Surat Gas Project Water Resource Monitoring and Management Plan

Subsidence

Revision history

Revision	Revision Date	Revision Summary
1	26 June 2025	Initial Issue

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1 Introduction

This document is intended to outline Arrow Energy's approach to monitoring and management of CSG-induced subsidence in relation to Matters of National Environmental Significance. It supersedes the *Arrow Energy Pty Ltd (Arrow) Surat Gas Project (SGP) Water Monitoring and Management Plan (2018)* and *Updated CSG Water Monitoring and Management Plan (2019)*.

As part of a previous programme of work for the Arrow Energy Pty Ltd (Arrow) Surat Gas Project (SGP) Water Monitoring and Management Plan (WMMP), Coffey Services Australia Pty Ltd (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 satellite-borne interferometric synthetic aperture radar (InSAR) observations and groundwater monitoring data available in 2018 (covering the period July 2012 to December 2015), and provided:

- Assessment of the long-term subsidence associated with proposed Arrow SGP operations at that time 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.

Since the Technical Memorandum, Arrow has continued to monitor subsidence with InSAR, aircraft-borne light detection and ranging (LiDAR), and installation of real-time ground movement monitoring devices. With the ongoing monitoring Arrow has observed that, whilst 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 as a result of frequent changes in the character of the ground surface reflection. LiDAR surveys are well suited to capture relative movement across the landform, as opposed to vertical movement for InSAR, and can be used to accurately determine changes in surface gradient and is routinely conducted in areas of low InSAR coherence.

The Queensland Office of Groundwater Impact Assessment (OGIA) undertook a preliminary risk-based assessment of potential impact to environmental values due to CSG induced subsidence for the 2019 Underground Water Impact Repot (UWIR). The approach in the 2019 UWIR incorporated an assessment of the likelihood of CSG induced subsidence and a description of the environmental values located within risk areas (OGIA, 2019a). The likelihood of CSG induced subsidence was assessed using an estimate of total compaction within the Walloon Coal Measures using the predictions of groundwater level change; and the presence or absence of overlying consolidated sandstone formations that may attenuate any potential subsidence at the surface. On this basis, all areas containing environmental values within Arrow tenures were found to be at low to moderate risk of subsidence.

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For the 2021 UWIR, OGIA developed a numerical model coupling geomechanics to groundwater depressurisation, predicting magnitude of subsidence and change in slope as a result of CSG operations in the area of the Condamine Alluvium, and an analytical model predicting magnitude of subsidence in the greater Surat Basin (OGIA, 2021a). The OGIA modelling was history matched to observed ground movement data from InSAR in areas of existing CSG production, allowing improved parameterisation and estimates of predictive uncertainty. With respect to aquatic ecosystems associated with surface watercourses in the Surat Basin, OGIA considered that depending upon the magnitude, CSG induced subsidence may change the slope of tributaries, resulting in changes in flow and direction that could affect aquatic systems. However, OGIA found that observed and predicted subsidence in the Surat Basin, including Arrow's SGP area, is very small and unlikely to materially change surface flows to watercourses (OGIA, 2021a). The potential to alter the porosity and permeability of the surrounding aquifers was found likely to be inconsequential as they are less prone to compaction compared to the CSG target formation.

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

- Discussion of the theoretical mechanism of subsidence
- Assessment of the compressibility of the Walloon Coal Measures
- InSAR ground movement monitoring data over the period August 2015 to June 2024
- Assessment of the uniformity of ground movement
- Discussion of natural ground movements not related to CSG extraction
- Groundwater level monitoring and its relation to observed ground movement
- Predictions of future subsidence from the updated UWIR analytical and geomechanical models (OGIA, 2021a)
- The potential impacts to Matters of National Environmental Significance (MNES) that could result from CSG induced subsidence, being impairment of aquifer integrity or changes to landform that impact groundwater or surface water resources and dependent aquatic or groundwater dependent ecosystems.
- Development of screening levels, investigation levels, trigger thresholds and action plans for potential impacts to MNES protected measures
- Monitoring methods and reporting protocols.

2 Background

This report addresses subsidence and groundwater levels in the Arrow SGP operations and surrounding areas. The planned Arrow SGP operations area totals 5,385 km^2 with projected CSG groundwater production of 380 GL over 42 years involving up to 2,766 wells. The extent of the SGP development area tenure is shown in Figure 2-1.

Arrow also has four domestic gas production fields in the Surat Basin which do not form part of the SGP, and locations are shown approximately on Figure 2-1. The domestic gas production by Arrow has occurred since 2006 at:

- Tipton West - approximately 40 km southwest of Dalby, commencing production in September 2006;
- Contiguous fields Kogan North, Daandine and Stratheden approximately 30 km west of Dalby, commencing production in January 2006.

Production drilling of Arrow's Surat Basin domestic 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

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the Walloon Coal Measures. While these domestic operations do not form part of the Arrow SGP they provide valuable experience in relation to groundwater drawdown and subsidence occurring during their operation.

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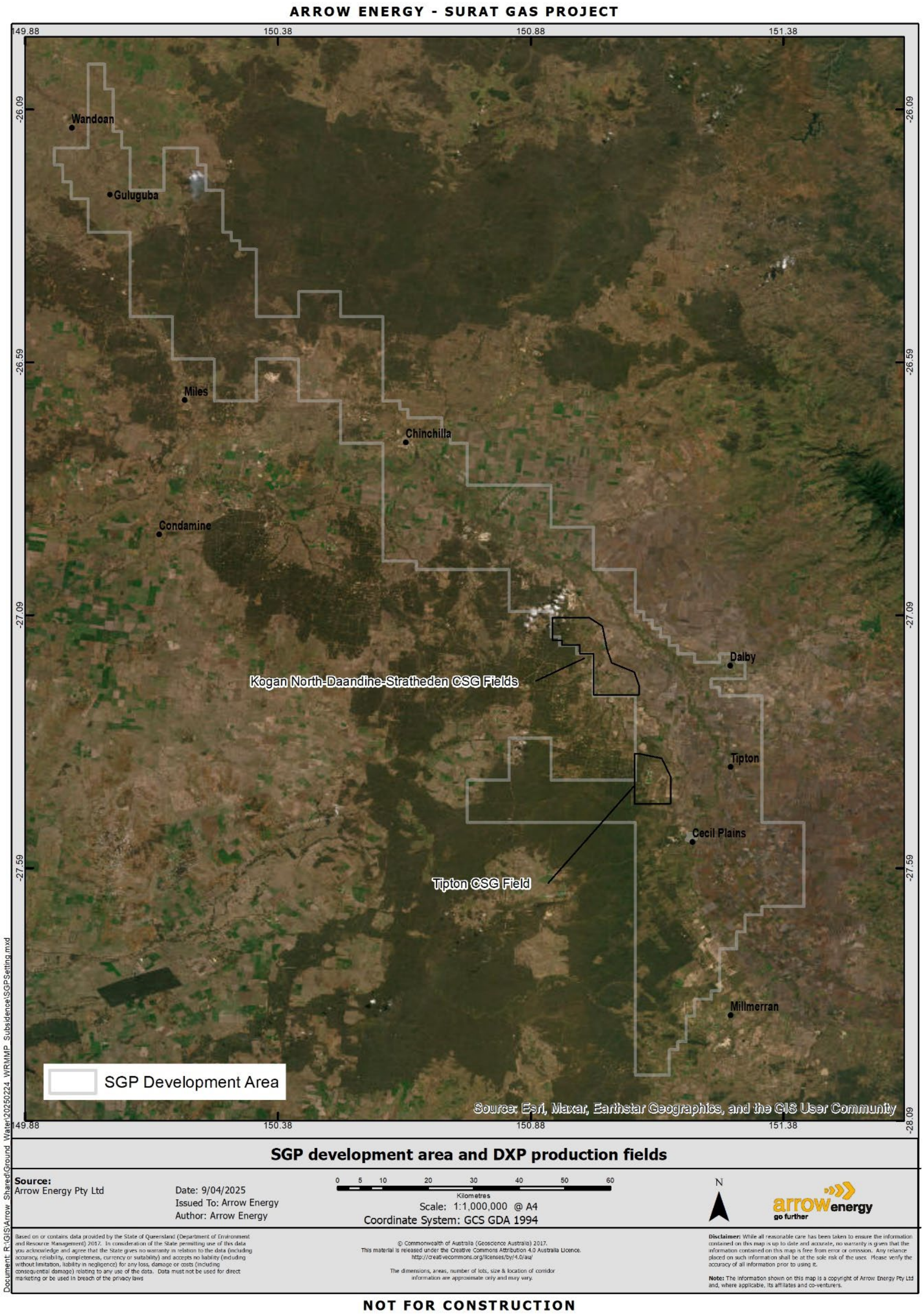

Figure 2-1: Extent of SGP development tenures and location of DXP operating fields

2.1 Geological setting

A description of the geological setting within the Surat Cumulative Management Area (CMA) is provided in OGIA (2021b). Elements of this in the context of their properties as relevant to groundwater behaviour are discussed below.

The SGP lies within three major structural Mesozoic basins: the Surat Basin (in the south and west) which unconformably overlies the Bowen Basin in the north and is continuous to the Clarence-Moreton basin to the east across the anticlinal Kumbarilla Ridge. Figure 2-2 presents important structural elements of the study area.

Disconformably underlying parts of the Surat Basin is a gently folded Permian to Triassic sequence of the north-south aligned Taroom Trough, which is the sub-surface extension of the Bowen Basin. In this area, a sedimentary sequence up to 2,500 m thick in the down-warped south/south-east to north/north-west trending Mimosa Syncline has been recorded (Reiser, 1971).

The Surat Basin stratigraphy includes gently folded sedimentary sequences, intersected in places by faults. These fault structures can be fully or partially penetrating through the full geological sequence, and major faulting within the Surat Basin is generally an expression of boundary faults of the underlying Bowen Basin (Arrow Energy, 2013).

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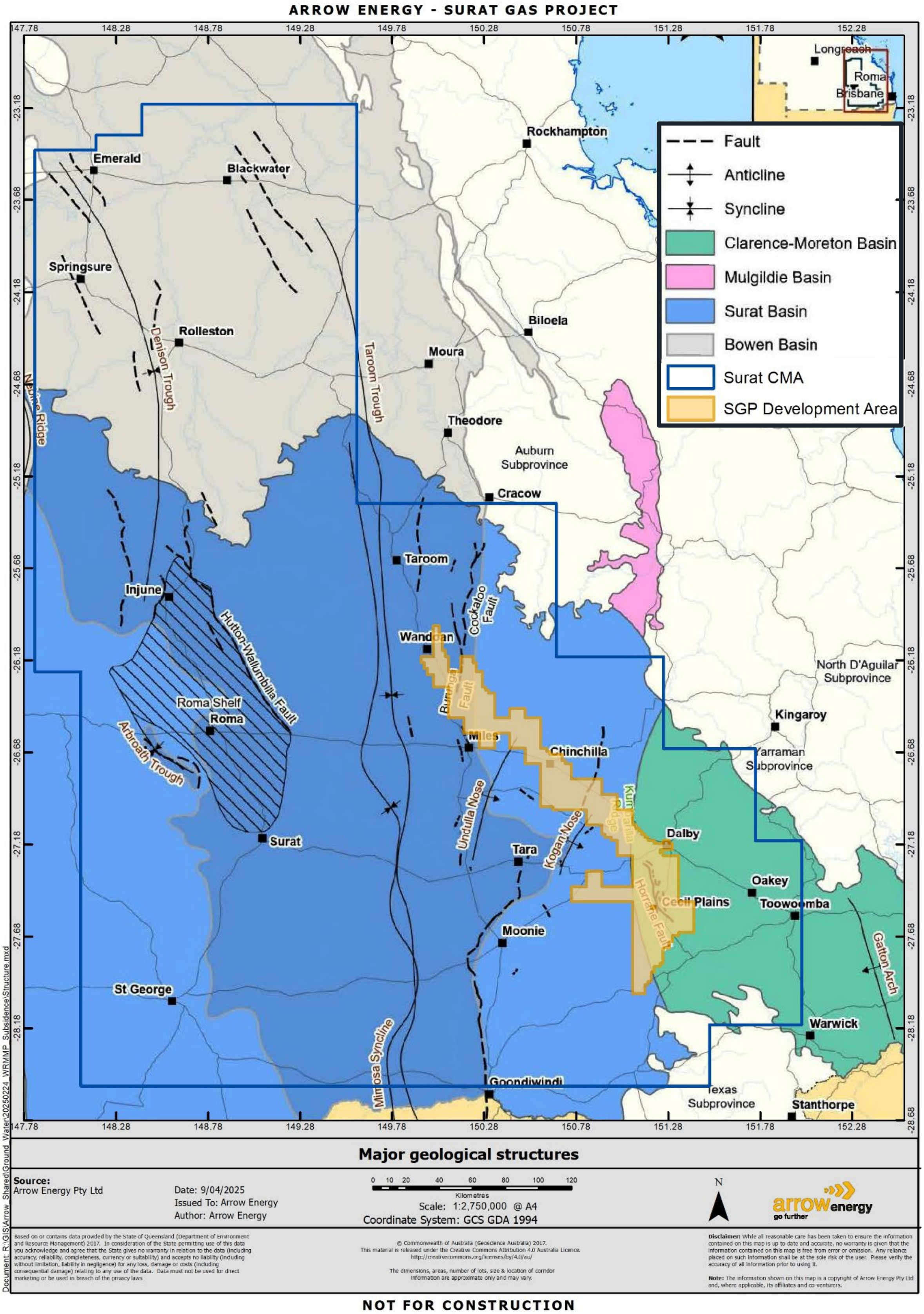

Figure 2-2: Major geological structures in the Surat CMA (adapted from OGIA, 2021b)

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Figure 2-3 sets out the typical stratigraphic and hydrostratigraphic profile within the Surat and Clarence Moreton Basins in areas of Arrow SGP operations. In the context of CSG induced subsidence in the area of the SGP operations, the Jurassic Walloon Coal Measures, Springbok Sandstone, and Westbourne Formation and Cenozoic Condamine Alluvium are the most relevant formations to consider.

The Walloon Coal Measures is the host formation of the coal seam gas. It is subdivided into the Juandah Coal Measures and the Taroom Coal Measures, which are the target strata for Arrow SGP wells. The coal seams are generally the more permeable units within the Walloon Coal Measures, with hydraulic conductivity of 0.001 metres to 1 metre per day (m/d), sitting within an interburden of mainly mudstones, siltstones or fine-grained sandstones, with hydraulic conductivity of $1x10^{-7}$ to $1x10^{-5}$ m/d (OGIA, 2021a). The lower permeability and relatively thin Tangalooma Sandstone unit separates the Juandah Coal Measures in the upper Walloon Coal Measures from the Taroom Coal Measures in the lower Walloon Coal Measures. The Juandah Coal Measures are subdivided into coal seam packages, from shallowest to deepest being the Kogan coal seam, Macalister coal seam, Wambo coal seam, and Argyle coal seam. The Taroom Coal Measures are divided into two seam packages in Arrow's SGP development area, the Upper Taroom coal seam and Condamine coal seam. The formations of the Surat Basin dip generally to the southwest or west in the area of the SGP operations, with the Walloon Coal Measures outcropping in the north or subcropping below the Condamine Alluvium in the east.

Overlying the Walloon Coal Measures are the Gubberamunda Sandstone, the Westbourne Formation and the Springbok Sandstone. In outcrop or subcrop where they are poorly differentiated, these units are known as the Kumbarilla Beds. The Springbok Sandstone is a tight aquifer and the Westbourne Formation is a tight aquitard (OGIA, 2021a), and outcrop over most of the area of the SGP operations, while the Gubberamunda Sandstone is a regional aquifer which is only present in a small area of the SGP operations northwest of Tipton.

The Condamine Alluvium is present in lower lying areas flanking the Condamine River in the east of the SGP operations area, between Millmerran and Chinchilla. The alluvium is up to 150 m thick and 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 regionally significant aquifer water resource.

Underlying the Walloon Coal Measures is the Eurombah (Durabilla) Formation. This aquitard reduces the influence of drawdown and associated formation compaction 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. Within the areas of the Arrow SGP operations, the Walloon Coal Measures are typically less than 450 m thick, and thin towards the eastern margin where they are truncated at the erosional contact with overlying Springbok Sandstone or Condamine

Alluvium or in outcrop. Figure 2-4 presents contours of the thickness of the Walloon Coal Measures, as presented by Office of Groundwater Impact Assessment (2019b).

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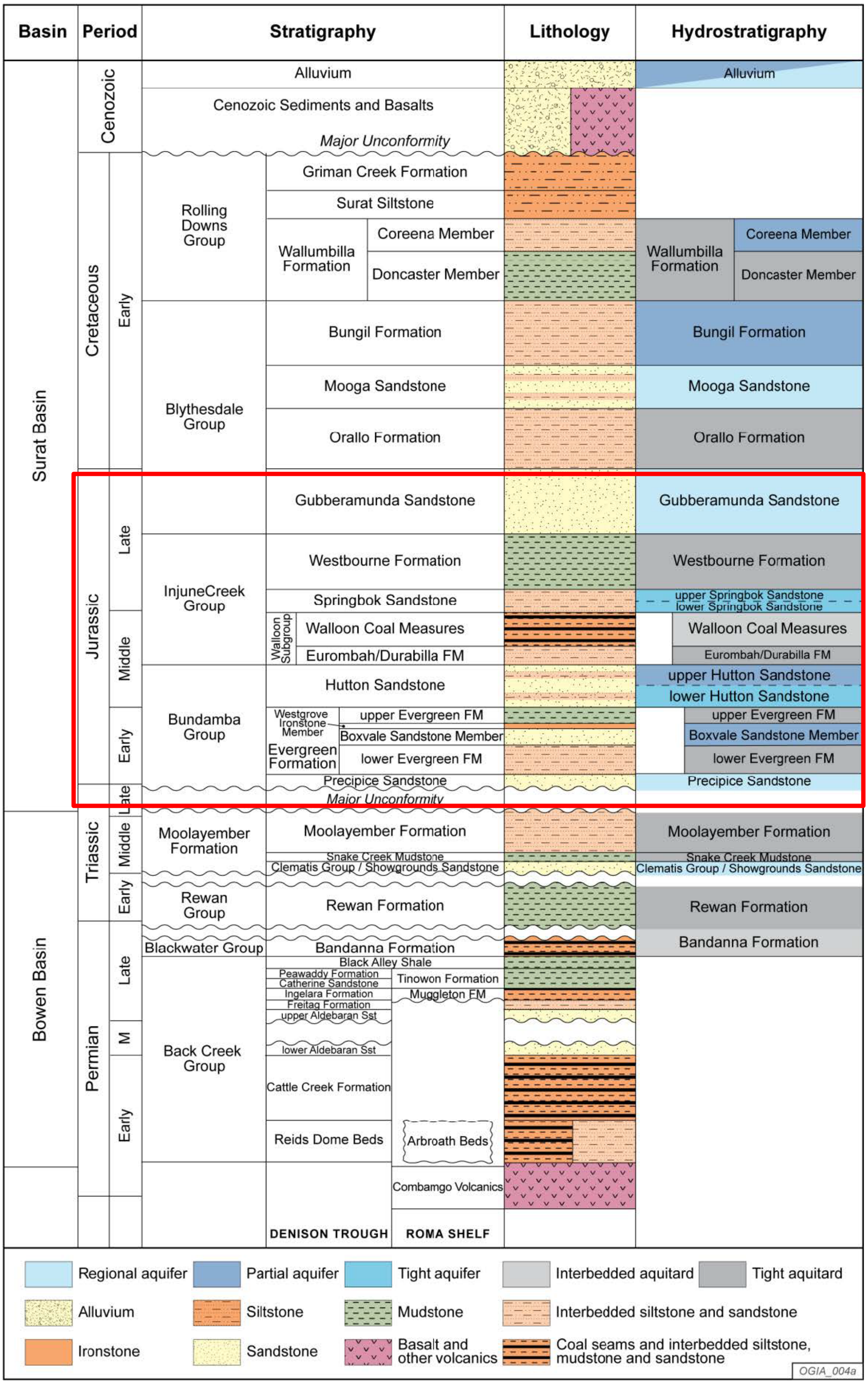

Figure 2-3: Stratigraphic profile within the Surat Cumulative Management Area, with profile of the Surat Basin within Arrow SGP tenements highlighted in red box (adapted from OGIA, 2021a)

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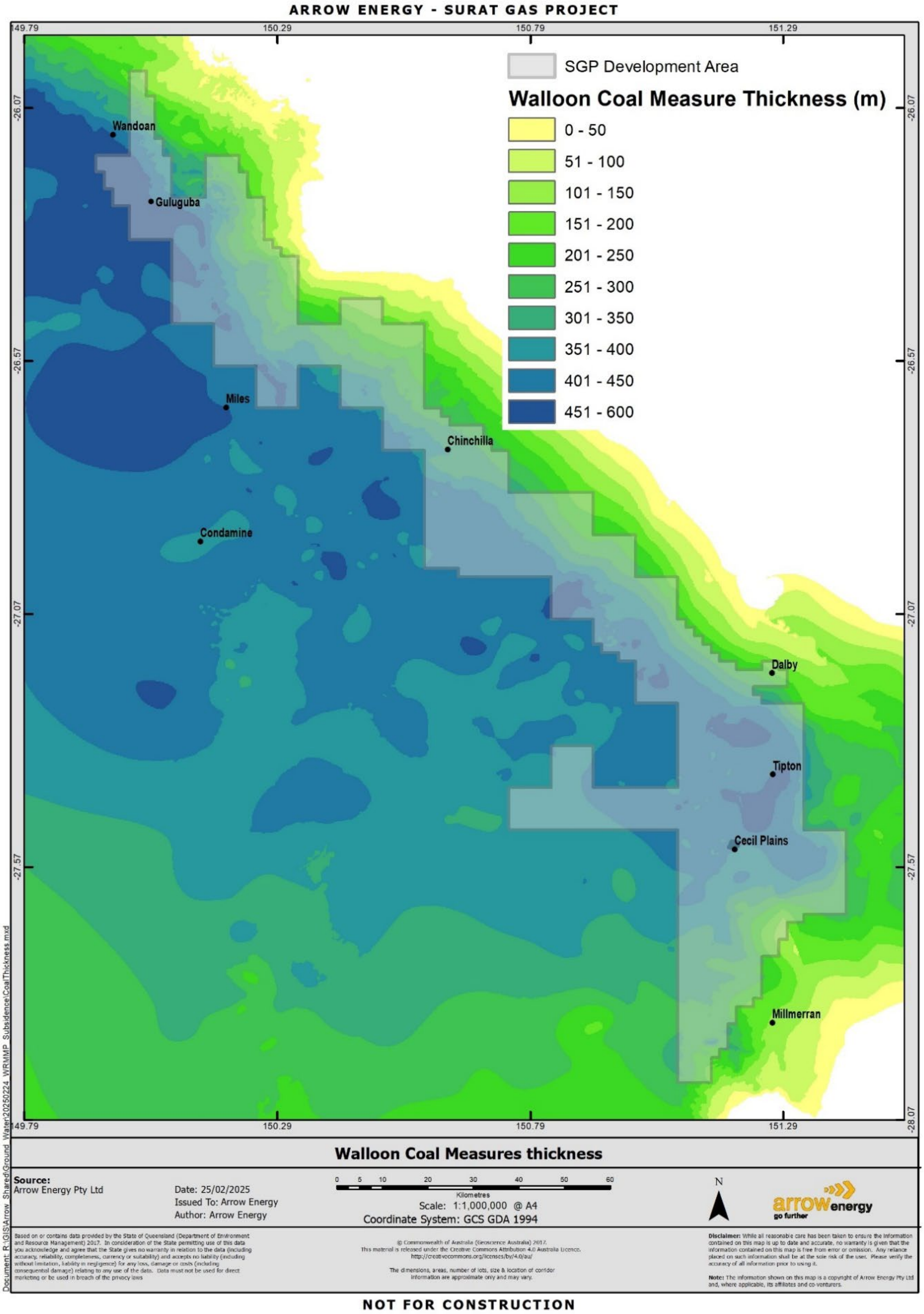

Figure 2-4: Walloon Coal Measure thickness (m)

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Figure 2-5 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.

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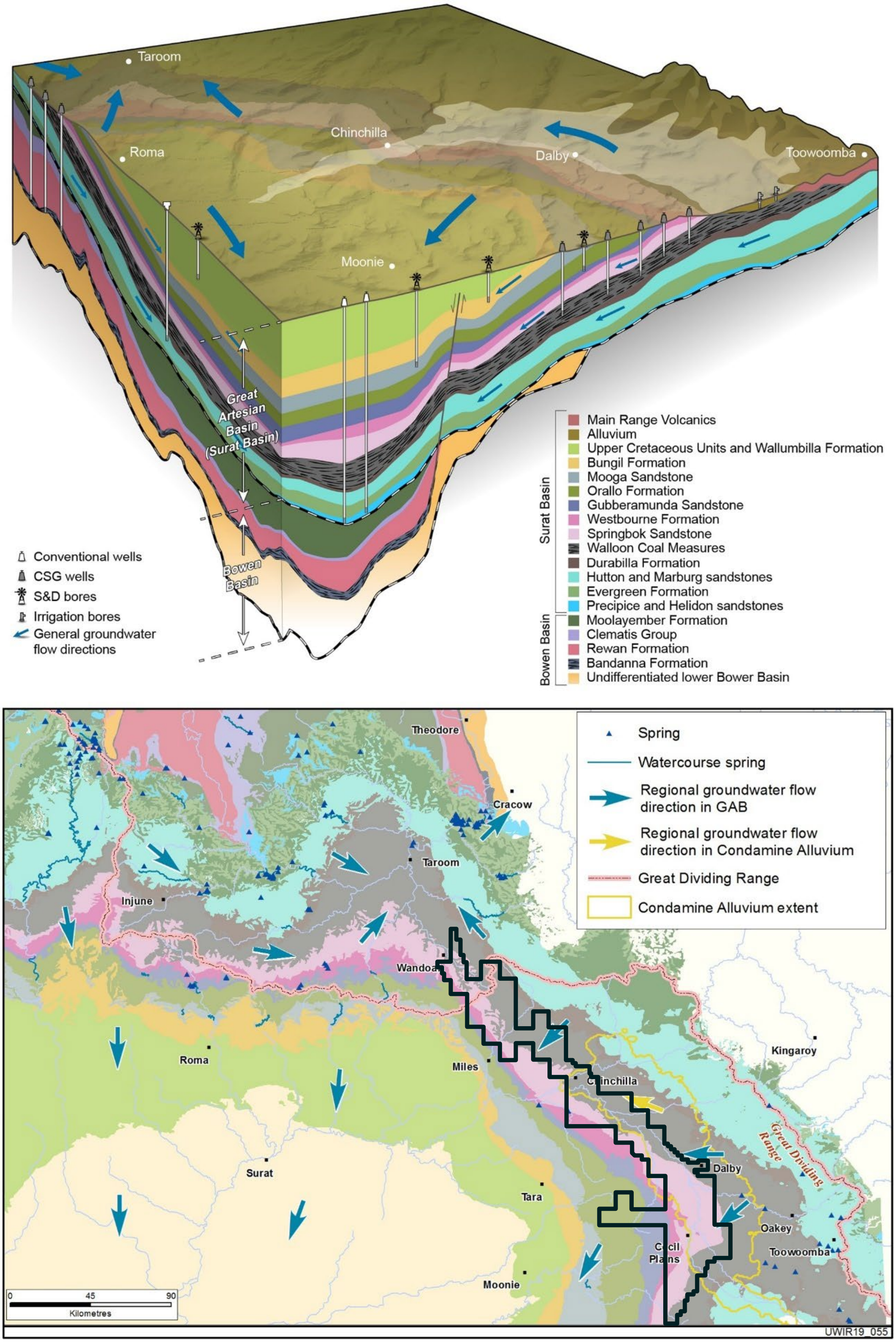

Figure 2-5: Conceptual model of the main groundwater systems in the Surat Basin, with Arrow SGP operation outlined in black (adapted from OGIA, 2019a)

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2.1 Cause of subsidence

Coal seam gas occurs within coal formations through adsorption of the gas 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 deformation of the rock. This is known as an increase in effective stress.

This process commonly occurs during dewatering for construction. In construction projects, the materials involved are typically soils, which are much more susceptible to deformation 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, known as coal shrinkage, and provide a further component of deformation. Desorption-induced deformation 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 combination of the reduction in water pressure and coal shrinkage results in compaction of the formation. The combined compaction over the thickness of the formation, together with any attenuation by the overburden, results in subsidence at the ground surface.

A comprehensive overview on the mechanisms of CSG induced subsidence can be found in the literature (Leonardi, 2024), including recent literature on assessing the potential for formation bridging (Aghighi et al, 2024a) and the contribution of desorption induced coal shrinkage (Dudley et al, 2019; Hummel et al 2021; Aghighi et al, 2023; Aghighi et al, 2024b) to CSG induced subsidence.

Other processes which cause ground movement include depressurisation resulting from groundwater use in aquifers overlying the target coal formation, seasonal shrink and swell of soils, erosional and depositional geomorphological processes, and land management practices such as irrigation, tillage and land contouring.

3 Ground movement monitoring

3.1 Interferometric Synthetic Aperture Radar (InSAR)

Satellite-mounted Synthetic Aperture Radar (SAR) sensors acquire images of the Earth’s surface by transmitting electromagnetic pulses from the microwave spectrum and analysing any backscatter energy from the Earth’s surface. The pulse’s two-way travel time is used to determine surface characteristics. SAR satellites travel in a near polar sun-synchronous orbit, which enables two different viewing geometries. When travelling from the north pole towards the south pole it is considered a descending orbit and from the south towards the north pole is an ascending orbit. As a consequence, the same area of interest is revisited along the two orbits with ascending and descending imagery collected over it through time. The backscattered energy contains both amplitude and phase information for each pixel in a single look complex (SLC) image. The amplitude details the ground surface's backscatter properties and the phase represents the relative distance between the ground and the SAR receiver.

Interferometric SAR (InSAR) exploits the phase difference between two SLC images of the same area taken at different times with the same orbit orientation. If the Earth's surface has moved between the image acquisitions, a phase shift occurs and this will be shown as an interferogram. This phase shift represents changes in the relative distance between the surface and SAR satellite over time. Each interferogram contains different signal components. These signals include orbital geometry, topographic and atmospheric influences, and residual noise. To determine if subsidence or uplift is occurring over time, a stack of interferograms is required to generate a time-series dataset. Time-series processing involves mitigating these signals to isolate the surface movement signal. The time-series results reflect the total surface movement and cannot distinguish between natural and anthropogenic causes of the movement. Analysis with other datasets/models is required to estimate the contribution of CSG production on total observed surface movement.

The time-series datasets represent surface movement captured in one dimension, that is, along the line of sight (LOS) and not vertical. The LOS is the angle at which the microwave energy pulses are transmitted and received by the SAR satellites. If both ascending and descending data is available over the same area, the up-down and east-west movement can be resolved. Due to the near-polar orbit orientation of the SAR satellites, it is not possible to resolve the north-south movement. It is important to note that InSAR provides relative surface movement measurements. To obtain absolute measurements, the results need to be tied to a known ground point, such as a radar corner reflector. These reflectors have a surveyed ground position and are designed to be clearly seen in SAR imagery. InSAR is a well established technique for time series analysis of deformation of the Earth's surface, including subsidence and structural stability. Further description of the InSAR monitoring technique is provided in Leonardi (2024).

As with all scientific data, understanding the accuracy and precision of a particular dataset is important. Accuracy refers to how close the measurements are to the true or accepted value. Precision is independent of accuracy and relates to how close measurements are to each other, usually when measurements are repeatedly taken using the same methodology. In the case of InSAR, the accuracy can be measured to millimetre scale and can be compared against global navigation satellite systems (GNSS) data. Precision, however, is harder to quantify with InSAR because only a single measurement is acquired at a particular time point. This measurement cannot be repeated to determine precision as the time parameter cannot be replicated. Another way of interpreting precision with InSAR is how ground points behave through time. If stable ground points return similar values through time, it can be considered precise.

Several satellites are currently collecting SAR data suitable for InSAR analysis, as shown in Figure 3-1. The InSAR data used in this report was collected by Sentinel-1 constellation for the period August 2015 to June 2024, with historic data by Radarsat-2 and ALOS-1 for the periods July 2012 to November 2017 and December 2006 to March 2011, respectively also utilised by Arrow.

Sentinel-1 constellation 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/news/news/observer-celebrating-decade-copernicus-sentinel-1.

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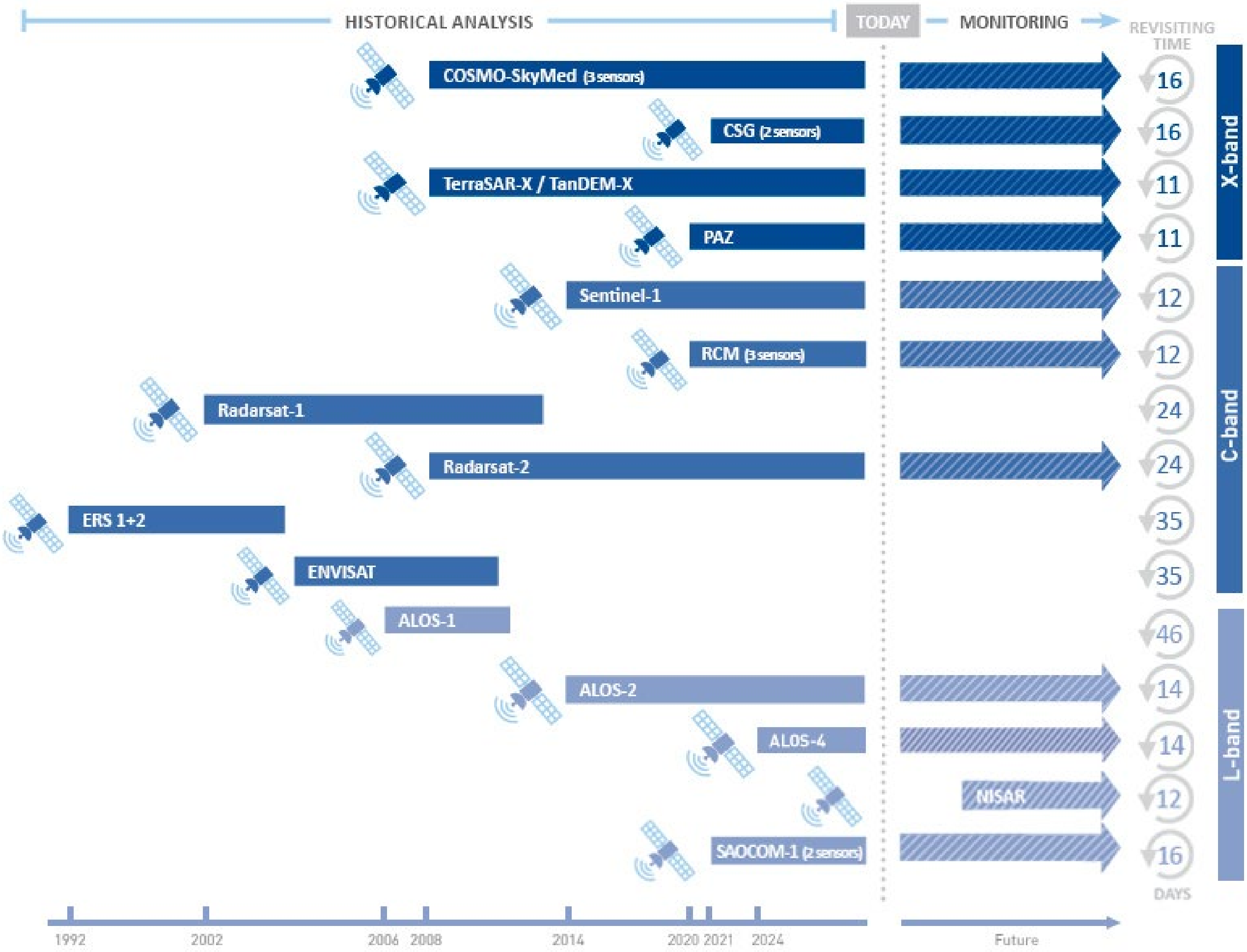

Figure 3-1: Satellites collecting SAR data historically and planned into the future (https://site.tre-altamira.com/company/our-technology/)

3.2 Geodetic ground point monitoring

Precise location information for a ground point can be derived from GNSS. GNSS is the generic term used for satellite positioning systems which consist of satellite constellations that transmit positioning and timing data to ground receivers, and is currently one of the most popular geodetic monitoring techniques for surveyors and engineers worldwide (Ng et al, 2023). Errors in GNSS observations at ground receivers can be caused by reflected GNSS signals interfering with the direct GNSS signal due to their common time origin but different path lengths. These errors can be mitigated via differential GNSS (DGNSS), by using data from one or more GNSS receiver stations whose precise locations are known (Hofmann-Wellenhof et al, 2008; Kaplan, 2017). DGNSS surveying involves the collection of precise code and carrier phase measurements recorded simultaneously at two or more survey control marks using high precision GNSS equipment and/or Continuously Operating Reference Stations (CORS). Those measurements can then be processed to derive GNSS baselines from which the 3D position and uncertainty for each survey control mark can be estimated.

Between November 2020 and May 2023, Arrow installed a network of 11 permanent continually operating GNSS ground movement monitoring stations within the area of the SGP operations. Daily processing of coordinates of these stations is provided by Leica Geosystems via the Leica Crosscheck system. Some of these locations for geotechnical ground movement monitoring are co-located with groundwater monitoring bores which provide information on the groundwater depressurisation potentially influenced by Arrow SGP operations. These instrumented sites are preferentially located within the topographically flatter area of Arrow SGP operations. At one location (Longswamp 40, 43 and 44) separate ground movement monitoring of the upper and lower parts of the Condamine Alluvium and the Springbok Sandstone is undertaken.

Since 2020 Arrow has also undertaken, at a minimum, annual survey of selected permanent survey marks identified as GNSS compatible in the Queensland Survey Control Database (SCDB). Static surveys of these marks are undertaken with a six (6) hour observation time. Post-processing of these surveys to provide survey mark coordinates is then undertaken using Geoscience Australia's Auspos online GPS processing service.

The location of the continually operating GNSS ground movement monitoring stations and permanent survey marks, as shown in Figure 3-2, were selected based on:

- Land resource area (combination of geology, topography, soil, vegetation and land use);
- Spatial distribution across field development areas; and
- Proximity to persistent scatters in InSAR.

Survey Uncertainty of GNSS techniques for ellipsoidal height improves with observation time. Quick static surveys are generally considered +/- 30-40mm vertical accuracy. However, this is reduced to less than +/- 20mm when a 6hr observation is undertaken. Continuously operating sites are considered to be better than +/- 3mm vertical accuracy.

3.3 Light Detection and Ranging (LiDAR)

Light Detection And Ranging (LiDAR) is a remote-sensing technique using airborne scanning systems emitting focussed electromagnetic waves in the visible light to infrared ranges, with the reflected signal used to develop a distance map of objects in the scene including vegetation, buildings and the ground, resulting in a detailed three-dimensional point cloud. Processing is undertaken to remove the non-ground points from the point cloud resulting in a detailed snapshot of elevation of the land and derived slopes at moment of capture.

LiDAR surveys, which provide for detailed assessment of slopes at property and regional scale, were acquired for all SGP for Arrow in 2012 with follow-up surveys of some SGP areas in 2014, 2020 and 2021. Following a further survey of all existing and future development plan areas in the SGP in 2022, surveys within the area of the Condamine Alluvium (which is more sensitive to slope changes affecting surface flows) have been conducted in May, August and October in both 2023 and 2024. The extent of all surveys relative to the SGP development area are shown in Figure 3-3. The LiDAR data provides a temporal baseline from which future data can be assessed to determine changes in slope.

Survey uncertainty for LiDAR techniques has improved over time with advancements in technology and processing. The 2012 and 2014 LiDAR survey undertaken by Arrow Energy had vertical uncertainty of +/- 0.12m and +/- 0.07m respectively, for data points in the point cloud. Since 2020 the surveys have been better than +/- 0.05m (at 1 standard deviation) for data points.

Ground points measured with LiDAR are used to generate a Digital Elevation Model (DEM). Since 2021 Arrow Energy has specified Intergovernmental Committee on Survey and Mapping (ICSM) Level 3 ground correction, which identifies ground points with 99% confidence. The digital elevation models are typically generated to 1m

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resolution. The specification of the LiDAR is to achieve greater than 4 points per square metre. Overall this results in a DEM with derived point accuracy of +/- 0.1m.

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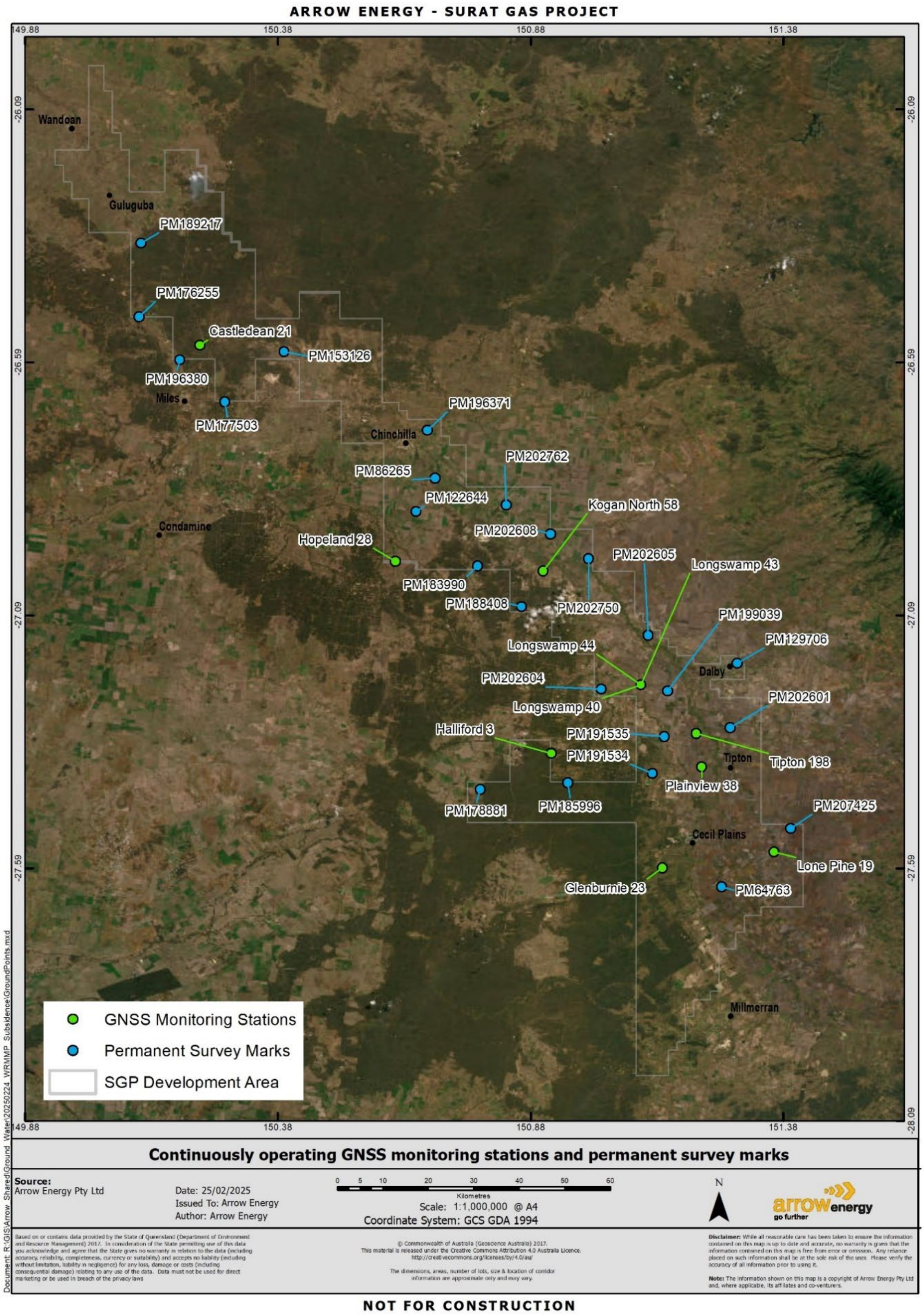

Figure 3-2: Location of continuously operating GNSS monitoring stations and regularly observed permanent survey marks

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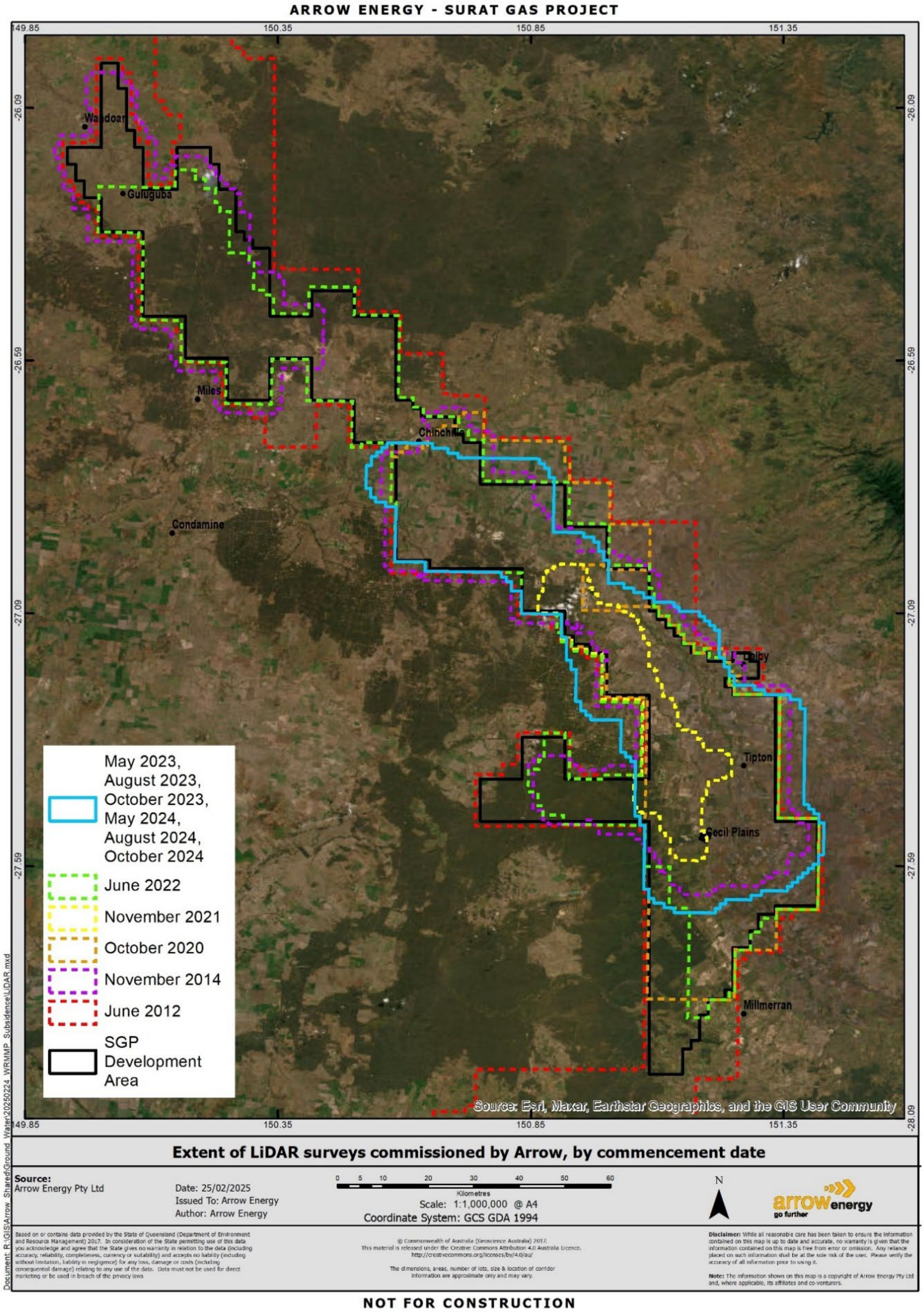

Figure 3-3: Extent of LiDAR surveys commissioned by Arrow around the SGP development area between 2012 and 2024

4 Subsidence Assessment

4.1 Observations of slope and ground movement

4.1.1 Slope

Slopes within the Arrow tenements prior to the SGP commencement were derived from the 2012 LiDAR data at a 10 m resolution (downsampled from the original 1 m resolution to remove the effects of surface roughness). The results of the area and percentage of each slope class across the whole Arrow tenement are presented in Table 4-1, with the dominant slope class being greater than 0.5 % (5 m in 1 km). The slope increments/classes were selected to focus on the flatter slopes in the landscape that are more sensitive to slope changes affecting surface flows to watercourses. Slopes of less than 0.03 % (0.3 m in 1 km) occupy less than 1 % of the area of the SGP.

Table 4-1: Slope classes within Arrow SGP development area

Slope Class	Area (ha)	Area (%)
< 0.01%	465	0.07%
0.01 - 0.03%	3,650	0.52%
0.03 - 0.06%	11,766	1.68%
0.06 - 0.12%	39,420	5.62%
0.12 - 0.5%	190,452	27.15%
> 0.5%	455,790	64.97%

4.1.2 Regional vertical ground movement from InSAR

InSAR ground movement monitoring data for the period August 2015 to June 2024 is the latest data set available, derived from InSAR data captured by the Sentinel-1 satellite. This period encompasses the commencement of the Arrow SGP on 22 October 2020. The area of the Arrow SGP operations is covered by two descending tracks (track 45 and 147) and one ascending track (track 111) from Sentinel-1. Tre-Altamira, a 3rd party InSAR supplier, applied their proprietary SqueeSAR® technology to the data stack for each track separately to obtain the line of sight (LOS) result for each acquisition geometry. By combining the two LOS results, the vertical and east-west horizontal motions are then derived based on the method of 2D decomposition. Vertical ground movement within the area of the Arrow SGP operations is provided in Figure 4-1. The ascending and descending tracks provided a total of 7,656,174 measurement points within the area of interest, resulting in 744,088 measurement points for the vertical 2D decomposition (both ascending and descending data within a 60 m square grid cell are required for the decomposition). Lower density of processed persistent and distributed scattered InSAR data is available in cropping areas, where major surface changes such as vegetation growth, soil shrink/swell with change in moisture content, or tillage, result in temporal decorrelation of InSAR.

Most of the displacement observed in the LOS corresponds to displacement in the vertical direction, with horizontal displacement (east-west) being negligible.

As well as CSG induced subsidence, other anthropogenic and natural ground movement processes also affect surface elevations and slopes. Reactive clays such as the vertisols of the Condamine River floodplain swell and shrink in response to moisture changes, an effect which is greatest close to the surface where the clay is less confined by overburden and where the moisture content can be more quickly changed by rainfall or irrigation and by evapo-transpiration. OGIA (2021a) analysed available InSAR data and found that "*ground* *movement unrelated to CSG depressurisation and away from existing CSG development, both within and outside the Condamine Alluvium, suggests that the ground can frequently move up and down by around 25 mm/year and the ground movement can also vary significantly at a local scale (by up to 25 mm within 100 m). This is likely to be due to variations in soil type and associated changes in moisture content*". DataFarming (2021) also looked at the natural variations in the surface due to the swell shrink nature of the vertisol clays present on the Darlings Downs. Anecdotal evidence from soil experts suggest that vertical movement is up to 200mm between wet and dry, and assessment of strip cropping by DataFarming found likely vertical movement due to differences in soil water content of up to 200mm. These variations in non-CSG ground movement at a local scale will result in changes in slope.

Over the data period August 2015 to June 2024, the fastest subsidence rate (-63 mm/year) is observed in spoil dump areas of the Kogan and Wilkie Creek coal mines north west of Dalby as shown in Figure 4-1, with total settlement of up to 0.5 m observed. Within the CSG fields, the deformation rate is slower (up to -26 mm/year) with total subsidence up to about 0.1 m observed in the Daandine field and 0.05 m in the Tipton field. The fastest uplift rates (up to 22 mm/year) are observable at individual measuring points, distributed over the eastern area over agricultural lands and around Dalby. The uplifts in the agricultural areas are likely related to water content changes in the deep alluvial soils from significantly above average rainfall observed through 2021, 2022 and 2024. These subsidence rates and total subsidence are comparable to those observed by OGIA (2021a), including natural or background ground motion unrelated to CSG development in the order of +/- 25 mm/year.

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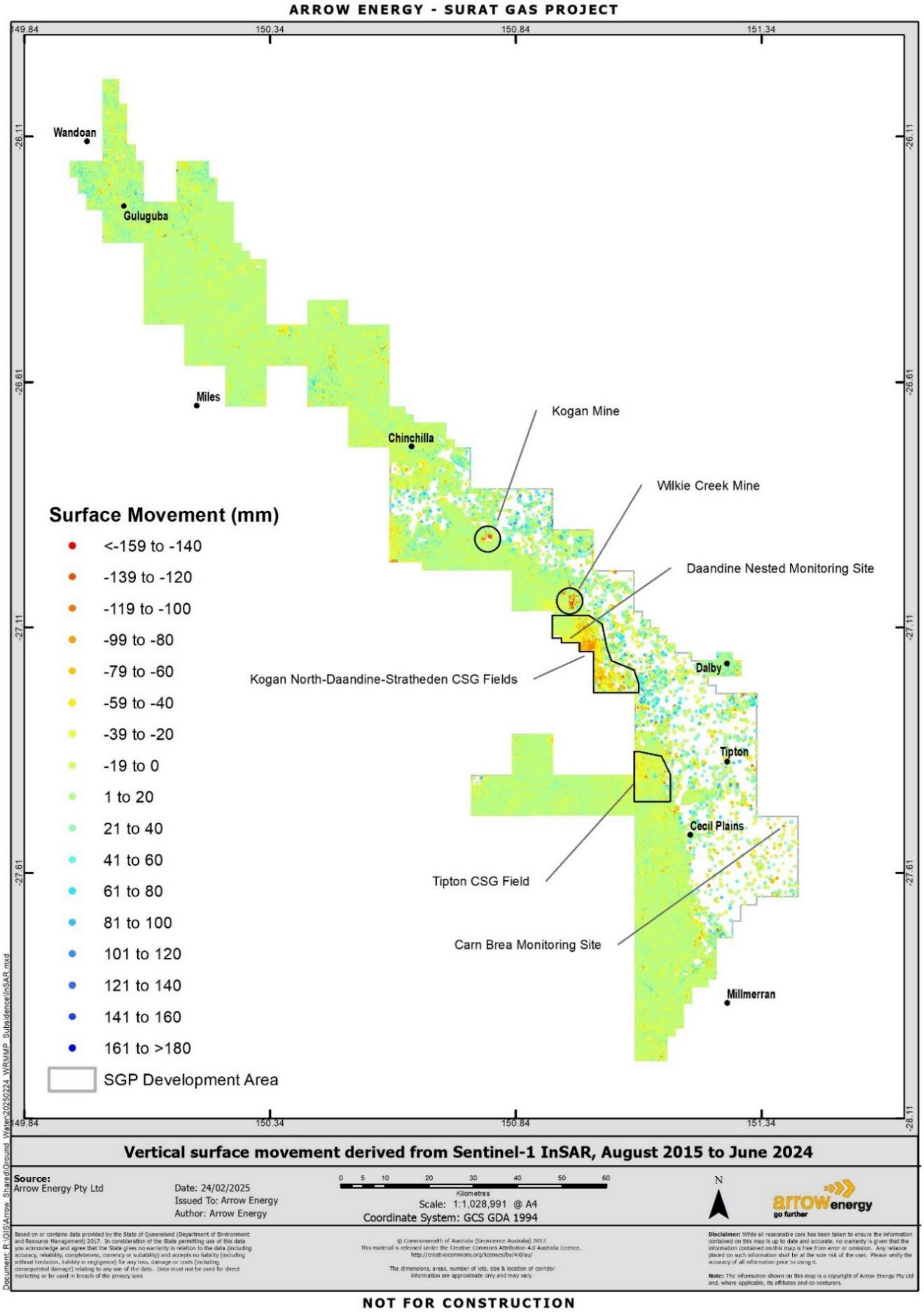

Figure 4-1: 2D decomposition of vertical ground surface movement within SGP development area derived from Sentinel-1 InSAR, August 2015 to June 2024

Subsidence

4.1.3 Groundwater level and vertical ground movement monitoring

A large number of groundwater monitoring bores are in operation in the Surat Basin in support of CSG operations, including Arrow operated monitoring bores in and around the SGP development area. Monitoring data from these bores is accessible via the Queensland Globe service provided by the Queensland Government.

