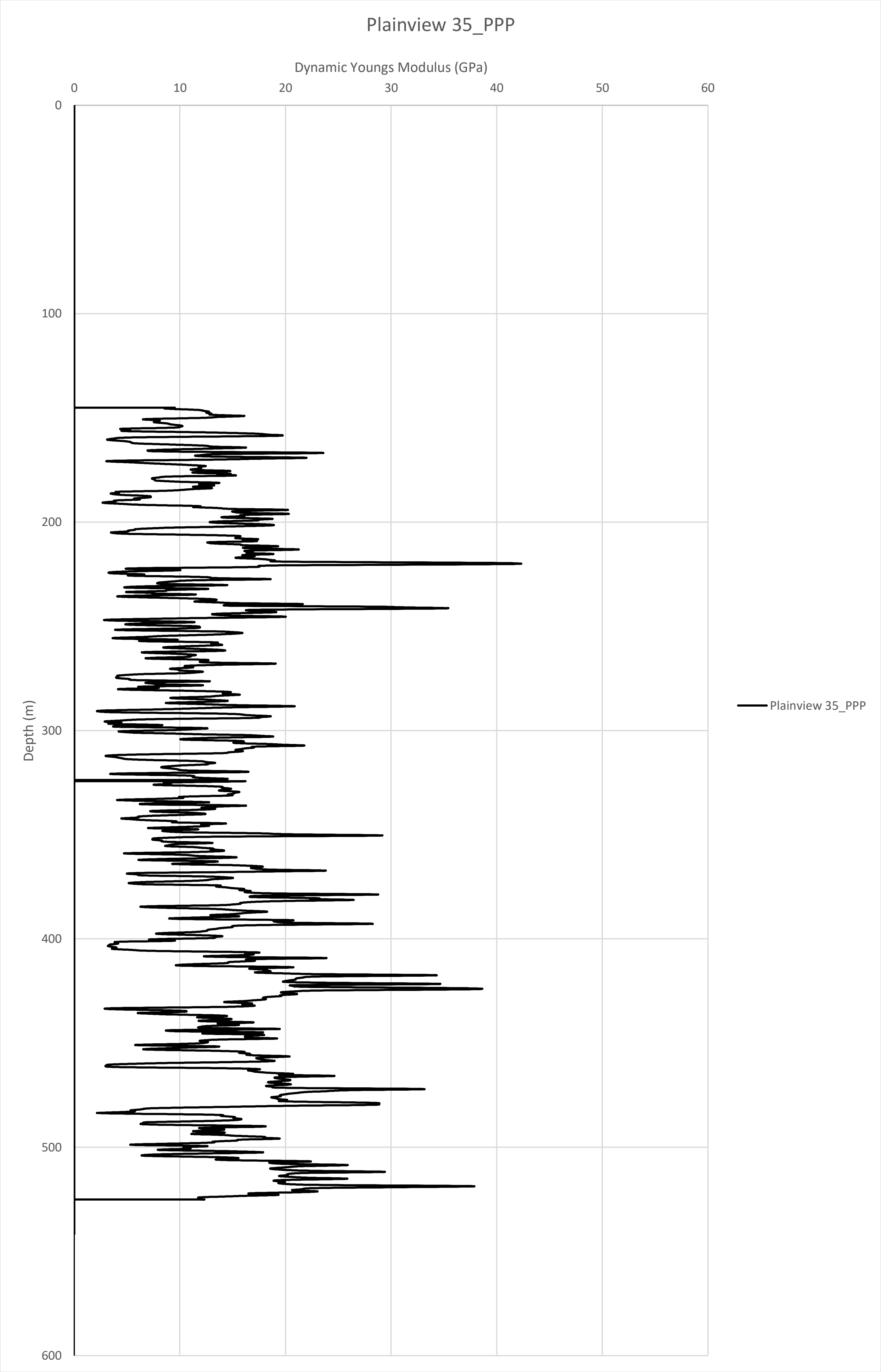
Depth (m)
Plainview 34_PPP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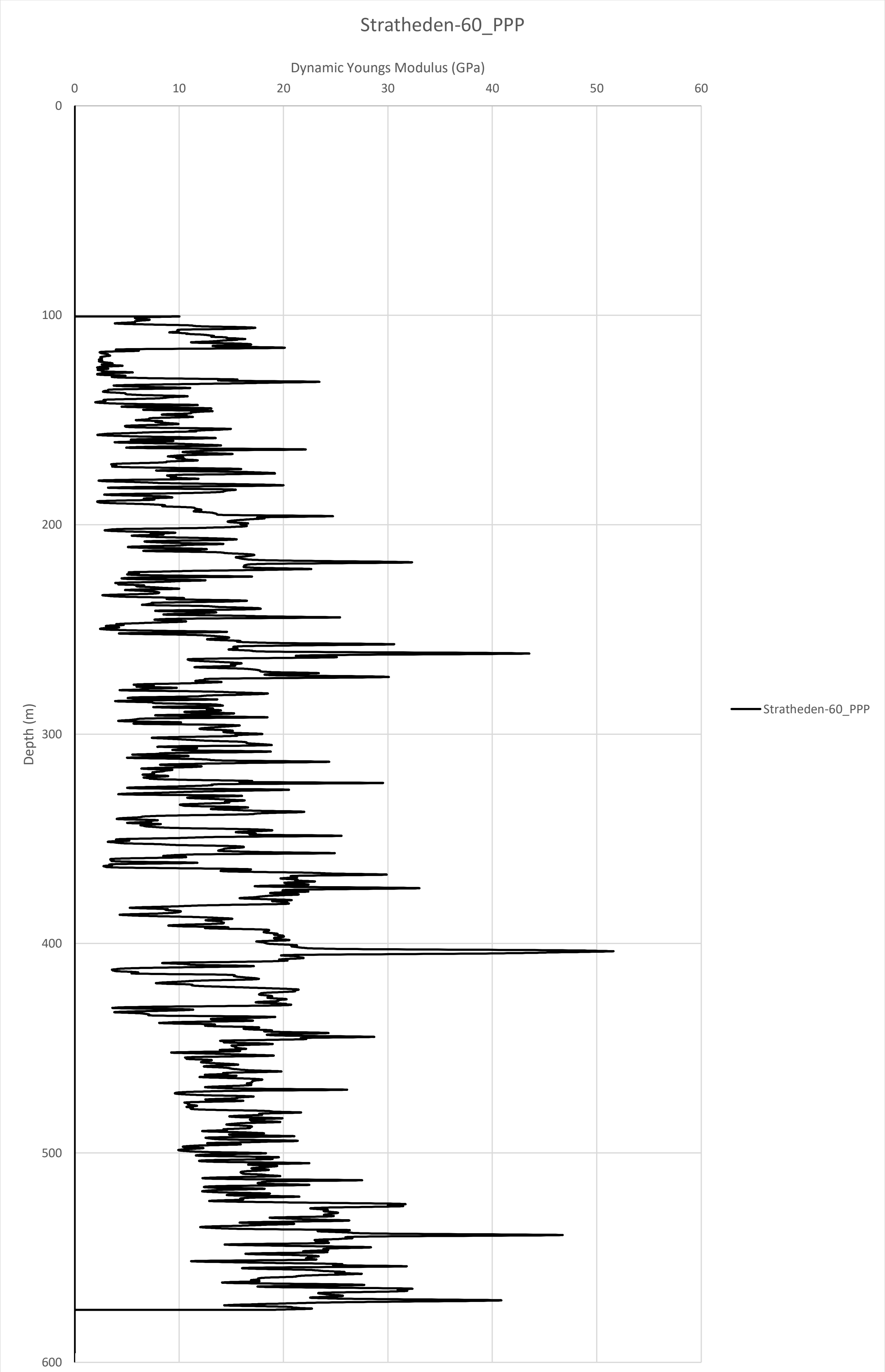
600
Depth (m)