The Carn Brea monitoring site is located approximately 17 km east of Cecil Plains in the south of the SGP development area (Figure 4-1). This monitoring site includes a groundwater monitoring bore, Carn Brea-17, installed in the Condamine Alluvium aquifer and a large farm equipment shed, surrounded by a gravel hardstand area. The shed and gravel hardstand area provide high coherence reflectors for InSAR signal processing. Groundwater levels in the alluvium, which respond to water extraction for agricultural irrigation, reflect the trend in cumulative rainfall departure (CRD) as shown in Figure 4-2. Maximum groundwater level in October each year after recovery following the irrigation season is similar between 2014 and 2016, reflective of the average rainfall conditions observed in the CRD in Figure 4-2. Between 2017 and 2019 the CRD is trending downward with below average rainfall conditions, and the maximum groundwater level recovery in October each year is also lower, reflective of the likely greater reliance on groundwater for irrigation during this period. During this period, the ground movement trend observed from InSAR was also downward with a magnitude of approximately 6 mm as shown in Figure 4-2. Following average rainfall conditions in 2020, above average rainfall conditions persisted throughout 2021 and 2022, resulting in increasing maximum recovered groundwater levels and upward ground movement of approximately 10 mm. Ground movement trends in this area, which is more than 17 km from any current CSG production, are likely to be caused by a combination of soil shrink-swell with wetting and drying as a result of rainfall conditions, and elastic compaction of the Condamine Alluvium aquifer in response to groundwater extraction.

Subsidence

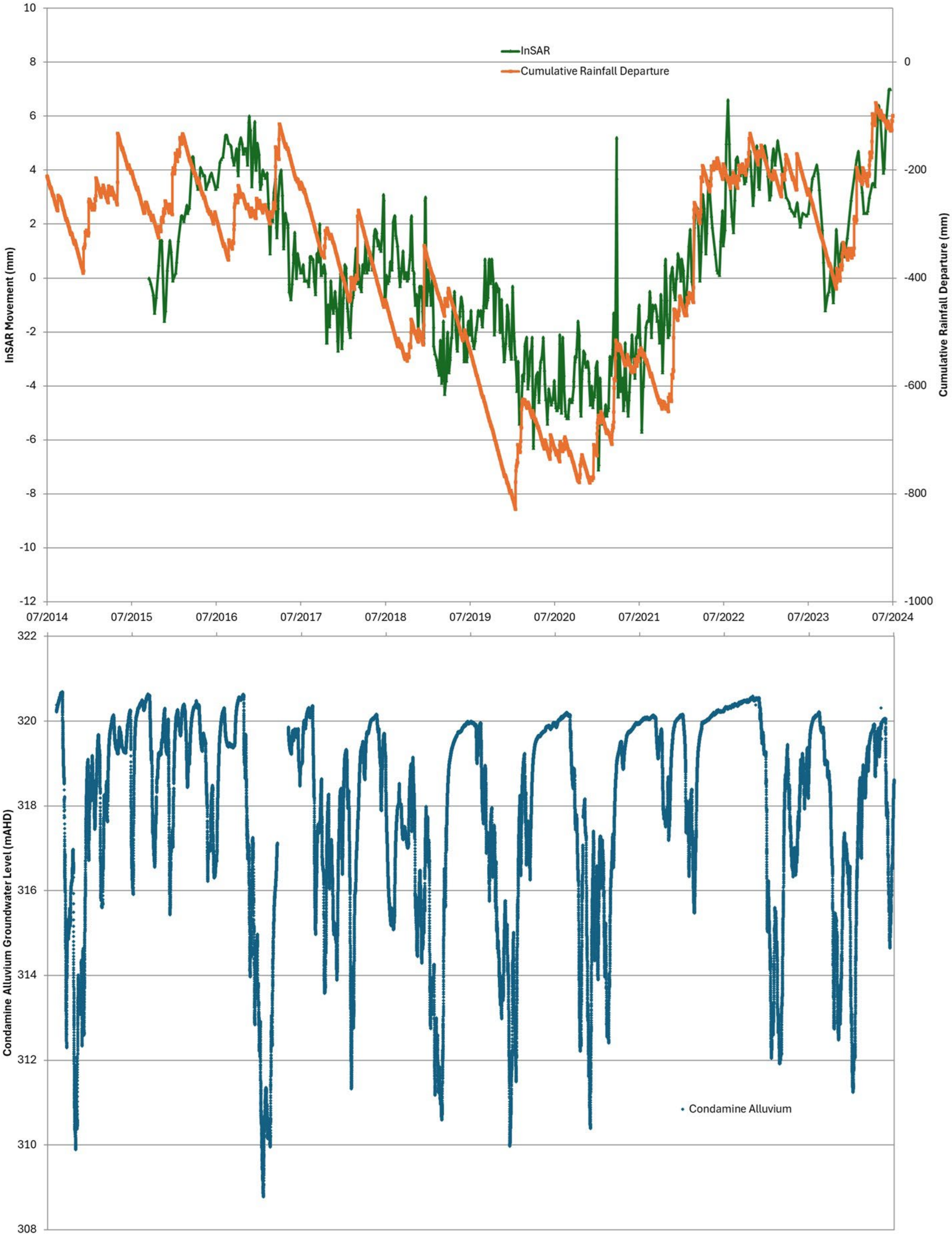

Figure 4-2: Cumulative rainfall departure, InSAR ground movement, and Condamine Alluvium groundwater levels at the Carn Brea monitoring site

Subsidence

The Tipton-198 GNSS ground movement monitoring station (Figure 3-2) is located northeast of the original Tipton CSG field near the boundary of the recently developed Plainview CSG field, and is co-located with a nested groundwater monitoring site Tipton-197 monitoring three coal seams in the Walloon Coal Measures. To assess relationships between ground motion and drawdown, groundwater levels and GNSS data for this site have been overlayed and are presented in Figure 4-3. Groundwater levels in coal seams of the Walloon Coal Measures in the multi-level monitoring bore were approximately 322 to 332 mAHD prior to commencement of CSG production in the area in October 2023. Following commencement of CSG production, groundwater levels have fallen by up to 214 m, to between 108 mAHD for the deepest Condamine coal seam and 308 mAHD for the shallowest Macalister coal seam, with a downward ground movement trend of approximately 40 mm to October 2024. The undulations in the ground movement trend are likely due to effects of rainfall and temperature, but the overall decline is expected to be a result of subsidence associated with the CSG depressurisation.

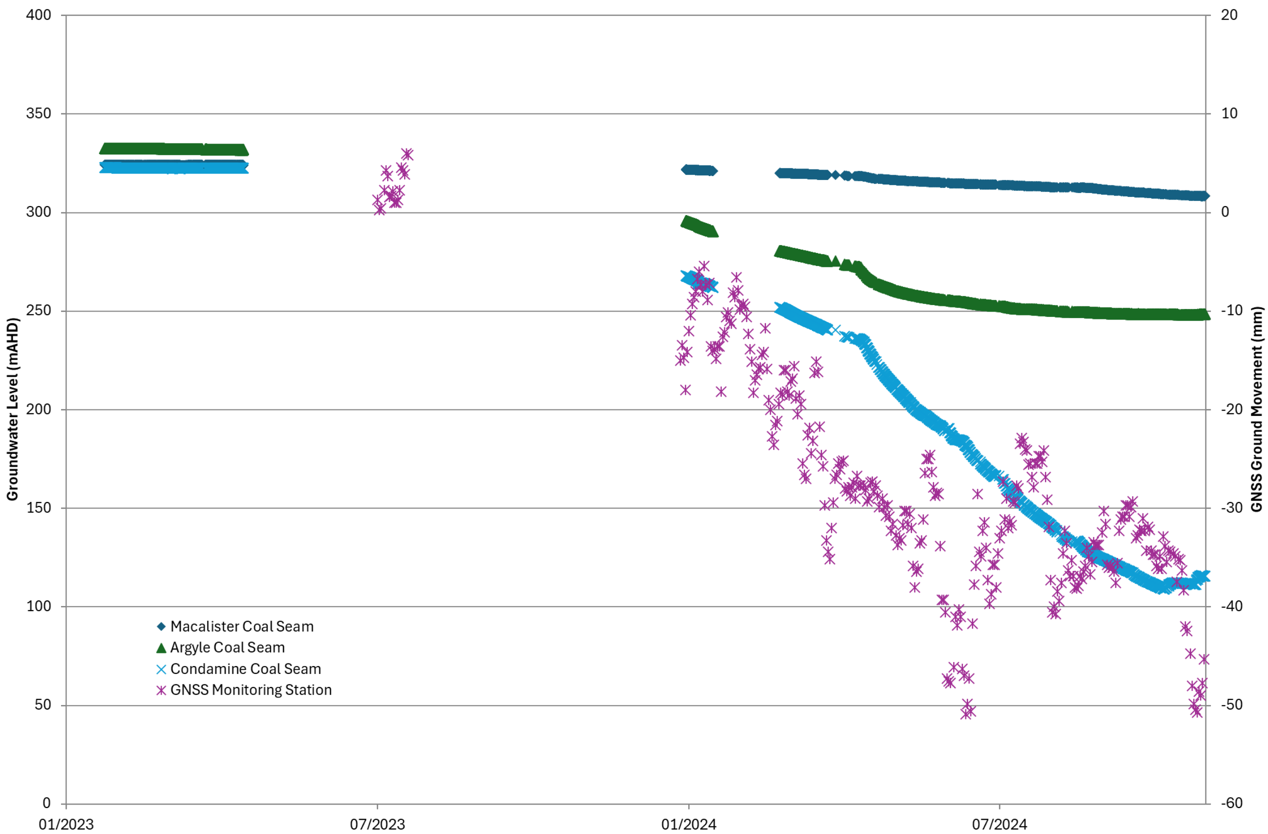

Figure 4-3: Groundwater levels in coal seams and GNSS station data at Tipton-198

Coffey (2018) assessed ground movement from InSAR and groundwater level drawdown in ‘Area C’, which is the Daandine nested monitoring bore site of Daandine-123, 134 and 254 in the Daandine CSG field (Figure 4-1). InSAR ground movement detected by the Radarsat-2 system between April 2012 and December 2016 was identified to be a gradual downward trend of 30 mm within 150 m of the nested monitoring bores. For the period November 2014 to March 2016, Coffey (2018) found that groundwater levels in the coal seams of the Juandah (Argyle coal seam) and Taroom (Condamine coal seam) Coal Measures were drawn down 78 and 49 m respectively due to CSG operation, with a corresponding downward ground movement of 11.4 mm during the same period. Figure 4-4 presents the measured groundwater levels from November 2014 to June 2024 for the nested monitoring bores. Observed ground movement from August 2015 to June 2024 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 shows rapid drawdown in the coal seams of the Walloon Coal Measures initially, with the drawdown rate reducing with time, stabilising toward the end of 2023 as CSG production in the area matured. Ground movement from August 2015 to June 2024 was approximately 50 mm, with groundwater drawdown between approximately 38 m for the shallowest Macalister coal seam and 142 m for the deepest Condamine coal seam. Groundwater level observations for the other geological units with groundwater monitoring shown in Figure 4-4 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.

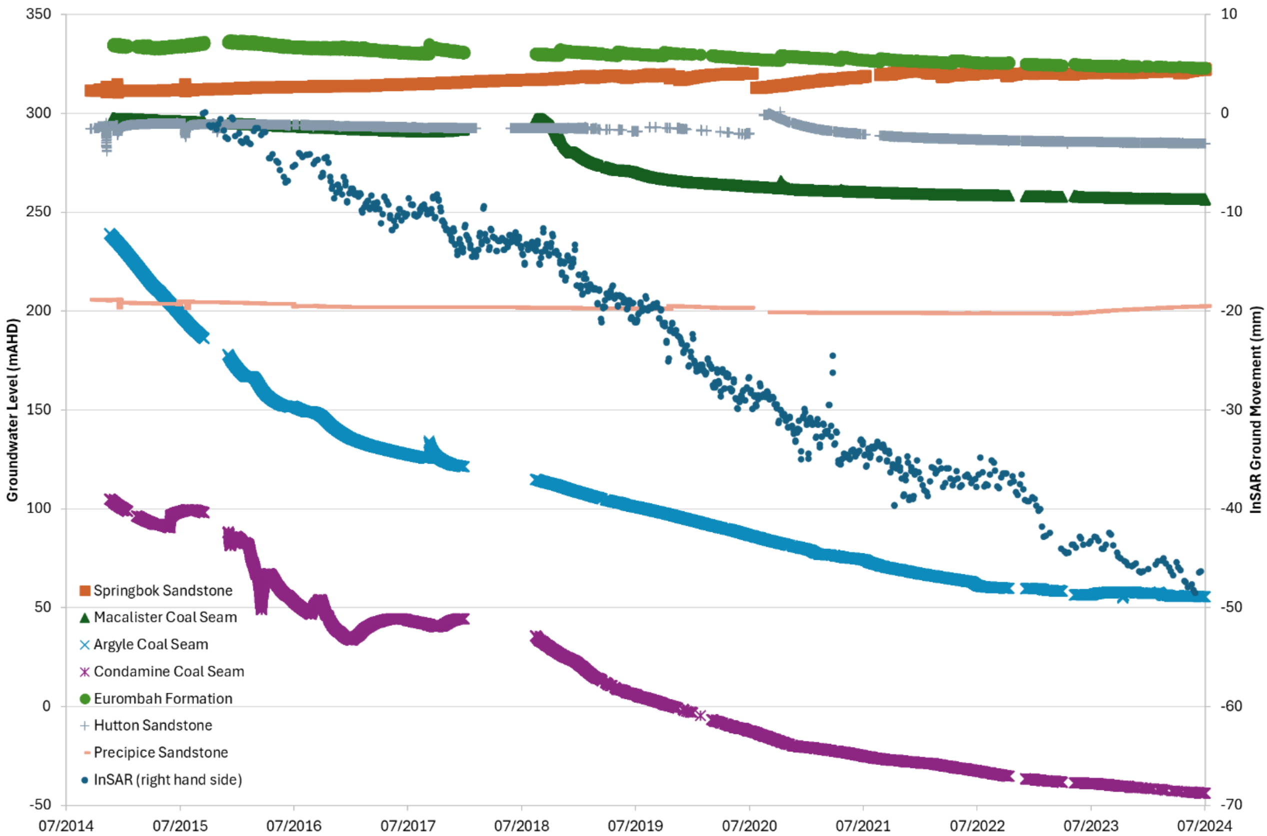

Figure 4-4: InSAR ground movement and groundwater levels at a nested monitoring site in the Daandine CSG field

4.2 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. Coffey (2018) used this approach and determined a drained Young's modulus of 7.8 GPa and 13.6 GPa for the Taroom Coal Measures in the Daandine CSG field and Juandah Coal Measures in the Tipton CSG field respectively.

Coffey (2018) also reported on the results of unconfined compression tests of core samples from borehole Stratheden-61 in the Stratheden CSG field as shown on Figure 4-5. Coffey's review of the test results, presented in Table 4-2, indicated that the secant Young's modulus values interpreted were based in some cases after the sample was in significant distress and may therefore not be representative of behaviour of intact material at depth under lateral confinement. In particular, sandstone is expected to be significantly stiffer than coal. In an earlier assessment of subsidence at Moranbah (located in the Bowen Basin) Coffey adopted the following values:

- Modulus of sandstone 10 GPa
- Modulus of coal seams 3 GPa

Table 4-2: UCS test results, Stratheden-61 core

Sample ID	Depth (mbgl)	Lithology	Formation	Uniaxial Compressive Strength (MPa)	Secant Young's Modulus (GPa)	Corrected Poisson's Ratio
GT016	92.39	Sandstone	Kogan (Juandah)	9.3	8.30	0.42
GT018	102.09	Siltstone	Kogan (Juandah)	9.7	4.18	0.09
GT024	117.10	Coal	Macalister (Juandah)	7.0	2.45	0.22
GT025	123.49	Coal	Macalister (Juandah)	9.5	3.13	0.30
GT027	126.84	Sandstone	Macalister (Juandah)	9.4	1.34	0.25

Triaxial compressive tests on rock core from wells at the Daandine, Kogan North, Tipton and Meenawarra CSG fields as shown in Figure 4-5 were undertaken by Trilab, with the results presented in Appendix A. It is noted that the core samples were up to 10 years old, and this is likely to have some influence on the results of the triaxial tests. Table 4-3 presents a summary of the depths of the tested core, confining pressures and reported tangent modulus values. The tangent modulus values from the triaxial compressive tests 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 Table 4-3 are therefore assessed to typically understate the modulus relevant to settlement assessment by more than a factor of 2. The reported tangent modulus for the triaxial compressive tests, allowing for this factor, is then similar to the drained Young's modulus for the Taroom Coal Measures and the Juandah Coal Measures determined by Coffey (2018) from observed groundwater level drawdown and settlement.

Table 4-3: Triaxial test results, Daandine, Kogan, Tipton and Meenawarra core wells

Well and sample ID	Depth (mbgl)	Lithology	Formation	Confining Pressure (MPa)	Tangent Modulus (GPa)
Daandine 4 - 114304	140.0	Interbedded sandstone	Springbok	3.5	4.3
Daandine 4 - 114306	202.5	Siltstone	Macalister (Juandah)	5.1	15.1
Daandine 4 - 114307	306.6	Clayey sandstone	Argyle (Juandah)	7.6	3.7
Daandine 4 - 114308	320.2	Interbedded siltstone	Argyle (Juandah)	7.9	3.8

Subsidence

Well and sample ID	Depth (mbgl)	Lithology	Formation	Confining Pressure (MPa)	Tangent Modulus (GPa)
Daandine 4 - 114309	423.1	Carbonaceous mudstone	Upper Taroom (Taroom)	10.7	2.0
Daandine 4 - 114310	451.1	Mudstone	Condamine (Taroom)	11.2	3.0
Kogan North 76 - 114311	200.0	Carbonaceous siltstone	Argyle (Juandah)	5.0	4.8
Kogan North 76 - 114312	271.5	Sandstone	Upper Taroom (Taroom)	6.7	9.0
Kogan North 76 - 114313	298.3	Mudstone	Condamine (Taroom)	7.4	4.5
Tipton 26A - 114314	282.7	Interbedded sandstone and siltstone	Wambo (Juandah)	7.0	5.2
Tipton 26A - 114315	471.4	Siltstone	Upper Taroom (Taroom)	11.7	5.7
Meenawarra 16 - 114327	203.9	Coal	Macalister (Juandah)	5.1	3.2
Meenawarra 16 - 114317	263.6	Coarse sandstone	Wambo (Juandah)	6.6	4.0
Meenawarra 16 - 114318	267.3	Fine sandstone	Wambo (Juandah)	6.6	3.0
Meenawarra 16 - 114319	282.4	Siltstone	Wambo (Juandah)	7.0	4.0
Meenawarra 16 - 114320	363.7	Carbonaceous shale	Argyle (Juandah)	9.1	6.6
Meenawarra 16 - 114321	419.9	Coal	Upper Taroom (Taroom)	10.4	2.6
Meenawarra 16 - 114323	435.7	Carbonaceous mudstone	Upper Taroom (Taroom)	10.7	3.5
Meenawarra 16 - 114324	470.1	Siltstone	Upper Taroom (Taroom)	11.5	6.1
Meenawarra 16 - 114325	478.5	Carbonaceous mudstone	Condamine (Taroom)	11.9	3.4

Geophysical downhole survey information for boreholes at 22 locations shown in Figure 4-5 was evaluated, providing profiles of interpreted dynamic Young's Modulus and unconfined compressive stress for depths up to 1200 m. 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, including 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 Young's modulus in GPa

$E_{dynamic}$ is the dynamic Young's modulus in GPa.

Subsidence

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 Young's modulus in GPa

$E_{dynamic}$ is the dynamic Young's modulus in GPa

γ is the density in t/m^3.

Figure 4-6 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 in the units underlying the Walloon Coal Measures noted 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 work undertaken by Coffey (2018), and the range of triaxial test results discussed above, when the difference between initial modulus and the reported tangent modulus is taken into account.

Subsidence

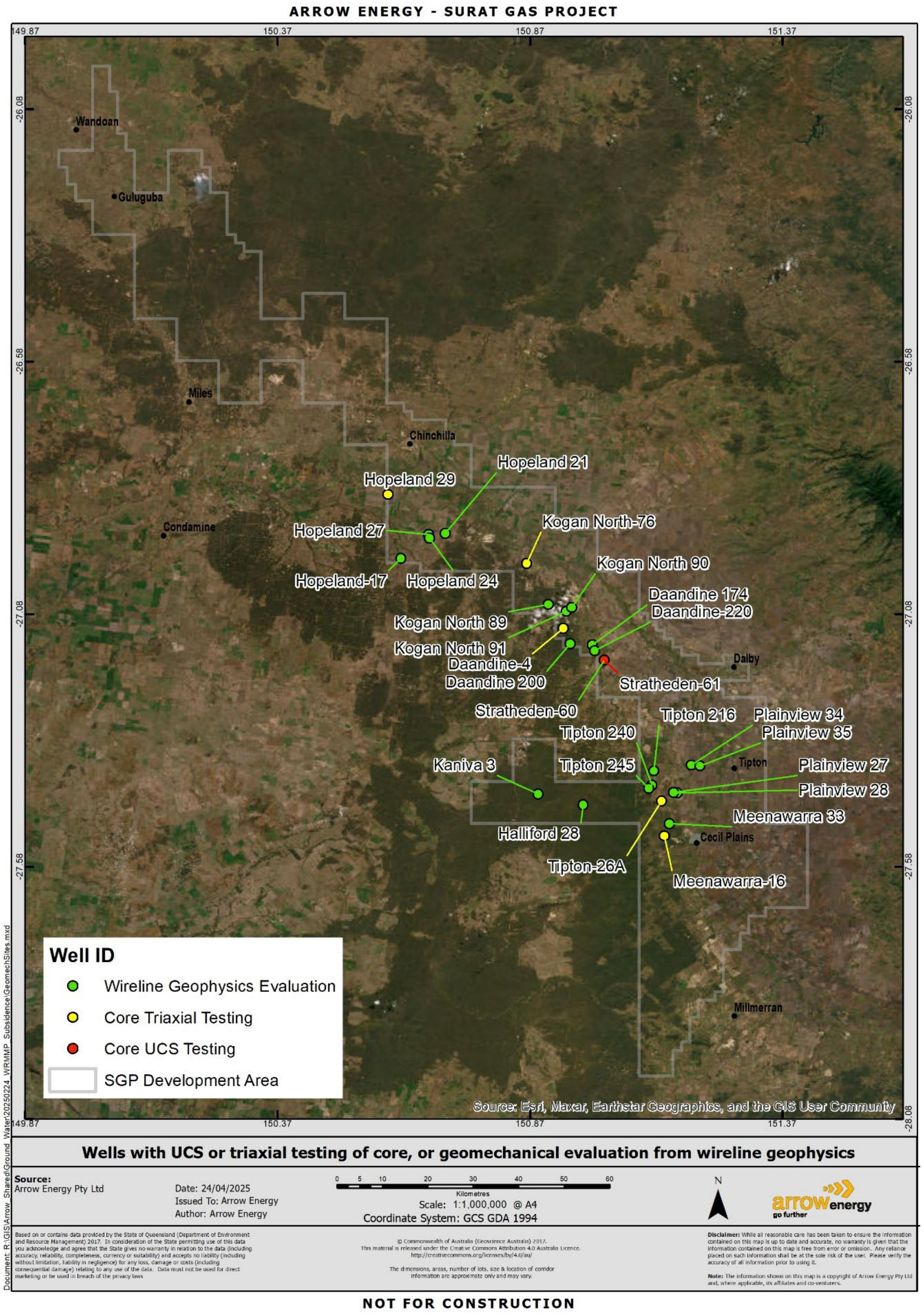

Figure 4-5: Wells with UCS testing of core, triaxial testing of core, or geomechanical evaluation from wireline geophysical logs

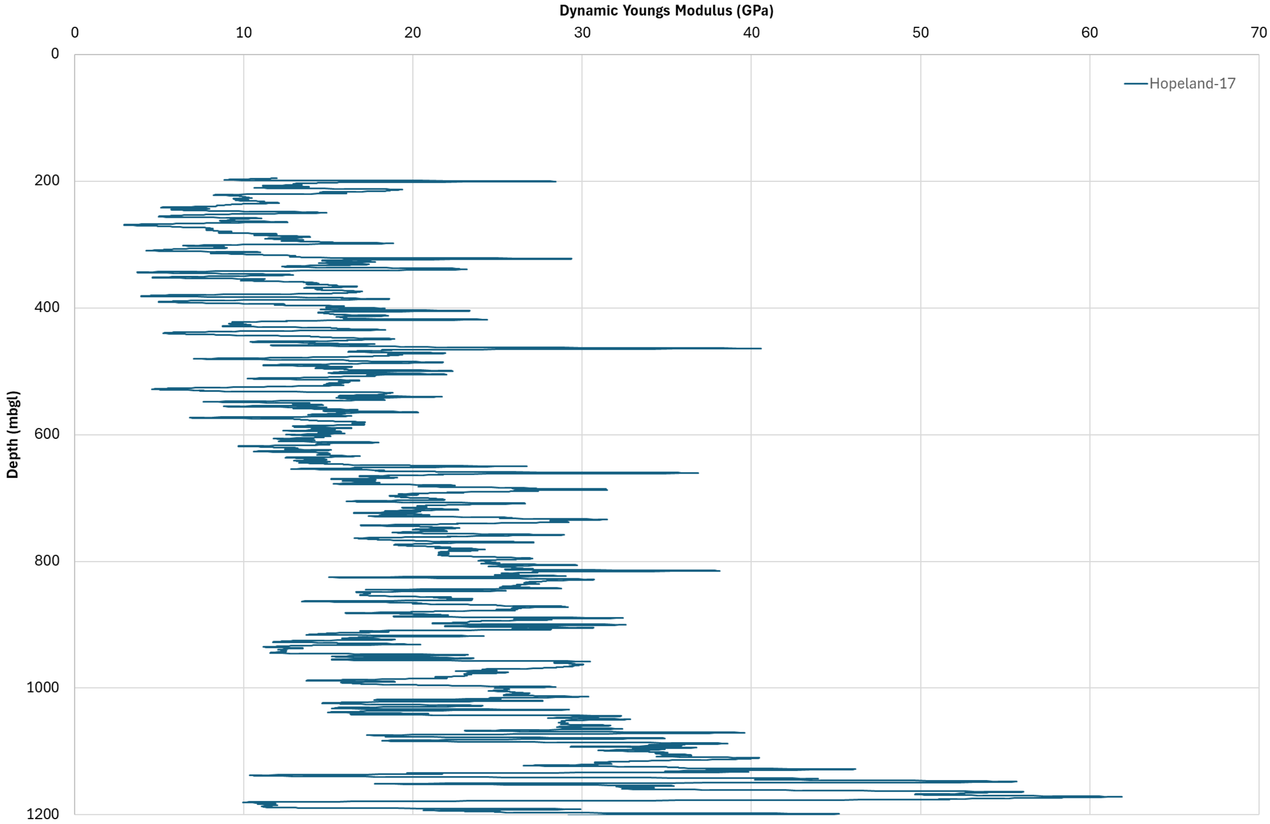

Figure 4-6: Sample wireline test interpretation of dynamic Young's modulus – Hopeland-17

5 Natural (non-CSG) ground movements

5.1 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. Reactive clay soils are sensitive to this process which is limited to the upper soil profile. The effect is important for the design of shallow building foundations for houses, and 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 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. 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. Within the Arrow SGP development area, the Condamine River valley contains deep vertosol soils that have a high percentage of expansive soils. Highly reactive soils are associated with shrink swell movement of up to 75 mm (Standards Australia, 2011), and in southeast Queensland extremely reactive soils are known to move up to and in excess of 100 to 150 mm (Queensland Building and Construction Commission 2022). Soil moisture changes associated with growth of vegetation also receive special mention in AS 2870-2011 as these can result in local ground movement, affecting the performance of house foundations. Further discussion of natural sources of ground movement is provided in Leonardi (2024).

5.2 Ground movement monitoring in areas with no CSG activity

As presented in Figure 4-1, many small patches of uplift and subsidence related to natural or anthropogenic factors are found throughout the SGP area. Observed ground movement in areas with no CSG activity was assessed by considering InSAR observations in four reference areas, as shown in Figure 5-1. These areas are located away from areas with CSG activity, including adjacent to the SGP development area, and were chosen based on the availability of InSAR data points. Two locations were selected on cleared agricultural properties within the extent of the Condamine Alluvium, one on residential land in Dalby, and one on a non-farmed forested area outside the Condamine Alluvium.

Figure 5-2 shows the observed 2D-decomposition vertical ground movement between August 2015 and June 2024 for nine InSAR derived points located within 180m of each other, and the average vertical ground movement of these points, for the four reference locations.

The Forested Area is located outside the Condamine Alluvium, with ground movement of individual InSAR derived points up to approximately 15 mm and a range of approximately 20 mm across the points from the reference level at August 2015. The average ground movement is also relatively stable through the monitoring period. This site has the lowest individual and range of ground movement of the reference sites, reflective of the less expansive nature of the soils and lack of a readily recharged aquifer compared to the other reference sites. The data also indicate that InSAR results are likely to show temporal 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 period only. This noise can be reduced by averaging readings over a small number of consecutive times.

Ground movement observed in the Residential Area is up to approximately 40 mm for individual InSAR derived points, with a range of approximately 30 mm across the points from the reference level at August 2015. The average ground movement here displays similar characteristics to the Carn Brea monitoring site (Section 4.1.3 and Figure 4-2), with ground movement due to shrink-swell of expansive soils and the Condamine Alluvium aquifer responding to longer term rainfall. The range of movement between the monitoring points is less than for Agricultural Area 1 and 2 (discussed below), as InSAR points are likely to be derived from buildings or hardstand areas rather than the soil surface, and so are affected by more uniform deeper processes than the shrink-swell of soil at surface.

At Agricultural Area 1 located within but towards the edge of the Condamine Alluvium and used for stock, ground movement of individual InSAR derived points is up to approximately 20 mm, with a range of approximately 40 mm across the points from the reference level at August 2015. Although the average ground movement of the InSAR derived points is relatively stable through the monitoring period, change in ground slope from the InSAR derived points within the area is at least approximately 0.016% or 160 mm/km (based on 180 m square area, and 30 mm difference in movement between points after removing 10 mm temporal variability) over the approximately nine years of monitoring.

Agricultural Area 2 is located more centrally within the Condamine Alluvium and used for mixed stock and dryland cropping, with ground movement of individual InSAR derived points up to approximately 40 mm, with a range of over 50 mm across the points from the reference level at August 2015, the largest range of any of the reference sites. The average ground movement here displays similar characteristics to the Carn Brea monitoring site, with ground movement due to shrink-swell of expansive soils and the Condamine Alluvium aquifer responding to longer term rainfall. Where the expansive soils are subject to periodic inundation and desiccation in a farming setting, or where agricultural activities such as cultivation to enhance water ingress are undertaken, this movement is likely to be more severe than that experienced in areas developed for low rise residential use. Vertical movement as much as 200 mm between wet and dry soil profiles were interpreted from LIDAR records of fields under strip cropping (Data Farming, 2021). The change in ground slope from the InSAR derived points within this area is at least approximately 0.022% or 220 mm/km (based on 180 m square area, and 40 mm difference in movement between points after removing 10 mm temporal variability) over the approximately nine years of monitoring.

These natural ground movements observed from InSAR in the reference areas are consistent with the range of movement reported by OGIA (2021a) that the ground can frequently move up and down by around 25 mm/year and the ground movement can also vary significantly at a local scale by up to 25 mm within 100 m.

Subsidence

Figure 5-1: Natural ground movement reference sites located away from areas of CSG activity

Subsidence

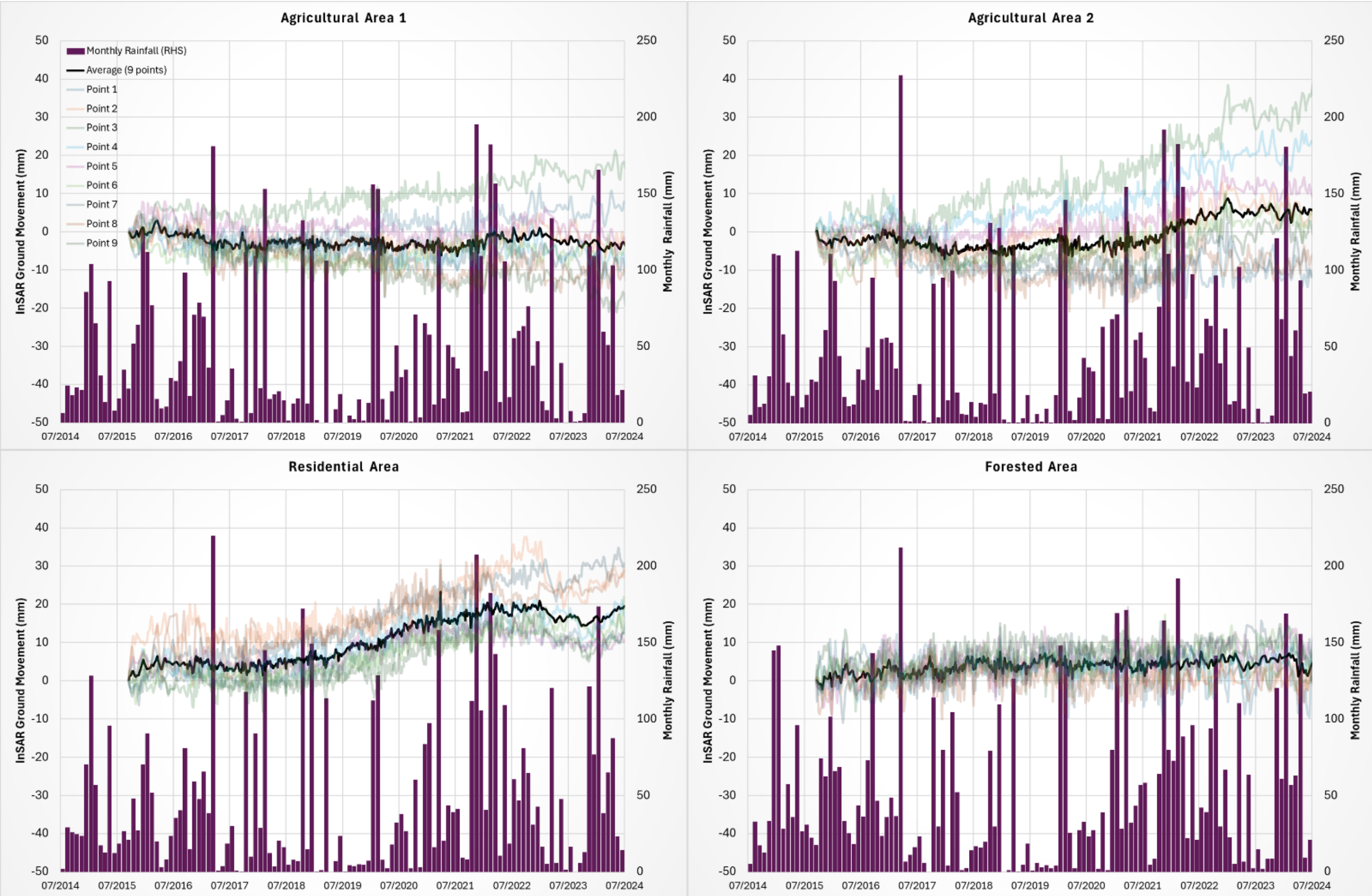

Figure 5-2: Observed ground movement between August 2015 and June 2024 for nine 2D-decomposition InSAR monitoring points within 150m and the average movement for four reference locations with minimal CSG activity

6 Predicted subsidence

Predictions of subsidence due to CSG operations has been undertaken through the SGP Stage 1 WMMP (Arrow Energy, 2018) and through the 2021 UWIR (OGIA, 2021a). A summary of these two predictions is provided in the following sections.

These predictions are sensitive to the adopted values of:

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

Whilst there is some uncertainty in these parameters, Arrow Energy (2018) and OGIA (2021a) both assessed uncertainty as part of predictions, and 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 noted that the thickness of the compressible formations (principally the Walloon Coal Measures) changes over large distances and the depressurisation of those formations is diffusive. These two key drivers of CSG-induced subsidence vary in space over distances in the order of hundreds of metres, and therefore the compaction and associated subsidence at surface is expected to change over large areas and not result in small scale differential movement.

6.1 2018 Water monitoring and management plan

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 compression of each stratigraphic component. The total subsidence experienced at the surface can then be determined by integrating the individual component compressions. Subsidence associated with this mechanical process is expressed using the following relationship (based upon integration of one-dimensional settlement of an elastic material under pore-pressure change – stress stain relationships as described in Sanderson (2012)):

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

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
	v'	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

Coffey (2018) undertook analytical modelling using this approach to predict the magnitude of subsidence within Arrow's tenements due to CSG operations. The approach adopted by Coffey for this assessment was as follows:

- Records of subsidence within the Daandine CSG field from InSAR were reviewed.
- Records of drawdown measured within the Daandine CSG field were reviewed.
- Correlation between the measured drawdown and interpreted subsidence used to develop an effective Young's modulus for the Walloon Coal Measures.
- Predictions of maximum drawdown were used to assess maximum subsidence within Arrow SGP.

Coffey's use of field scale measurement readily took account of the averaging across the thickness of the affected geological units to obtain average behaviour, without needing to make separate assessments for changes in lithology within each geological formation. Coffey used predictions of drawdown resulting from the Arrow SGP operations as presented in a technical memorandum prepared by Coffey (SGP Stage 1 CSG WMMP: Groundwater modelling technical memorandum, 1 December 2017) for Arrow. Predictions of drawdown were developed for the effects of operations by Arrow alone as well as predictions of Arrow in combination with the other CSG producers in the Surat CMA.

Coffey (2018) made two assessments of long term subsidence associated with CSG extraction for the Arrow SGP. These assessments used different modulus values and drawdown estimates, a low assessment using a higher effective modulus value (13.6 GPa) and a high assessment using a lower effective modulus (7.8 GPa), with a range of drawdown values covering drawdown predictions. Thickness of the Walloon Coal Measures were combined with the predicted drawdown using the methods described in this section to assess subsidence. Coffey determined that the largest subsidence within the SGP area due to Arrow operations in isolation was 100 mm, with up to 120 mm predicted as the cumulative impact of Arrow and other company CSG operations.

6.2 2021 Underground Water Impact Report

The subsidence modelling undertaken by OGIA (2021a), which incorporates the most recent depressurisation data and predictions of the 2021 UWIR and is history matched to the ground movement monitoring data, is the most up to date and advanced prediction of CSG induced subsidence within the Surat Basin.

OGIA developed a 3D numerical geomechanical model for the Condamine Alluvium and adjacent CSG production, encompassing an area of 50 km × 130 km, incorporating all available data on local geomechanical properties and lithological distribution. The 3D numerical geomechanical model is underpinned by a regional geological model developed by OGIA, a calibrated 1D mechanical earth model (MEM) developed by Schlumberger, and pressure predictions from OGIA's regional groundwater flow model. The model extends from the ground surface to the base of the Eurombah/Durabilla Formation, with the Walloon Coal Measures subdivided into 12 layers to differentiate between the coal and interburden units, with coal layer thickness constrained by mapping from wireline logs. To support numerical stability, the model was further subdivided into 88 vertical layers, with a model grid ranging from 250 × 250 m to 750 × 750 m to account for variations in lithology. Rock properties were derived from 41 wells for the 1D MEM, including the available wireline geophysics from Arrow wells discussed in Section 4.2. When assessing subsidence impacts, OGIA considered both the absolute subsidence magnitude, as well as progressive development of subsidence as the CSG fields are developed resulting in change in slope with time.

For the greater Surat Basin, OGIA developed an analytical model integrating geomechanical rock properties and predicted depressurisation, similar to that developed by Coffey as described in Section 6.1. The domain of this model covers an area of around 460 km × 650 km, encompassing the entire Arrow SGP area and includes CSG activities by other resource companies. For the same geomechanical properties and pressure distribution, OGIA found the analytical model was able to approximate predictions of subsidence comparable to the 3D numerical geomechanical model of the Condamine Alluvium area. For the analytical model, OGIA generated a set of 1,000 models from stochastic realisations of geomechanical properties to explore the range of uncertainty in predictions. History matching these models to the available InSAR data in the vicinity of the Condamine Alluvium allowed the 50 best fitting models to be selected to generate predictions of subsidence. Predicted subsidence and change in slope are therefore reported statistically in the 2021 UWIR as a median (P50) prediction derived from those 50 model runs. Predicted subsidence from the 2021 UWIR, including predicted temporal development of subsidence at specific locations, is presented in Figure 6-1, with predicted maximum changes in slope within the areas of the Condamine River floodplain presented in Figure 6-2.

OGIA processed outputs from the uncertainty analysis to derive probability of magnitudes of subsidence and slope occurring at each model cell. This is presented as maps of the probability of 0.001 % (0.01 m in 1 km) and 0.005 % (0.05 m in 1 km) slope change at any time, together with probability of 100 mm and 150 mm magnitude subsidence occurring within the area of the Condamine River floodplain, the area most susceptible to changes in slope affecting overland flow to MNES, in Figure 6-3. OGIA found that, within the area of the Condamine Alluvium, the greatest change in slope is predicted across the Horrane Fault, as a result of differential drawdown patterns either side of the fault. The Horrane Fault is a large north-south trending fault zone east of Cecil Plains, with displacement of up to approximately 100 m. Displacement of the fault and the low permeability of the fault core, as described by Viljoen et al (2020), can result in differential depressurisation patterns either side of the fault. In this Horrane Fault area there is about 80 % probability of change in slope of 0.005 %, while most of the area between Dalby and Cecil Plains is likely to experience 0.001 % or less change in slope. In terms of the magnitude, this area near the Horrane Fault is also predicted to have a 50 % chance of 150 mm of CSG induced subsidence occurring, while other areas of the SGP are expected to have less than 100 mm of CSG induced subsidence. Co-ordinated development of coal depressurisation on either side of the fault may be used to mitigate development of these changes in slope.

Subsidence

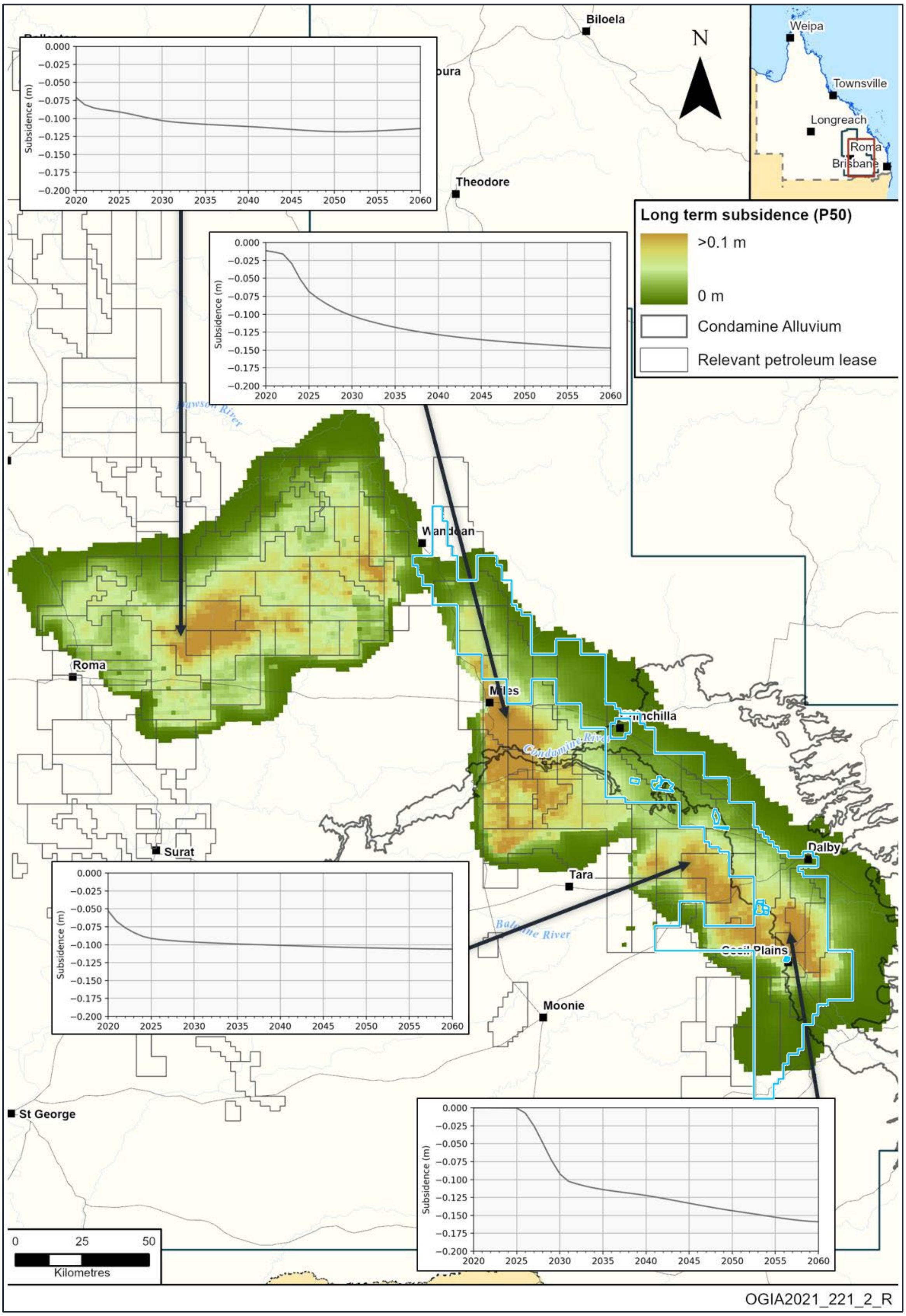

Figure 6-1: Predicted long-term subsidence from the 2021 UWIR for the Surat CMA (from OGIA, 2021a, modified with outline of Arrow tenements in blue)

Subsidence

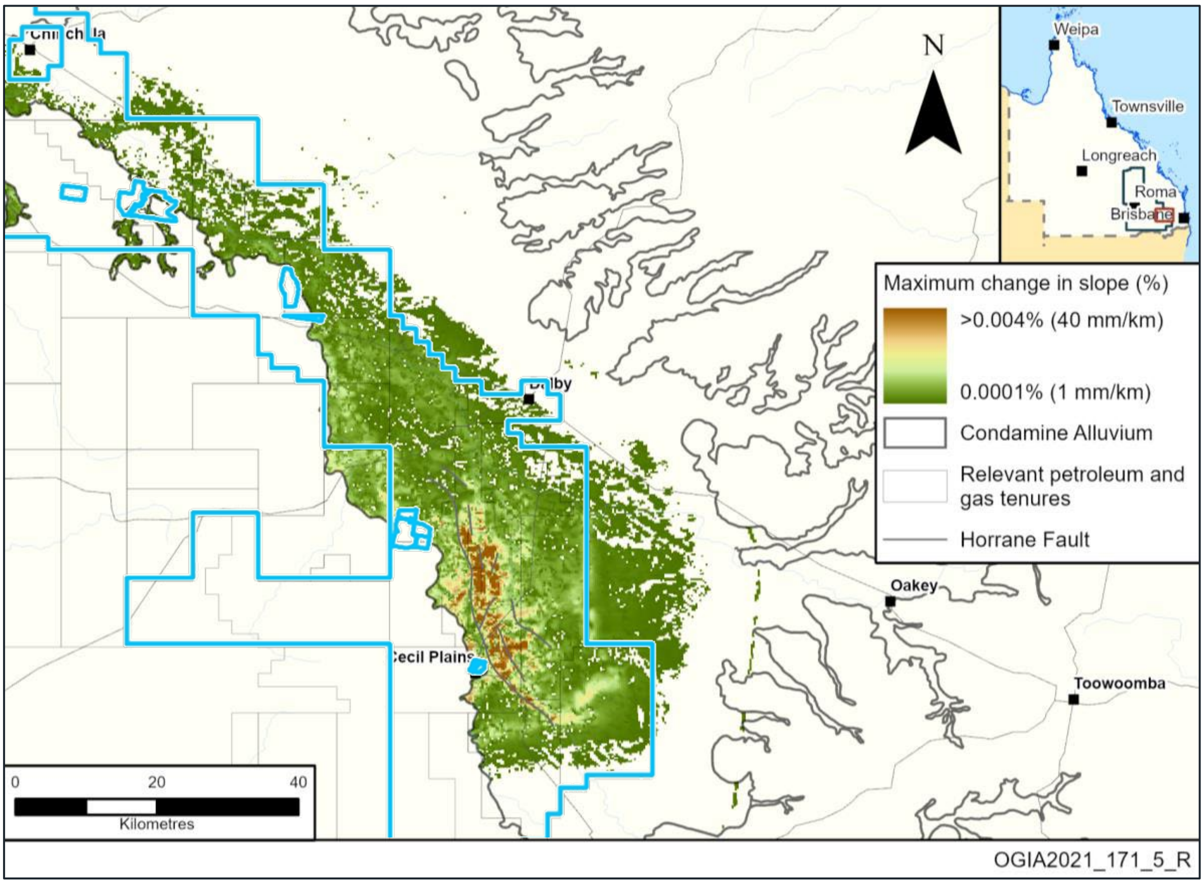

Figure 6-2: Predicted maximum change in ground slope in the Condamine Alluvium area from the 2021 UWIR (from OGIA, 2021a, modified with outline of Arrow tenements in blue)

Subsidence

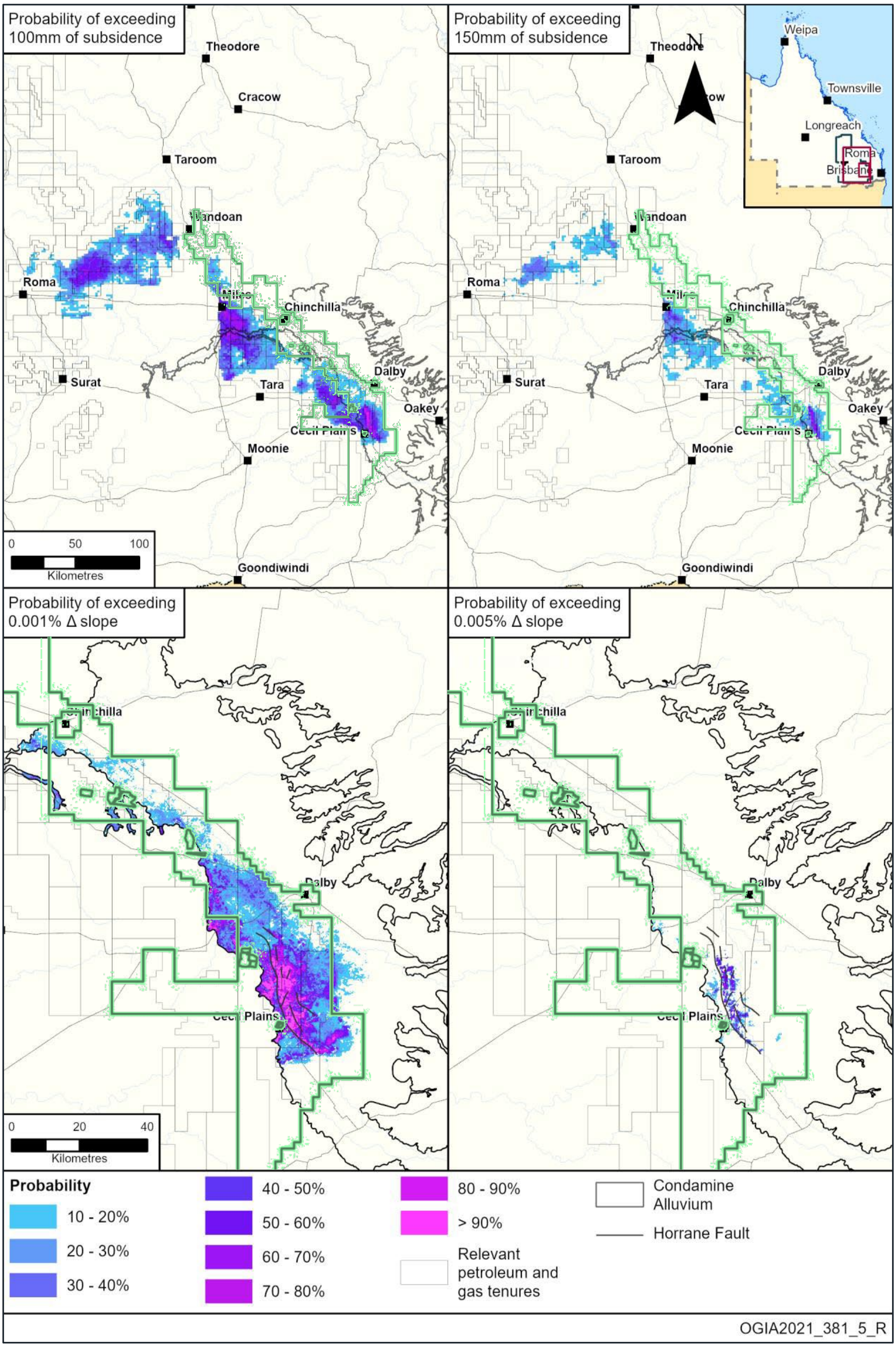

Figure 6-3: Uncertainty output of probabilities of predicted subsidence and change in ground slope in the Condamine Alluvium area from the 2021 UWIR (from OGIA, 2021a, modified with outline of Arrow tenements in green)

7 Risk assessment

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

Risks associated with subsidence are developed through a consideration of the likelihood of impacts of a nominated magnitude and the consequence of such an event. Subsidence, in the context of MNES protected matters, can have an impact on the surface water or groundwater systems and their associated environmental values within the Arrow SGP and in the vicinity.

In assessing potential impacts consideration needs to be given to absolute magnitude and the differential magnitude or change in gradient.

Leonardi (2024) listed groundwater withdrawal (including from CSG) induced subsidence potential impacts to surface water systems including change in the drainage pattern of streams and channels; ponding of water in subsidence troughs (if they form); deepening or widening of pools in streams; alteration of riparian ecosystems and geomorphological stability; and increase the impact of, or exposure to, riverine flooding or delayed drainage. OGIA (2021a) identified CSG induced subsidence potential impacts to groundwater systems as alteration to porosity and permeability of rocks. These potential impacts to surface water or groundwater systems may then have detrimental impacts on aquatic ecosystems, subterranean groundwater dependent ecosystems (GDEs), or terrestrial GDEs.

7.1 Risk assessment approach

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, being a MNES protected matter. A consequence/likelihood matrix approach has been adopted for assessment of risks of an event. 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.

For the purpose of this assessment the definitions of likelihood and consequence in Table 7-1 and Table 7-2 are adopted.

Table 7-1: 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 lease area
Probable	Will occur over most of the area
Certain	The event will occur over a widespread area

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Table 7-2: Consequence category definition

Consequence	Description
Insignificant	Little influence
Minor	Noticeable influence without serious consequences Change caused tolerated
Medium	Rectification works or substantial additional monitoring required (costs less than $5m)
Major	Substantial rectification works in excess of $5m required Environmental damage requiring intervention or remedial works
Catastrophic	Serious environmental consequences Damage with major disruption to public facilities Loss of life or serious injury to people

From the likelihood and consequence, the risk evaluation matrix in Table 7-3 is employed.

Table 7-3: Risk Matrix

	Consequence Category Rating				
Likelihood 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 Groundwater systems

As described in Section 2.1, increase in effective stress from depressurisation and coal shrinkage result in compaction of the coal. Although the permeability of coal increases with desorption of methane and resultant coal shrinkage during gas during production, the increase in effective stress due to a reduction in pressure also tends to cause a reduction in coal permeability. Results from Harpalani & Chen (1997) suggest that the decrease in permeability due to increased effective stress is balanced by the overall increase in permeability from matrix shrinkage. The CSG production induced pressure declines are much lower in the surrounding formations including the Springbok Sandstone than in the Walloon Coal Measures, and the mechanical properties of these surrounding formations, particularly the sandstone aquifers, are less prone to compaction. For these surrounding formations, reduction in porosity and permeability is therefore likely to be inconsequential (OGIA, 2021a).

To result in adverse differential movement of rock formations, the subsidence would need to be significant and occur on a localised scale, at differing rates. Both the magnitude and lateral extent of depressurisation of the coal seams from individual production wells overlap each other with time within the CSG fields and tapers away from the CSG field. This infers that compaction will also occur over a broader area than the footprint of the CSG well field, and is reflected in assessment conducted by OGIA (2021a) using ground movement observed from InSAR, with the magnitude of downward ground movement gradually reducing away from the margin of gas fields. Due to this broad lateral extent of depressurisation, there is also likely to be little or no potential for a reduction in surface settlements through arching or similar mechanisms in depressurised CSG fields, particularly later in field life, and is consistent with the findings of the OGIA 3D geomechanical modelling (Aghighi et al, 2024a). Although fissuring can be produced through differential settlement of subsiding lands (Zekster, Loaiciga, & Wolf, 2005), coal seam gas formations are non-structurally controlled reservoirs in

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horizontal or sub-horizontal strata and the magnitude of compression that occurs at depth in the coal measures is likely to be closely reflected at the surface, therefore the stresses and strains of bending induced in the overburden will be significantly lower than in the case of underground mining or structurally complex formations. Consequently it is unlikely that CSG induced subsidence could lead to shear displacements of overburden materials and therefore cause an increased interconnection between the coal measures and overlying aquifers.

With the small magnitude of CSG induced subsidence and slope change, as observed in monitoring of existing CSG fields and predicted in OGIA (2021a) modelling, and the remote likelihood of fracturing of overburden materials, it is considered that the risk of affecting MNES water resources, including the hydrology of the Great Artesian Basin aquifers or the surficial aquifers such as the Condamine Alluvium, is low. The low risk is consistent with that determined in Arrow's SREIS (Arrow Energy, 2013).

7.3 Surface water systems

The Condamine River and associated floodplain occupies the area between Ellangowan (E151.67°, S27.92°) east of Millmerran 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 the floodplain is 15-40 km wide. The southern and eastern extents of the floodplain are outside the area of the SGP. The topography drops steadily from the south to the north, from +400 metres Australian Height Datum (mAHD) near Ellangowan outside the area of the SGP operation to +350 mAHD near Dalby and to +310 mAHD near Chinchilla, with an overall topographic gradient of 0.05% (500 mm in 1km). The uplands forming the western boundary of the Condamine floodplain in the area of the SGP, are characterised by gentle slopes developed with maximum elevations of around 420 mAHD. The Condamine River and tributary watercourses are generally incised with well-defined channels. Incision, bank erosion, channel migration and avulsion of the rivers and creeks have left palaeochannel meander scars and terraces within the more recent alluvial deposits. Depositional features, such as levees and sandbars are common, indicating that in recent geological times the watercourses have been dynamic systems. In the north of the SGP operations area, Juandah Creek and Dogwood Creek are headwater reaches with steeper slopes compared to the Condamine floodplain. Most of the second-order and greater reaches of these catchments are partly confined with widespread bedrock.

The occurrence of subsidence can cause changes to flood plain morphology (Zekster, Loaiciga, & Wolf, 2005). Small areas of the Condamine plain are predicted to have up to 0.005% (50 mm in 1 km) change in slope, while most of the area is predicted to have change in slope of 0.001% (10 mm in 1 km) or less (Section 6.2). Using the existing topographic gradient as a guide this results in subsidence leading to changes in gradient of up to 2% of the existing gradient (10 mm in 1 km = 2% of 500 mm in 1 km) across most of the area, and up to 10% in small areas. Predicted subsidence and slope change in the steeper Juandah Creek and Dogwood Creek catchments result in substantially lower change in gradients.

Alluvium (2013) as part of the SREIS (Arrow Energy, 2013) assessed geomorphology and undertook flood and hydraulic modelling to identify risks of changes to hydrology, flood inundation and geomorphic character from Arrow's then proposed SGP development. Alluvium's (2013) review of an InSAR study of the period December 2006 to February 2011, which covered the Surat Basin including Arrow's existing DXP development and then proposed SGP development, found that the observed ground movement (which was up to 16 mm/year and cumulative up to 80 mm at that time) was substantially smaller than the tolerances allowed for when configuring the hydrodynamic models, which include the accuracy of terrain data, configuration of hydrologic and hydrodynamic models and the reliability of model outputs. Alluvium (2013) concluded that small regional scale settlement of the Condamine River floodplain would not adversely affect the geomorphology of

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watercourses, with the risk of geomorphic change assessed as low, and that differential settlement at a local scale might induce geomorphic changes in low-resilience watercourses or alteration of overland flow and flood behaviour, although this is not expected. If differential settlement were to occur, mitigation measures to protect vulnerable reaches of affected watercourses from erosion and channel migration would be effective in managing the impacts. Alluvium (2013) also found that the broad flood plain across the Condamine River catchment suggests that changes to the topography would have minimal if any impact on flood levels, although this was not modelled. Alluvium also concluded that on steeper and more resilient waterways, such as observed in the Juandah Creek and Dogwood Creek catchments, induced geomorphic impacts or alteration in flood behaviour or flows as a result of CSG induced subsidence is not expected to be discernible.

The risk to vegetation communities from CSG induced subsidence is very low. This is based on studies investigating subsidence impacts from underground mining on Brigalow and Blue Grass communities in Queensland (Eco Logical Australia, 2015; Ensham Resources, 2024). Underground mining induced subsidence results in a larger magnitude of subsidence and change in slope then CSG induced subsidence, and also results in fracturing of rock formations causing connectivity between formations and with the surface. A combination of field survey, high resolution satellite image analysis and LiDAR analysis was used to look at these communities both on and off subsided areas. The studies found no statistical evidence of negative impacts on the vegetation communities due to mine induced subsidence.

Subsidence related impacts to aquatic ecosystems and GDEs may potentially occur if there are changes in the integrity of hydrological or hydrogeological connectivity, resulting in changes to surface water flow or groundwater levels that the aquatic ecosystems and GDEs rely on. CDM Smith (2016, 2018) assessed surface water-groundwater connectivity in the area of the SGP and found the majority of the length of the Condamine River and its tributaries function as disconnected losing streams. This disconnectedness, and the low risk of subsidence affecting MNES groundwater resources (Section 7.2), results in a very low risk of impacting surface water-groundwater connectivity and the reliant GDEs. The low to very low risk of geomorphic impacts or alteration in flood behaviour or flows, as described previously, results in a very low risk of impact to aquatic ecosystems.

The Condamine River is the major drainage system of the southern Queensland area, extending from its headwaters southeast of Warwick to the convergence with Dogwood Creek north of Glenmorgan. The Condamine flows through the Darling Downs region via Dalby, Chinchilla and Surat, where it becomes the Balonne River. The Balonne flows southwest to St George and then splits into a series of river channels including the Culgoa, Balonne-Minor, Ballandool, Bokhara and Narran Rivers and the Briarie Creek. The rivers of the distributary river system ultimately flow into the Barwon River, which in turn flows into the Darling River (DRDMW, 2024). The Condamine River has an annual stream flow of 1,305 GL at St. George and makes up approximately 13% of the Murray-Darling Basin (MDBA, 2023).

In relation to environmental surface water flows, an environmental assessment was completed by the Qld Government in 2019 to evaluate the environmental risks resulting from water resource development within the Condamine and Balonne water plan areas (DNRM, 2019). Of relevance to this WRMMP, environmental surface water risks evaluated as part of the assessment for the Upper and Middle Condamine areas included 1) risk of insufficient water available for the environment and poor health of water-dependent ecosystems (surface water); and 2) risk to the catchments' capacity to meet environmental watering (surface water), both potentially resulting from modification to 'cease-to-flow-events', 'low flow events', 'bank-full events' and 'over-bank events'.

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In the Middle Condamine area, downstream of Arrow's tenure, modification to 'cease-to-flow-events' were found to be a medium risk, however the causes of this event type were related to direct pumping from refugial waterholes during no flow spells, in-channel flow harvesting and dam operations all of which are not CSG related activities.

The assessment also found the risk due to modification to 'low flow events', 'bank-full events' and 'over-bank events' from water resource development (non-CSG) to be low. The cause of modifications to 'low flow events' was dam operations and extraction of groundwater (loss of baseflow). These causes are again not influenced by CSG-induced subsidence.

The sustainability indicators determining potential impact from 'bank-full events' are fluvial geomorphology and river forming processes. As mentioned above in this section, induced geomorphic impacts or alteration in flood behaviour or flows as a result of CSG-induced subsidence is not expected to be discernible, therefore this risk also remains low.

In relation to 'over bank events' minor-changes to floodplain geometry and morphology due to CSG-induced subsidence are not expected to result in retention of water in the landscape in excess of background variability typical across the flood plain. This is because the low slope changes predicted are not expected to result in reversal of drainage lines. Further, during 'over-bank events', there is surplus water in the river for environmental flows and therefore surplus water to meet environmental watering (surface water) requirements. On this basis, the risk during an 'over-bank event' to environmental surface water flows is considered low.

A summary of the risks and their ratings is provided in Table 7-4.

Table 7-4: Summary of risks to surface water systems

Risk	Consequence	Likelihood	Rating
Risk of geomorphic change to the Condamine River Floodplain due to CSG-induced subsidence	Minor	Unlikely	Low
Risk to vegetation communities due to CSG-induced subsidence	Insignificant	Unlikely	Very Low
Risk to aquatic ecosystems and GDEs (groundwater/surface water connectivity) due to CSG-induced subsidence	Insignificant	Unlikely	Very Low
Risk to environmental surface water flows in the Condamine River due to CSG-induced subsidence during:			
- cease-to-flow events	N/A		
- low flow events	N/A		
- bank-full events	Minor	Unlikely	Low
- over-bank events	Minor	Unlikely	Low

8 Trigger level development

A process of progressive trigger levels has been developed for CSG induced subsidence assessment as required by approval condition17A(c)(iii). They are derived from calculated risk assessments of potential subsidence described in Section 7. These thresholds are presented in Table 8-1, and further discussed below.

The process focusses on surface water systems risk and in particular screening for geomorphic changes to the Condamine River Floodplain that may be impeding free drainage following overbank events. Risks to groundwater, vegetation communities, aquatic ecosystems and GDEs from CSG-induced subsidence are considered very low or of insignificant consequence and have therefore not informed the process.

A three-level assessment process is set out. Initial assessment would involve a screening level to identify areas where significant subsidence is occurring, based upon the annual velocity reported from InSAR monitoring results or slope change from LiDAR results. In areas where this significant movement is recorded, further assessment against investigation levels will be carried out to identify CSG-induced movement with potential to impact on particular protected matters. Where investigation levels for potential impacts on protected matters are exceeded, site-specific investigations will be conducted to determine if actual impacts to MNES protected matters are more than minor and therefore exceed the trigger threshold.

8.1 Screening level

The screening level assessment includes two steps. Step 1 is screening of InSAR data for areas of vertical ground movement near to gas production. This allows focus areas to be identified where ground movement is occurring that may be related to CSG production. Step 2 is further screening of those areas for changes in slope that may be indicative of changes to floodplain morphology.

Step 1

OGIA (2021a) determined that InSAR is the most appropriate technique for ongoing monitoring of change in ground elevation for the purpose of establishing trends and subsequent identification of subsidence. OGIA (2021a) further identified that where the observed trend in ground movement from InSAR shows a decline of more than 10 mm/year over a 12-month period and there is CSG production within 2.5 km of the monitoring location, that additional monitoring such as LiDAR and field verification may be required to provide additional data in instances where ground movement deviates from the predicted rate of decline. A rate of change of 8 mm/year was adopted as a conservative screening level in the Stage 1 WMMP, however monitoring undertaken for the previous WMMP found this to be too conservative, with an area over 243 and 344 km^2 exceeding this rate of change during 2023 and 2024, the majority (68-73%) being away from gas production areas and therefore indicating natural background movement. Therefore, in this WRMMP the trigger has been determined as 20 mm/yr, which is still considered conservative regarding the type of changes across the flood plain necessary to result in the water resources or environmental impacts considered in the risk assessment. For reference, OGIA found ground movement in the region, including away from gas production, can frequently move up and down by 25 mm per year due to natural mechanisms (OGIA 2021a).

Screening is undertaken by spatially analysing an InSAR dataset every 6 months using a pre-defined 1 km grid. This is done by checking for changes of greater than 20 mm/year for greater than 50% of InSAR points within the 1 km grid cell. Where the 1 km grid cells have less than 5 InSAR points, they are progressed to Step 2 for assessment using LiDAR. At this stage, grid cells away from gas production are assumed as being from other causes (nominally 4.5 km or further from the well head). The basis of the 4.5 km area of influence is the 2.5 km as recommended by OGIA for further monitoring, plus an additional 2 km for allowance for deviated well paths, given that depressurisation occurs along the entire length of the well's slotted casing interval.

Any of the 1 km grid cells near to gas production that exceed 20 mm/year movement over the 12 months prior, or have less than 5 valid InSAR points, are then progressed to Step 2.

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Step 2

Step 2 of the screening process involves further analysis of the grid cells for areal slope change. The intent of applying this trigger across the Condamine floodplain is to identify areas where CSG-induced subsidence may be affecting water being able to drain to the receiving environment. The screening level adopted for slope change has been taken as 1 in 10,000 (0.01% or 100 mm/km). This is approximately equal to the existing grade of the flattest drainage features on the flood plain, such as certain sections of Long Swamp. For reference, OGIA found ground movement can vary significantly at a local scale, by up to 25 mm within 100 m (0.025%) due to natural mechanisms (OGIA 2021a).

To estimate areal slope change, the most recent LiDAR is used to generate a slope DEM and compared to LiDAR obtained closest to 12 months prior. At high DEM resolutions, error is introduced to slope calculations due to noise associated with LiDAR accuracy as well as effective corrugations in the earth surface due to furrows in cropping areas. Conversely, at low resolutions, truncation error may be introduced where features in the landscape are effectively truncated or cut out. The University of Queensland completed some unpublished research in 2024-2025 which has informed the screening process. This work found that 10 m is an optimal resolution to minimise these errors in cropping areas. The slope DEM is generated from the LiDAR derived ground points on a 10 m resolution by averaging the LiDAR ground points within that grid cell.

Areal slope statistics are calculated from the 10 m resolution DEM for the 1 km grid cells from Step 1 and compared to data collected approximately 12 months prior (depending on when the LiDAR capture occurred). Where the average areal slope change exceeds 1 in 10,000 (0.01% or 100 mm/km), those 1 km grid cells are progressed to an investigation level assessment. It is noted that traditional LiDAR is unable to penetrate water, however the point classification process can identify water points to high levels of confidence (99%). Water bodies, when processed using the above methodology, appear as holes in the DEM and slope statistics derived from the slope DEM will be based on the visible ground data only.

The screening levels are summarised in Table 8-1.

8.2 Investigation levels

In areas where the screening level is exceeded, further assessment of relevant data relating to subsidence will be undertaken. This will include an assessment of the CSG-related subsidence component of the reported InSAR or LiDAR measurements with consideration for the cumulative industry impact and reported subsidence since the commencement of the Arrow SGP operations.

Investigation levels have been defined as set out in Table 8-1.

Investigation levels are to be assessed based on change in slope derived from LiDAR. Investigation levels have been developed based on existing gradients of catchments and water courses (Sections 4.1.1 and 7.3), background changes in slope (Section 5, Data Farming (2021) and OGIA (2021a)), and risk of impacts (Sections 7.2 and 7.3) related to predicted changes in slope from subsidence. More than 97% of land area within the SGP area has existing gradients of greater than 0.06 % (60 mm/km), with less than 1 % of land area being less than 0.03 % (30 mm/km) gradient. Data Farming (2021) considered gradients of less than 0.03 % as already being poorly draining.

Assessment against investigation levels will consider the maximum differential settlement and change in slope along transects for comparison with the investigation values. Those areas where ground movement is obviously related to non-CSG natural or anthropogenic causes such as earthworks, land clearing, erosion/deposition, land levelling or tillage will be excluded from assessment. Identification of natural or anthropogenic causes will be based on imagery co-collected with LiDAR, and other available remote sensing data. Transects will be prepared parallel to, and perpendicular to, drainage features, with the gradient of each transect estimated by averaging the slope from one end to the other unless the lowest point on the transect clearly occurs away from either end. Multiple slopes may be fitted to the profile to best approximate the general slope of the transect. It is noted that variations in soil moisture content across areas and/or storm events that results in uneven soil wetting can also cause material changes to surface elevations, however these will not be excluded from further assessment because of these effects. The gradients of any slopes identified along the transect will be compared between the most recent measurement/survey event, and the pre-CSG[1] influenced measurement / survey event(s) considering the relative uncertainty of the surveys.

It is noted again that traditional LiDAR does not penetrate water. To address this, a check of where water was sitting during the surveys will also be undertaken as part of verification of drainage related impacts. This will be done by generating water polygons direct from the LiDAR points classified as water for each of the DEMs interrogated. This standing water mapping will be considered during the assessment to interpret where water is sitting and affecting slope results along the transects.

The change in gradients or differential movement will then be compared against the investigation levels defined in Table 8-1.

Where the CSG-related subsidence exceeds the investigation levels set out in Table 8-1, further assessment will be carried out to assess whether a detrimental impact to MNES protected matters has occurred as a result of the Arrow SGP operations.

8.3 Trigger threshold

The investigation levels nominated in Table 8-1 are anticipated to be conservative. Exceedance of these investigation levels will be followed by a review of affected MNES protected matters present in the affected area, and a review of potential detrimental effects and the development of mitigation measures as appropriate.

Assessment for trigger threshold exceedance will include site-specific investigations to identify and assess potentially affected MNES protected matters. Site-specific investigations are likely to include additional data such as imagery or multispectral remote sensing, ground investigation and verification. Site-specific investigation may include soil sampling, ecological assessment, or hydrological and hydraulic modelling. Consideration will be given to development of new local low points, gradients to existing low points, catchment area of low points, inundation of an area not previously known to be or could reasonably be assumed to have been inundated, total variation in slope, and total drainage in catchments or sub-catchments. This evaluation will include analysis of depressions, comparison of contours at 100 mm intervals, and drainage mapping to compare to pre-CSG drainage and slope.

Where adverse consequential impacts to a MNES protected matter are identified to have occurred due to CSG induced subsidence based on the results of the site-specific investigation, a trigger threshold is considered to have been exceeded and mitigation measures will be employed following the approach set out in Section 8.4. The trigger threshold will not be considered exceeded if it is reasonably apparent that the impact was caused

[1] Defined as any measurement/survey events conducted prior to production from any SGP CSG well which could reasonably have induced ground movement at any point along the transect. As a minimum this analysis must include the most recent pre-CSG measurement/survey event.

by a pre-existing characteristic of drainage or slope of the area or the alteration to drainage or slope was caused by a non-CSG factor, activity or event.

Table 8-1: Subsidence monitoring screening level, investigation levels and trigger threshold

Item	Description	Relevant assets	Criteria	Action / comment
Screening level – Step 1	Settlement rate from InSAR	All natural features	20 mm/year (for >50% of sampling points in 1 km by 1 km) within 4.5 km of CSG production wells	Areas where this criteria is exceeded will be subject to further screening for areal slope change and ponding areas (Step 2).
Screening level – Step 2	Change in slope	All natural features	0.01% change in average areal slope over 12 months (for 1 km by 1 km cell)	Areas where Step 1 criteria and this criteria are exceeded will be subject to investigation level assessment.
Investigation levels	Change in slope along transect from LiDAR	Drainage features across the Condamine River Floodplain.	Changes in slope of 0.01% or greater (for areas 0.03-0.09% existing slope), or absolute changes in slope greater than 20% of existing (for areas >0.09% existing slope) over ~12 month previous (nearest suitable LiDAR surveys), due to subsidence.	Areas where this criteria is exceeded will be subject to trigger level assessment. Existing gradients less than 0.03% are already poorly draining and not progressed.
Trigger threshold	Outcome of site specific investigation confirms detrimental impact on MNES protected matter due to CSG induced subsidence	Any natural feature	Site specific investigation determines consequence category of medium or greater and risk to asset is medium or greater	Individual threshold based on the local conditions for identified MNES protected matter. Eg: confirmation of material reduction in yield to the receiving environment by hydrological assessment.

8.4 Trigger threshold exceedance response actions

Approval condition 17A(c)(iii) requires the development and implementation of an action plan to address identified subsidence impacts on protected matters within 90 calendar days of a trigger threshold being exceeded.

Trigger threshold exceedance response actions are dependent on the evaluation of the cause of the exceedance, and if the potential for detrimental impacts is confirmed, a Trigger Threshold Exceedance Action Plan (TTEAP) will be developed and implemented within 90 days.

Actions in the TTEAP will be dependent on the:

- Evaluation of the cause of the exceedance;
- Magnitude, location and expected duration of the impacts;
- Site specific conditions e.g. hydrogeology, hydrology, ecology, soils, etc.;
- Remediation options; and

- Any other relevant factors.

The TTEAP will:

- Identify potential mitigation or remediation response actions;
- Select suitable response actions, tailored to site-specific conditions, impact cause, timing and magnitude;
- Evaluate time frames within which impacts would be expected to occur and within which mitigation actions would need to be successful;
- Schedule mitigation or remediation implementation, with consideration for the anticipated timing of the indicated impact; and
- Contain procedures to evaluate the effectiveness of the response actions.

Where an action plan is not developed and implemented within 90 calendar days of the identified trigger threshold exceedance this represents a non-compliance and the Minister will be notified.

The subsidence assessment process is illustrated in Figure 8-1.

It is worth noting that a TTEAP is unlikely to be required because the predicted cumulative CSG-induced subsidence and change in slope is low and is well below the thresholds likely to cause an impact to MNES protected matters.

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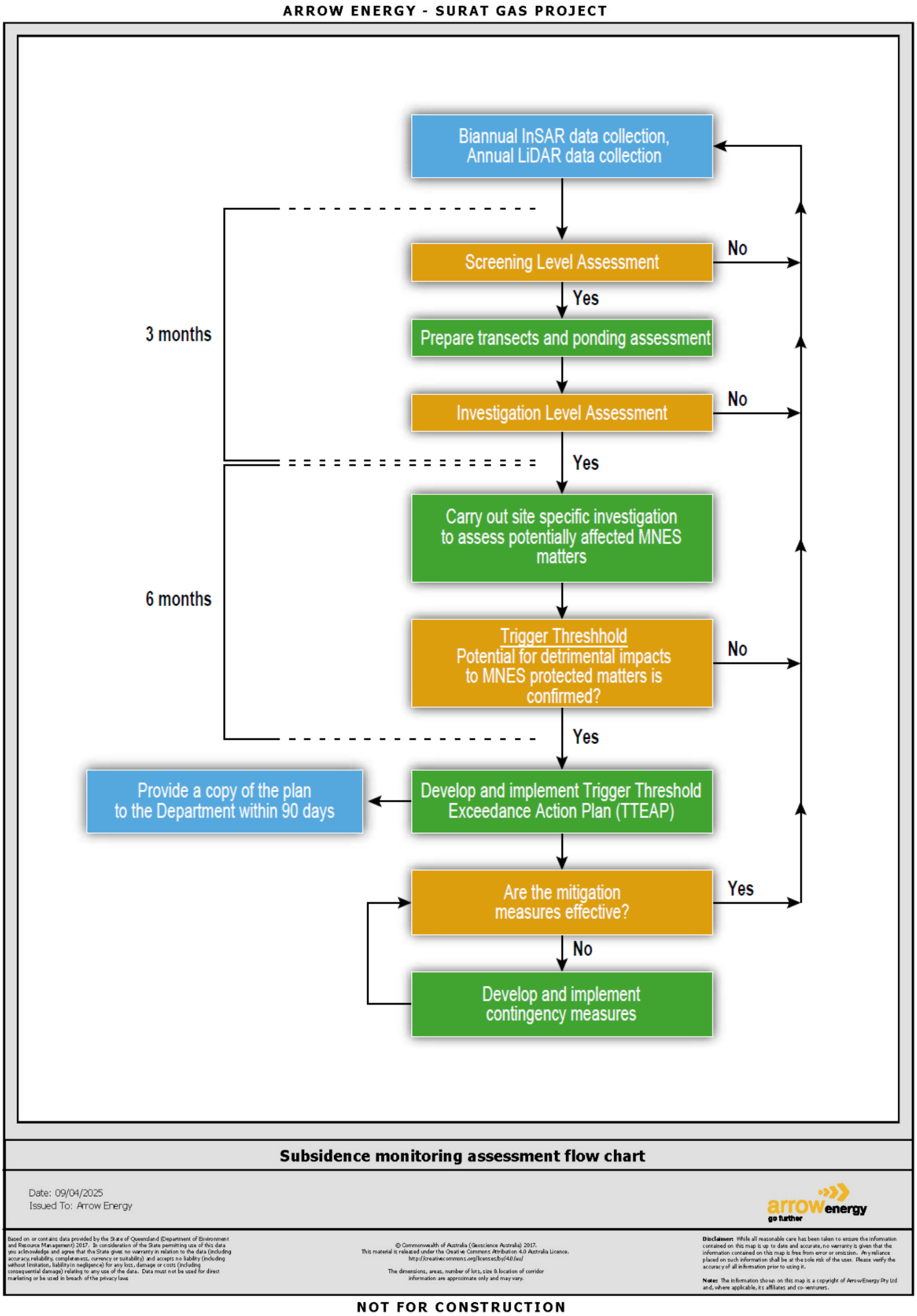

Figure 8-1: Subsidence assessment flowchart

9 Monitoring program

Based on the data on CSG induced subsidence in the area of the SGP operations available since 2006 and predictions of subsidence with further CSG development, it is considered that the magnitude of subsidence and slope change is not high, and it is recognised that the major pressure reductions will occur in geological formations comprising consolidated rock. Because of the significant depth to the coal bearing formations, and the large areal extent of the depressurisation, the likely effects of any subsidence are considered unlikely to have significant impact on MNES protected matters. Notwithstanding the low risk, ground deformation and water level monitoring will be carried out to verify the above modelling, interpretation and the assessed risk.

A program for ongoing monitoring will be implemented to confirm that subsidence is within the predicted behaviour of the strata over time. Where deviation from predictions is observed, revised predictions will be prepared and assessment of the significance of the predictions made.

The current monitoring program provides groundwater level monitoring and monitoring of subsidence using InSAR, LiDAR, and geodetic ground monitoring points as presented in Section 3. 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.

Arrow's ground movement monitoring program will consist of:

- InSAR data updates within the whole of the SGP boundary received on a 6-monthly basis from a 3rd party InSAR supplier, providing high resolution and wide coverage of ground movement. Processing and review of the InSAR against the screening level will be undertaken within 3 months of the data being received.
- LiDAR survey at least annually, on or around May when vegetative cover is minimised between cropping cycles, within 5 km of existing or planned CSG fields within the Condamine plain. Regular LIDAR surveys in this area where coherence of InSAR response is poor are useful to assess ground movement, in particular for changes in slope and hydrology.
- 11 permanent continually operating GNSS monitoring stations, as presented in Figure 3-2, with final orbit processed daily average co-ordinates. The permanent GNSS monitoring stations provide ground truthing for the results of InSAR and LiDAR monitoring.
- 24 permanent survey marks, as presented in Figure 3-2, with annual surveys of these marks undertaken with a six (6) hour observation time, post-processed to determine co-ordinates. The regular survey of permanent survey marks provide ground truthing for the results of InSAR and LiDAR monitoring.

These monitoring methods and locations are considered to provide appropriate coverage of the areas potentially affected by Arrow operations. An overview of the monitoring methods is provided in Table 9-1, including reference to the suitability to monitor for CSG induced subsidence, and future research areas.

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Table 9-1: Overview of selected ground movement monitoring methods

Monitoring method	Data Type	Data Products	Reference to Suitability	Future research
InSAR	C band SAR satellite (provides moderate capability to penetrate canopy of SGP vegetation to get a ground surface measurement)	• Time-series data for each data track (ascending and descending) • Conversion of ascending and descending time-series into vertical and east-west displacement Both data products to include: • cumulative displacement for each acquisition date (mm) • displacement rate (mm/year)	Leonardi (2024) Zhang et al (2025)	Investigate use of different InSAR processing methodologies (e.g. SBAS and TCS) to improve/maximise data coverage over agricultural areas of the Condamine Alluvium
LiDAR	Point cloud data and digital elevation model	• Classified point cloud, LAS format (.las) - orthometric heights. • 1m resolution DEM, GeoTIFF format (.tif) - orthometric heights.	Suitable for establishing digital terrain model and slopes (spatial measurement) (OGIA 2021a)	Alignment of survey frequency with crop cycle and weather. Use of 10m average DEMs to reduce uncertainty with slope calculations.
Geodetic Ground Point	GNSS survey data	• Time series of elevation data	Suitable for quality control on the two remote sensing techniques (Leonardi 2024)	Evaluation of differences between surface and sub-surface movement near to operations
Terrestrial Survey	GNSS survey data	• Time series of elevation data	Suitable for measuring absolute elevation (OGIA 2021a)	Evaluation and checking of LiDAR accuracy. Comparison of trends between survey marks and InSAR.

Groundwater monitoring at multiple locations within, above and below the WCM for groundwater level/depressurisation will be undertaken at the locations and frequencies specified in the most recent UWIR published by OGIA.

10 Reporting

Monitoring of subsidence and groundwater level variation based on existing data indicates that settlement is gradual and accompanies depressurisation of the Walloon Coal Measures. The changes develop gradually over months and years, and as a result a review of subsidence will be carried out on an annual basis. An annual report of this review will provide diagnostic plots of ground movement from each of the monitoring methods, and associated depressurisation. The annual review and reporting will cover:

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- 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 screening level, investigation levels, and trigger threshold.
- Review of the appropriateness of developed trigger levels.
- Consideration of complaints in relation to ground movement and impact on MNES.
- Recommendations in relation to monitoring methods, the future frequency of monitoring, repair or investigation of instruments producing inconsistent results.

11 References

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Appendix A Triaxial compressive test results on rock core

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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 (µe)	9288				
Diametral Strain (µe)	-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 (µe)	11971				
Diametral Strain (µe)	-14870				

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

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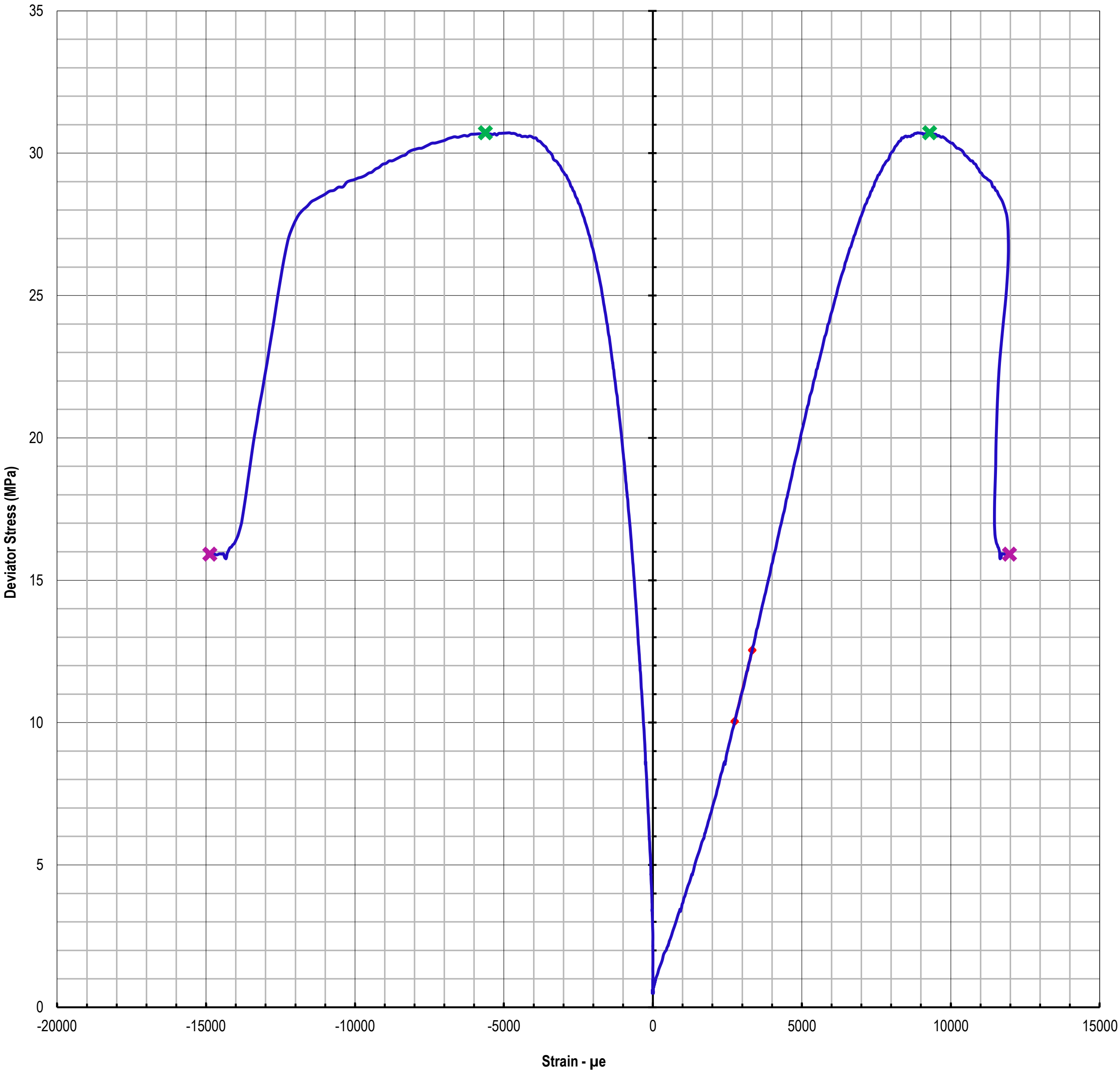
Client	Arrow Energy Pty Ltd	**Report No.**	20110051-RTX

Deviator Stress vs Axial Strain Plots



Notes/Remarks:

Graph not to scale

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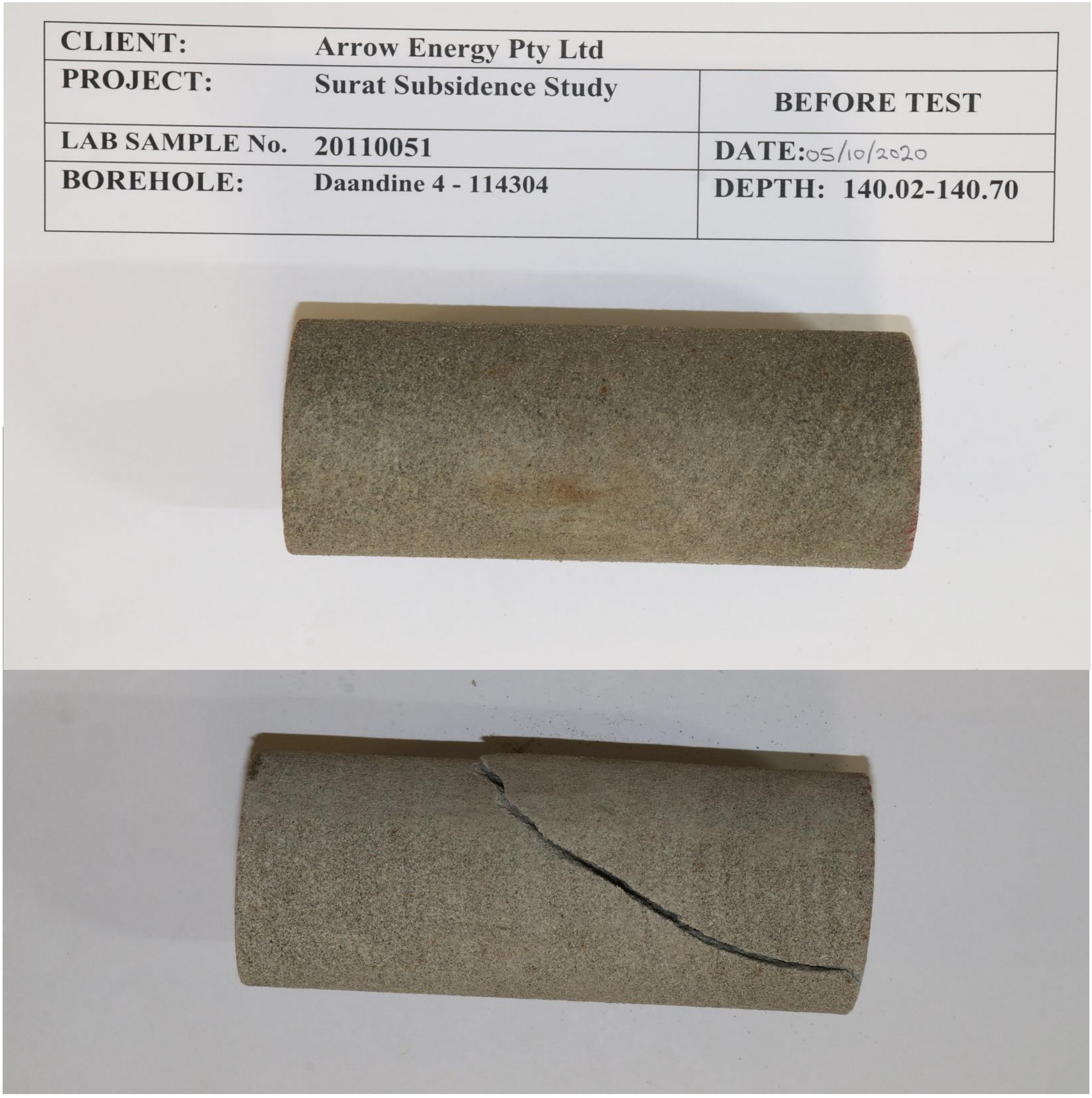
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos



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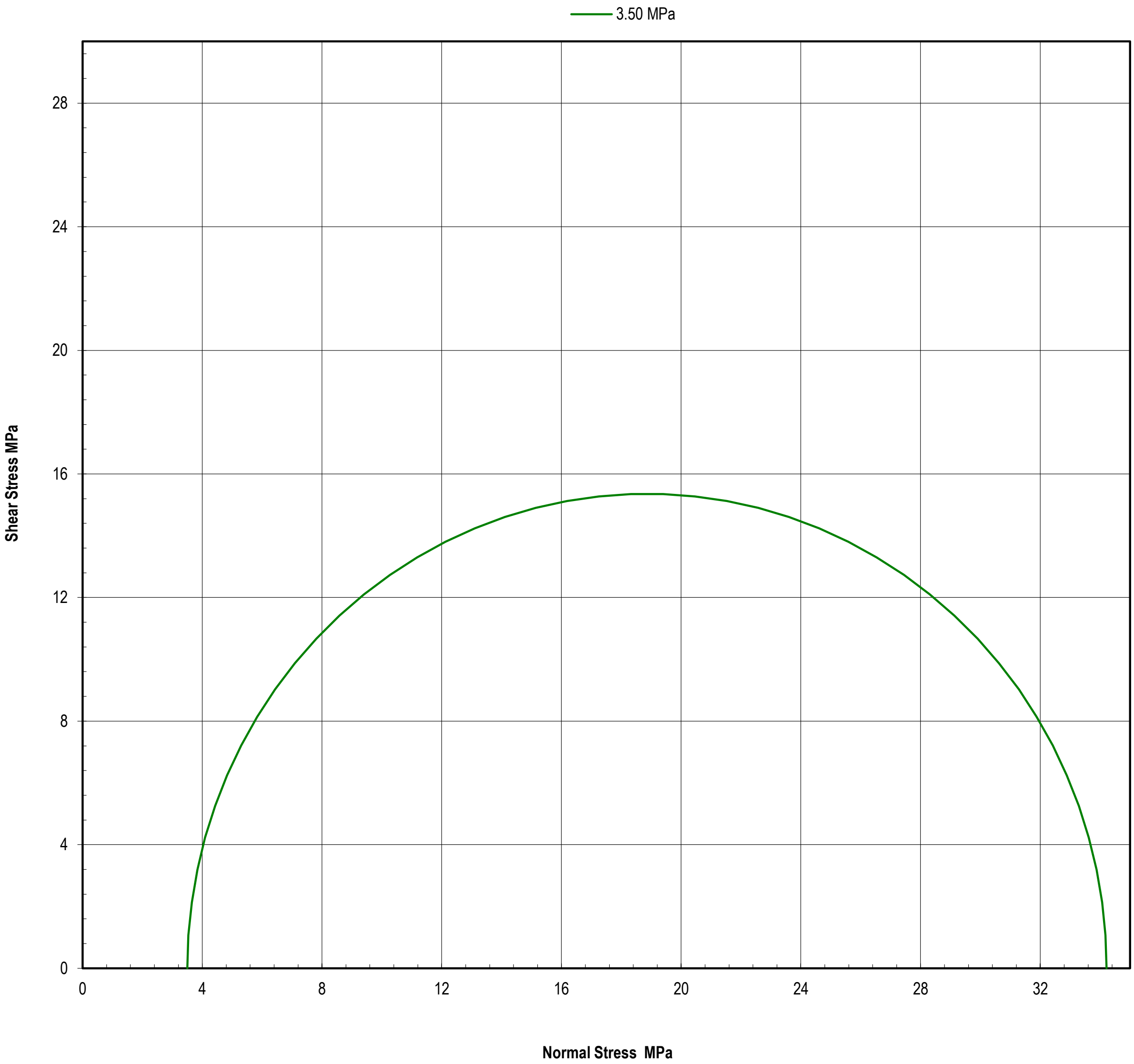
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Peak Stress Mohr Circle Plot



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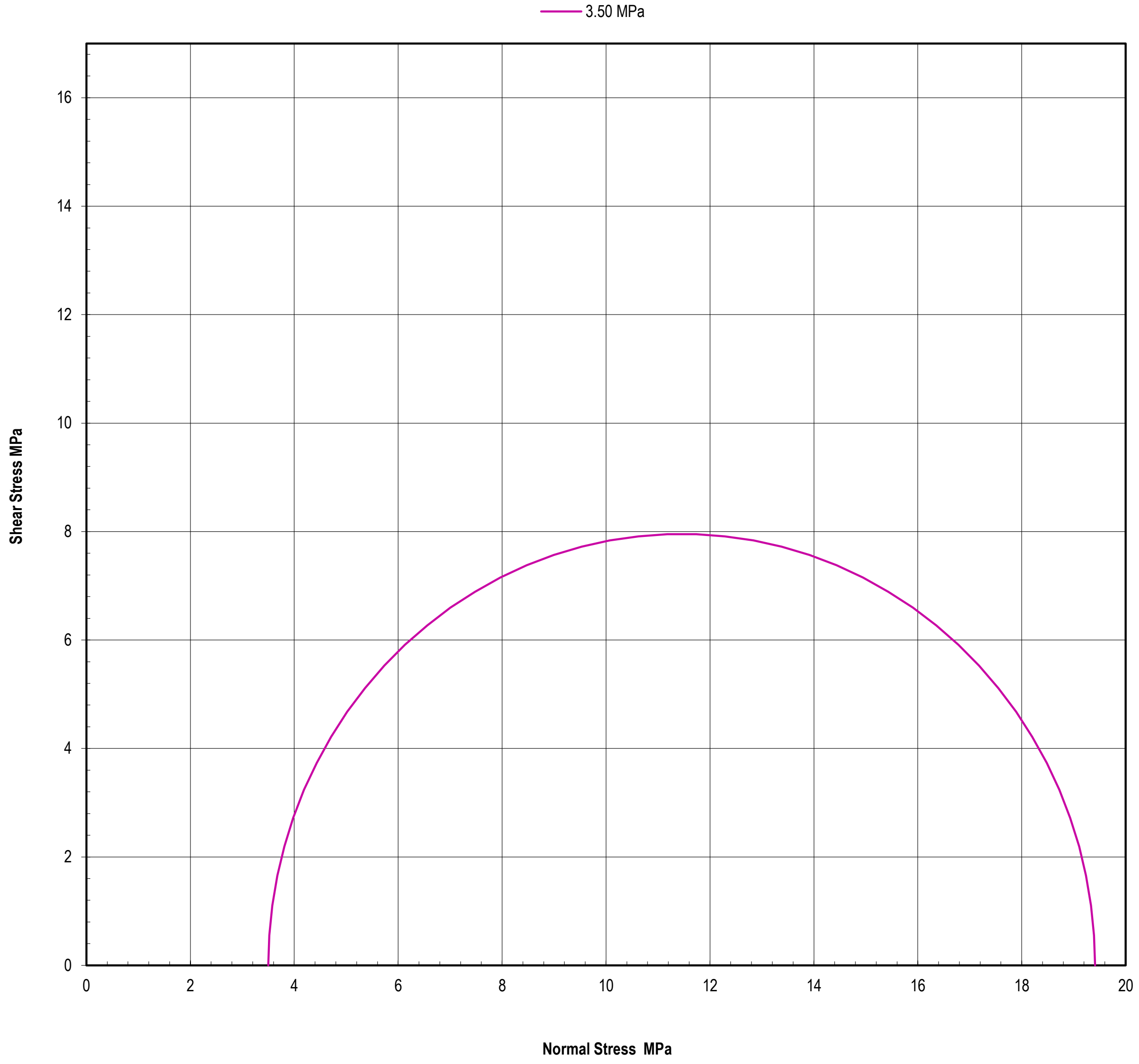
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110051-RTX

Residual Stress Mohr Circle Plot



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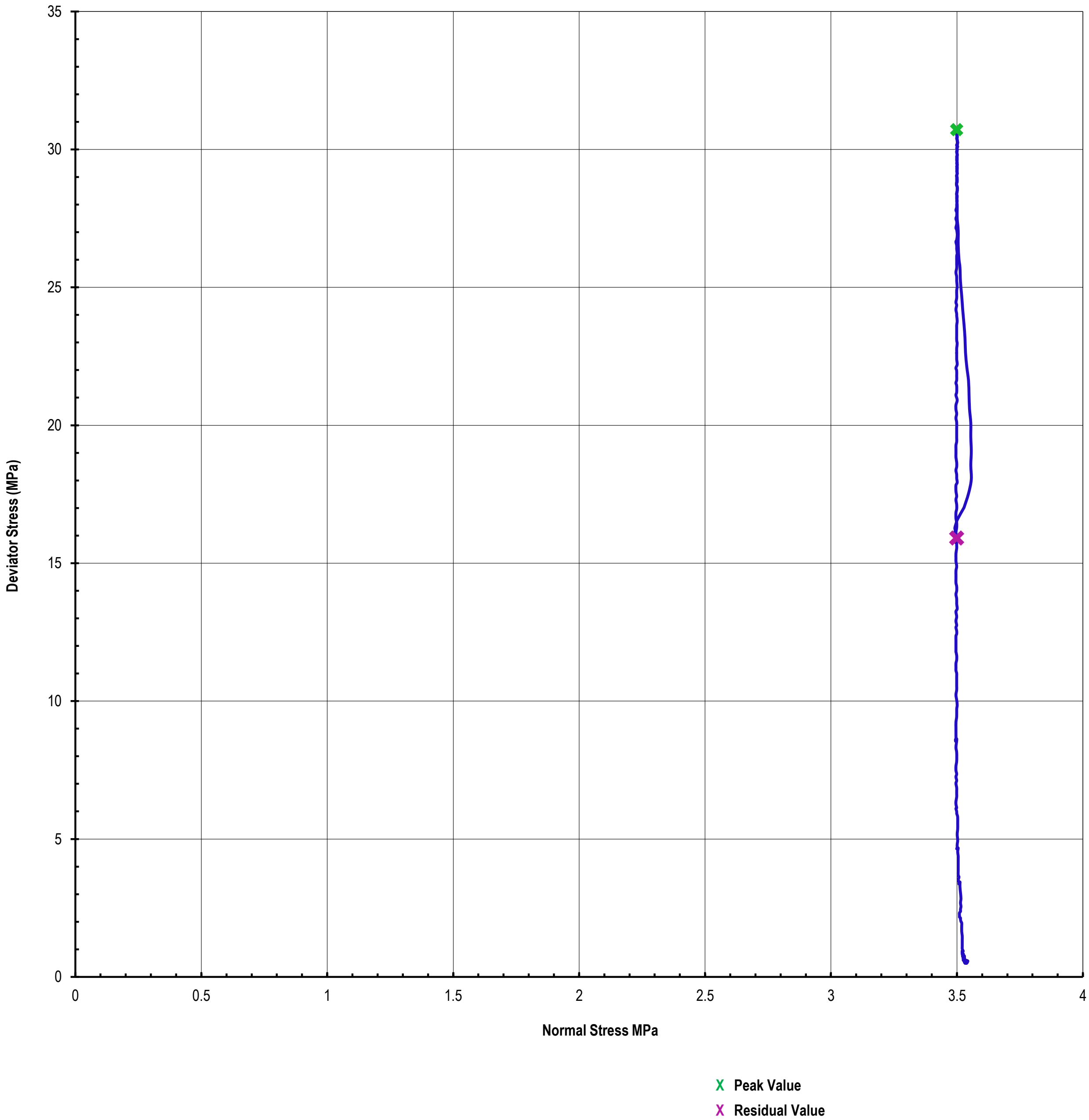
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110051-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.**	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 (με)	4214				
Diametral Strain (με)	-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 (με)	4080				
Diametral Strain (με)	-8155				

Notes/Remarks:

Sample/s supplied by client Tested as received

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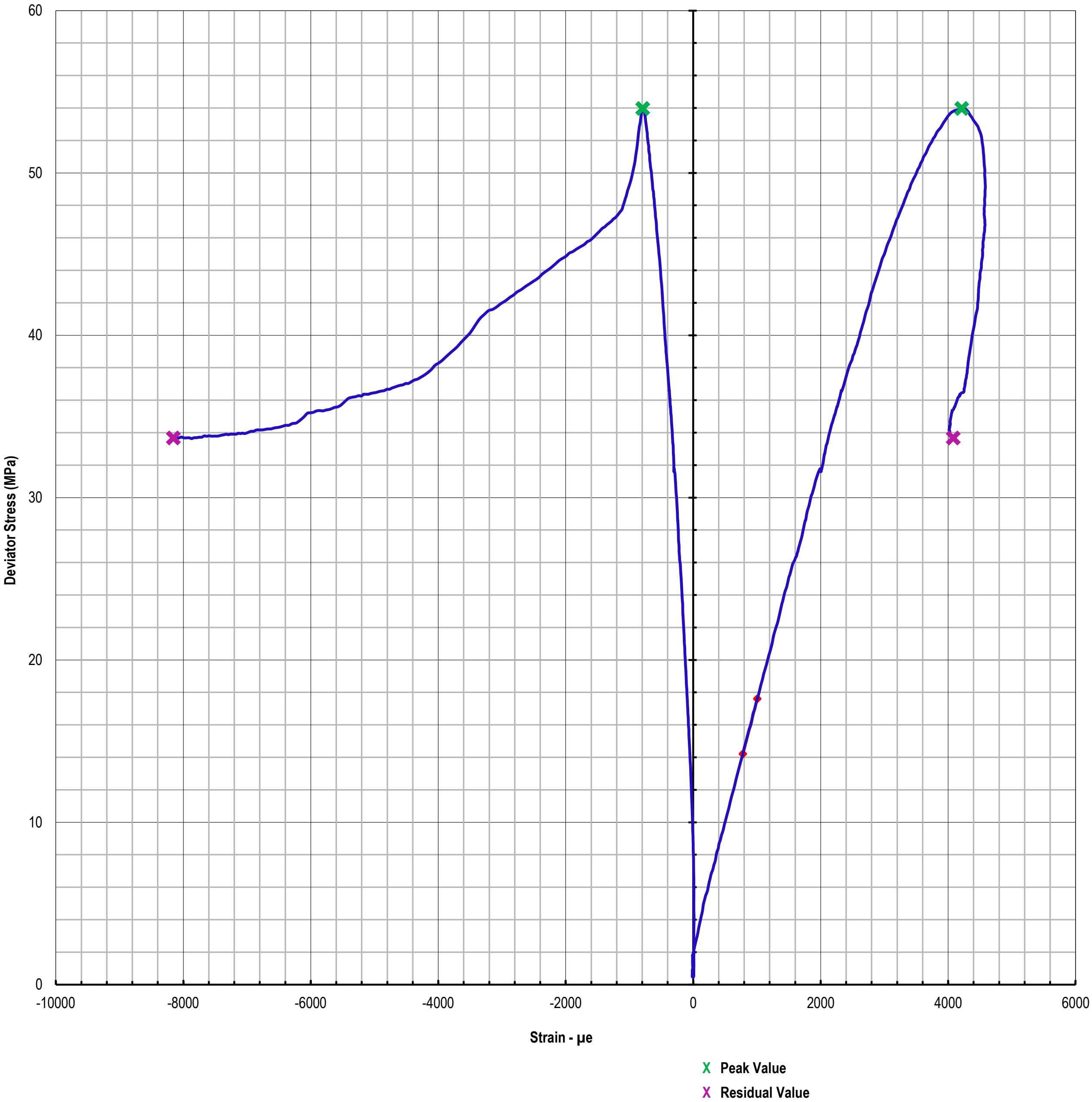
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Deviator Stress vs Axial Strain Plots