Plainview 35_PPP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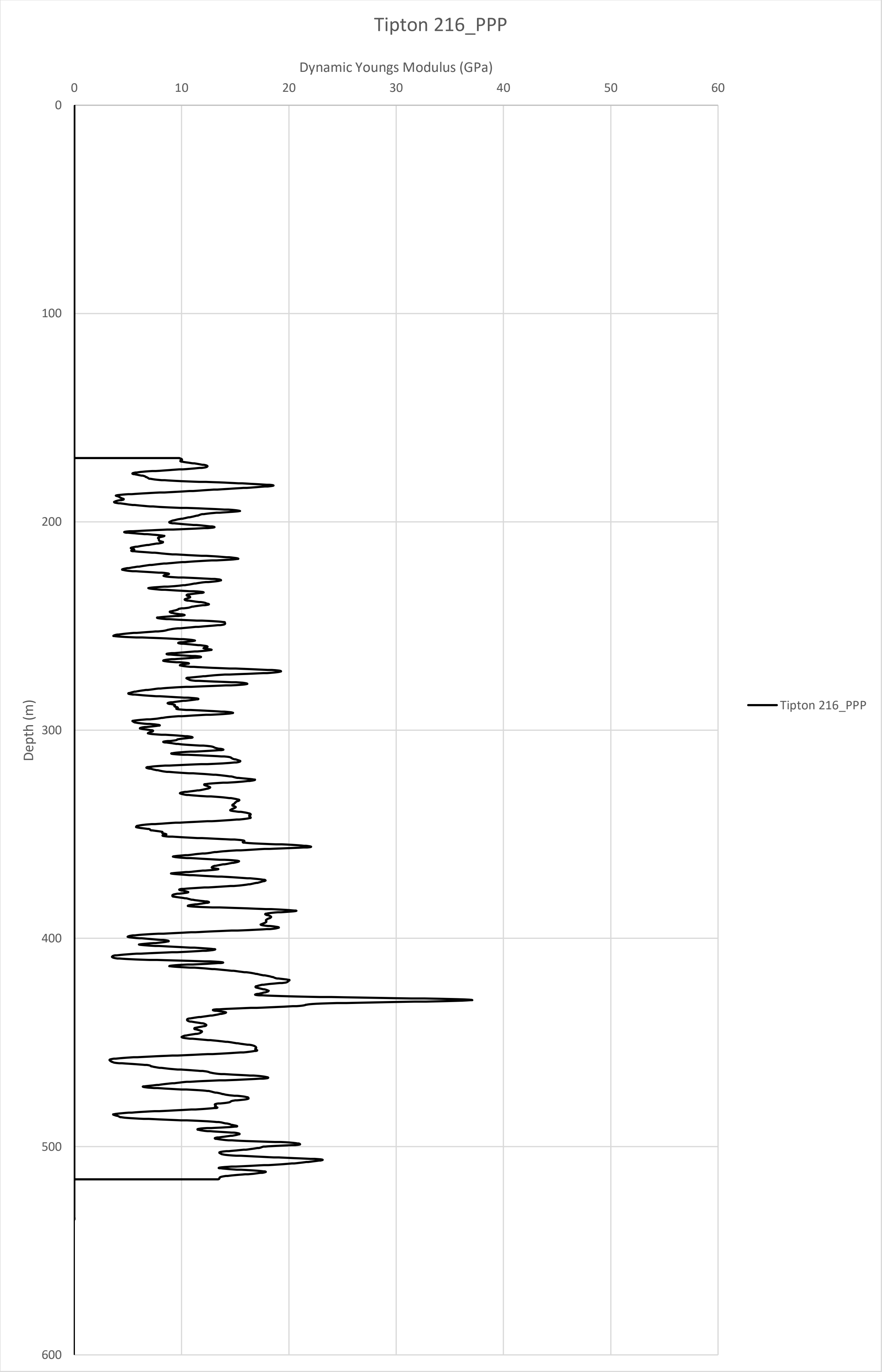
Depth (m)
Stratheden-60_PPP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