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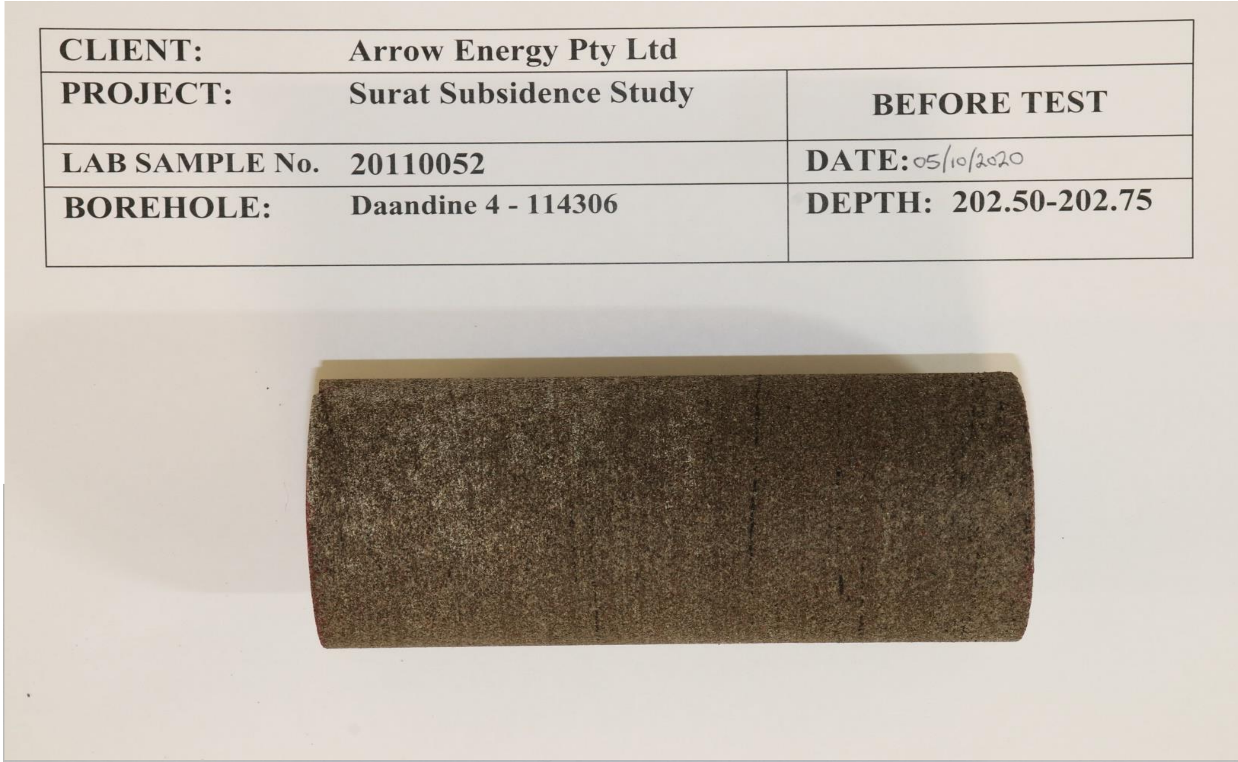
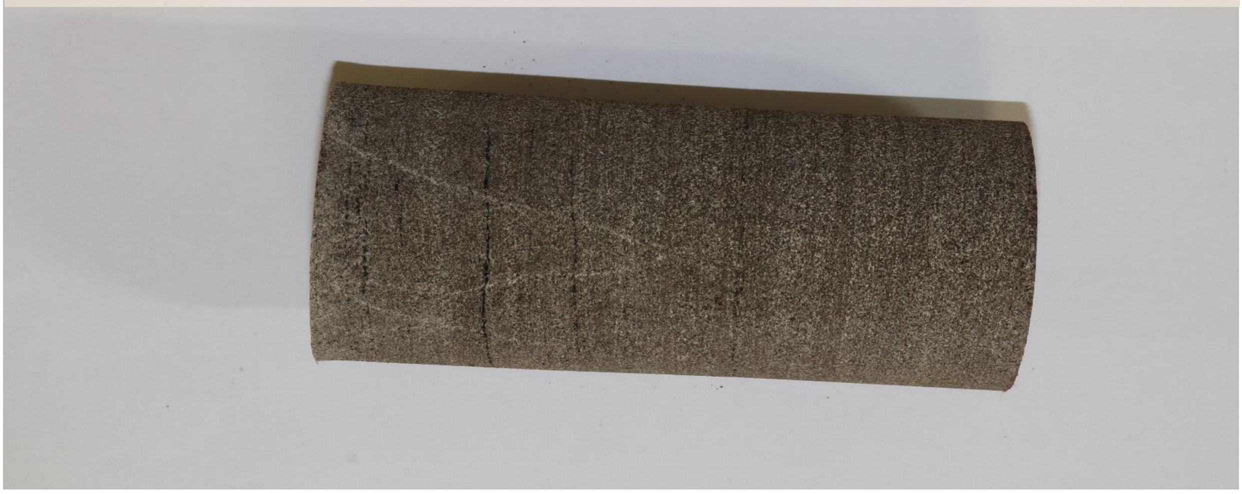
Client	Arrow Energy Pty Ltd	**Report No.**	20110052-RTX

Before and After Test Photos





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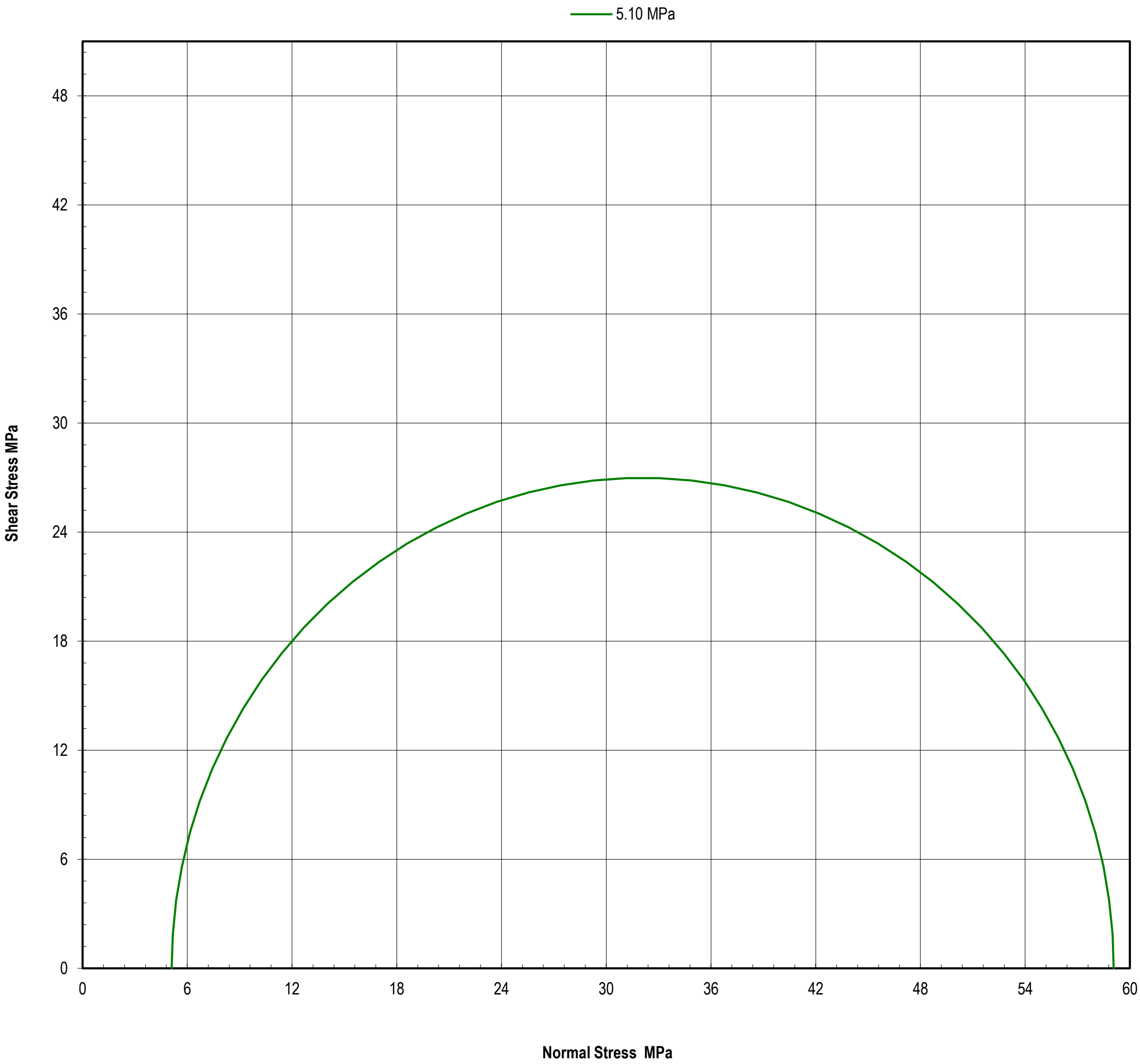
Client	Arrow Energy Pty Ltd	**Report No.**	20110052-RTX

Peak Stress Mohr Circle Plot



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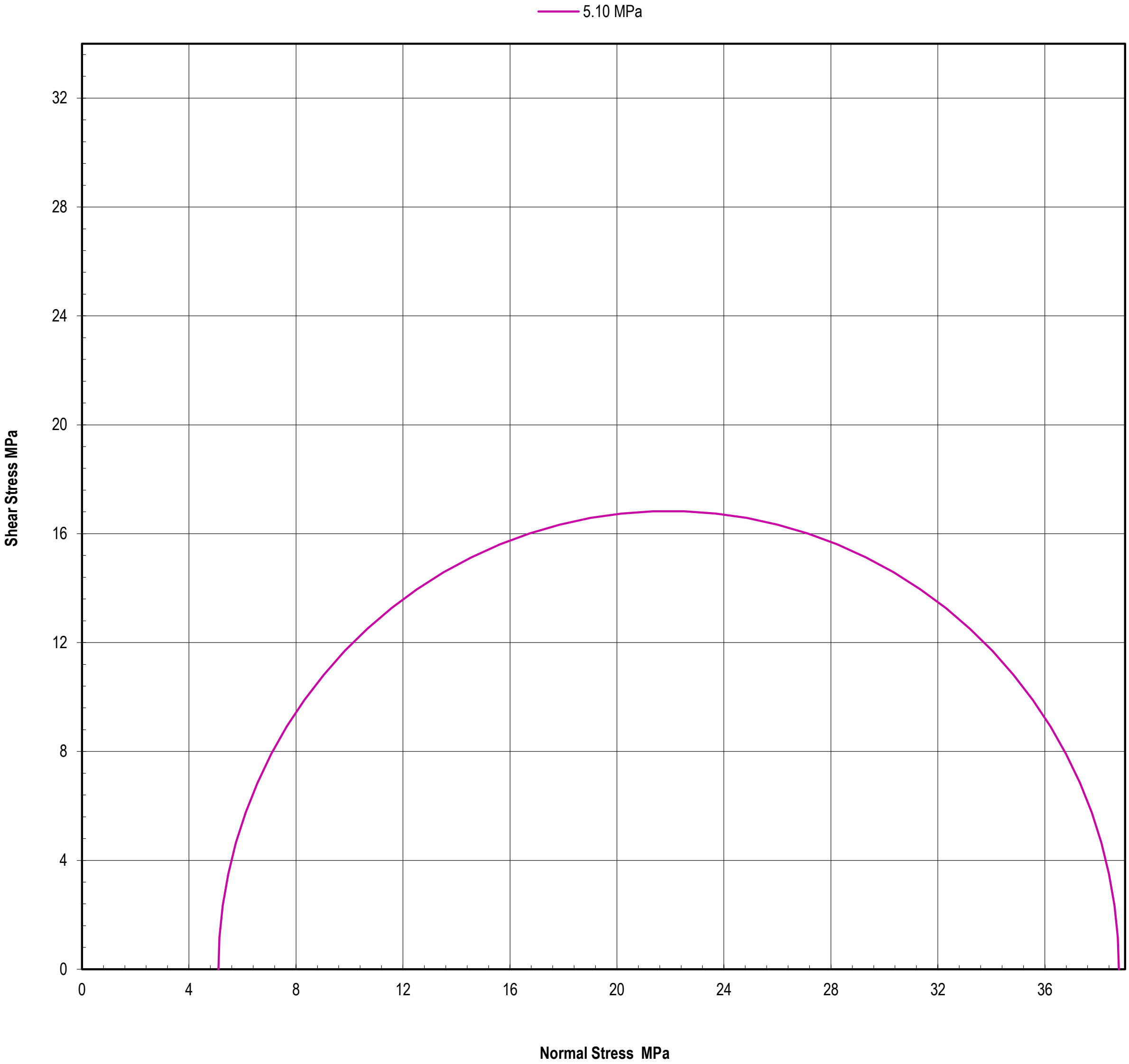
Client	Arrow Energy Pty Ltd	**Report No.**	20110052-RTX

Residual Stress Mohr Circle Plot



Notes/Remarks:

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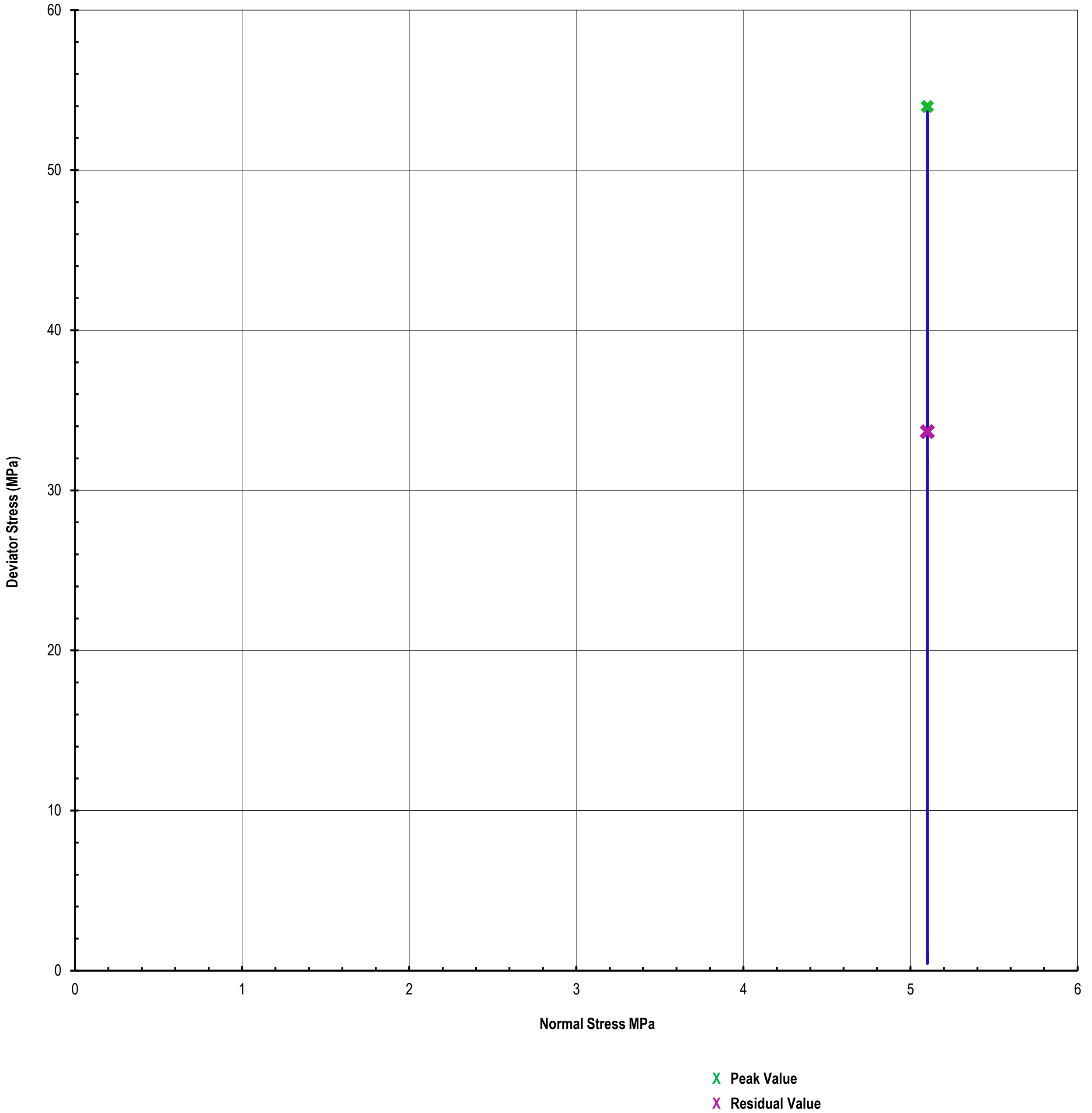
Client	Arrow Energy Pty Ltd	**Report No.**	20110052-RTX

Deviator Stress vs Normal Stress Plot



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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 (με)	12296				
Diametral Strain (με)	-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 (με)	18273				
Diametral Strain (με)	-8623				

Notes/Remarks:

Sample/s supplied by client   Tested as received

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

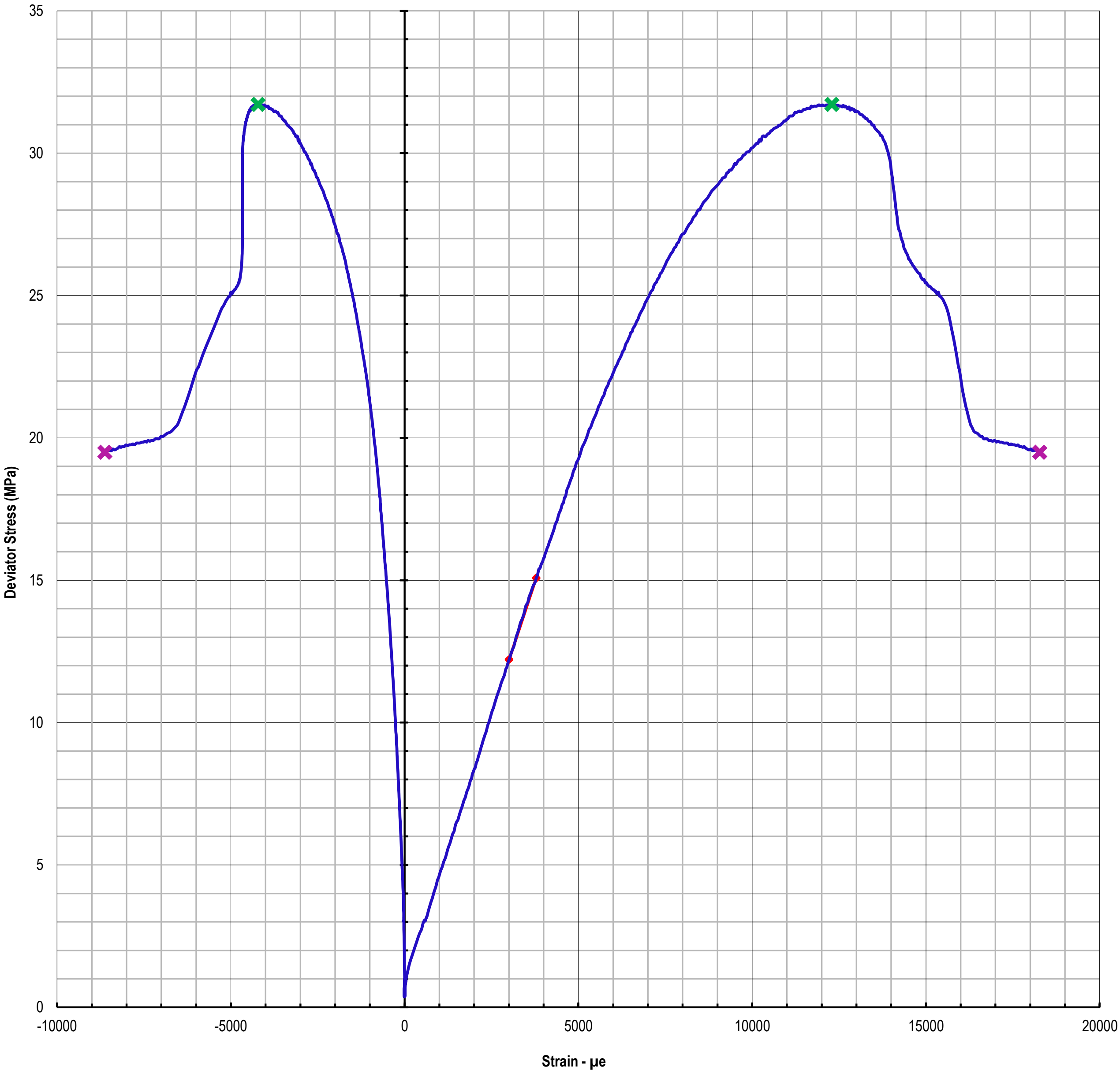
ASTM D7012

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.**	20110053-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

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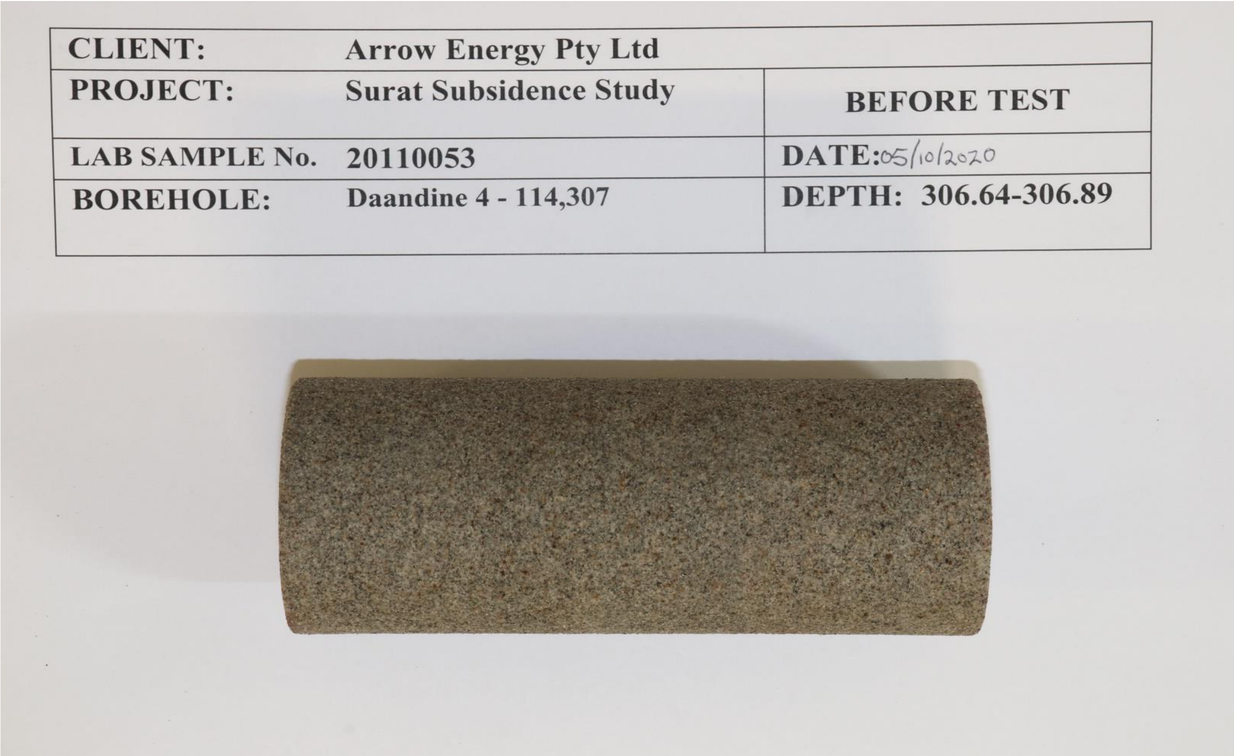
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos



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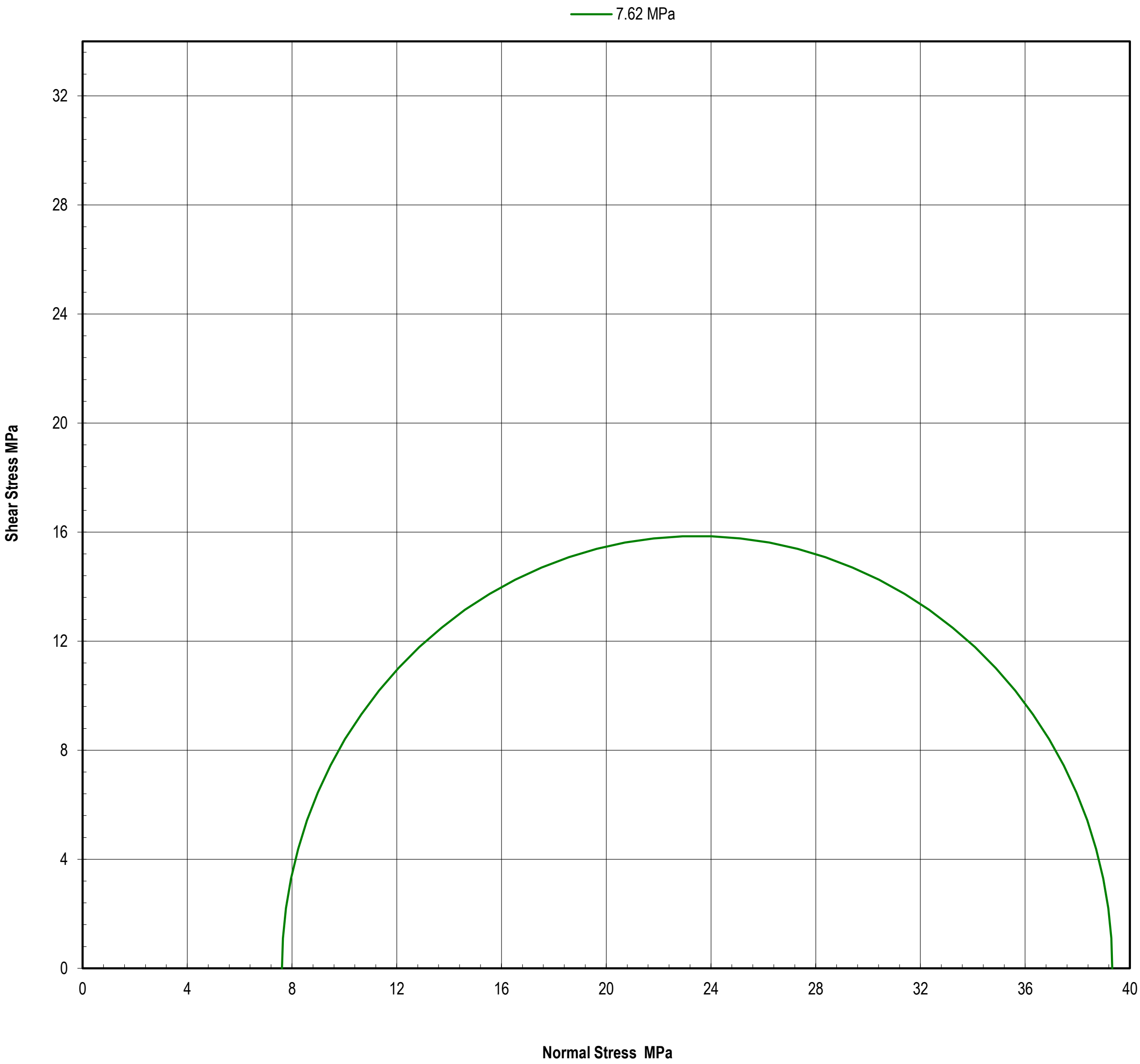
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Peak Stress Mohr Circle Plot



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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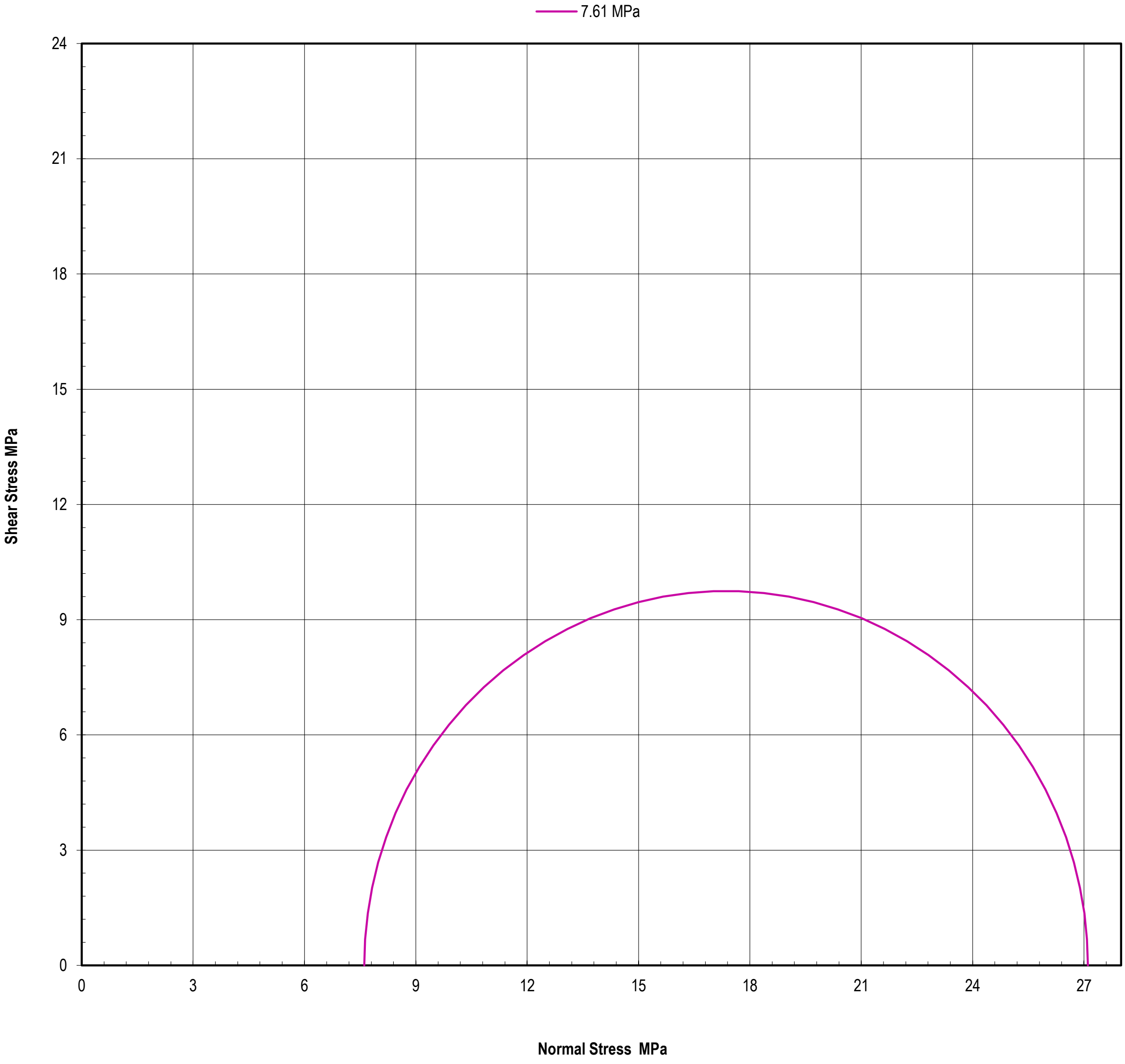
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Residual Stress Mohr Circle Plot



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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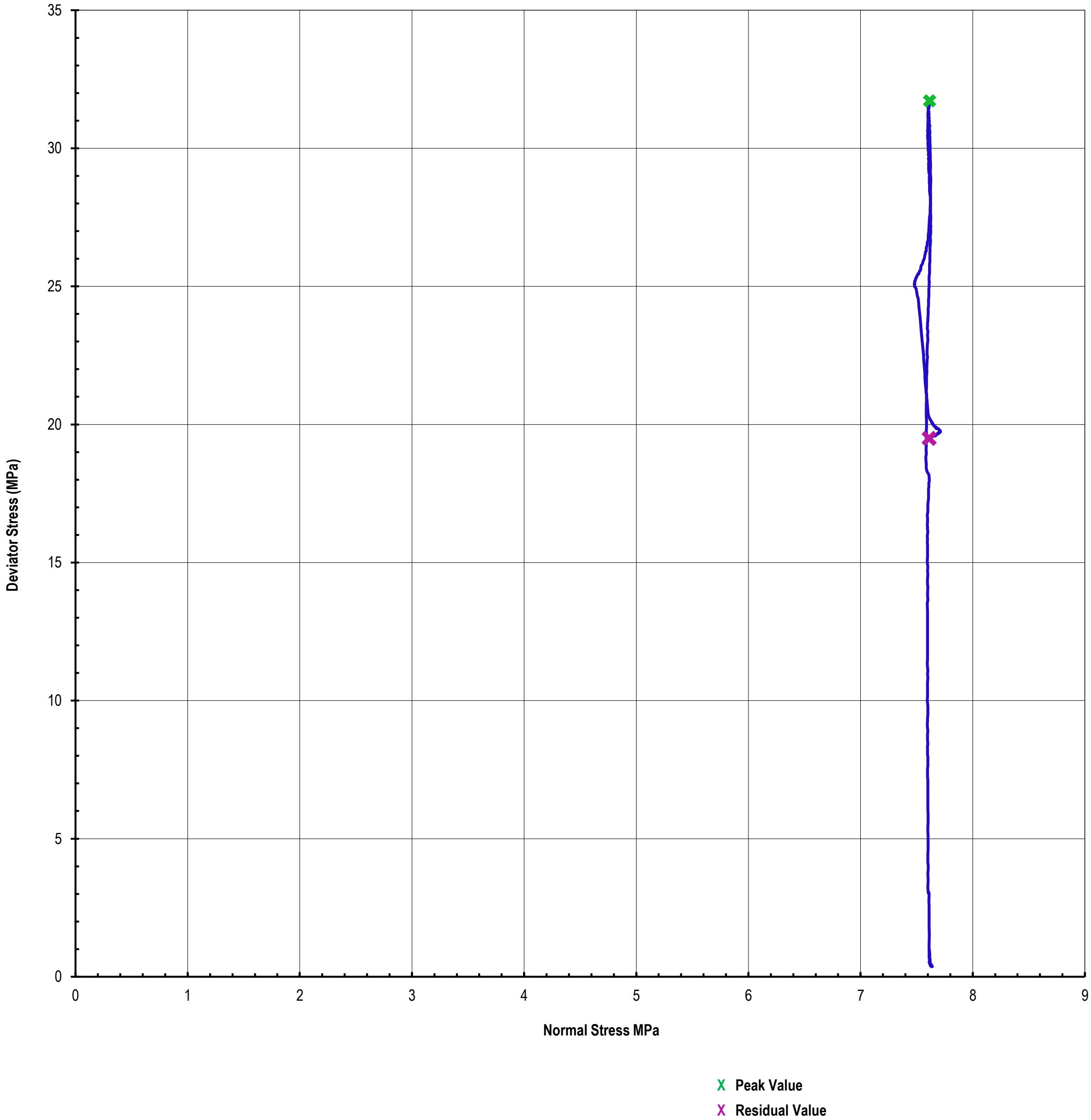
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

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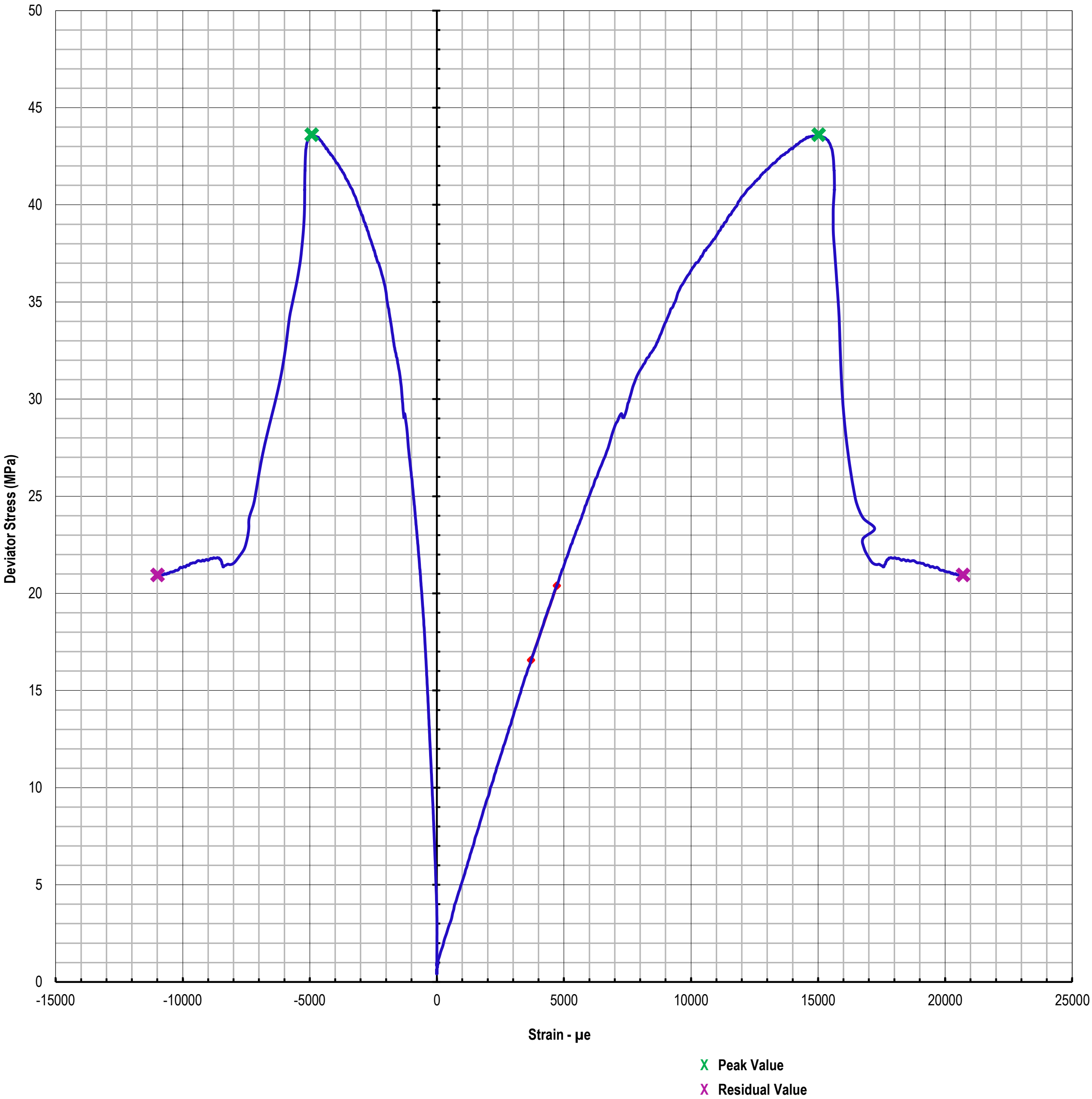
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

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

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

Deviator Stress vs Axial Strain Plots



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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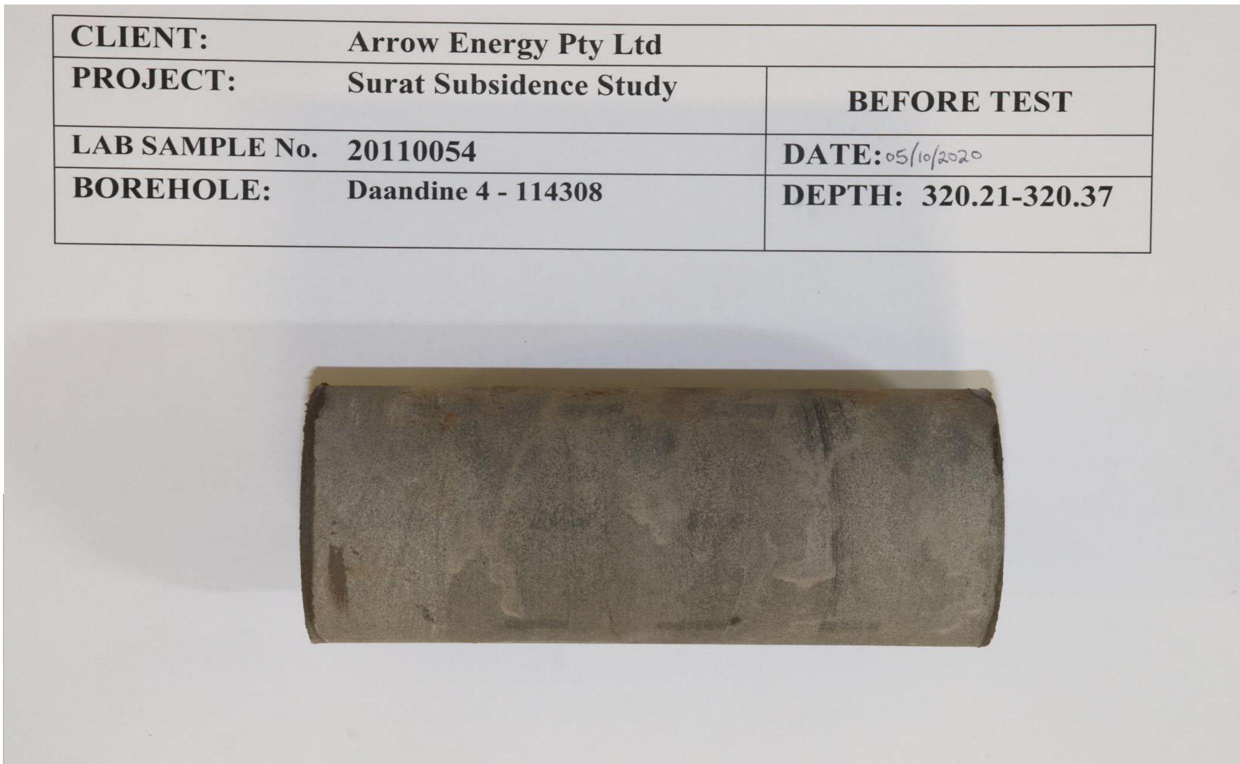
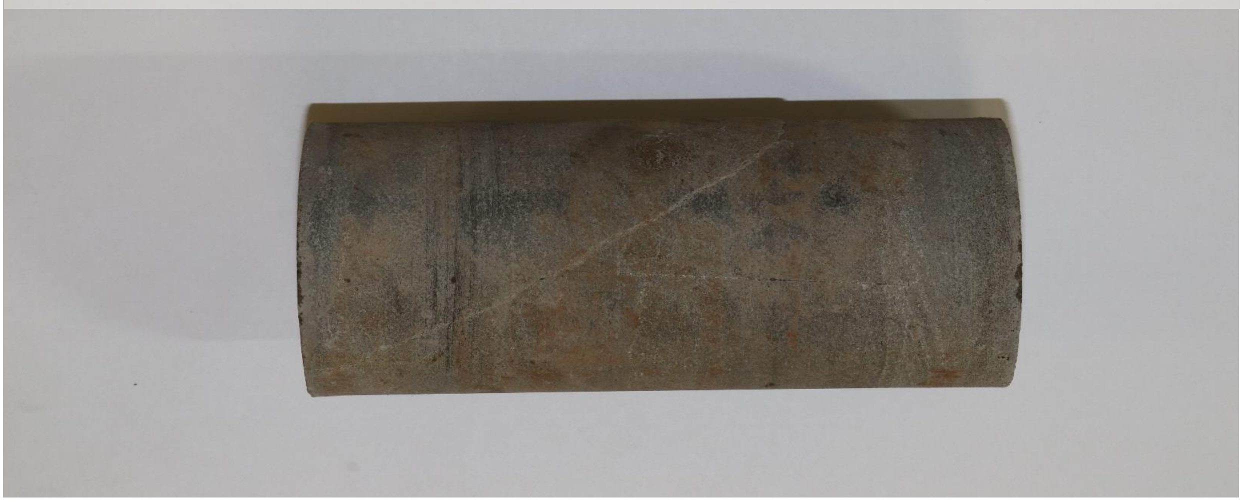
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos





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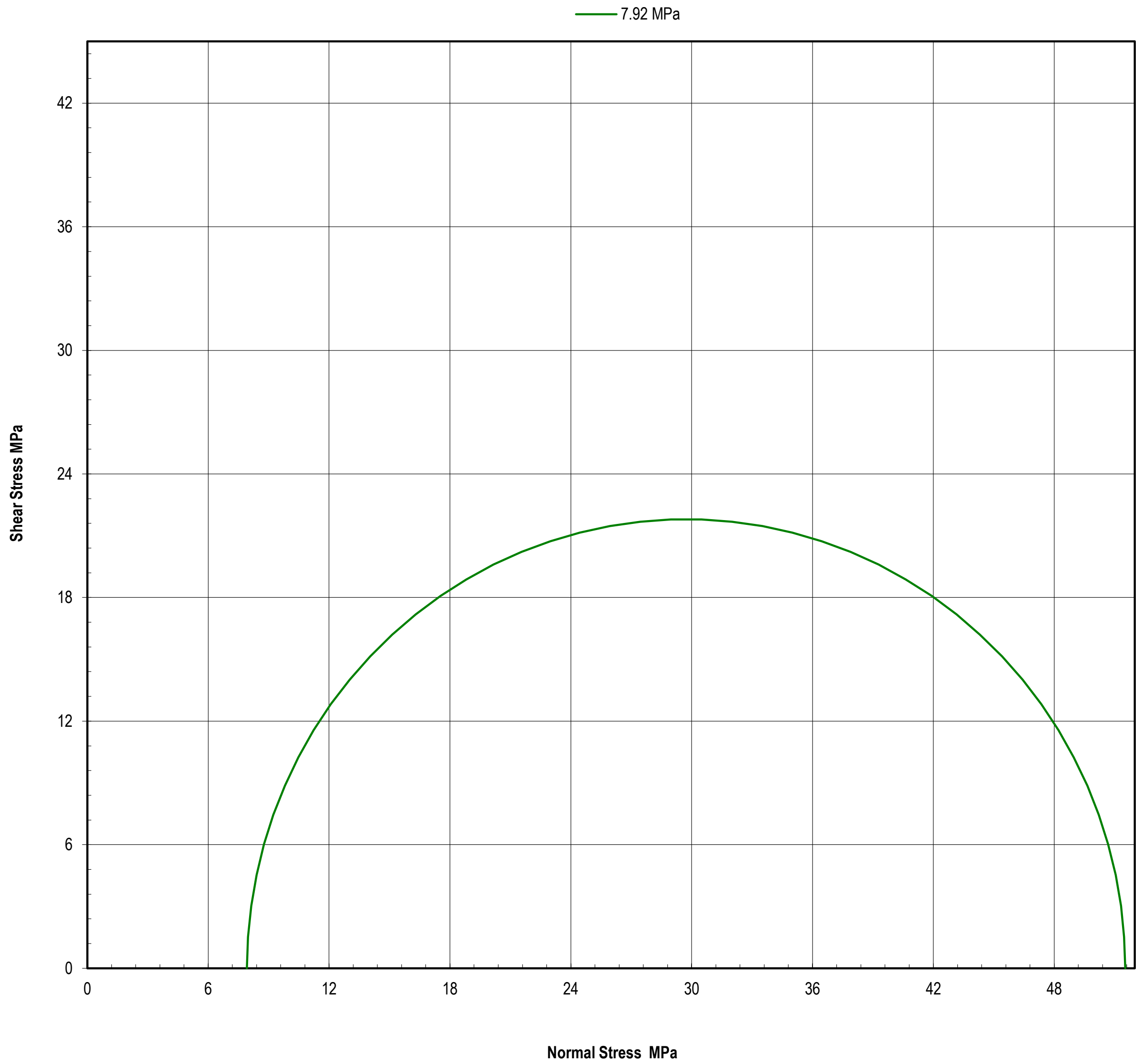
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Peak Stress Mohr Circle Plot



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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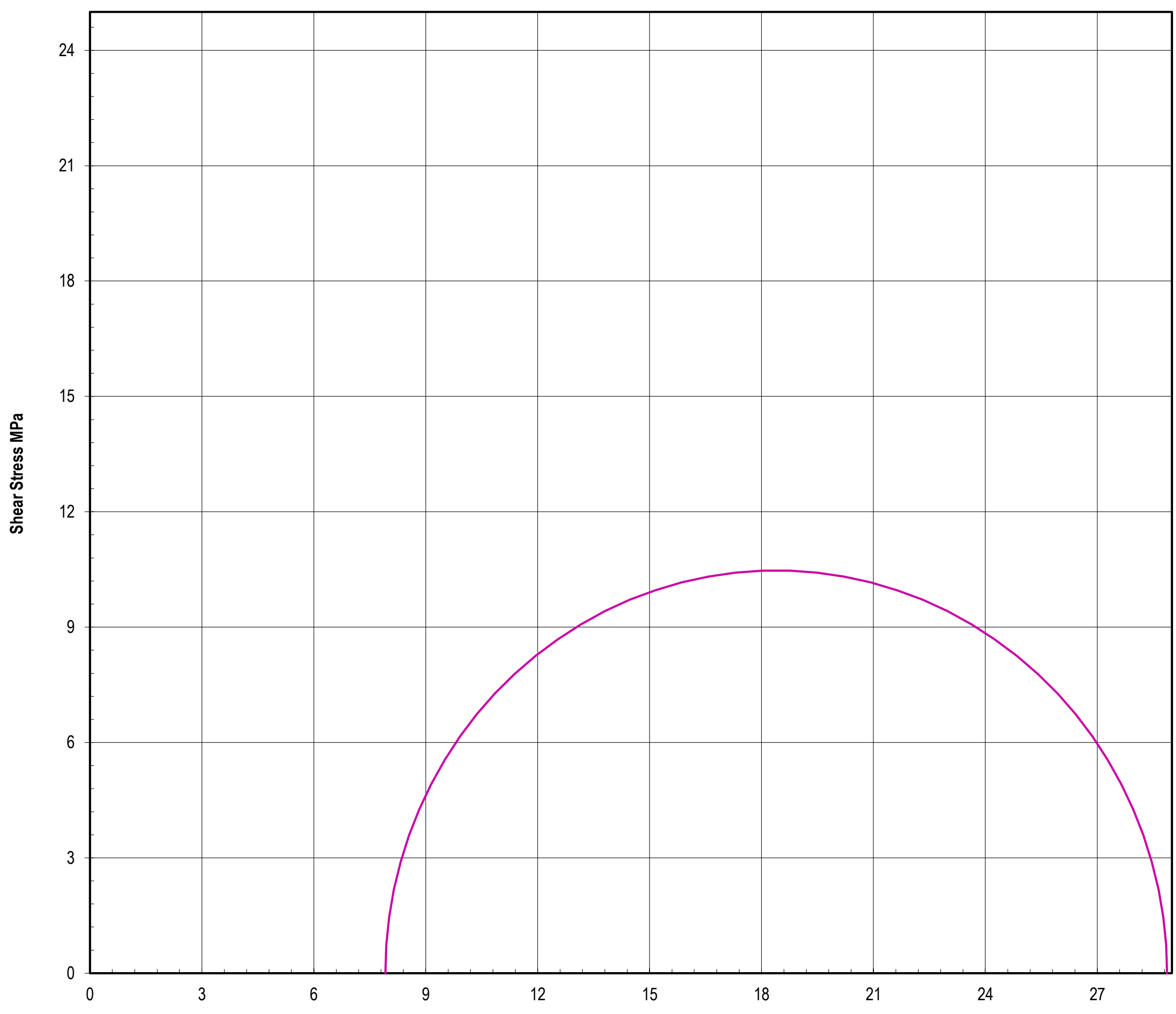
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

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

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

Residual Stress Mohr Circle Plot



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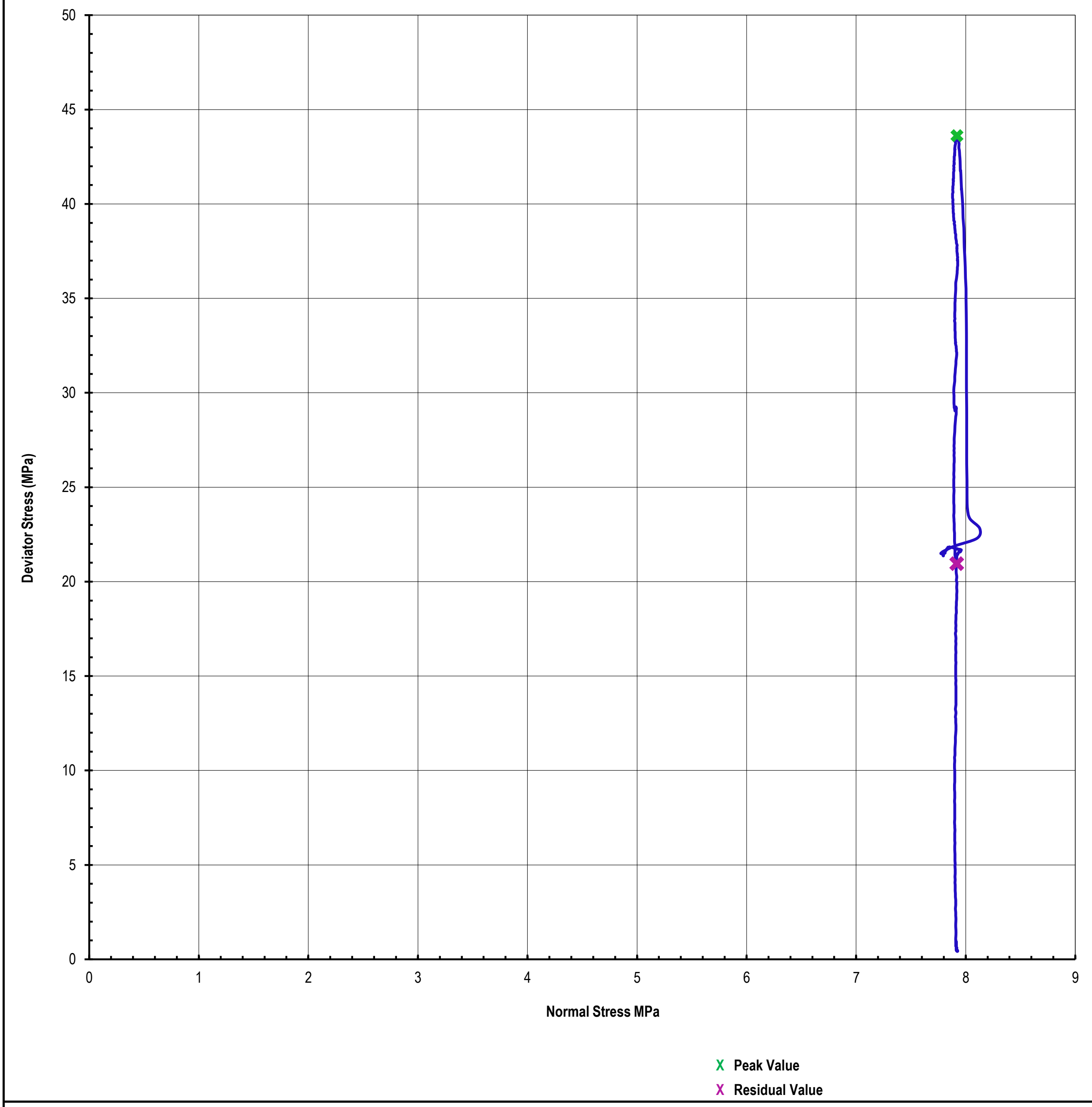
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Deviator Stress vs Normal Stress Plot



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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.**	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 (με)	28960				
Diametral Strain (με)	-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 (με)	36612				
Diametral Strain (με)	-17524				

Notes/Remarks:

Sample/s supplied by client Tested as received

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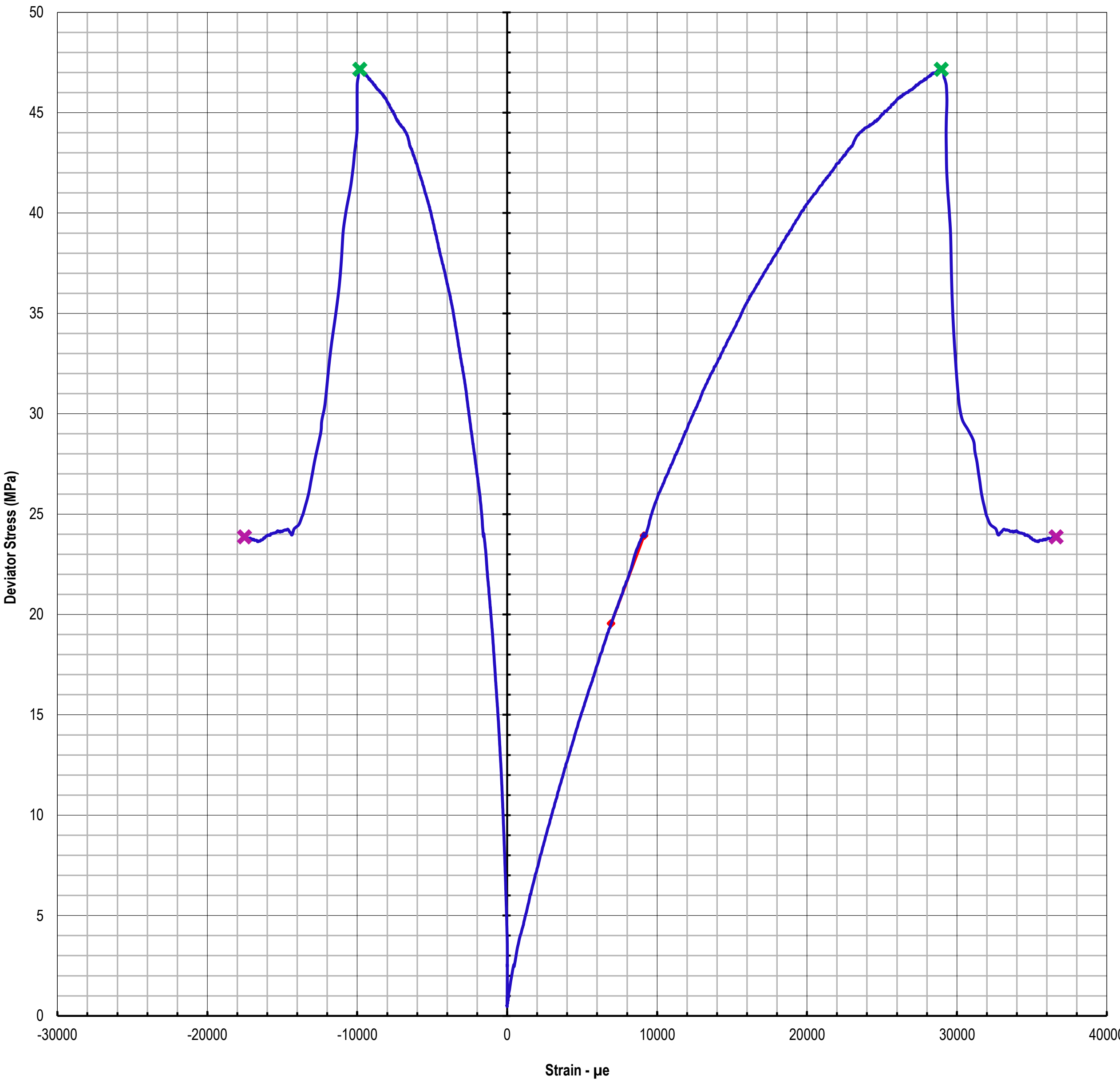
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Deviator Stress vs Axial Strain Plots



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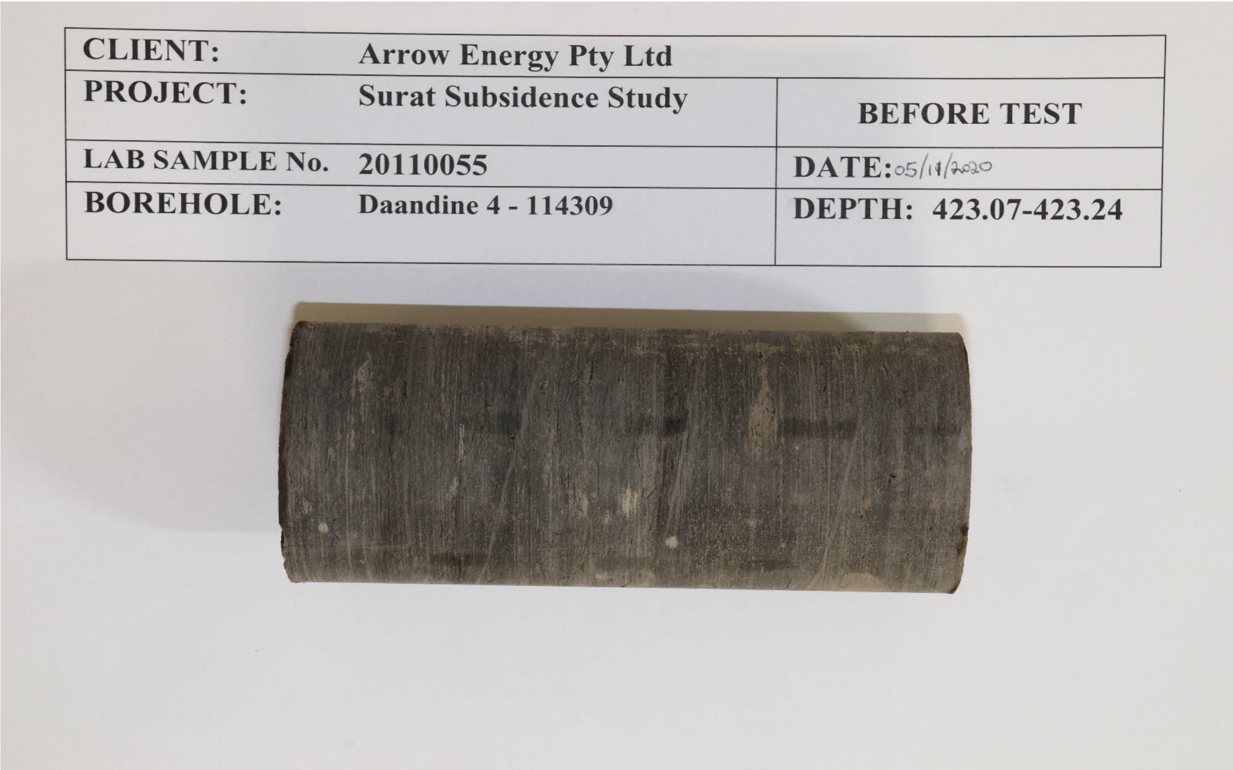
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos



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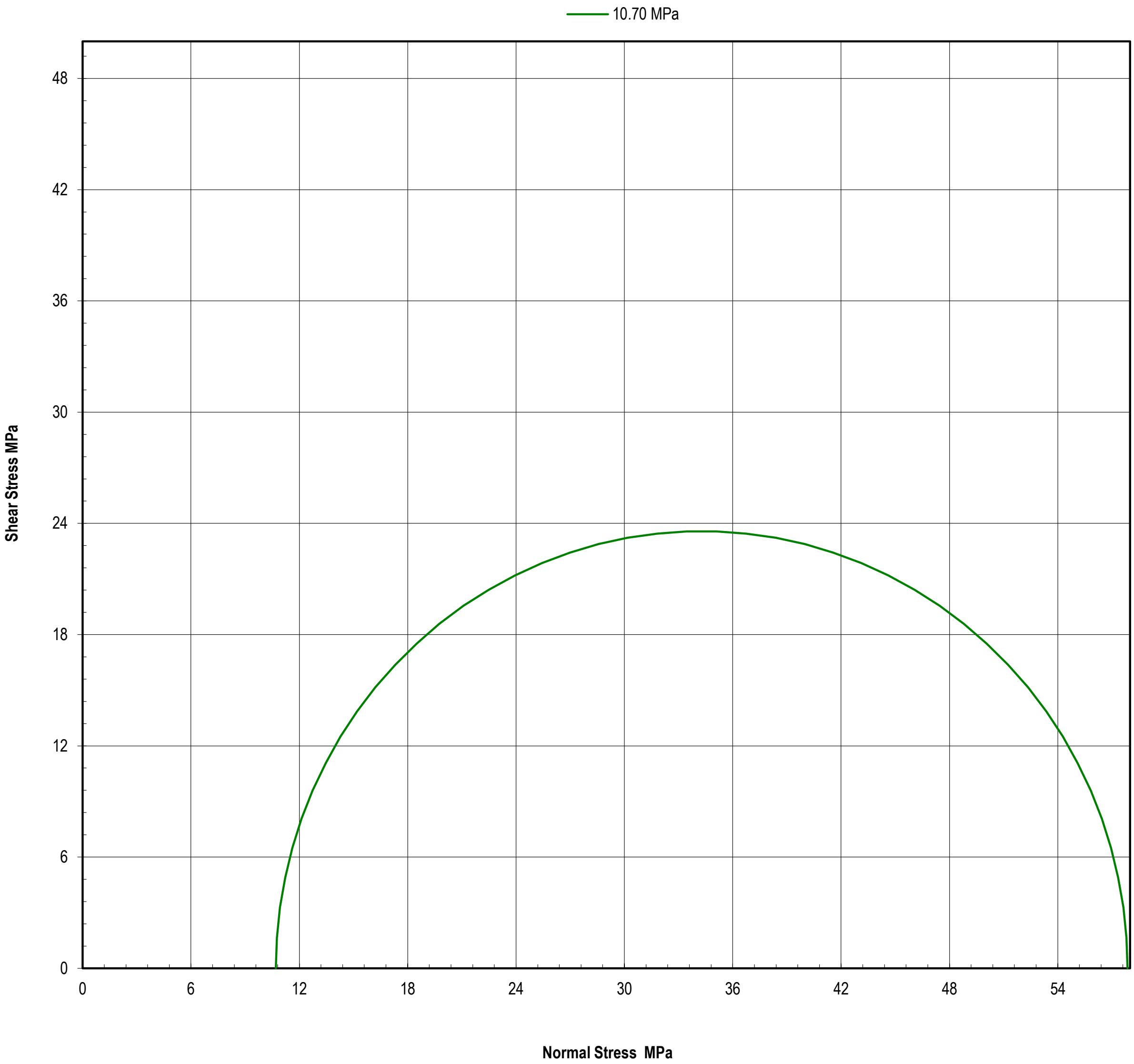
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Peak Stress Mohr Circle Plot



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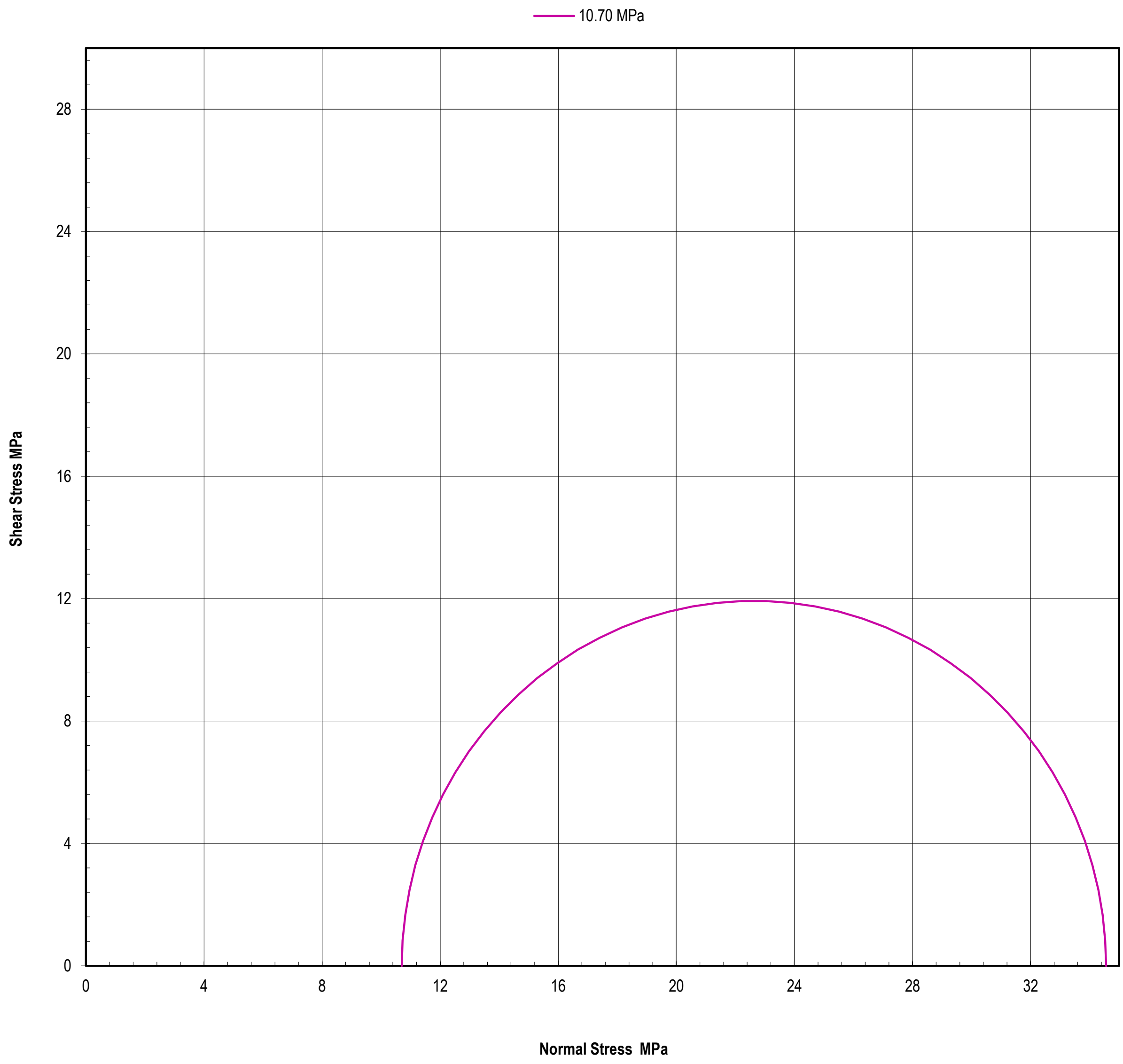
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110055-RTX

Residual Stress Mohr Circle Plot



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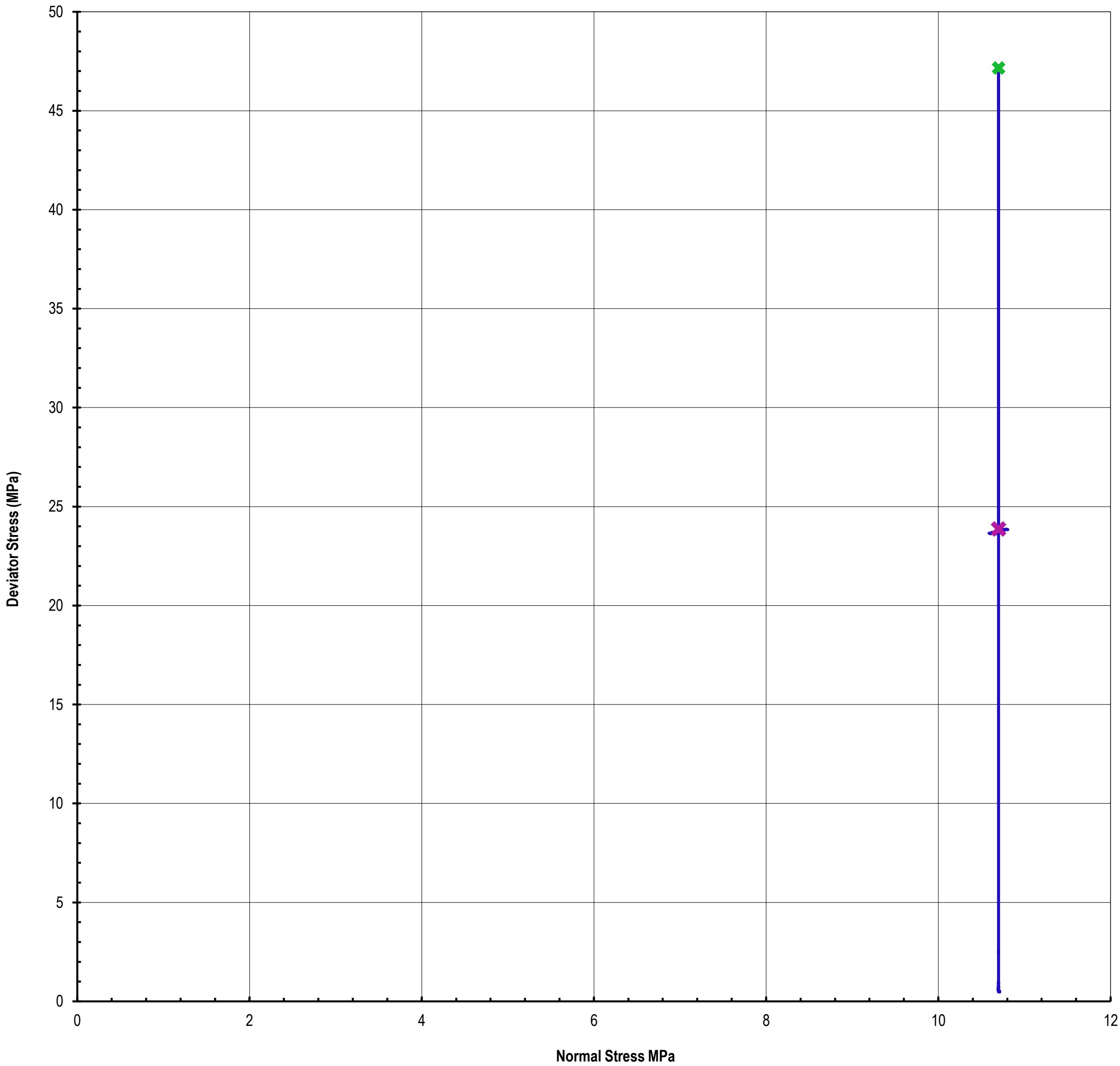
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110055-RTX

Deviator Stress vs Normal Stress Plot



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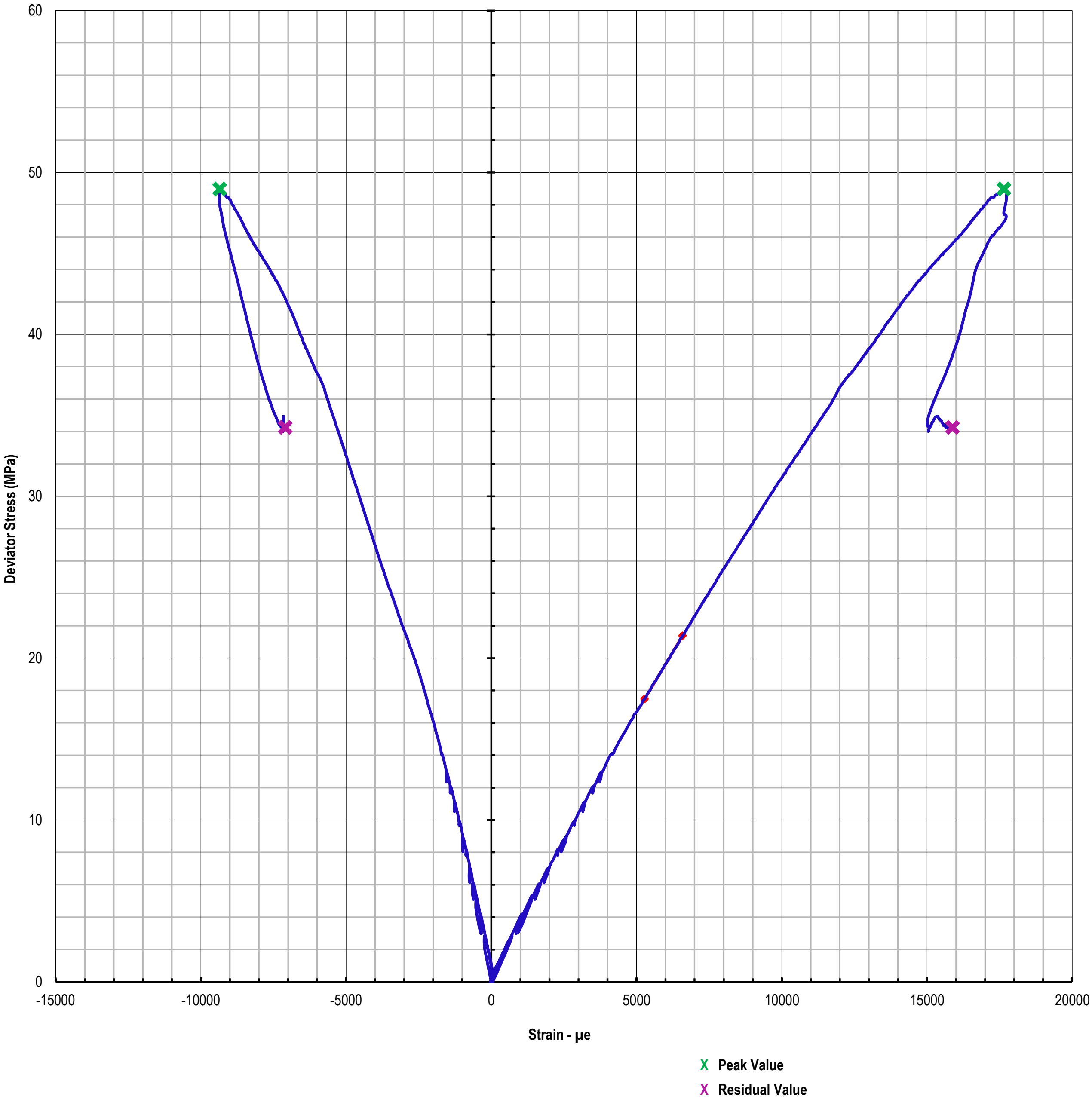
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Deviator Stress vs Axial Strain Plots



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

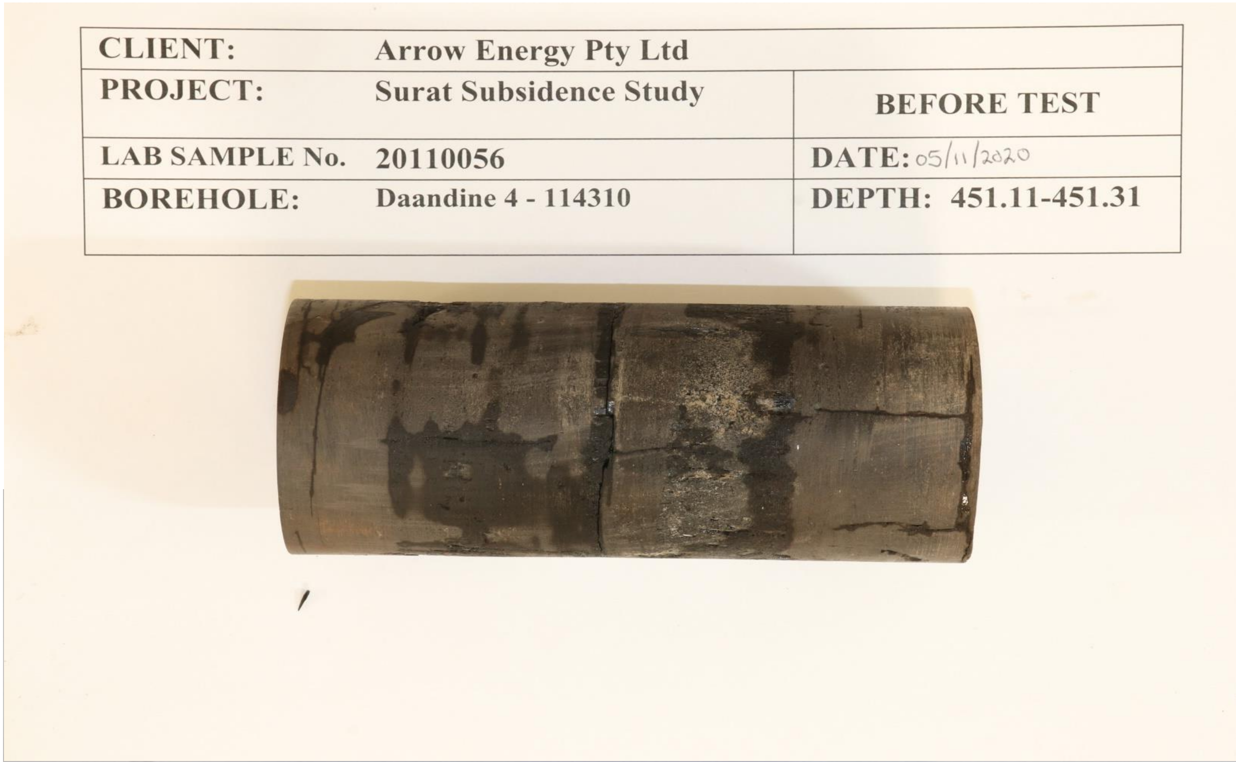
ASTM D7012

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

Before and After Test Photos



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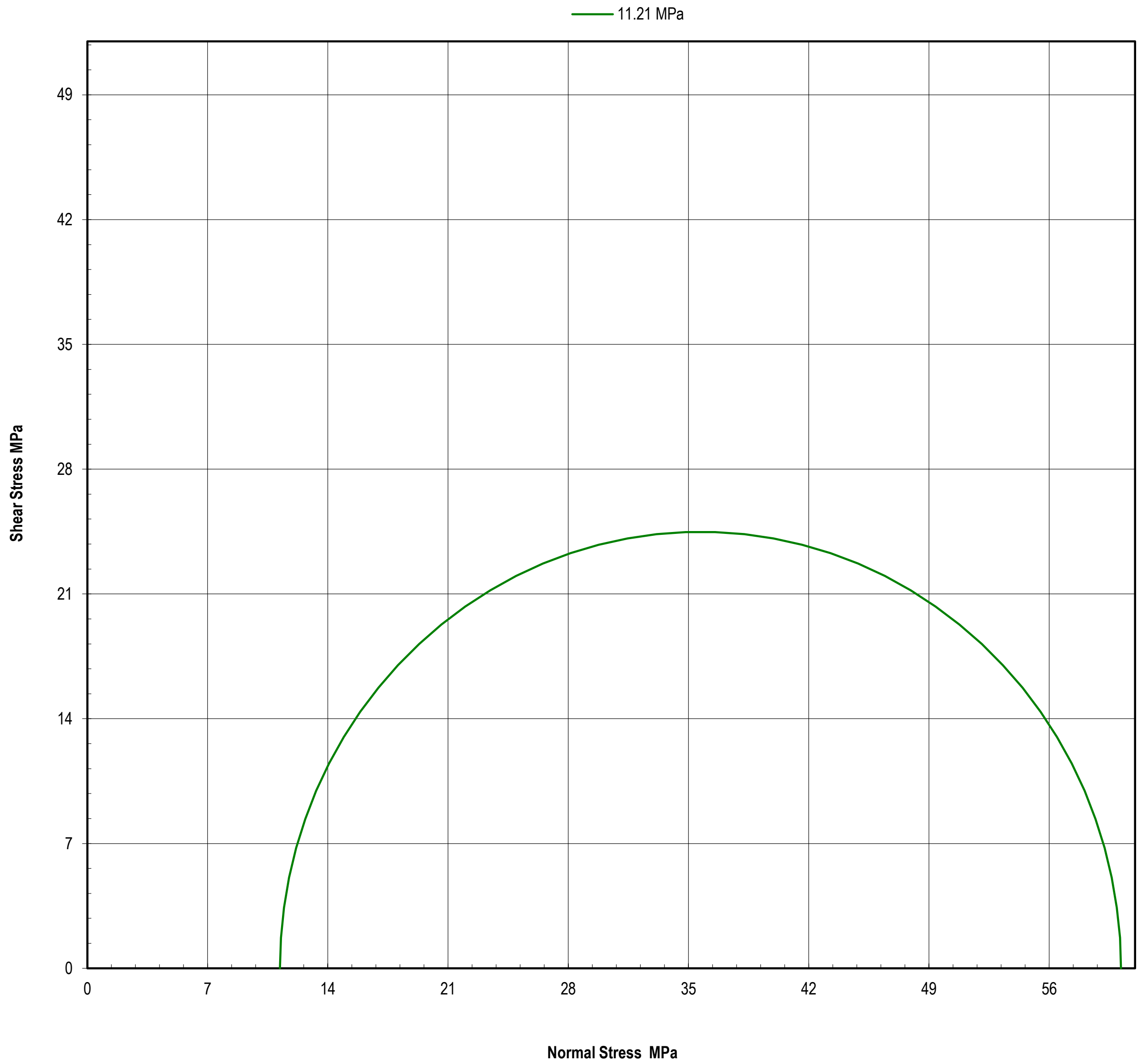
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Peak Stress Mohr Circle Plot



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Authorised Signatory

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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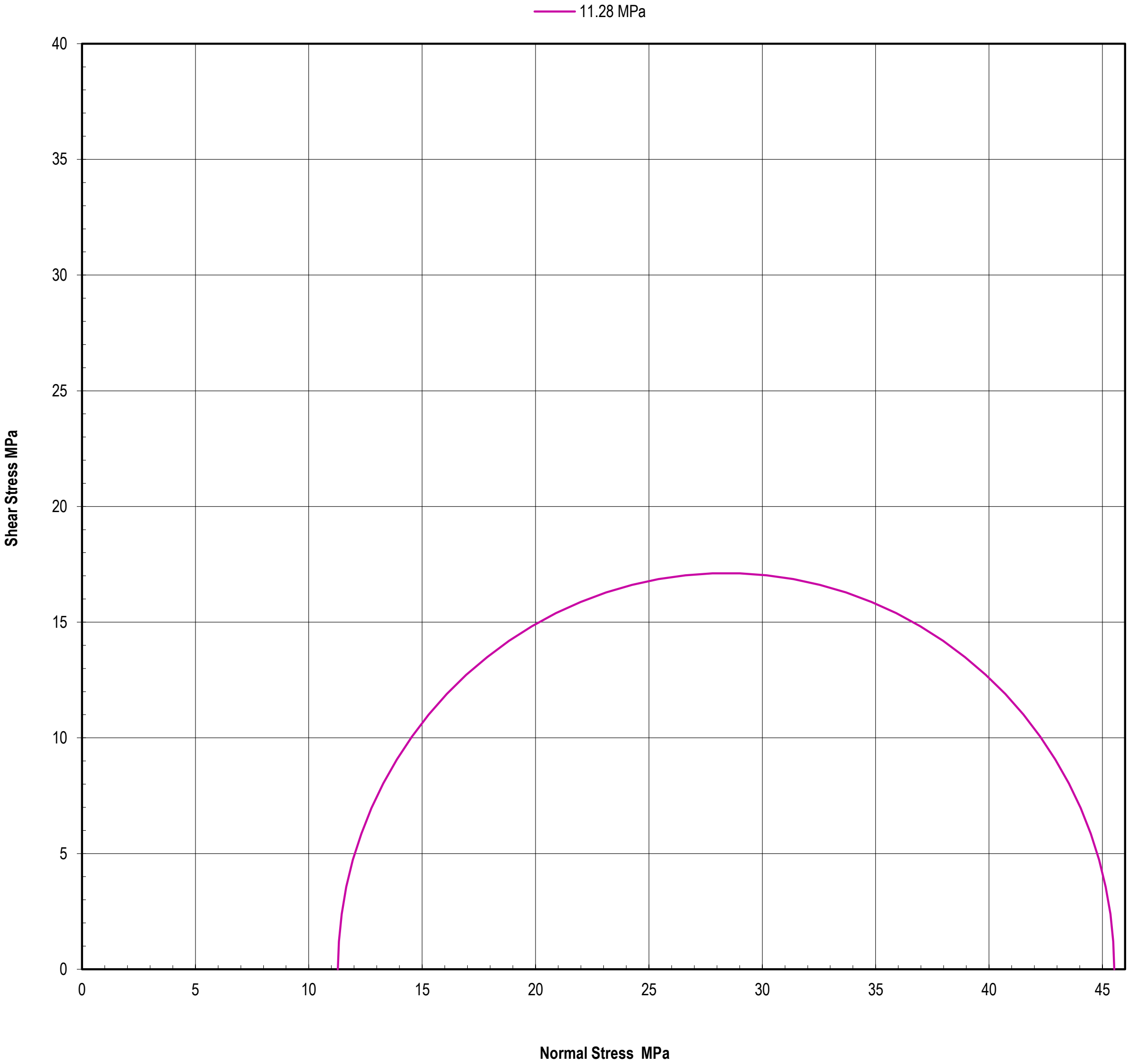
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Residual Stress Mohr Circle Plot



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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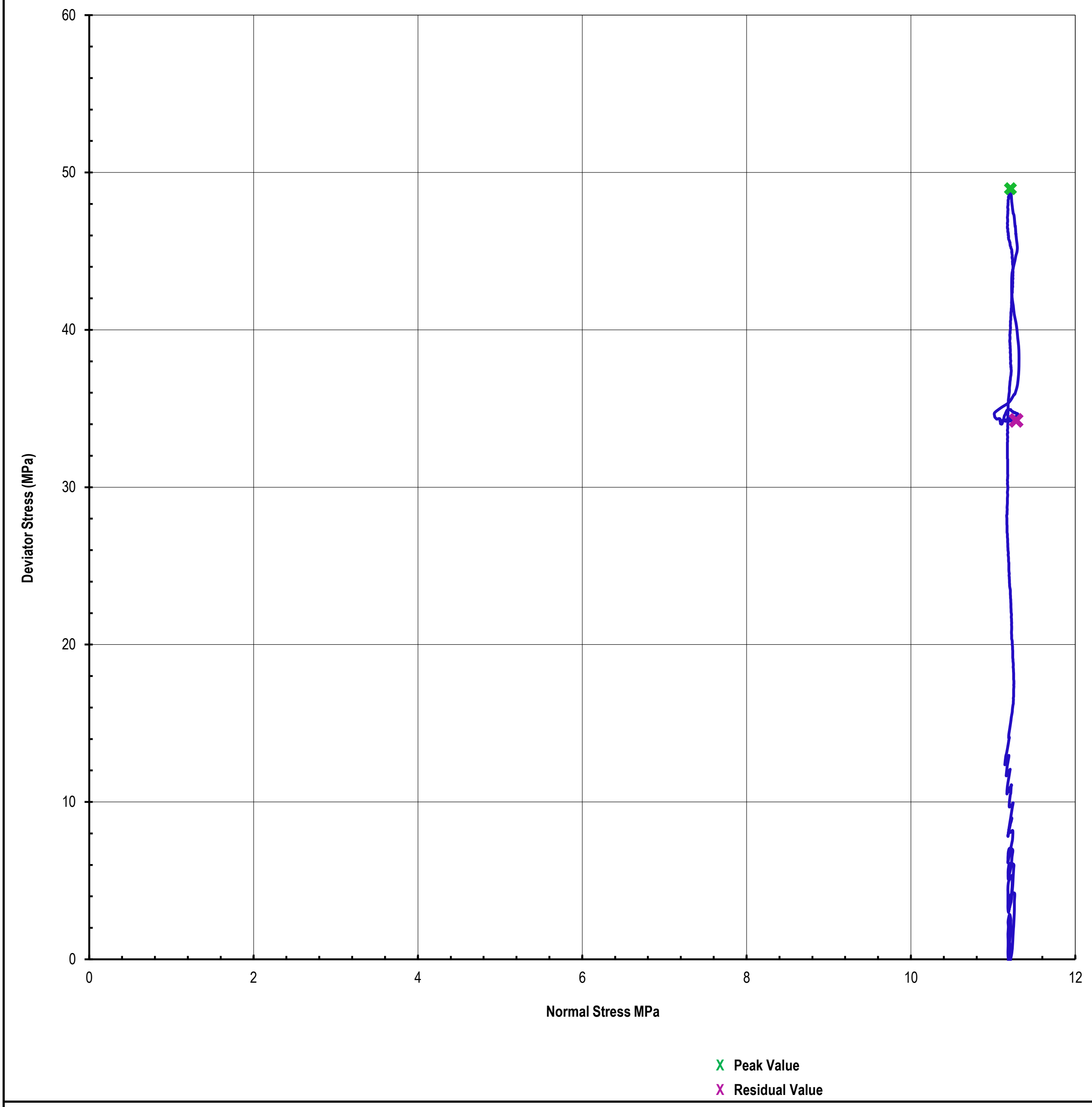
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110056-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.**	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 (με)	12008				
Diametral Strain (με)	-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 (με)	17320				
Diametral Strain (με)	-10780				

Notes/Remarks:

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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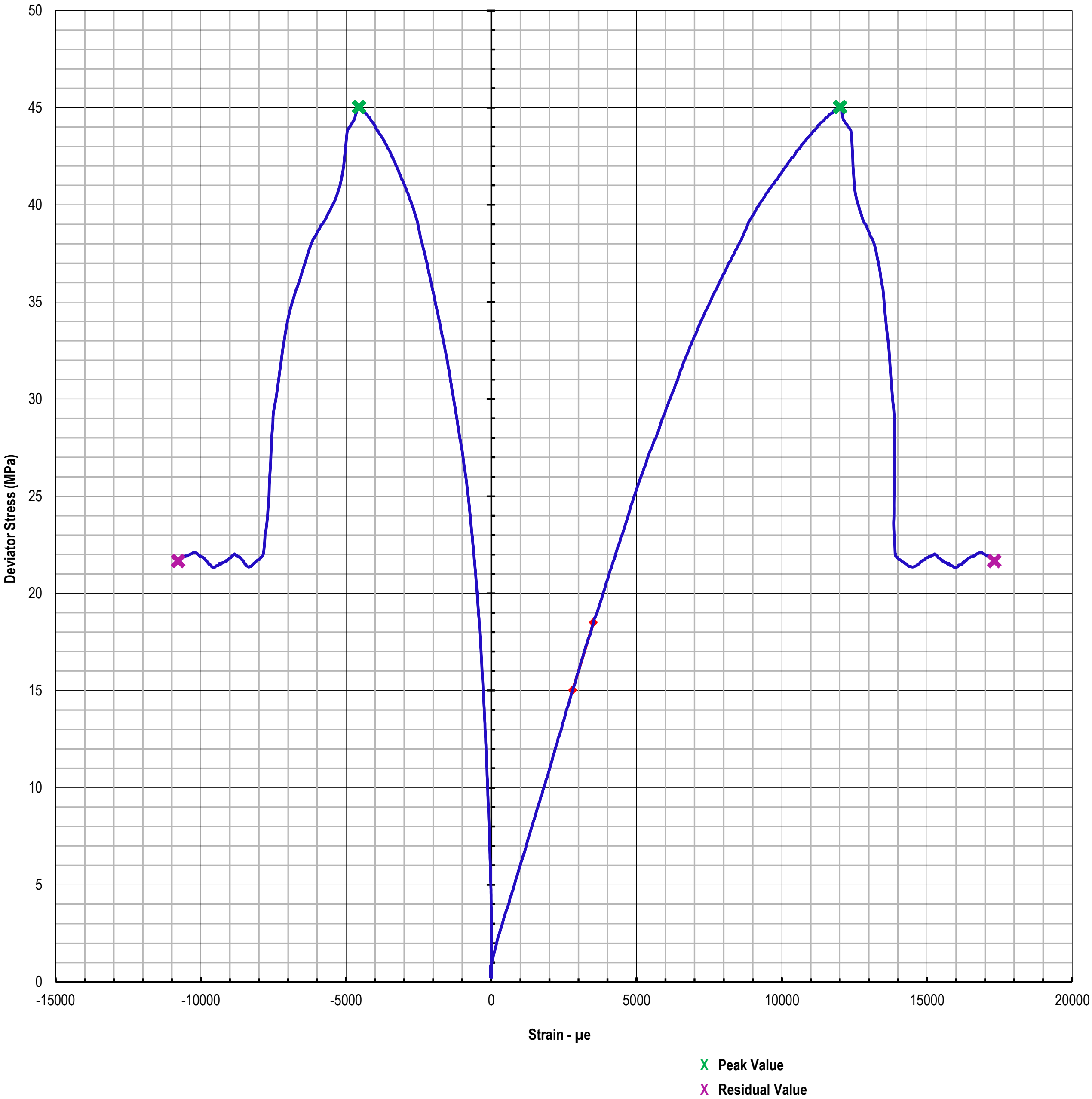
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

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

Client	Arrow Energy Pty Ltd	**Report No.**	20110057-RTX

Deviator Stress vs Axial Strain Plots



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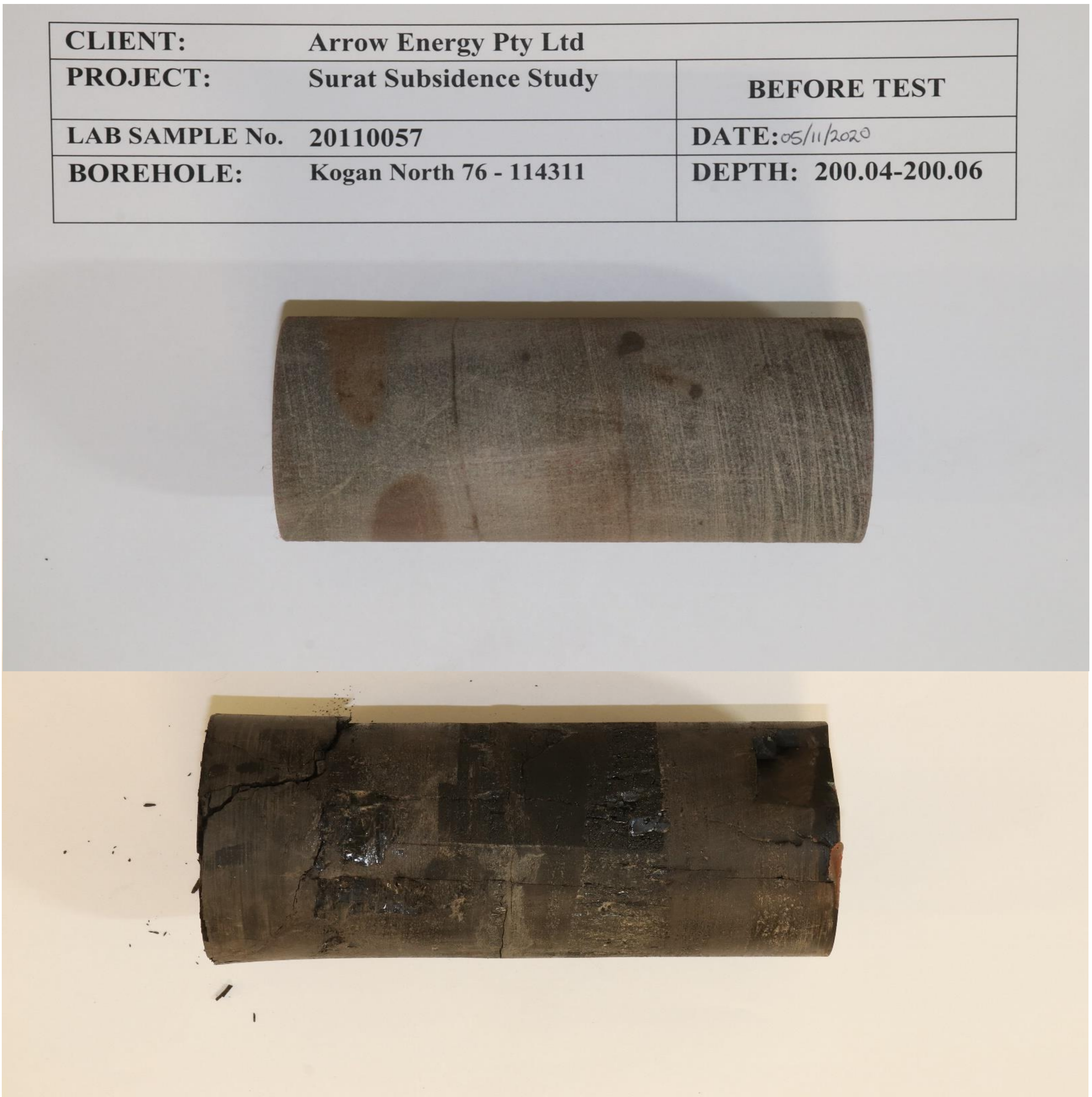
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110057-RTX

Before and After Test Photos



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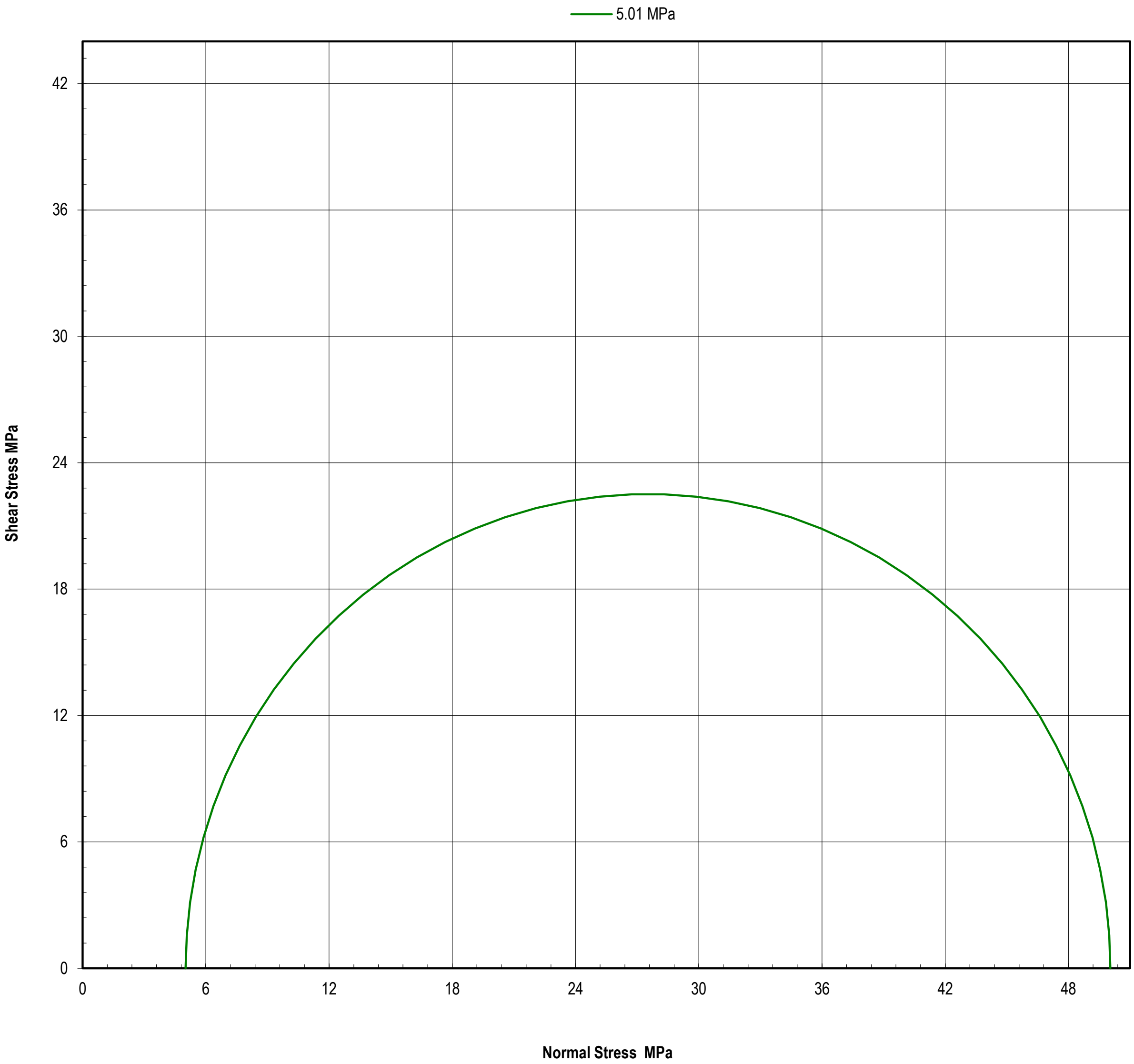
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110057-RTX

Peak Stress Mohr Circle Plot



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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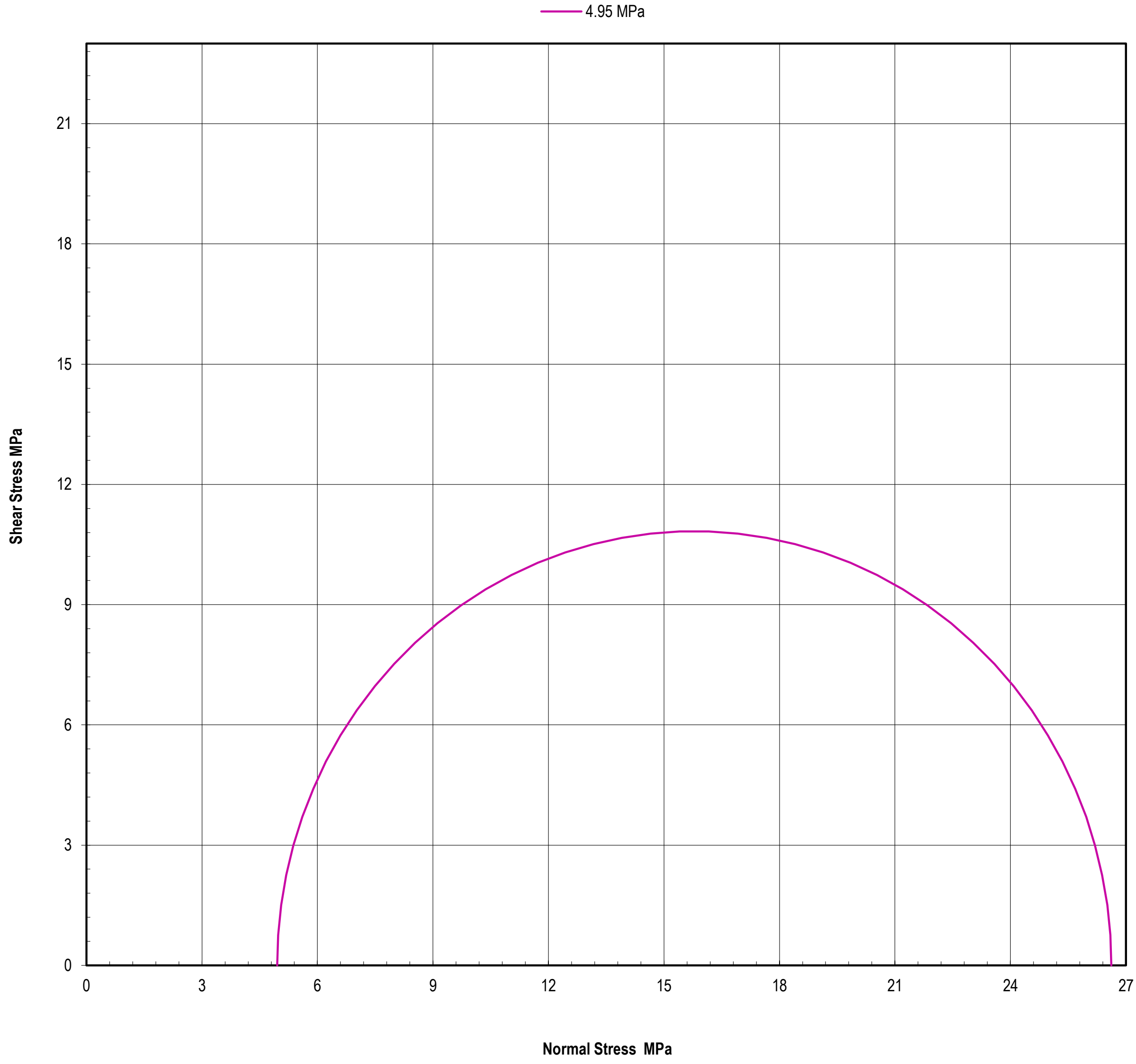
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110057-RTX