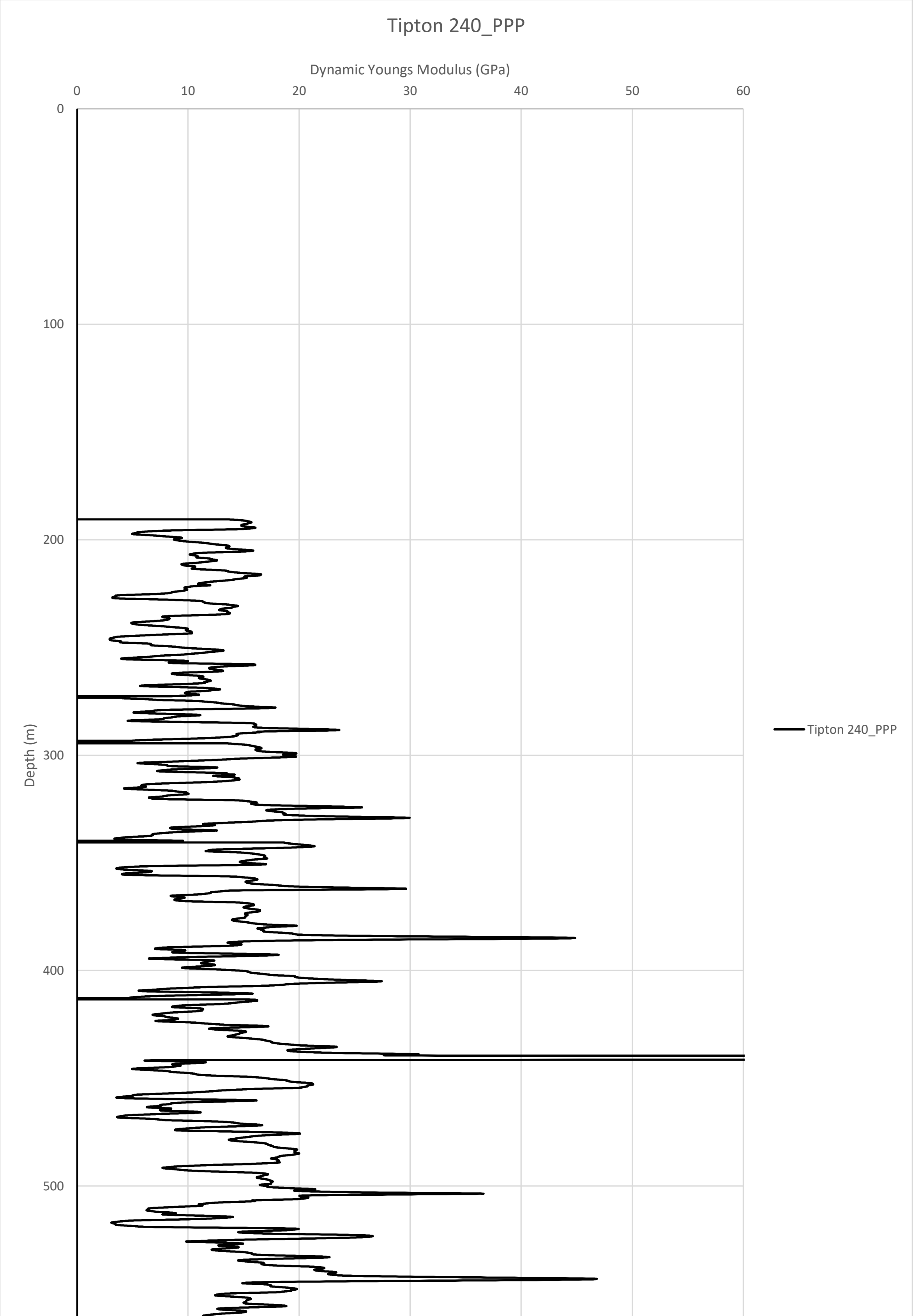
Depth (m)
Tipton 216_PPP


Tipton 240_PPP
Dynamic Youngs Modulus (GPa)
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60
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100
200
300
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500
600
Depth (m)
Tipton 240_PPP