Residual Stress Mohr Circle Plot



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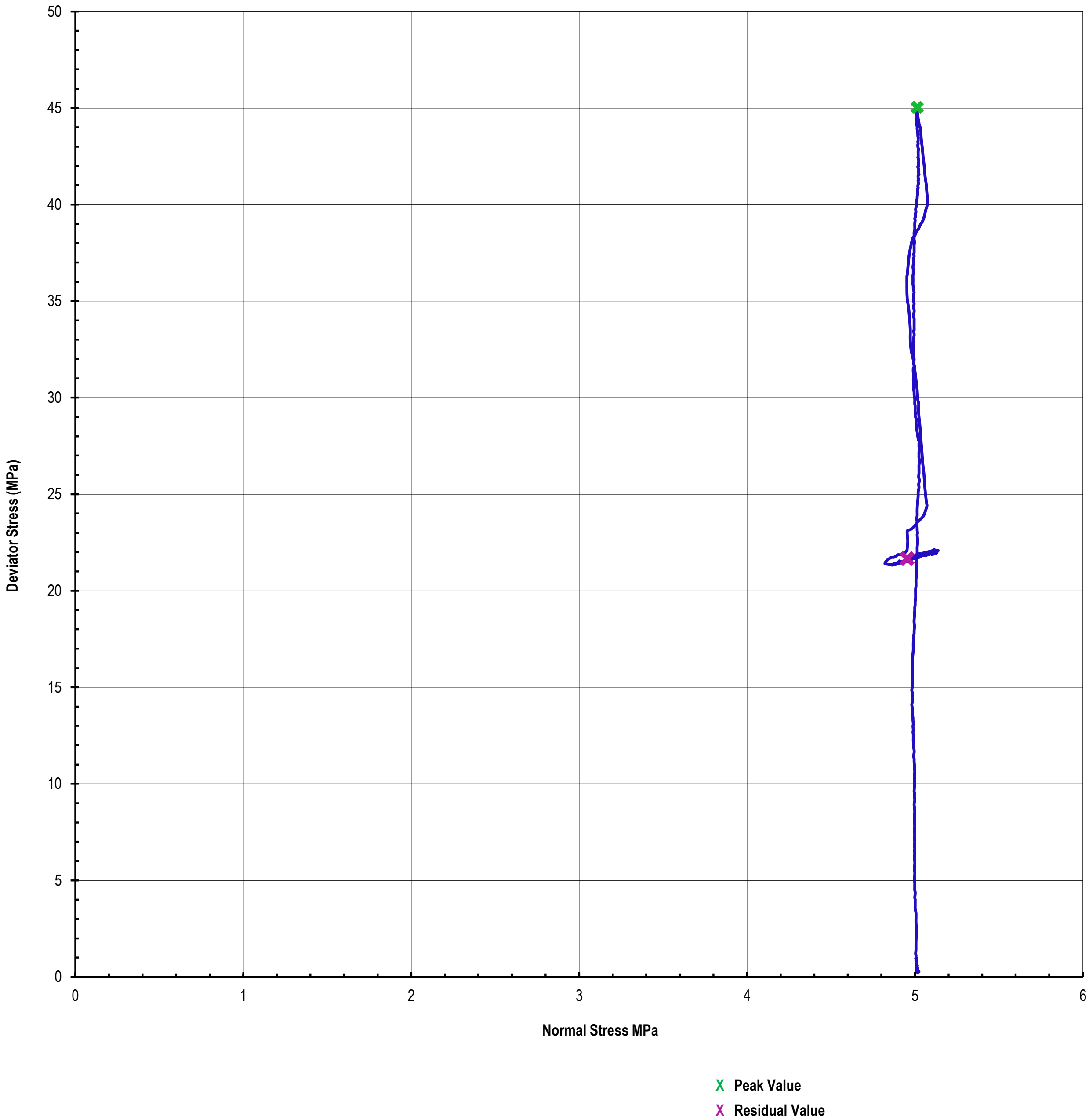
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110057-RTX

Deviator Stress vs Normal Stress Plot



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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.**	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 (με)	8743				
Diametral Strain (με)	-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 (με)	14166				
Diametral Strain (με)	-11889				

Notes/Remarks:

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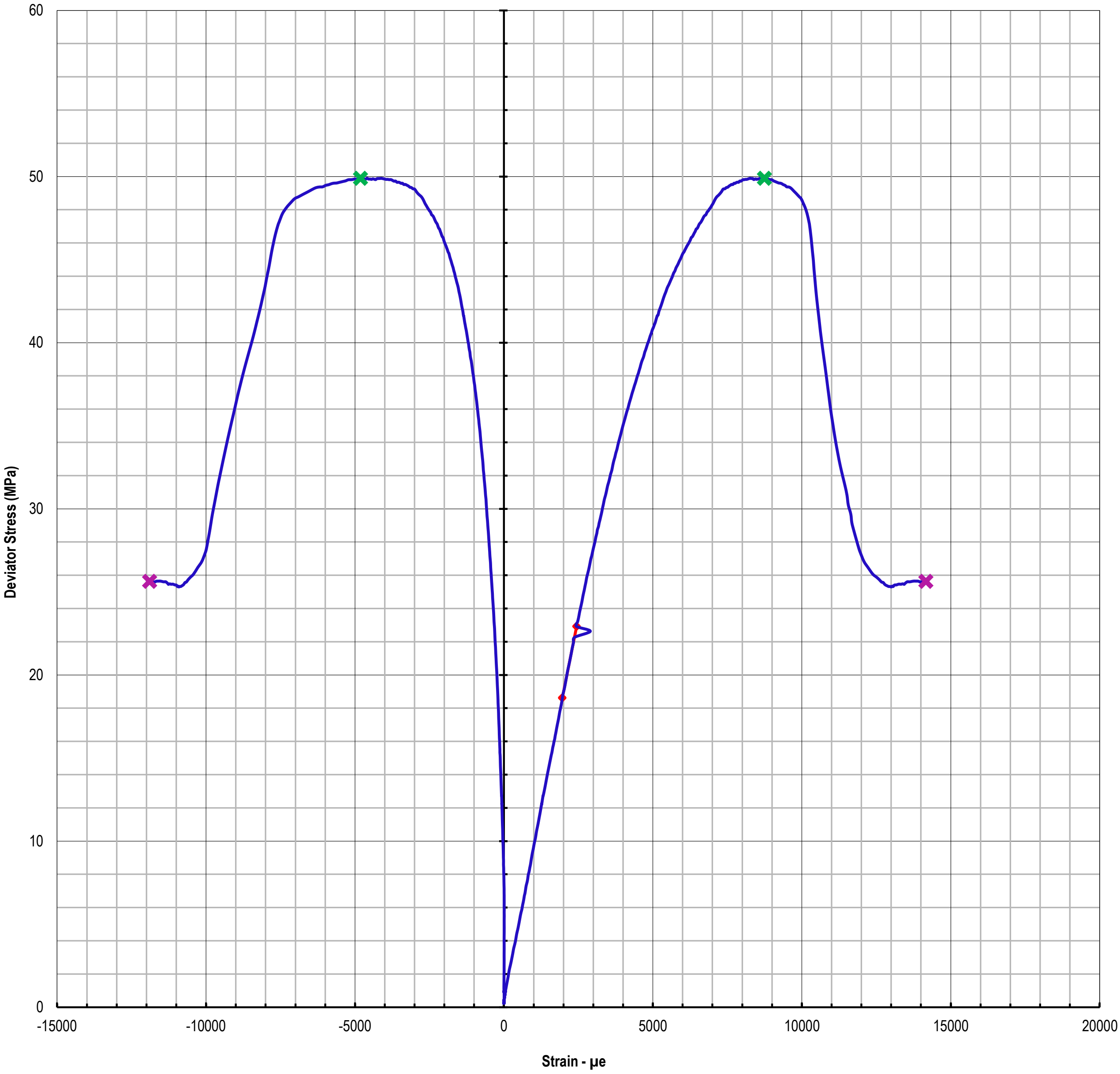
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Deviator Stress vs Axial Strain Plots



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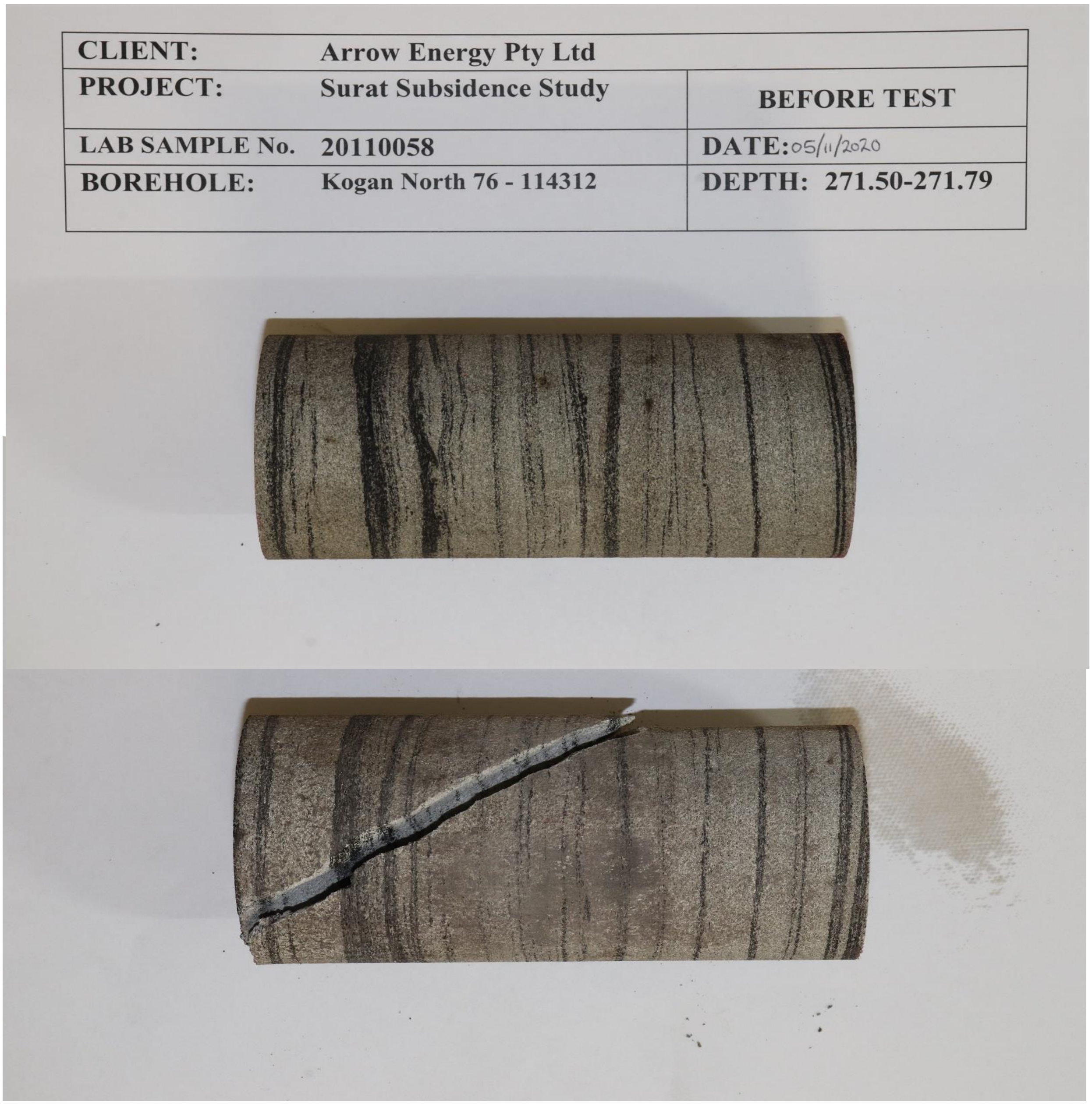
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos



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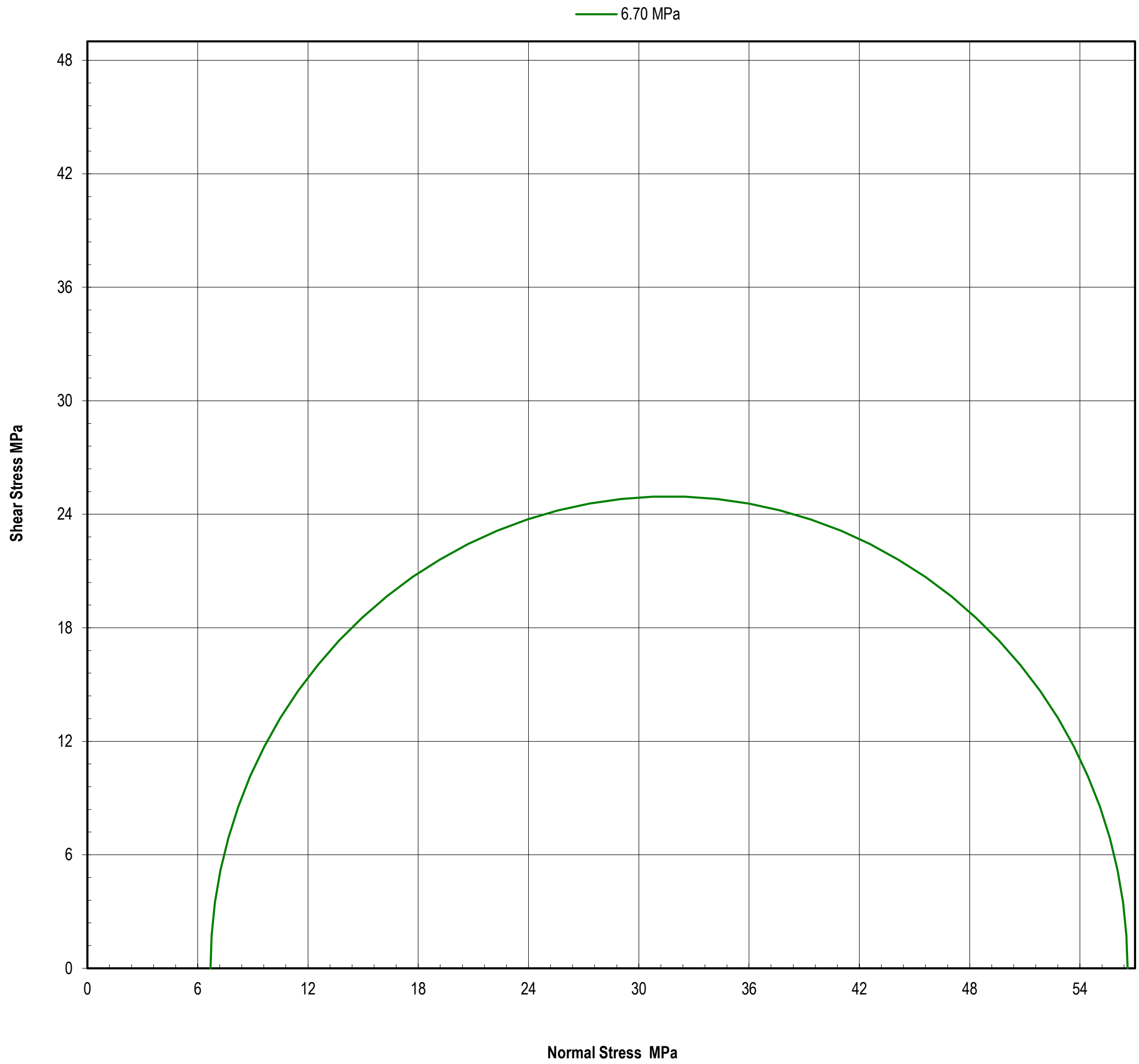
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Peak Stress Mohr Circle Plot



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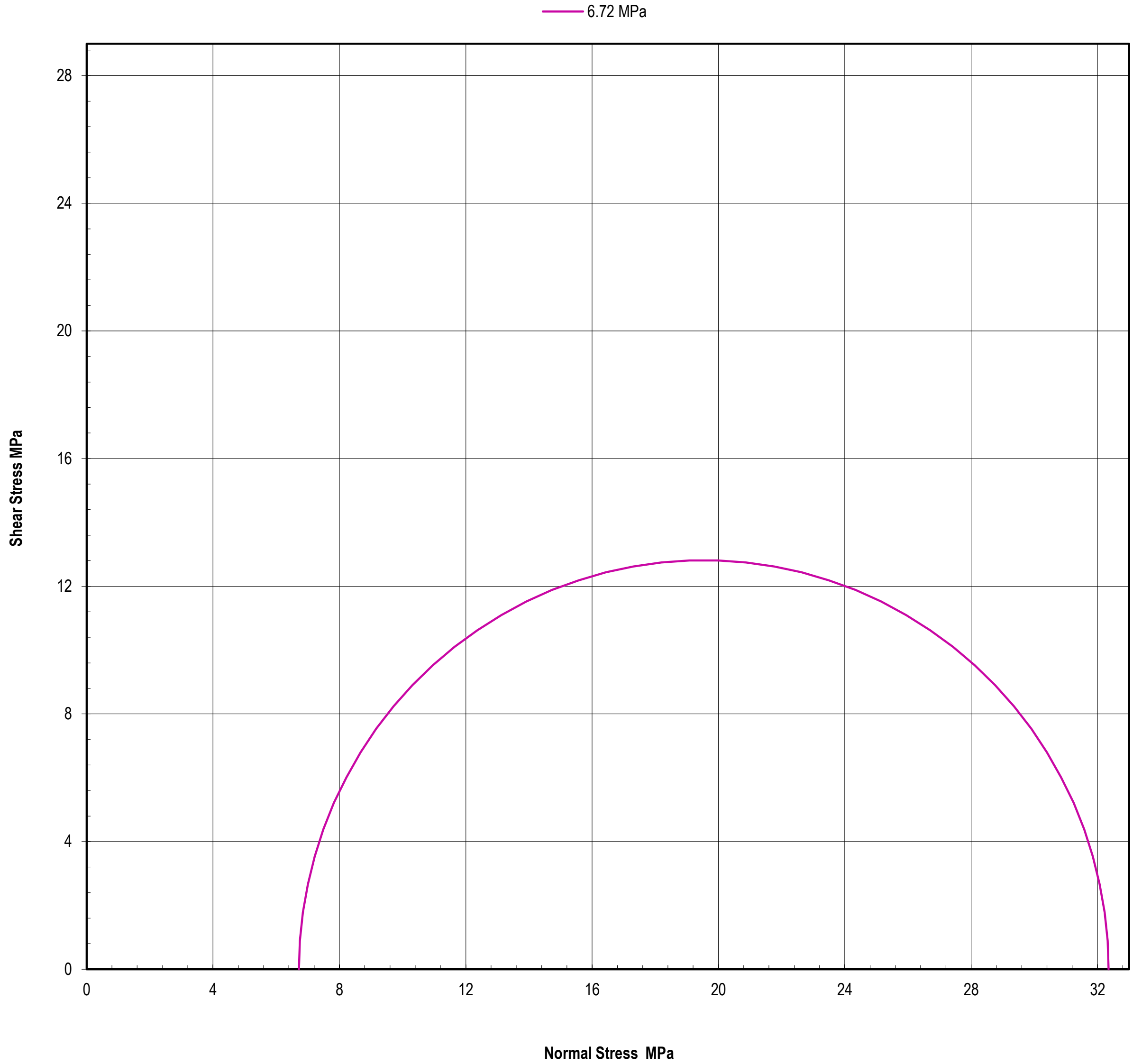
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Residual Stress Mohr Circle Plot



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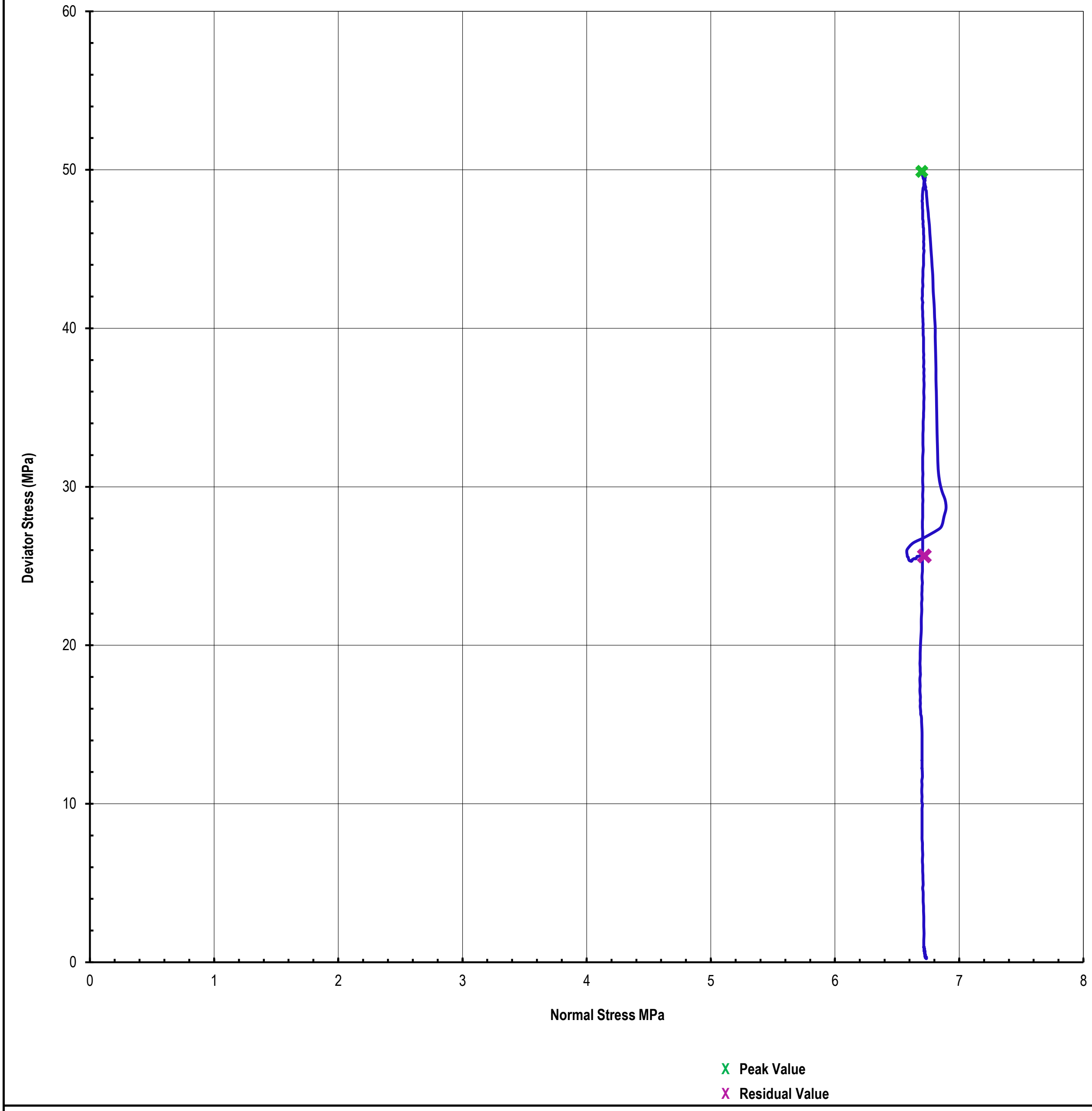
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Deviator Stress vs Normal Stress Plot



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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:

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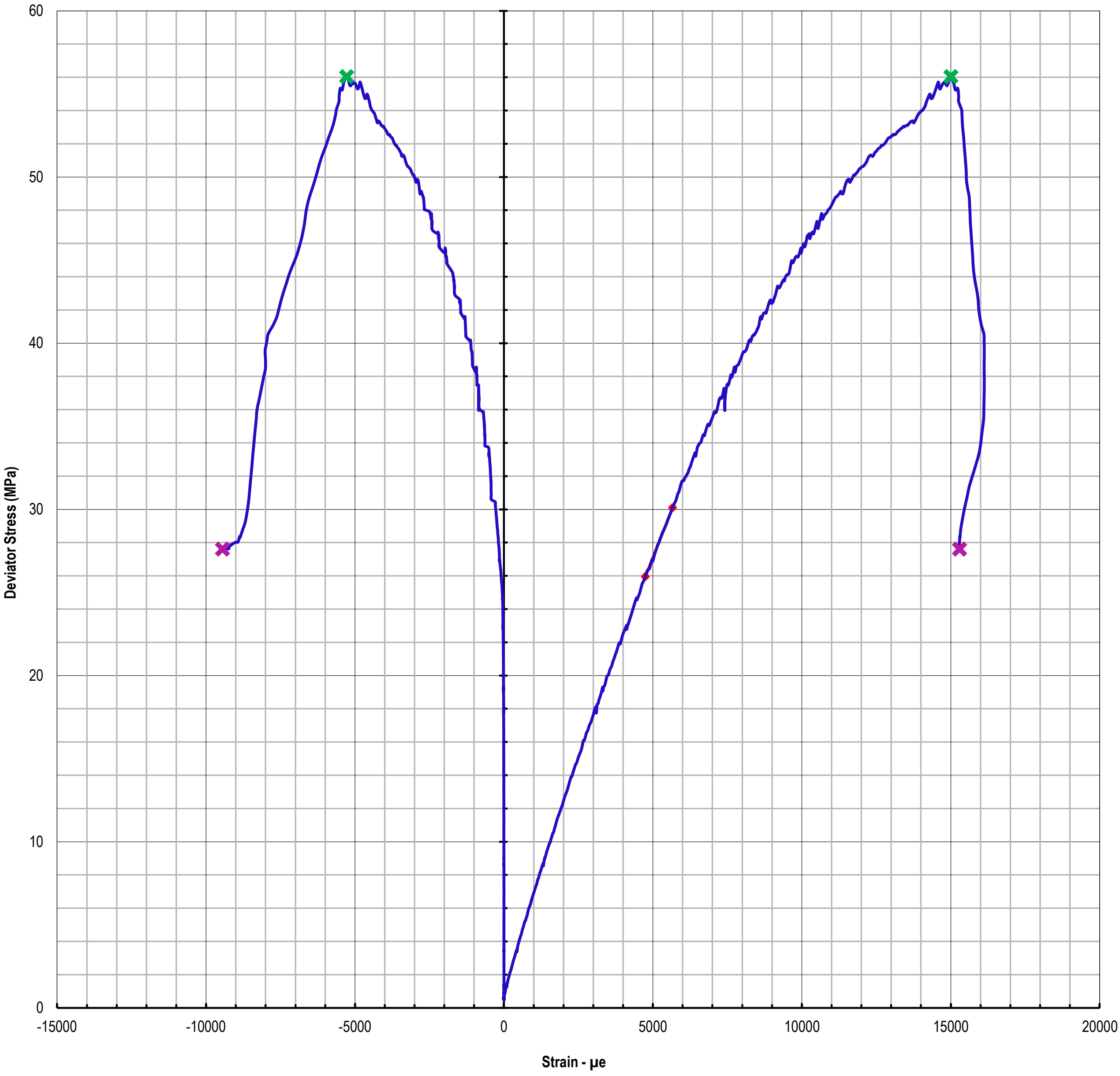
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Deviator Stress vs Axial Strain Plots



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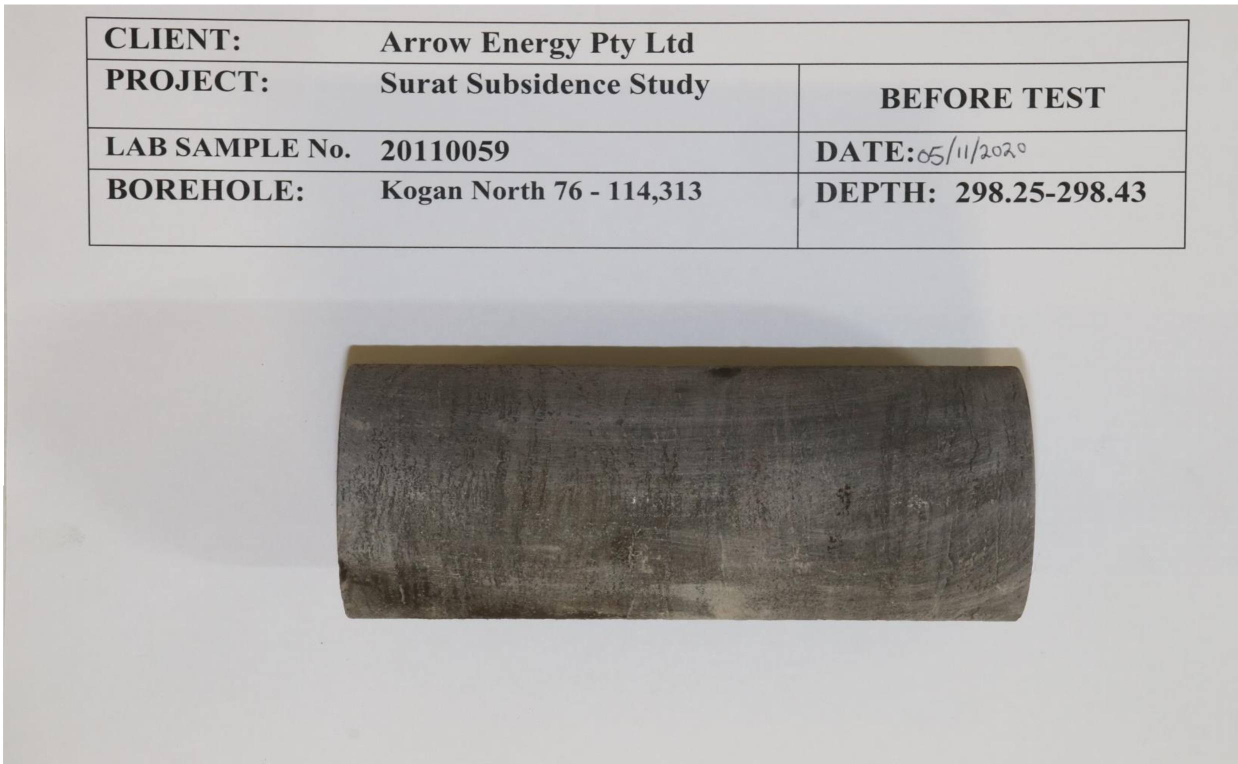
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos



Notes/Remarks:

Photo not to scale

Sample/s supplied by client

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

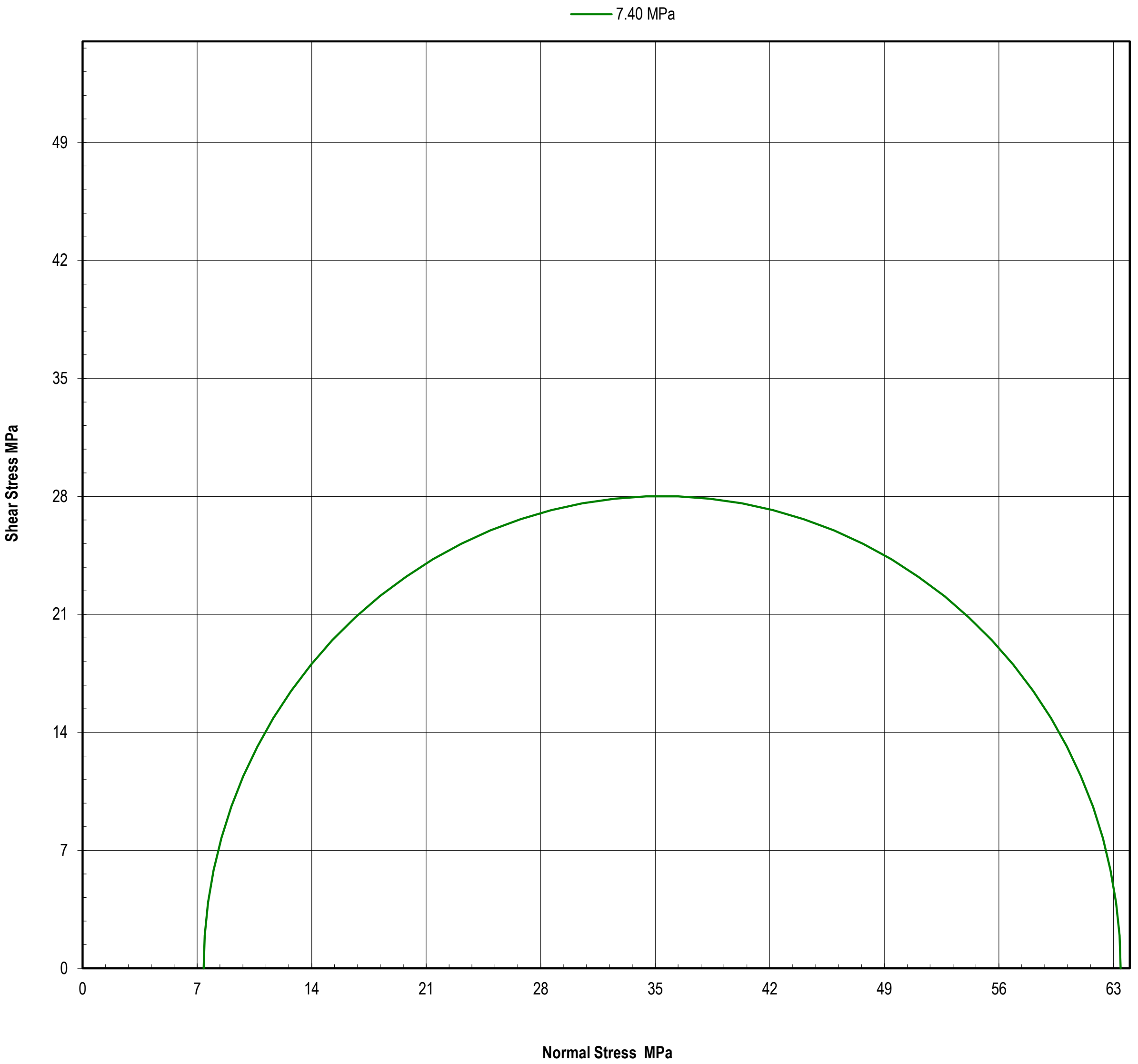
ASTM D7012

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.**	20110059-RTX

Peak Stress Mohr Circle Plot



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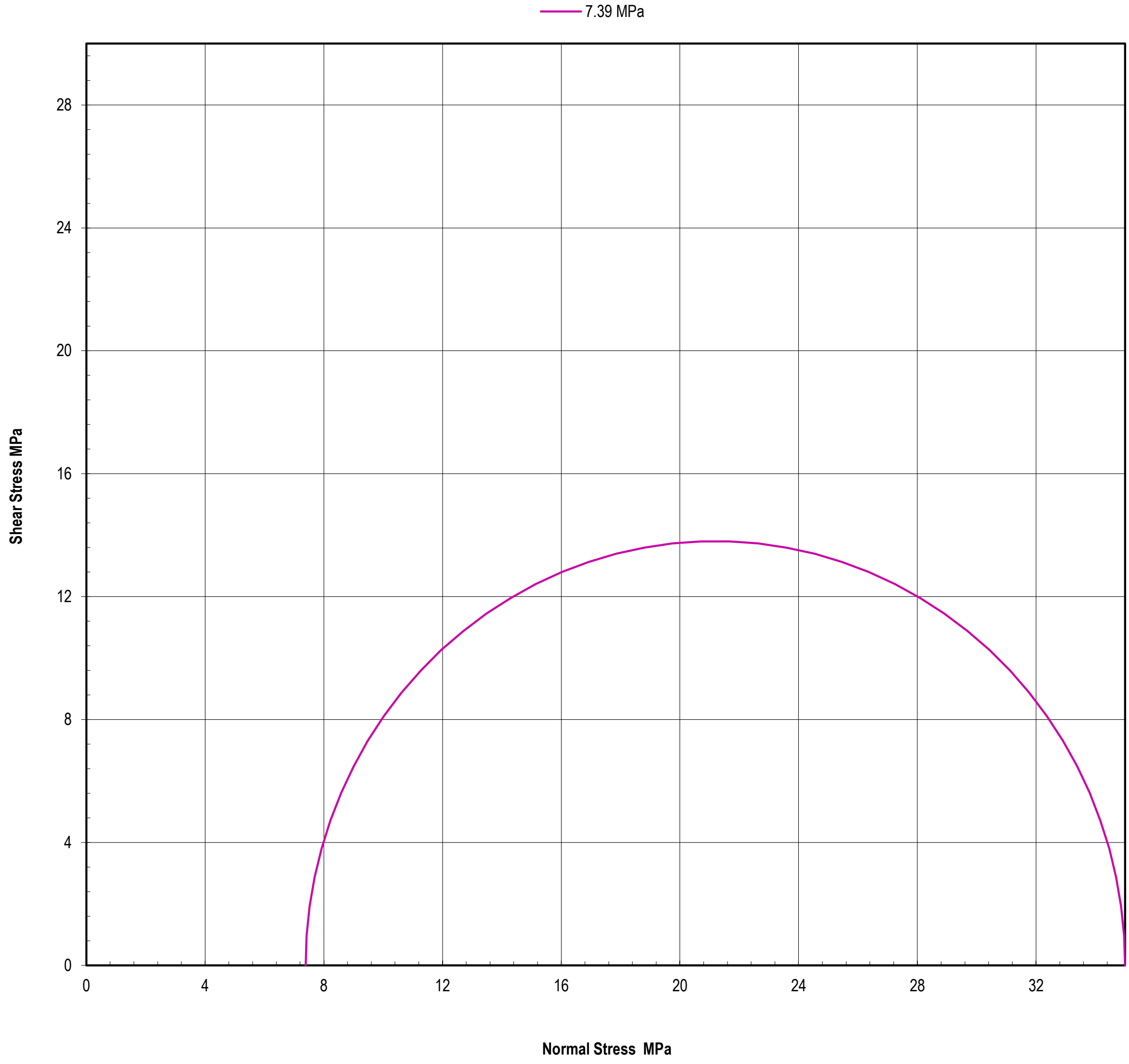
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110059-RTX

Residual Stress Mohr Circle Plot



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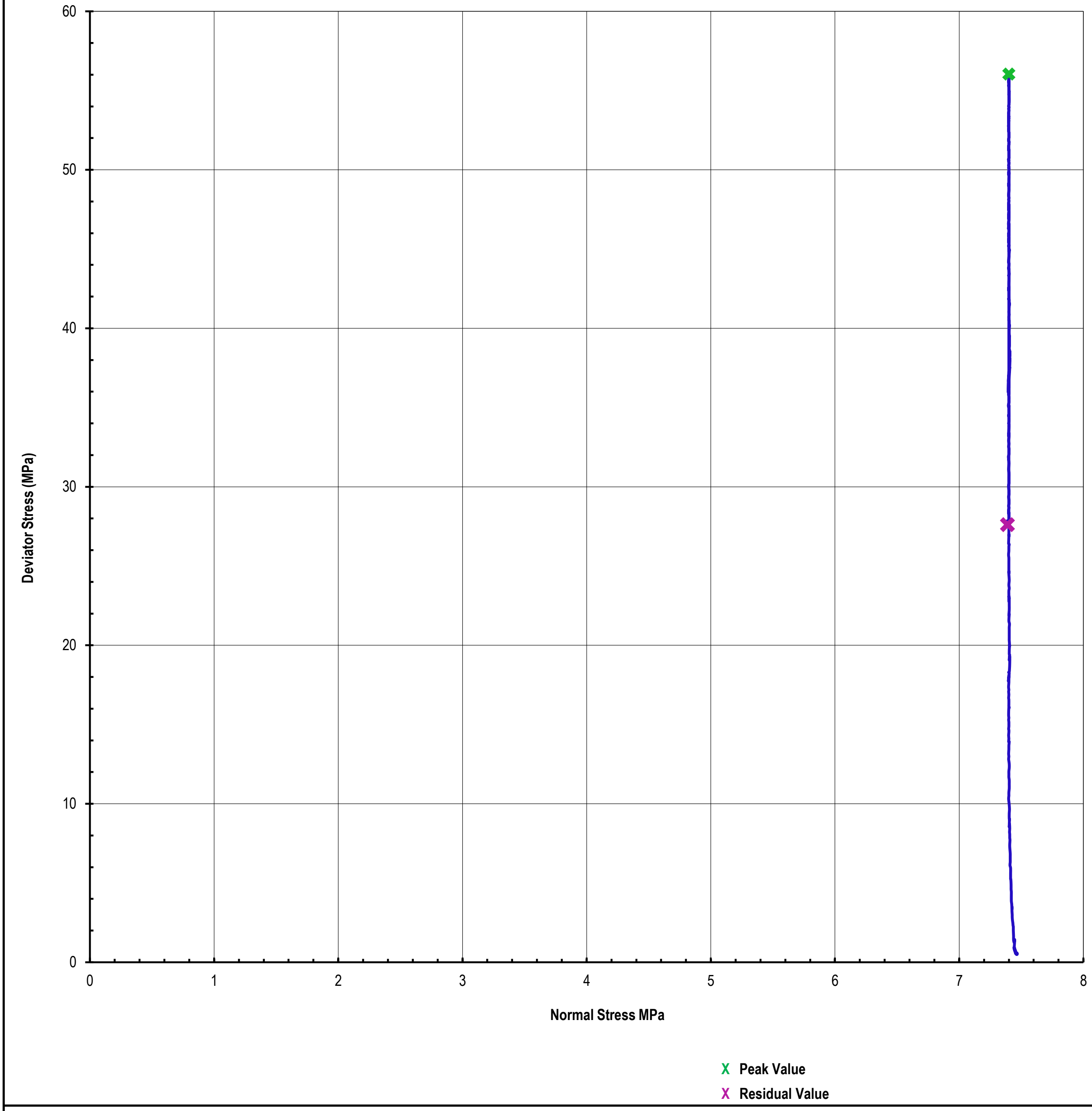
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Deviator Stress vs 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.**	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:

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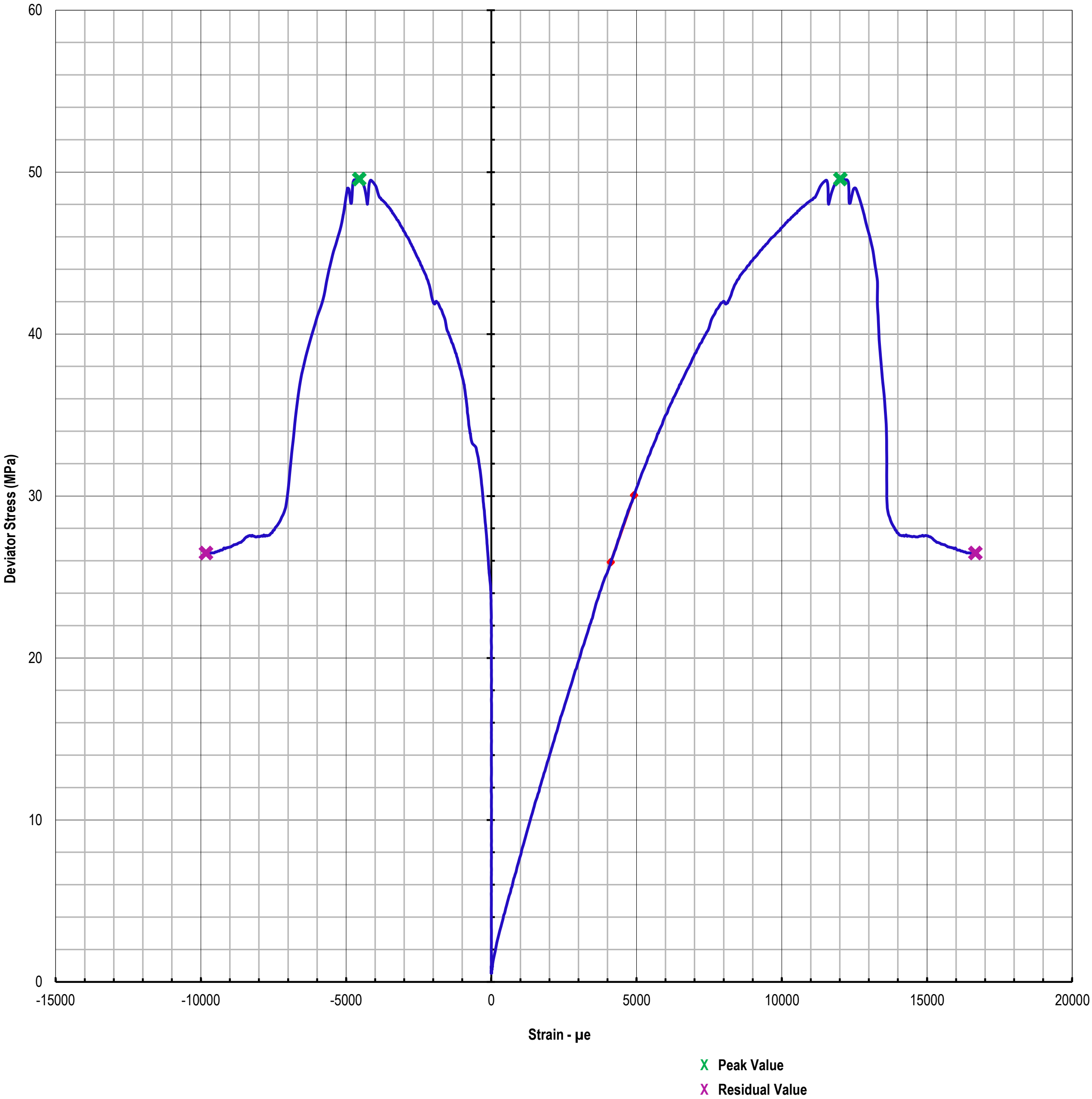
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Deviator Stress vs Axial Strain Plots



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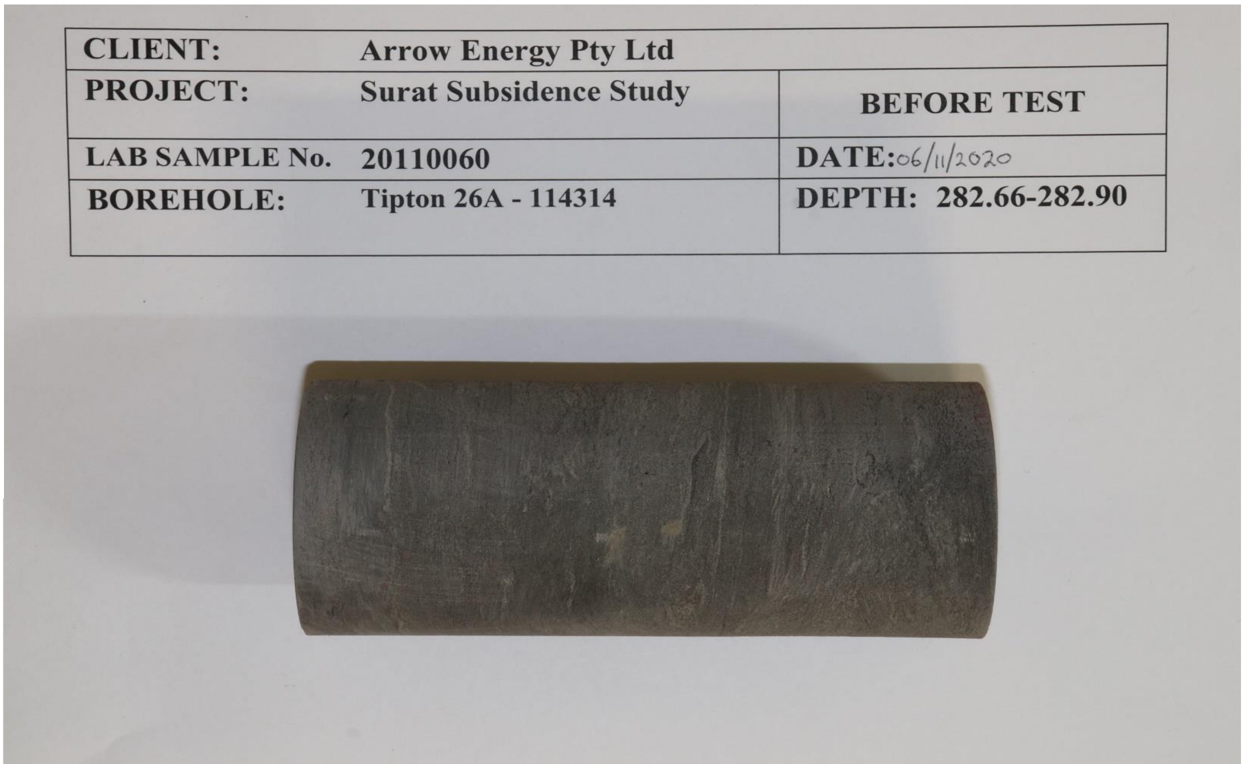
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos



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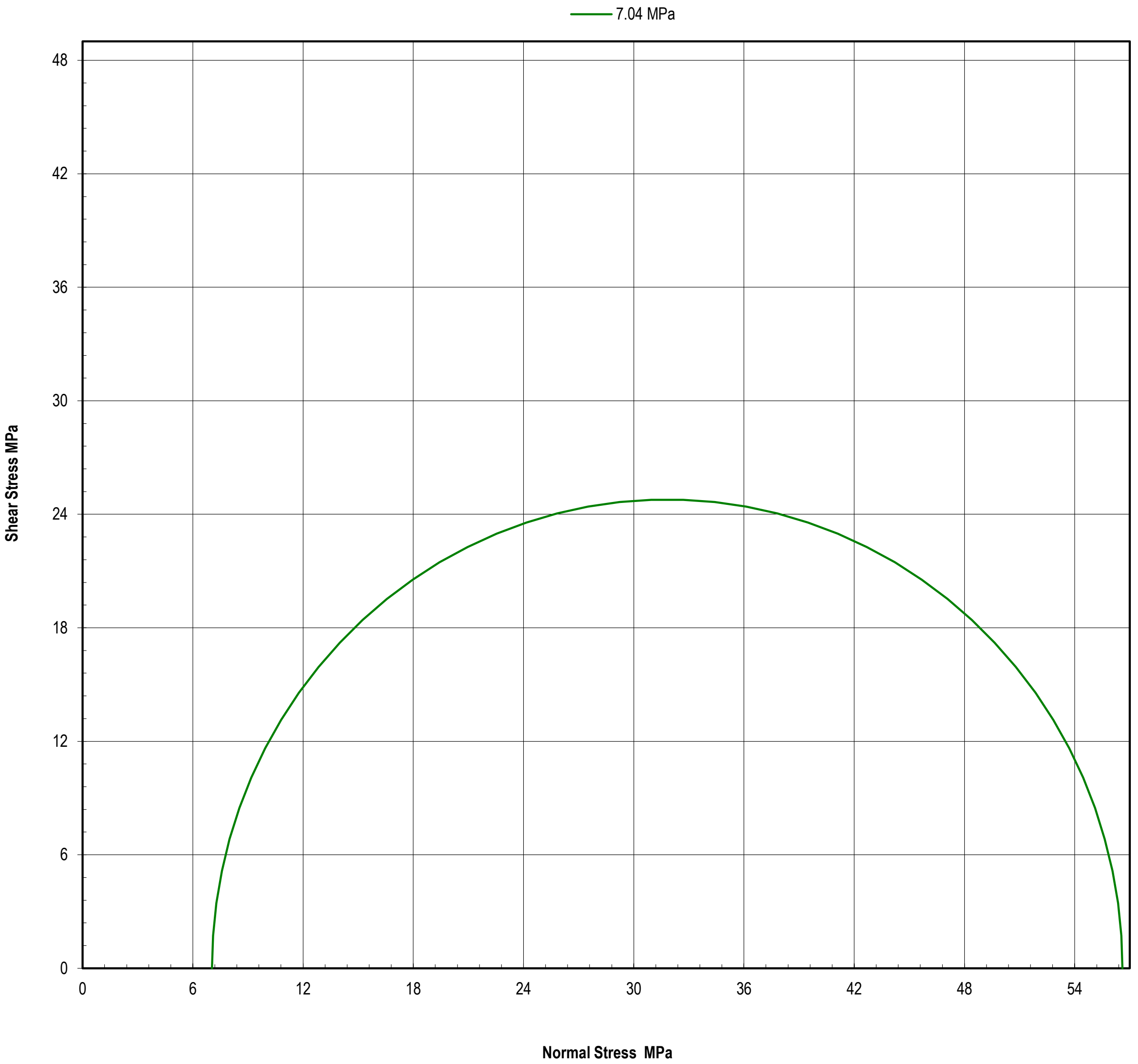
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Peak Stress Mohr Circle Plot



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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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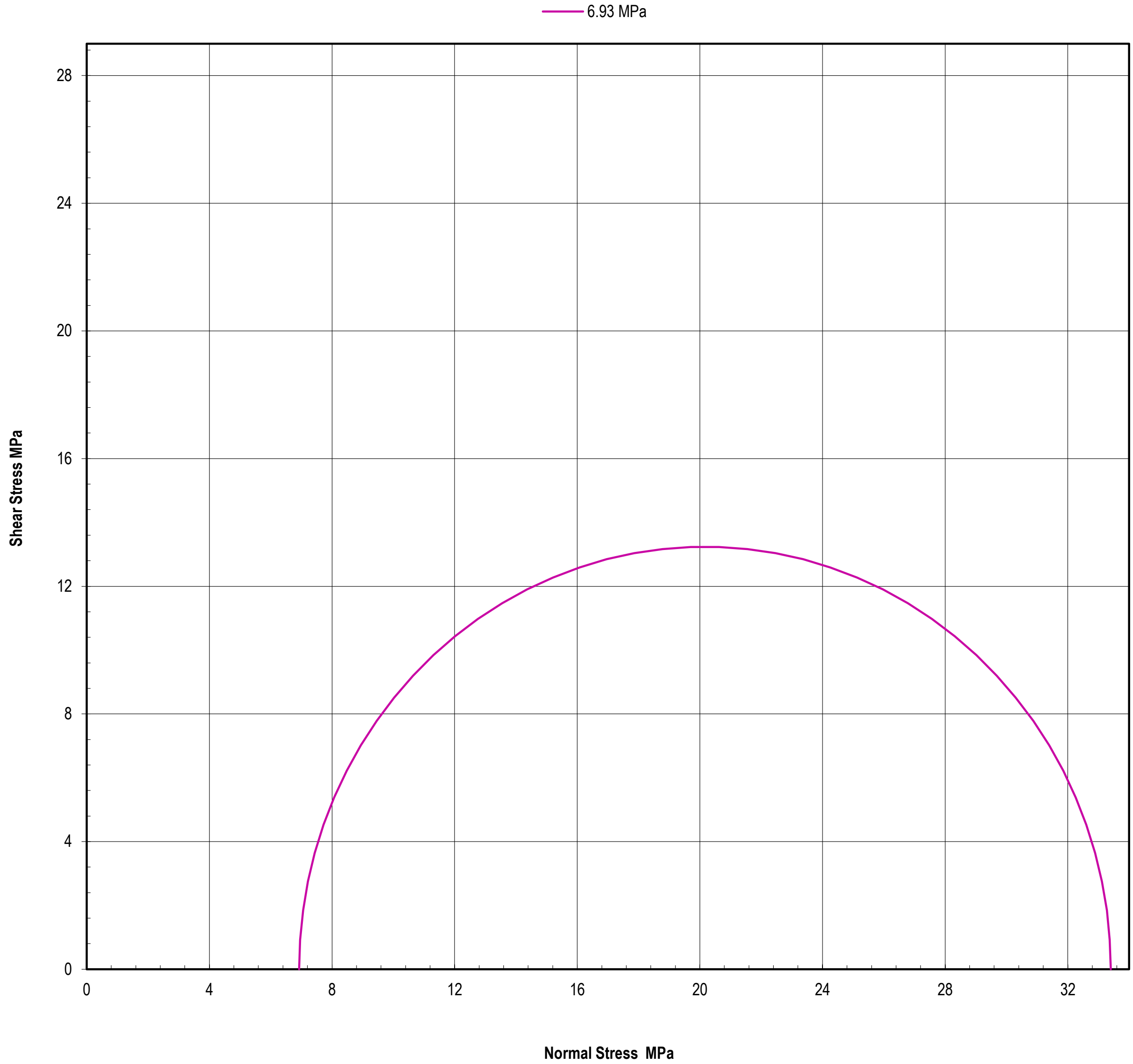
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

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

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

Residual Stress Mohr Circle Plot



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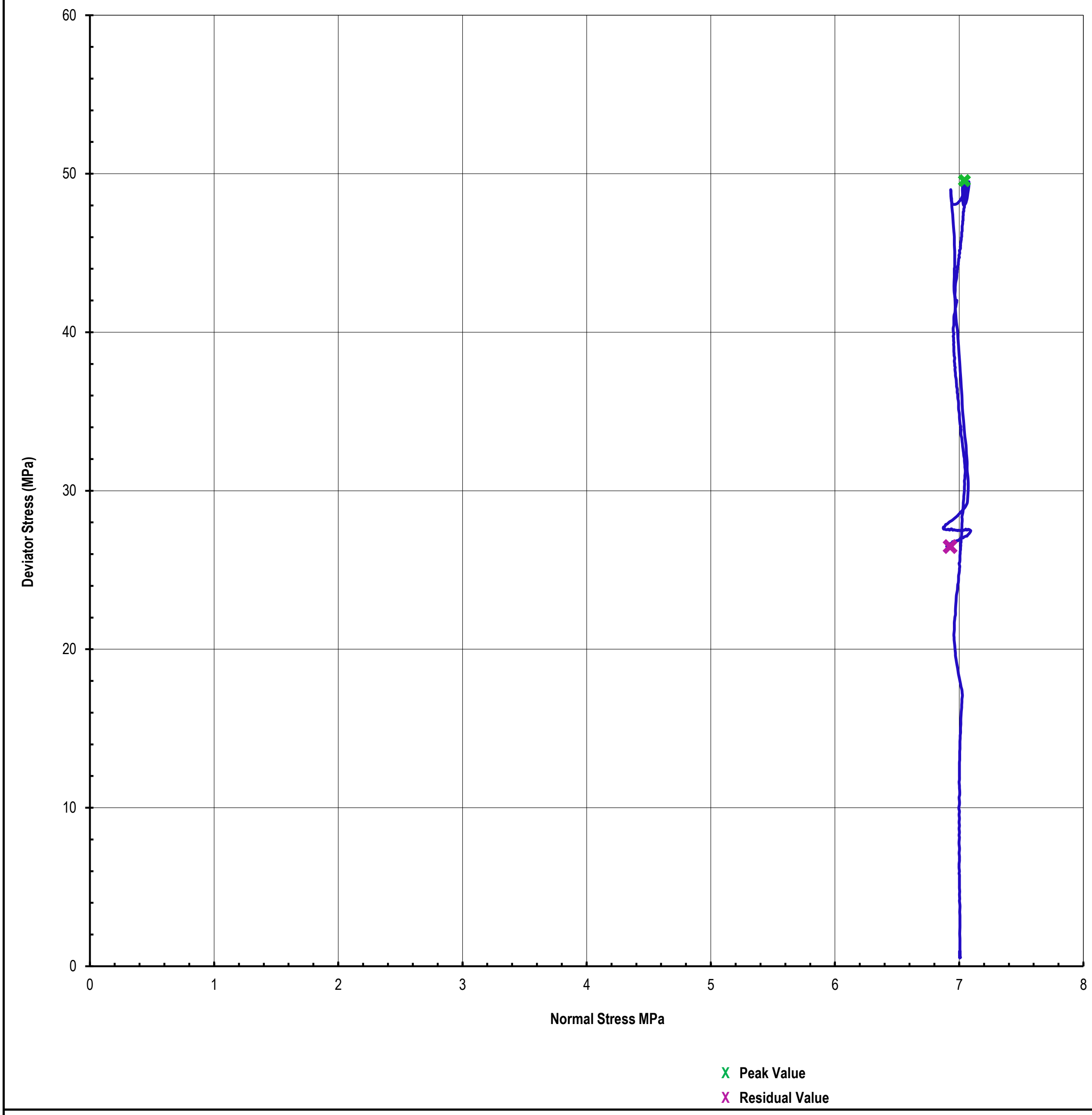
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Deviator Stress vs Normal Stress Plot



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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
		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 (µe)	16339				
Diametral Strain (µe)	-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 (µe)	21184				
Diametral Strain (µe)	-15171				

Notes/Remarks:

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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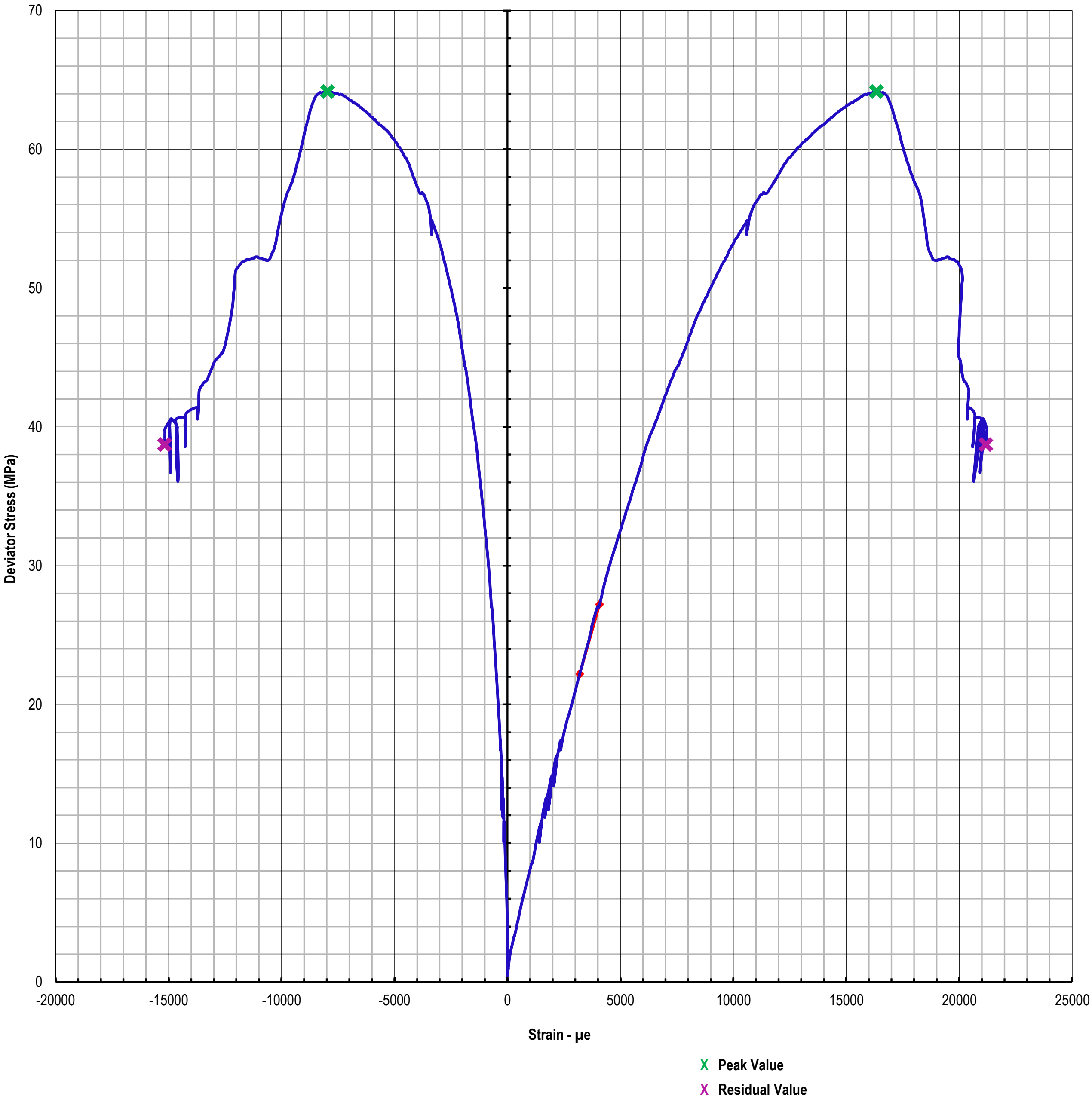
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110061-RTX

Deviator Stress vs Axial Strain Plots



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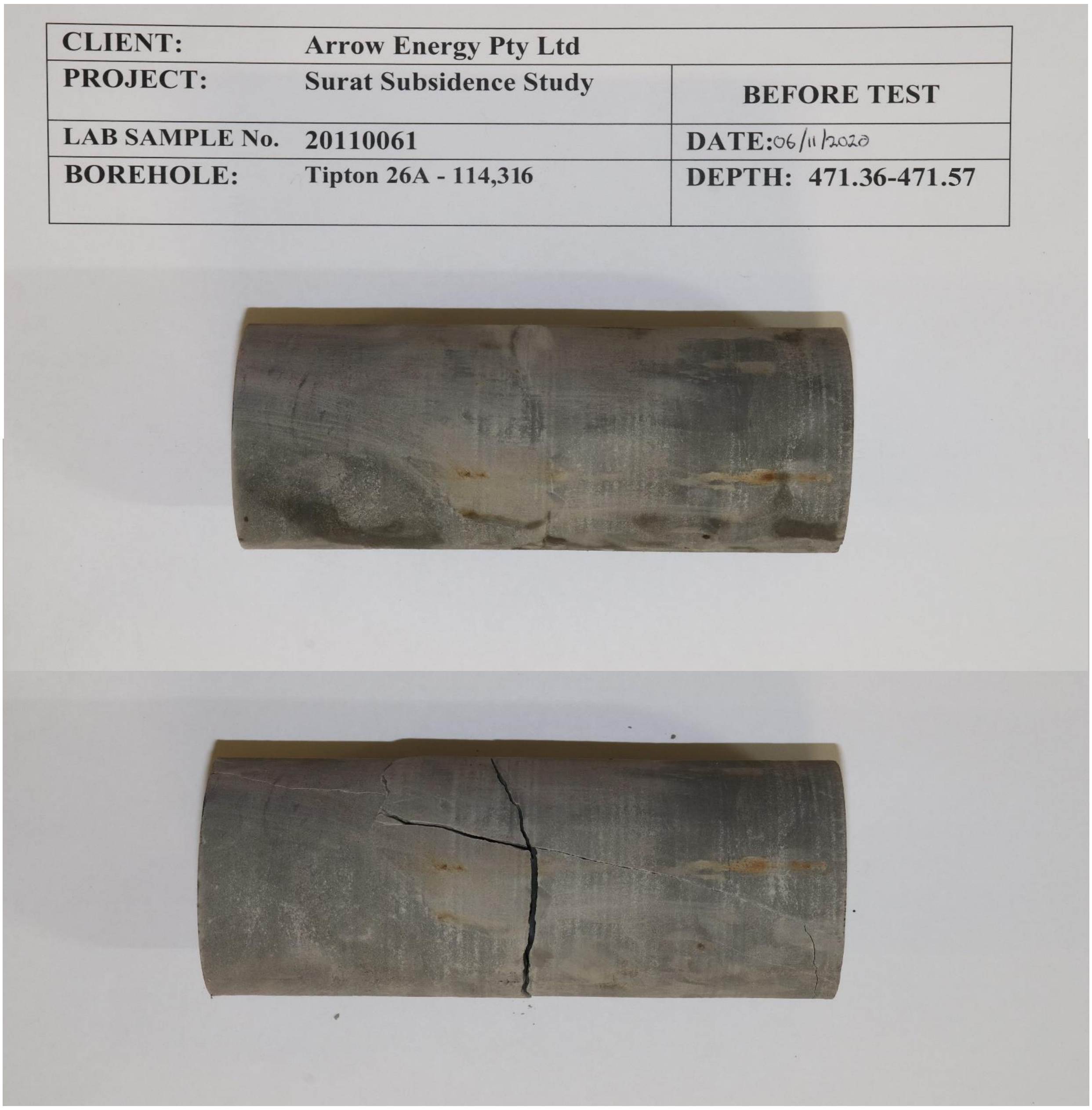
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos



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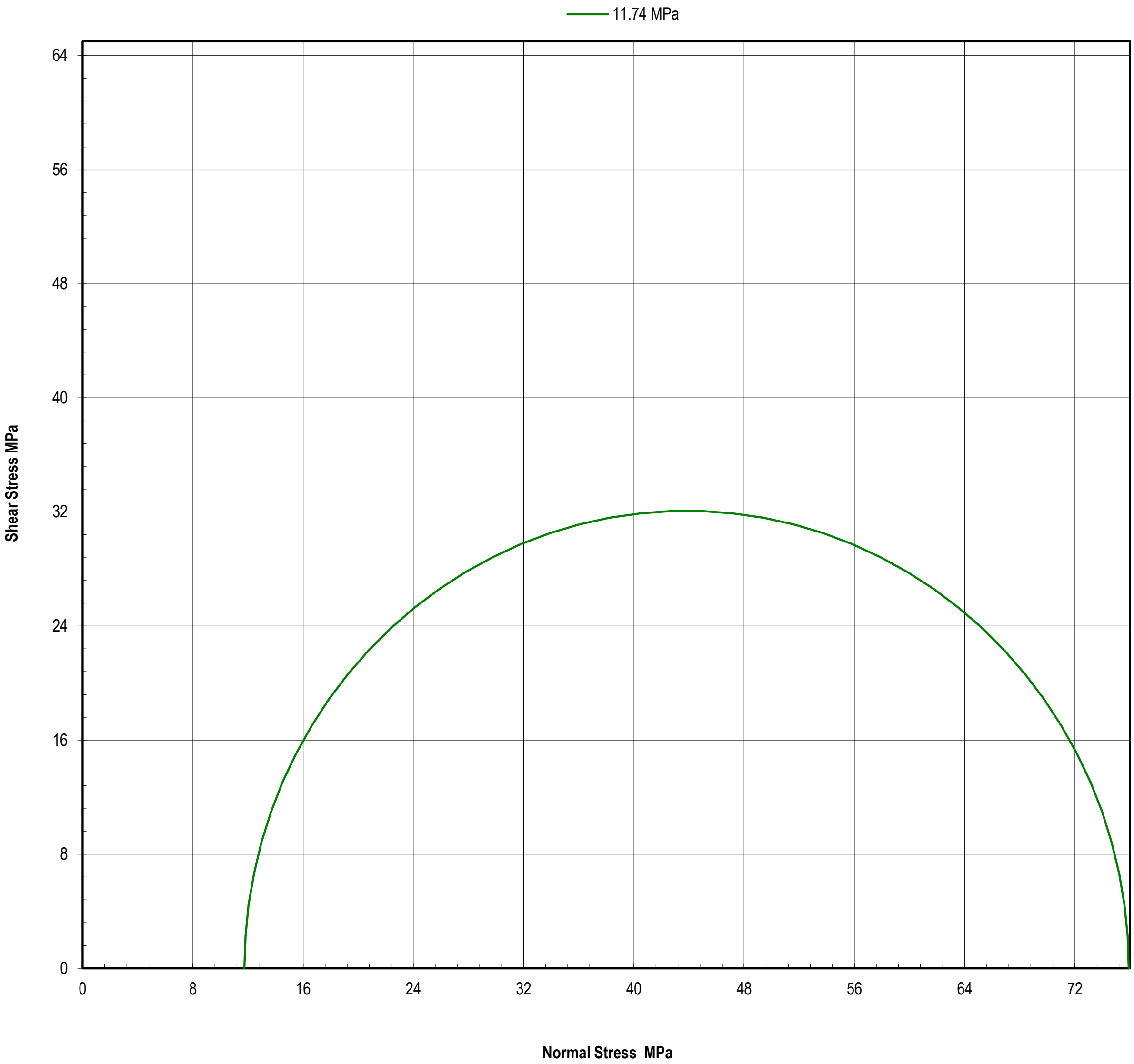
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Peak Stress Mohr Circle Plot



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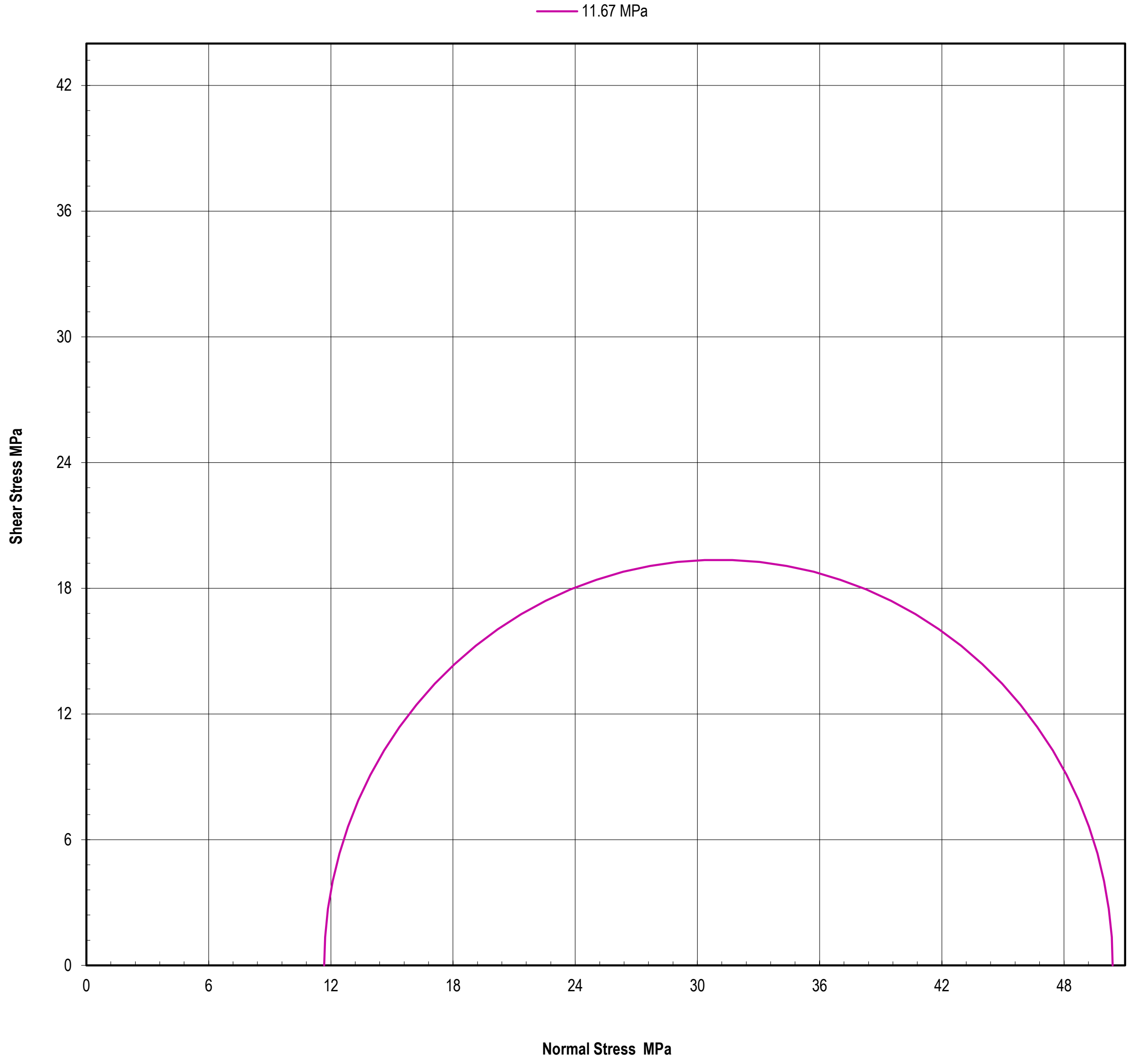
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Residual Stress Mohr Circle Plot



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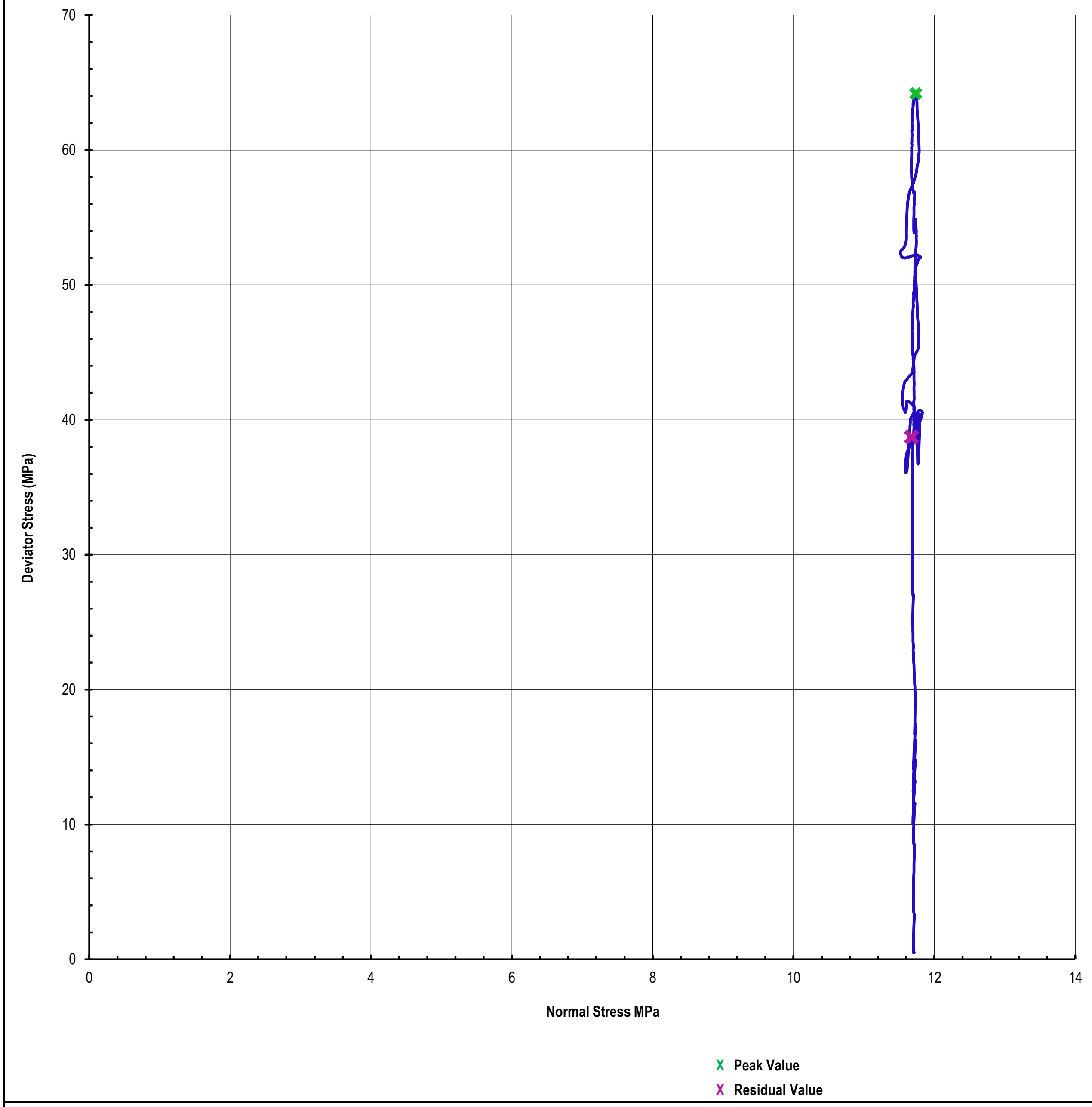
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 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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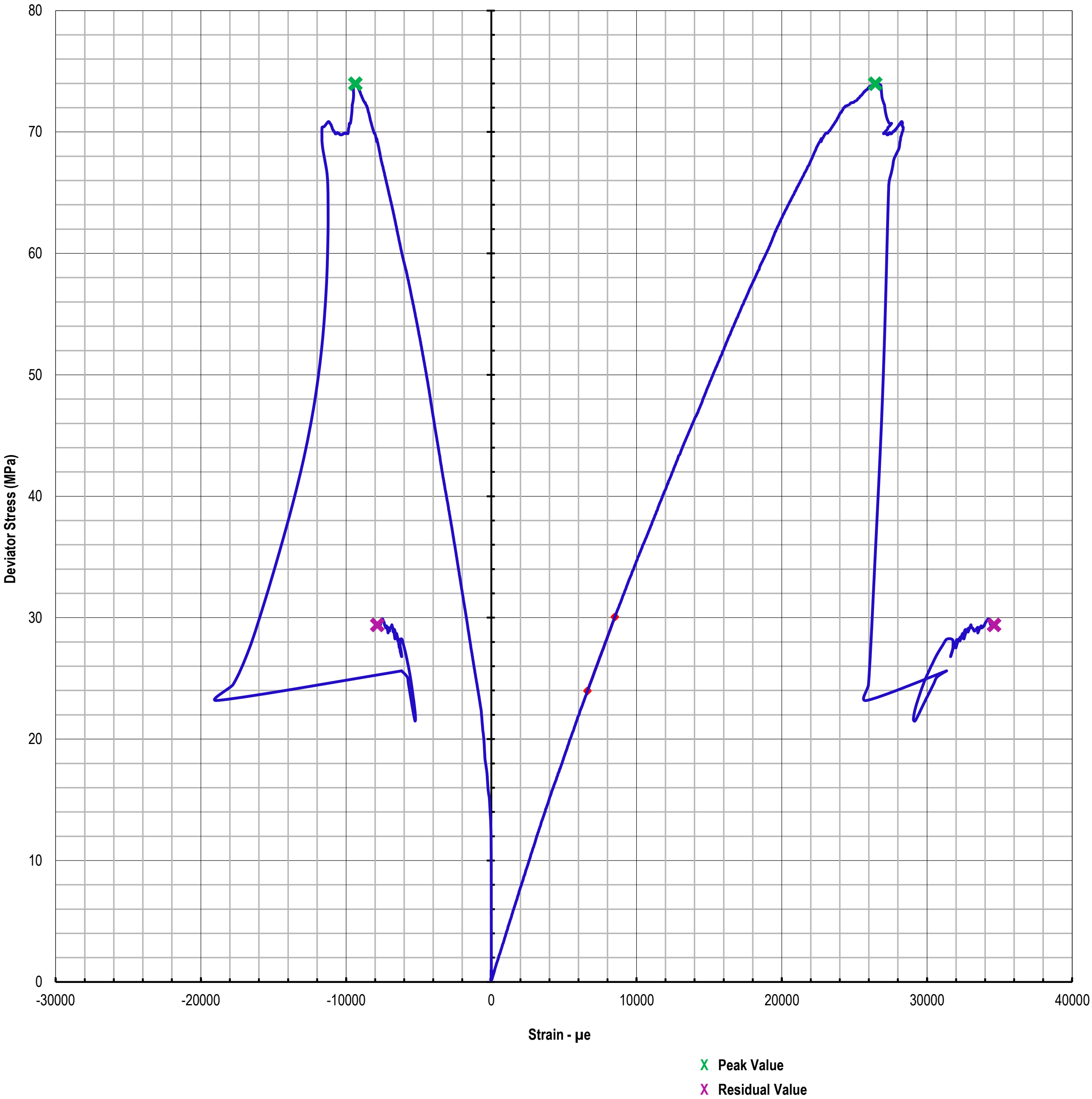
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Deviator Stress vs Axial Strain Plots



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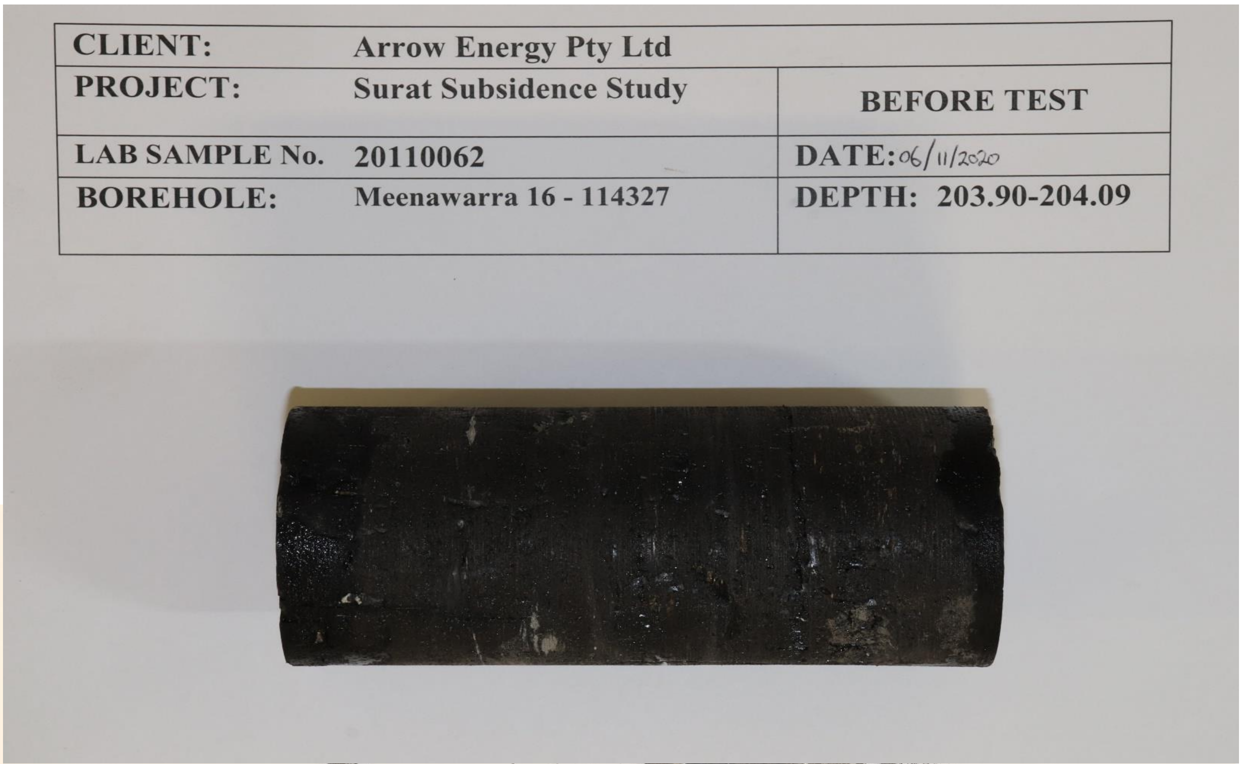
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos



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

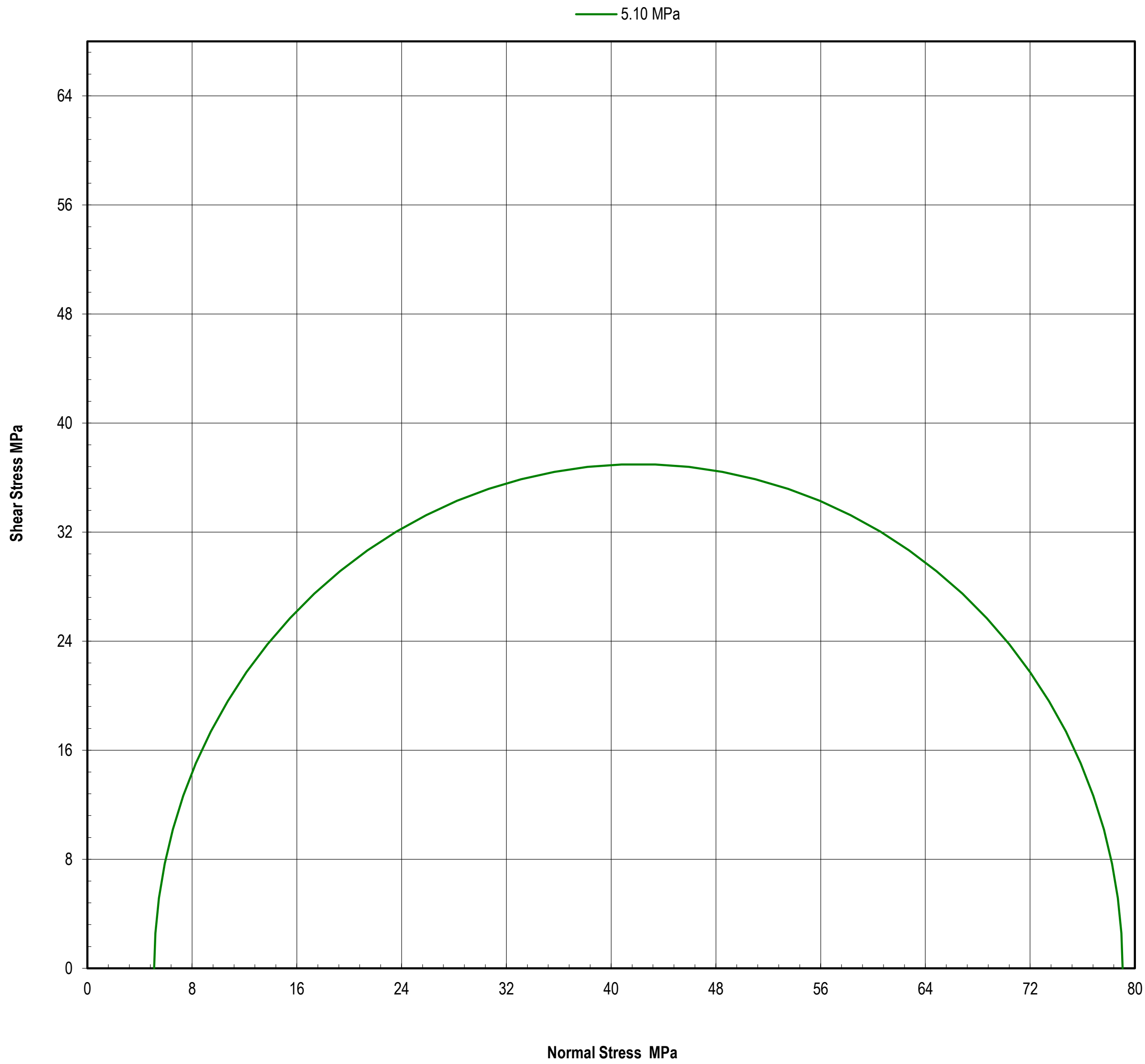
ASTM D7012

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.**	20110062-RTX

Peak Stress Mohr Circle Plot



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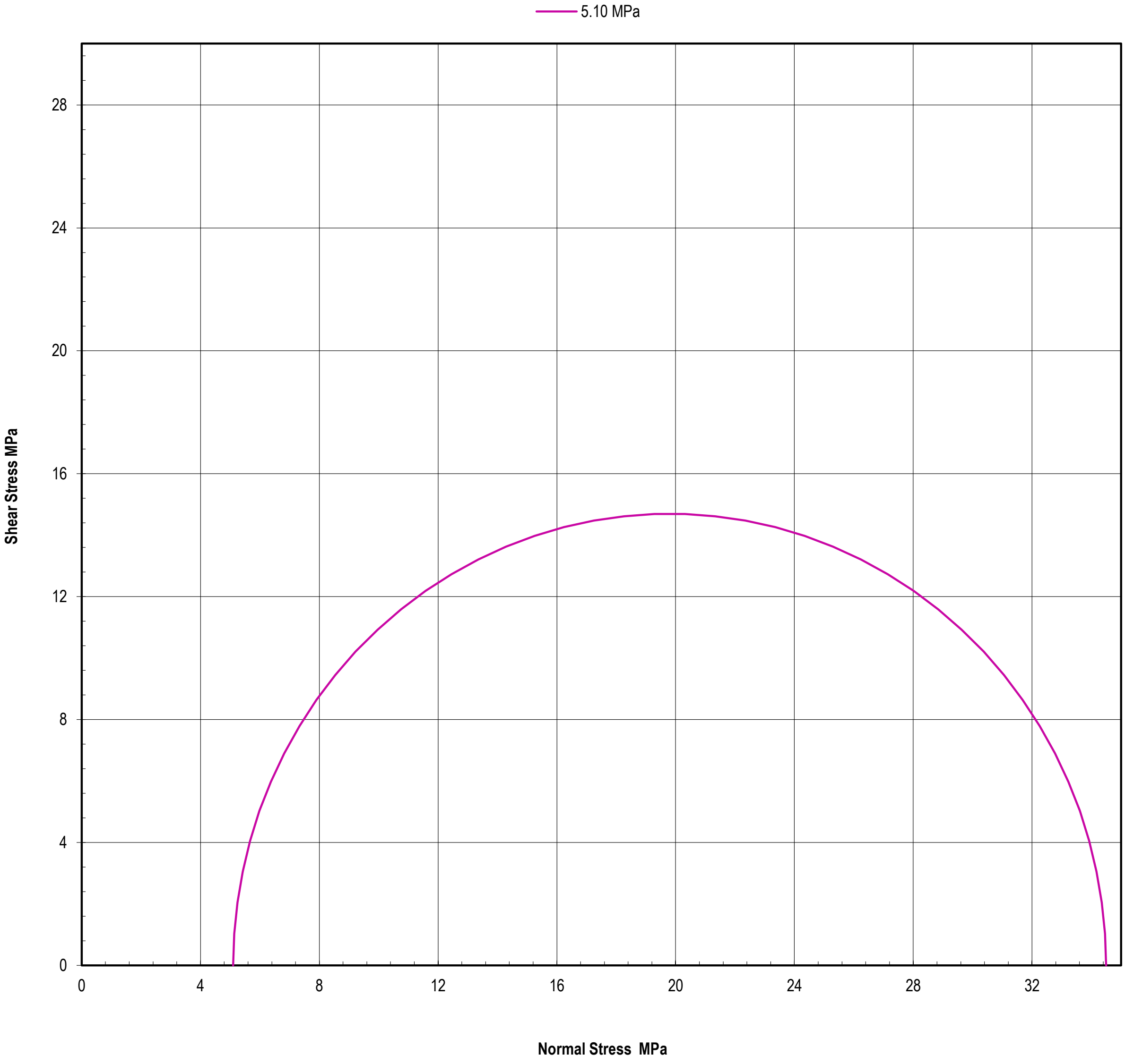
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Residual Stress Mohr Circle Plot



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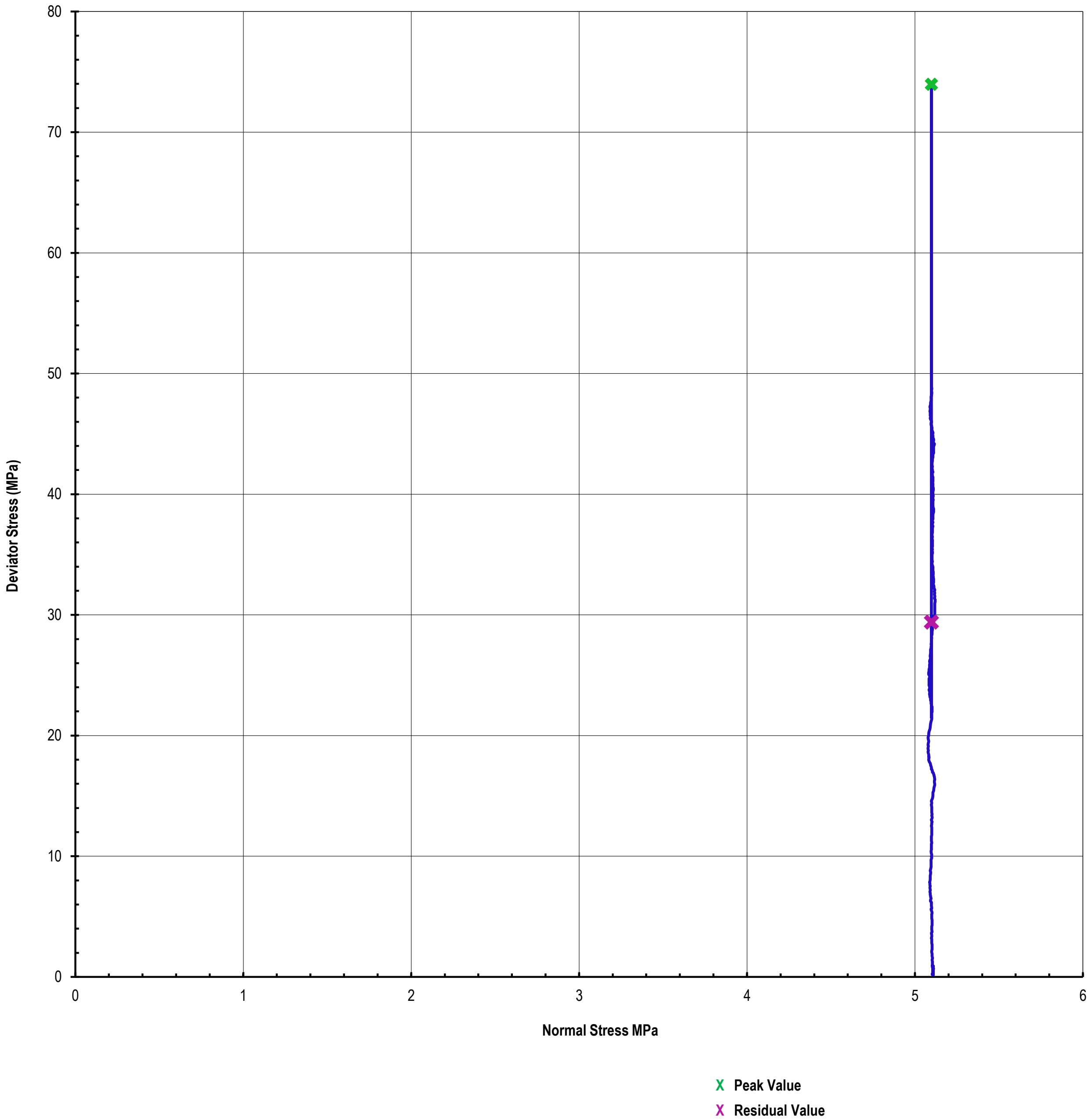
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

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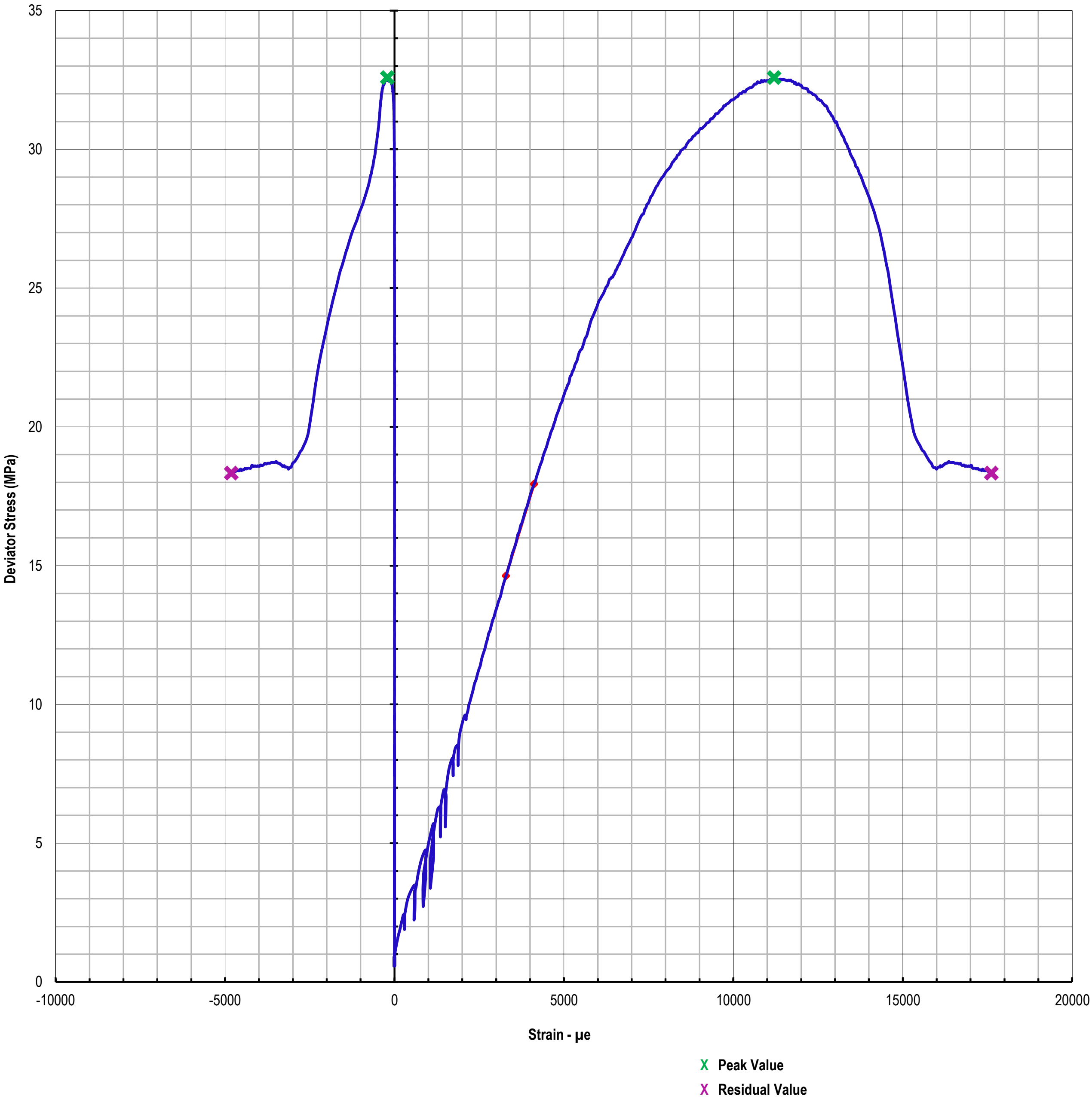
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110063-RTX

Deviator Stress vs Axial Strain Plots



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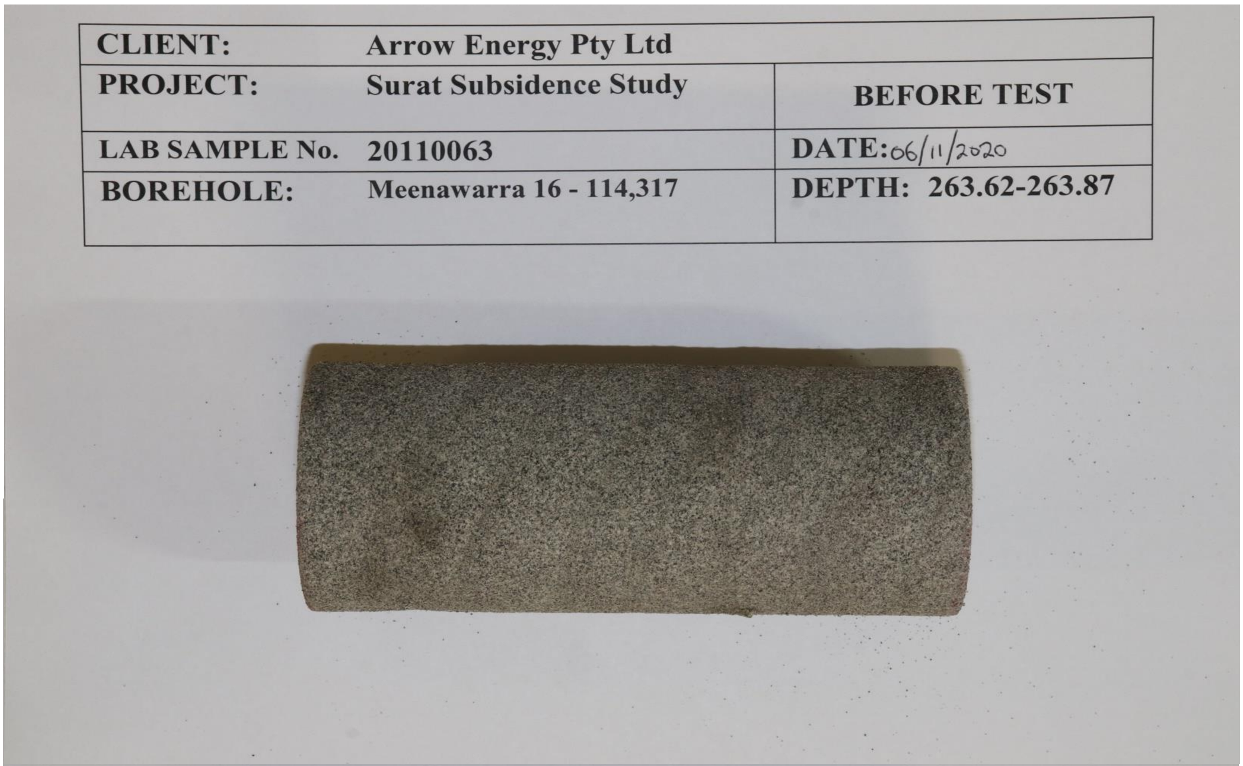
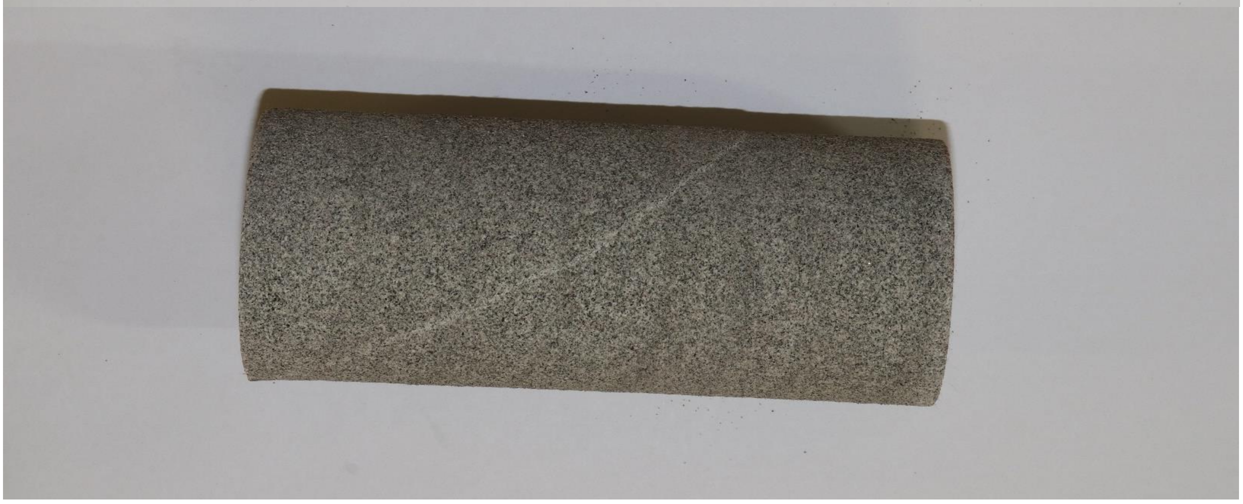
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110063-RTX

Before and After Test Photos





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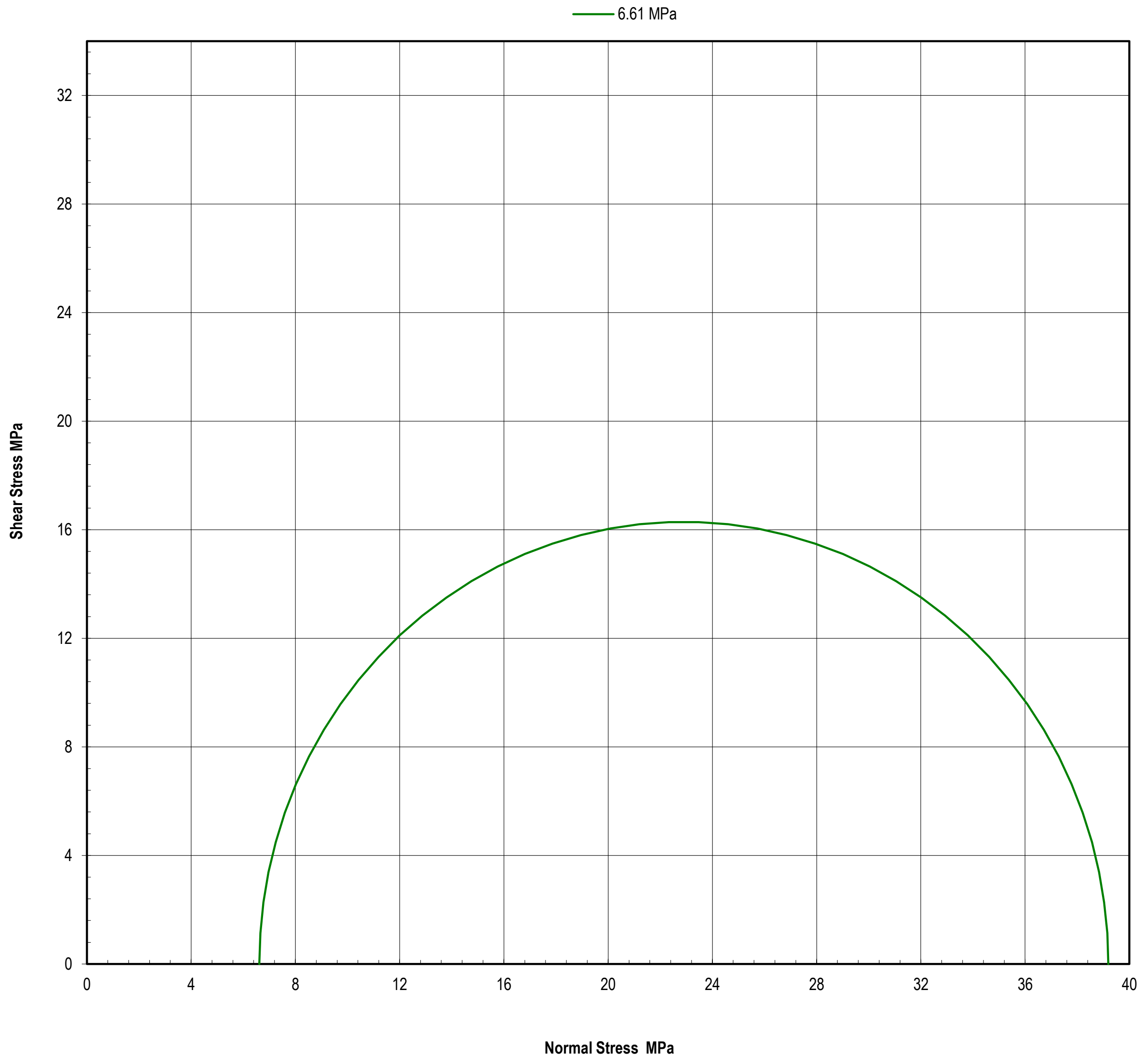
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110063-RTX

Peak Stress Mohr Circle Plot



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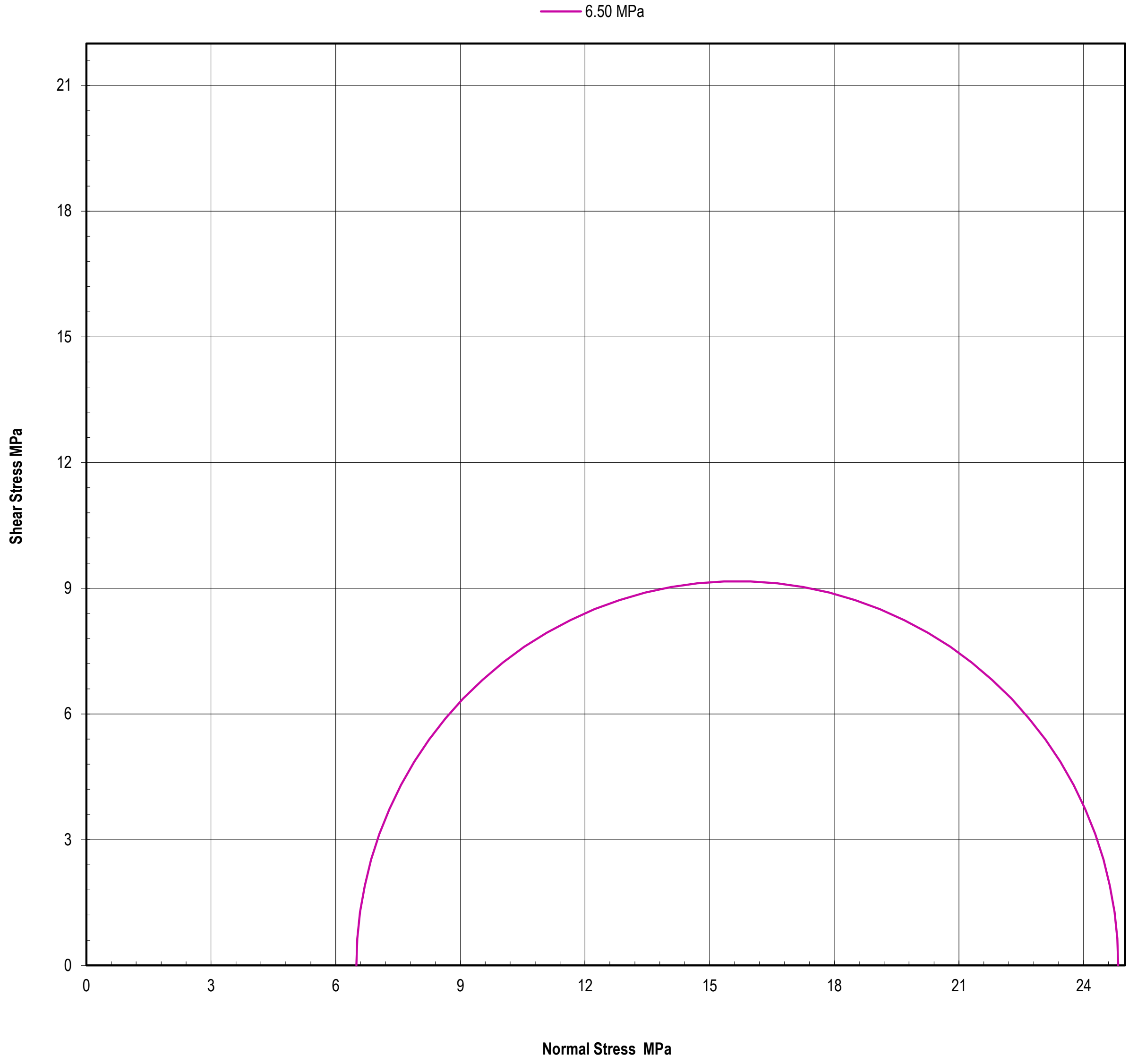
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110063-RTX

Residual Stress Mohr Circle Plot



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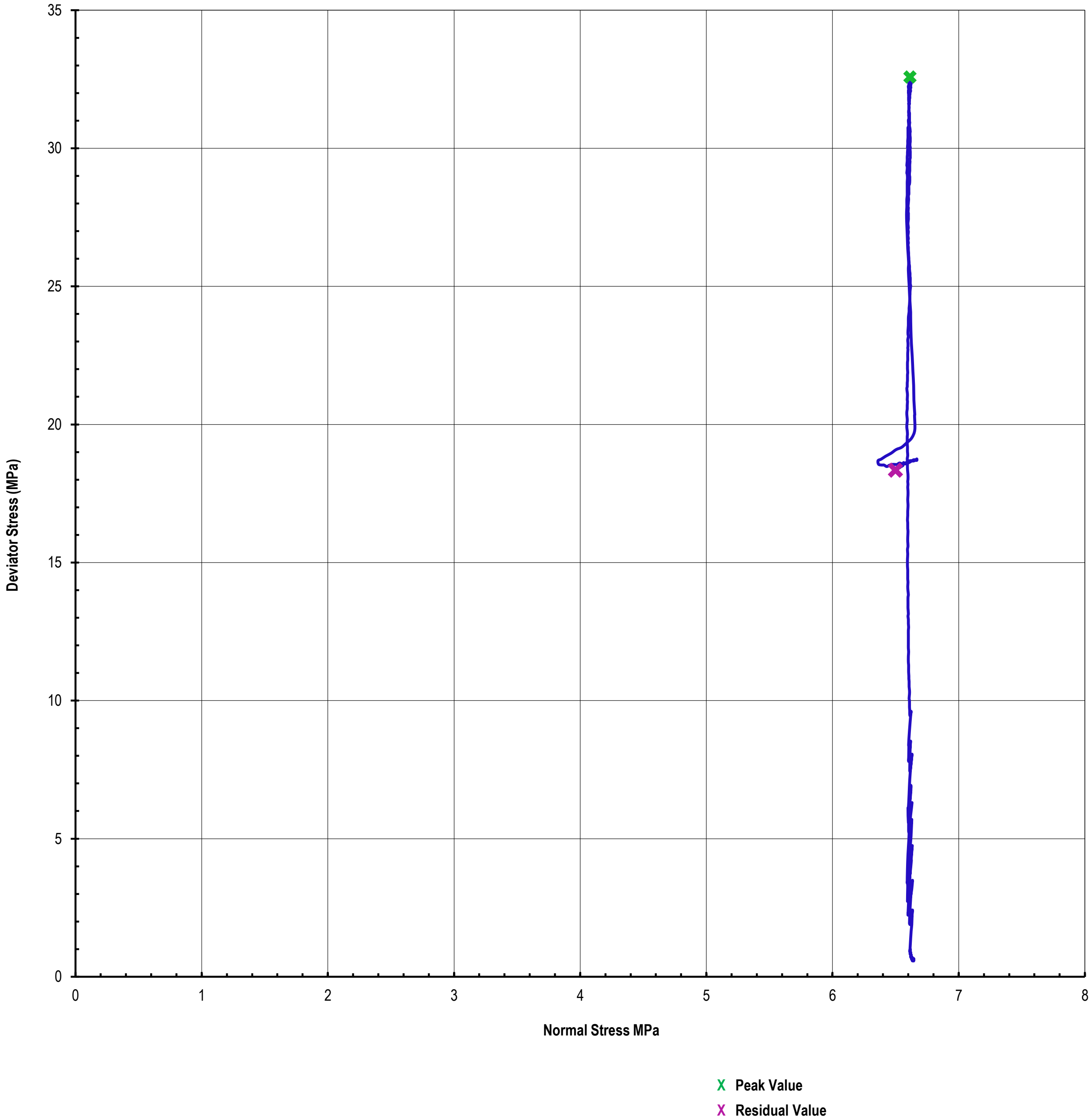
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110063-RTX

Deviator Stress vs Normal Stress Plot



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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
		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 (με)	18906				
Diametral Strain (με)	-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 (με)	21033				
Diametral Strain (με)	-11922				

Notes/Remarks:

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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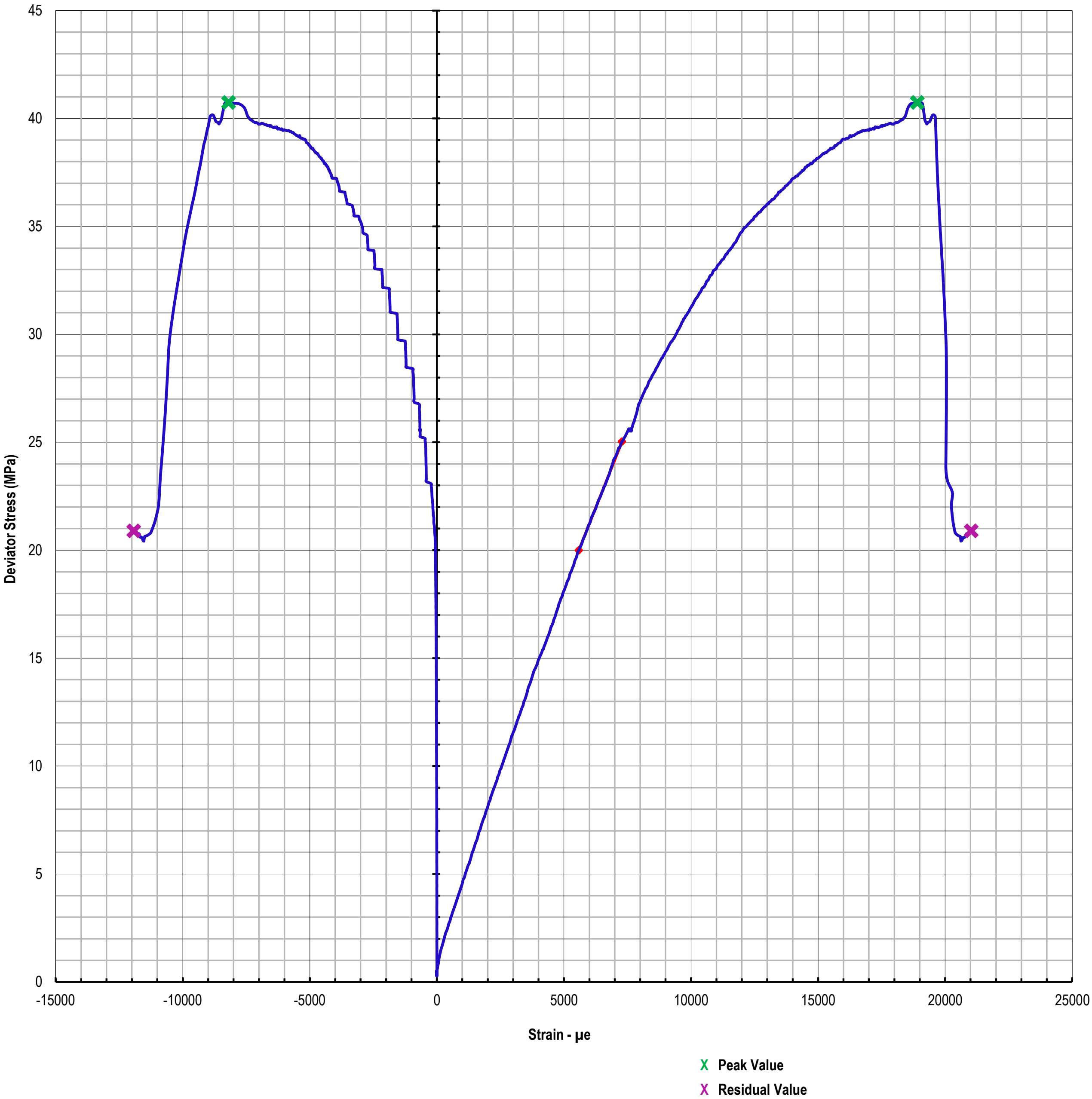
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

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

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

Deviator Stress vs Axial Strain Plots



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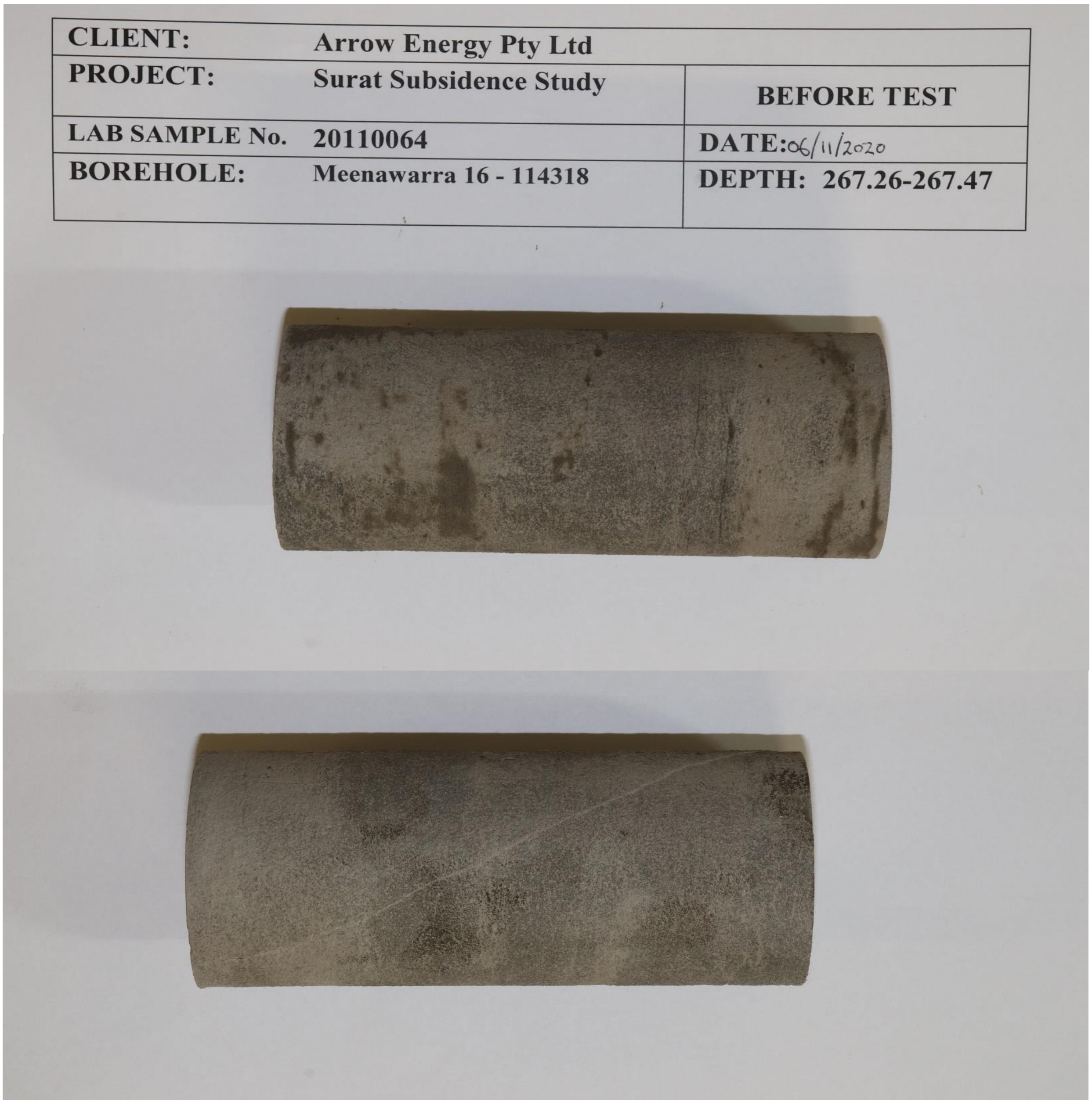
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos



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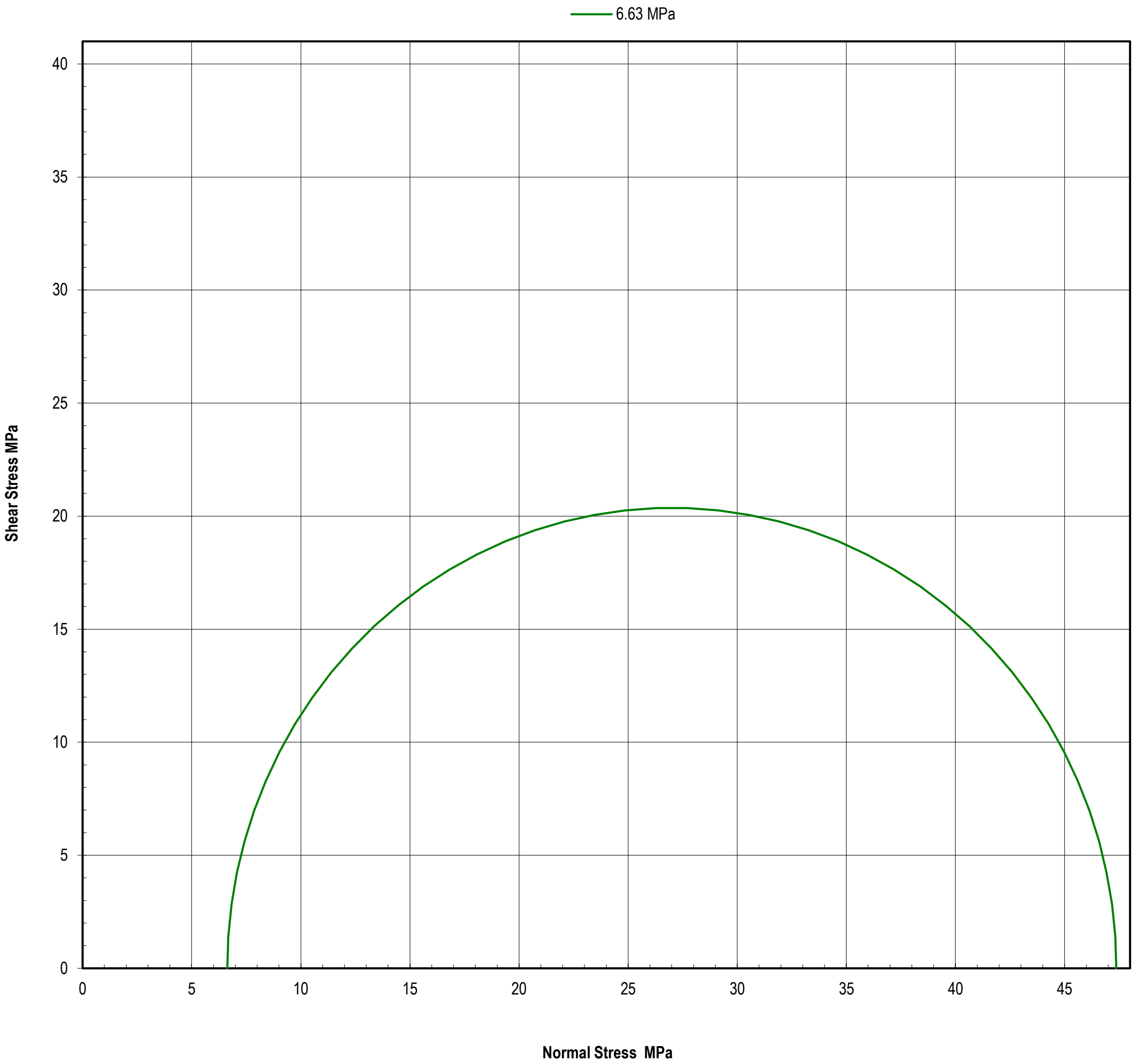
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Peak Stress Mohr Circle Plot



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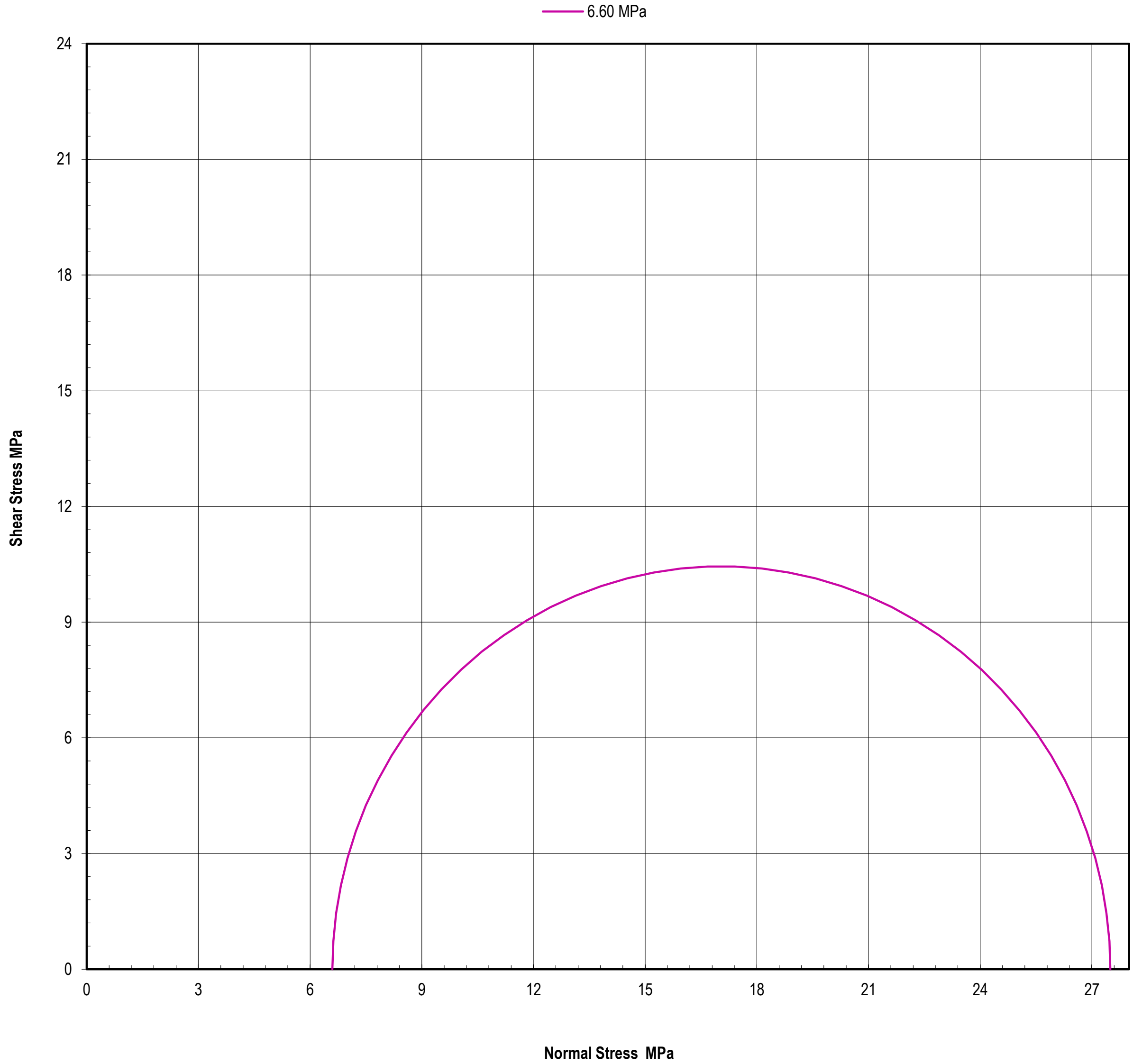
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Residual Stress Mohr Circle Plot



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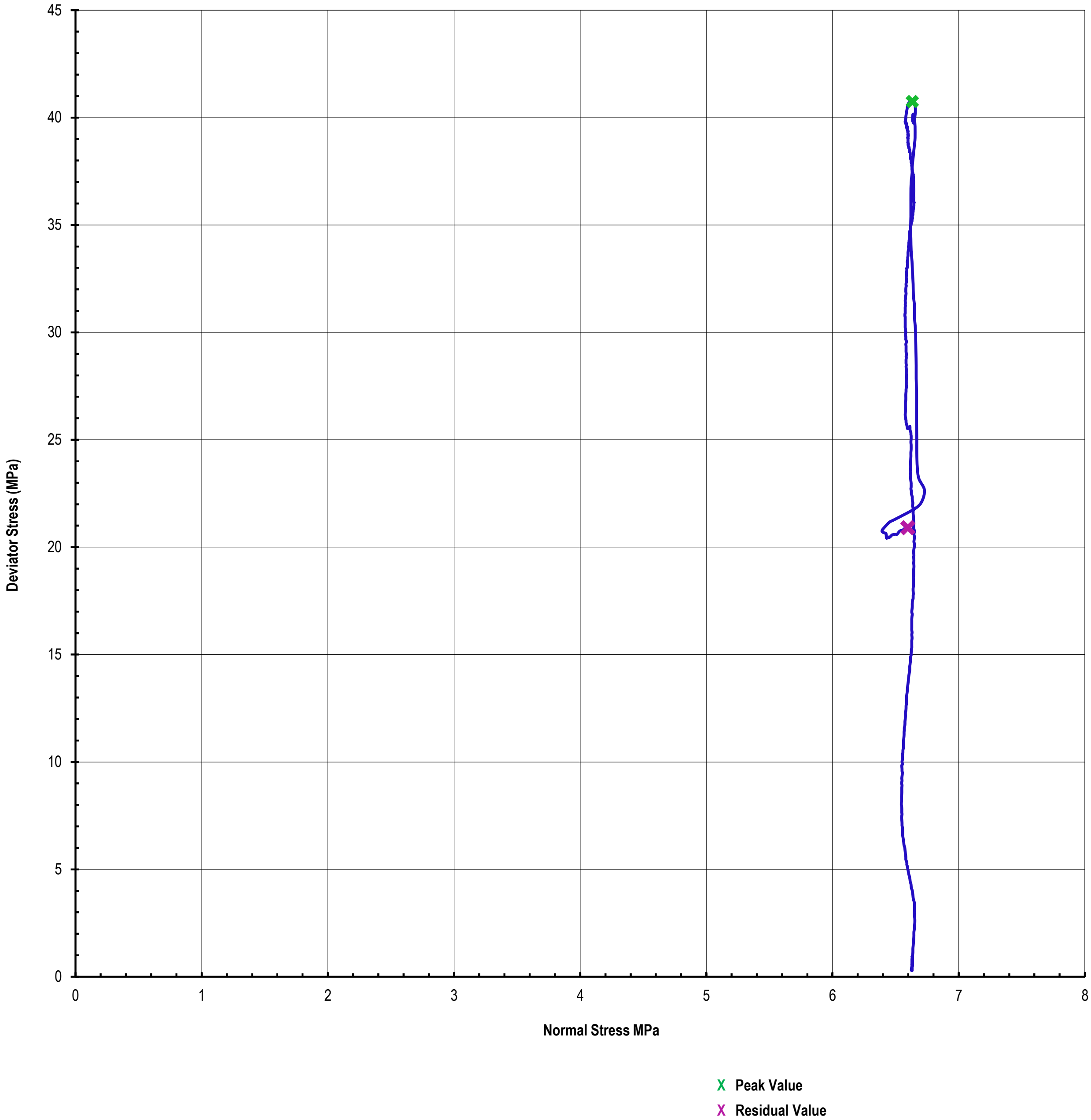
Client	Arrow Energy Pty Ltd	**Report No.**	20110064-RTX

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.**	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:

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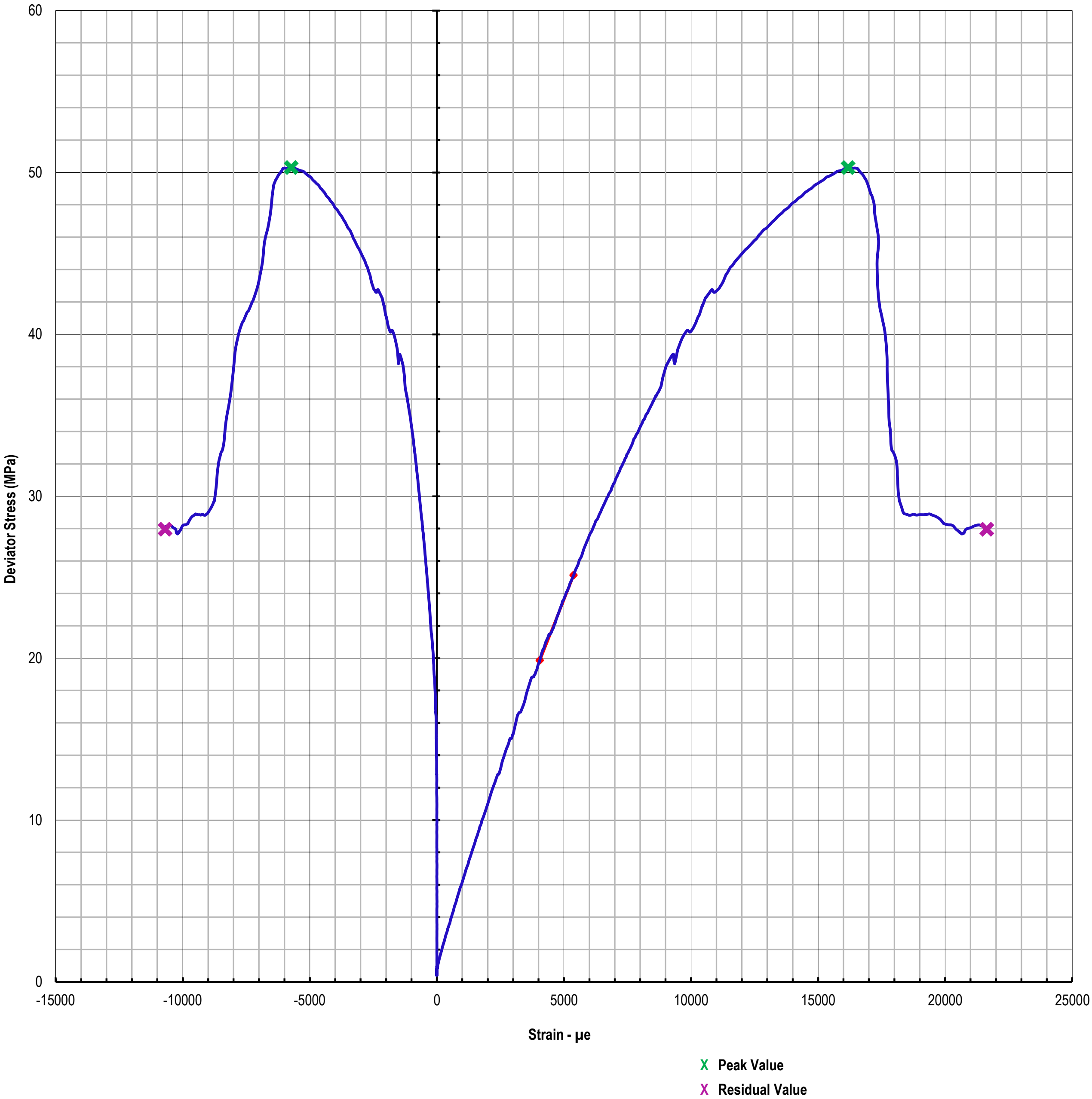
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Deviator Stress vs Axial Strain Plots



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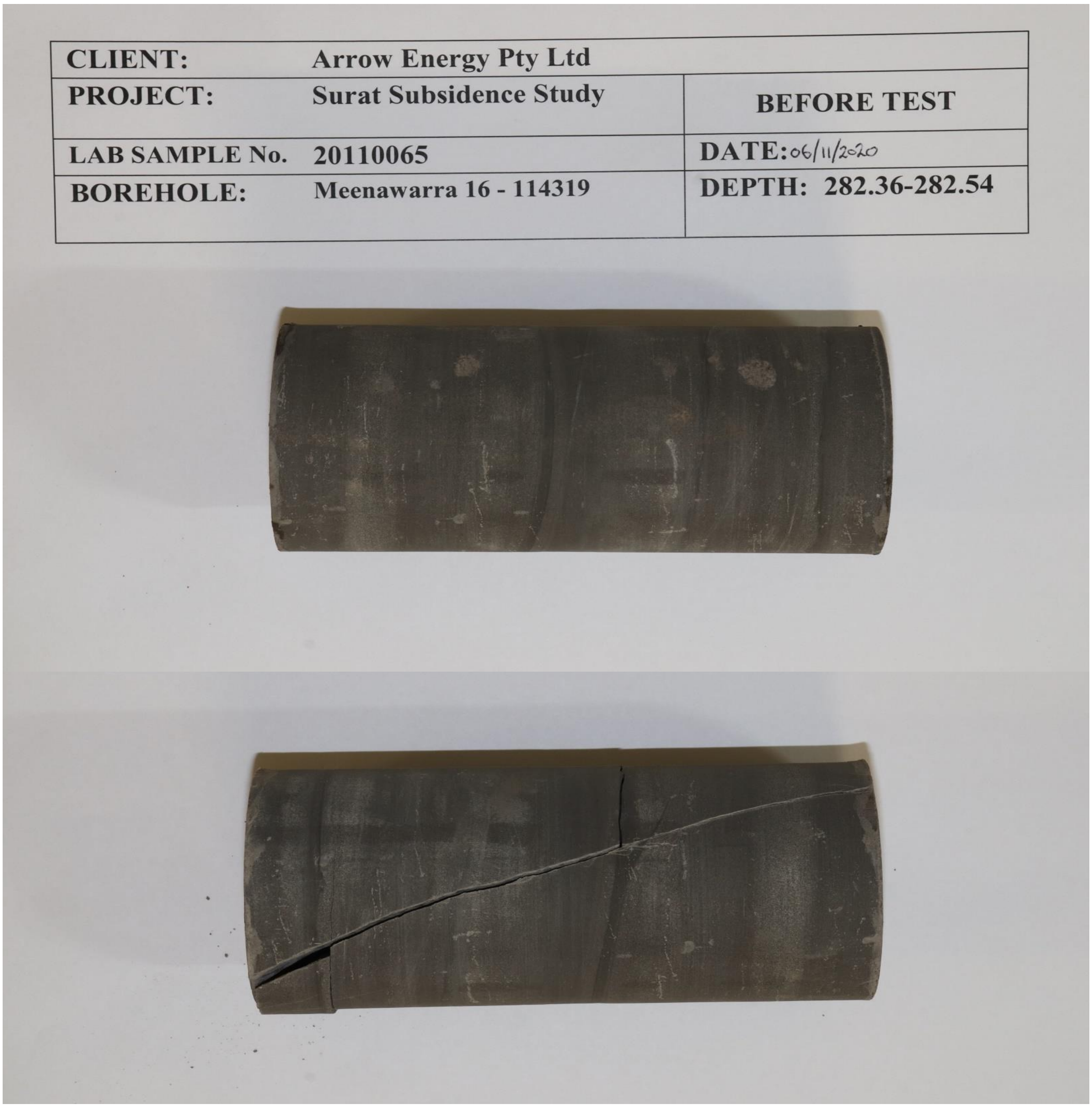
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos



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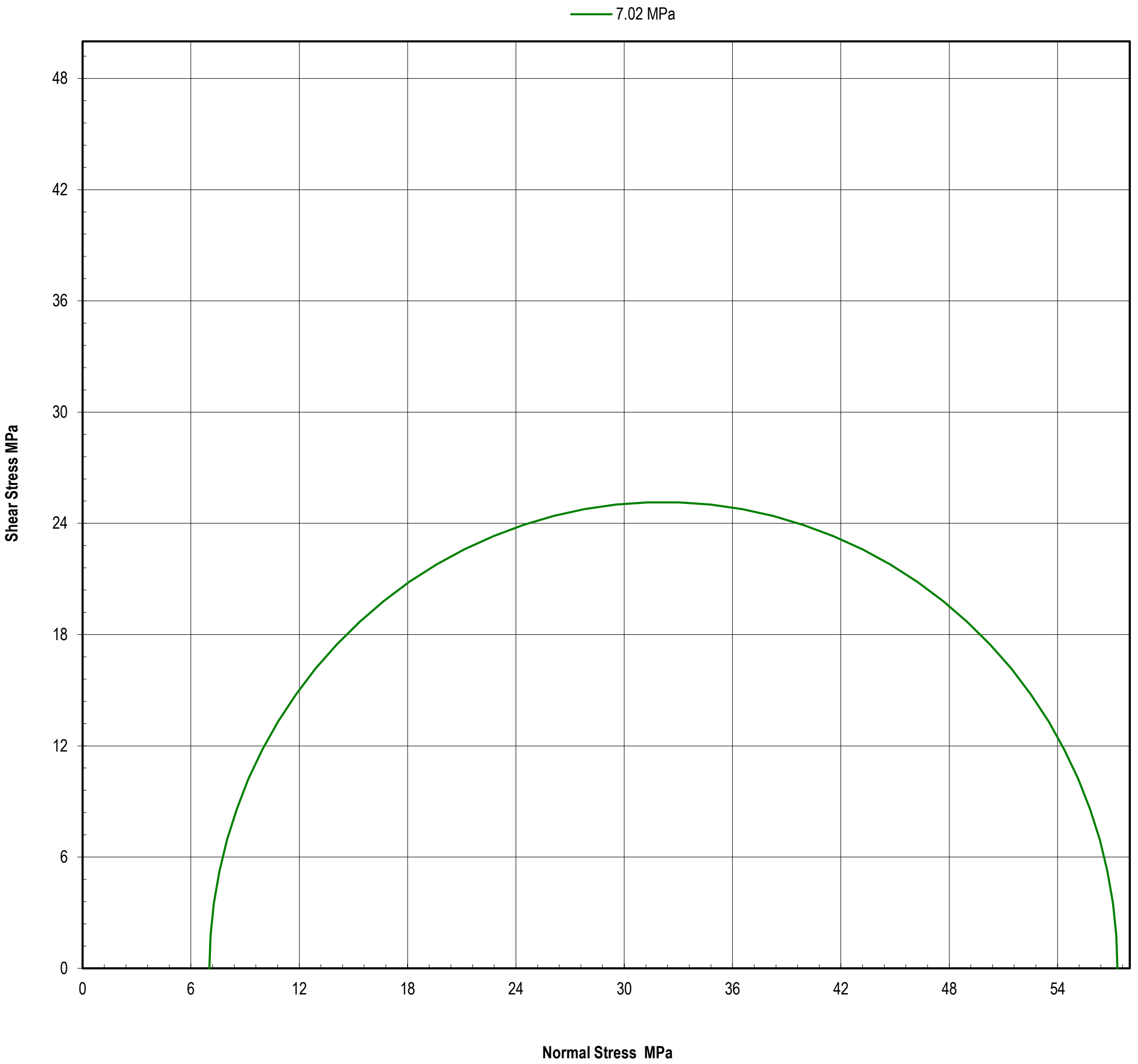
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

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

Peak Stress Mohr Circle Plot



Notes/Remarks:

Graph not to scale

Sample/s supplied by client

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Authorised Signatory

C. Purvis

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

ASTM D7012

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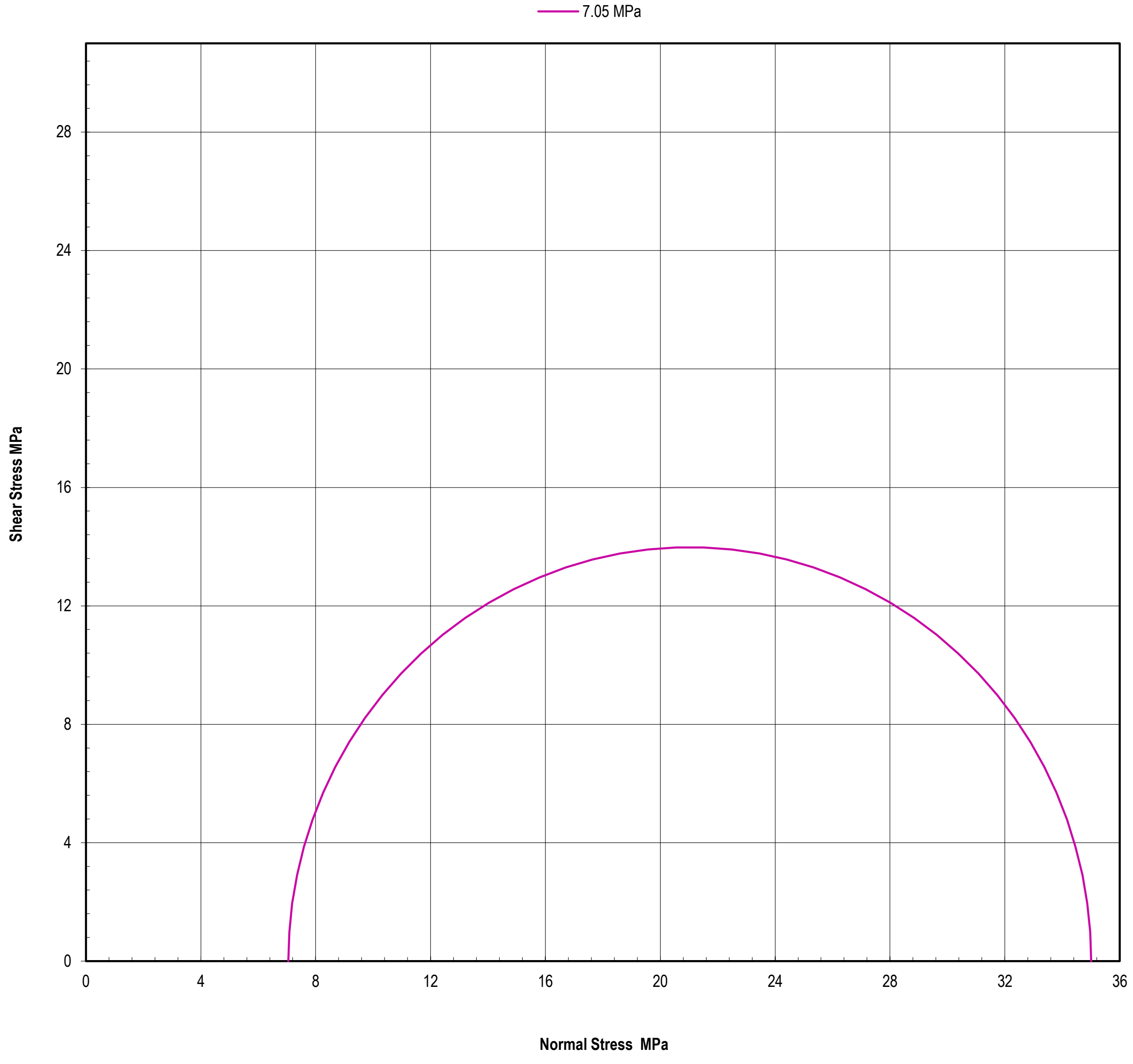
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Residual Stress Mohr Circle Plot



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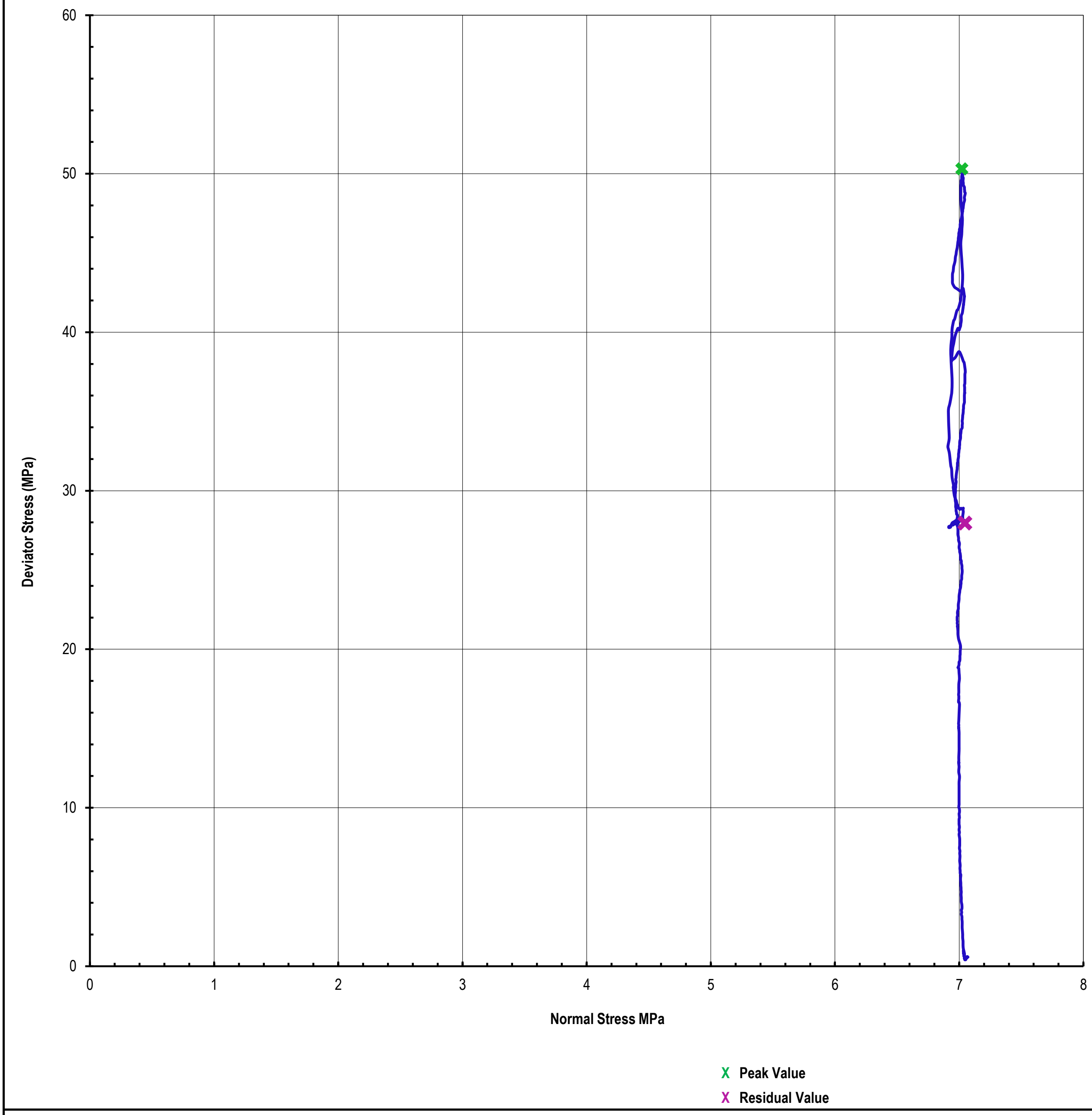
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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 (µe)	10264				
Diametral Strain (µe)	-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 (µe)	17193				
Diametral Strain (µe)	-8062				

Notes/Remarks:

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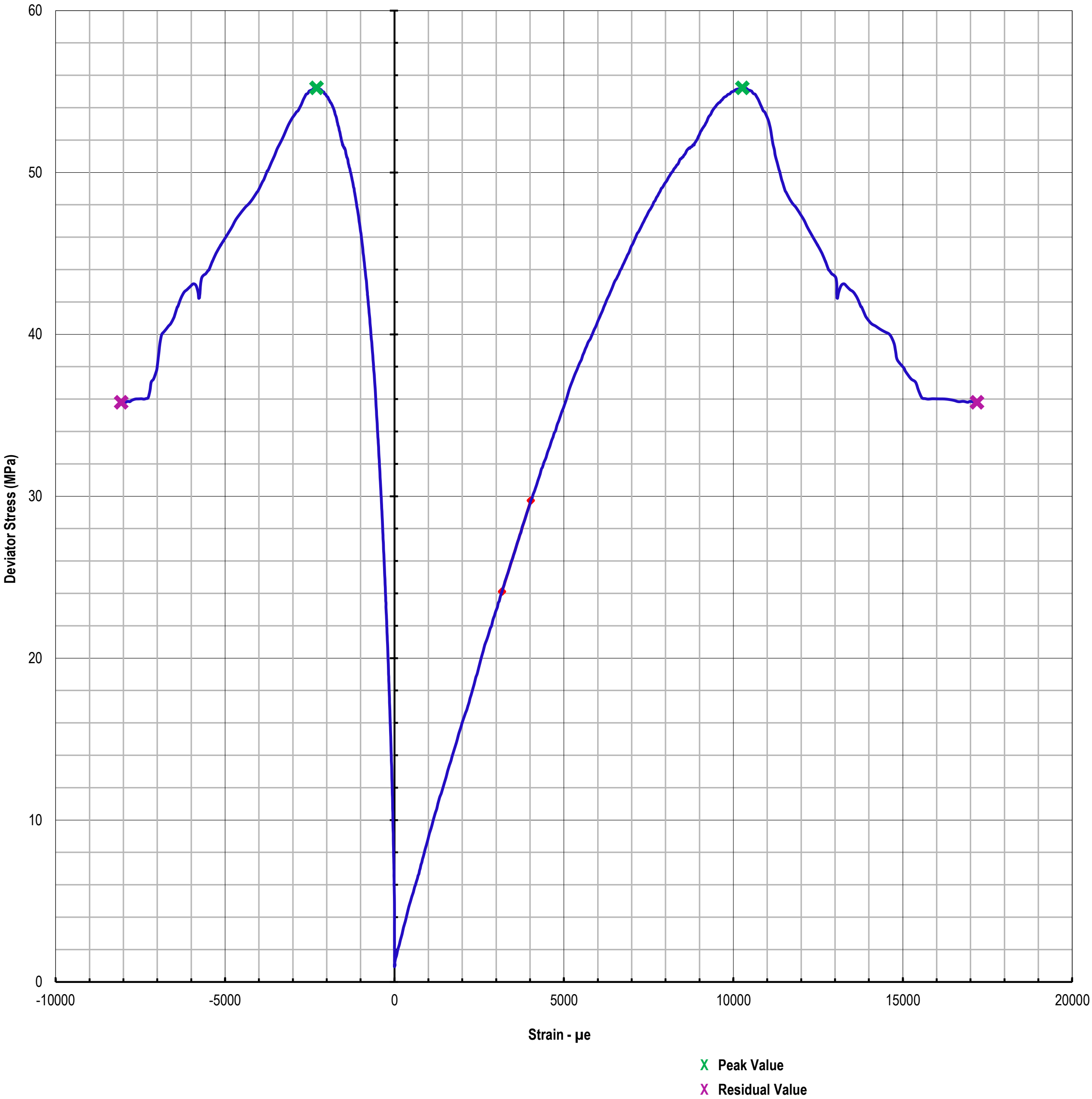
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Deviator Stress vs Axial Strain Plots



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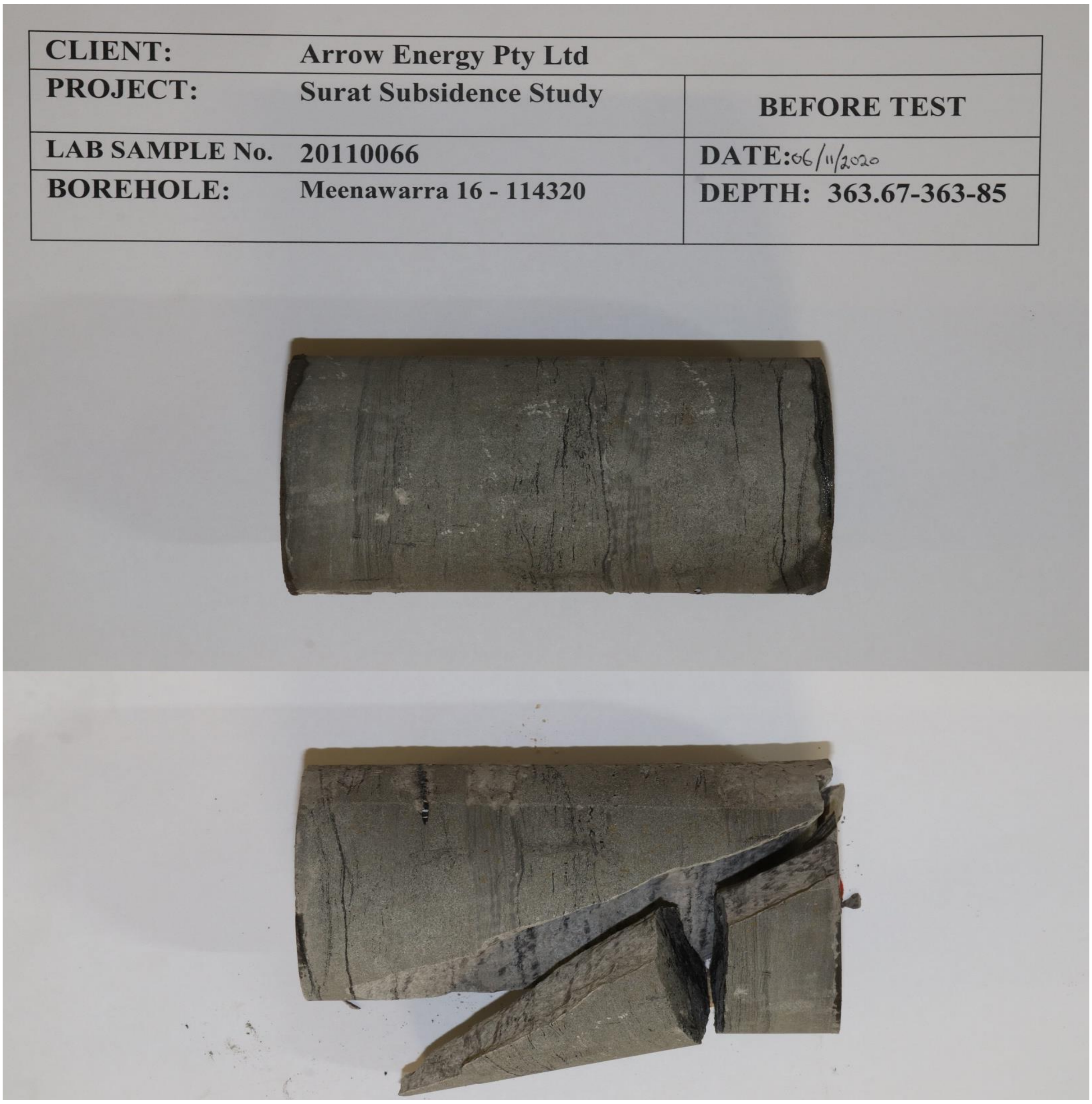
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos



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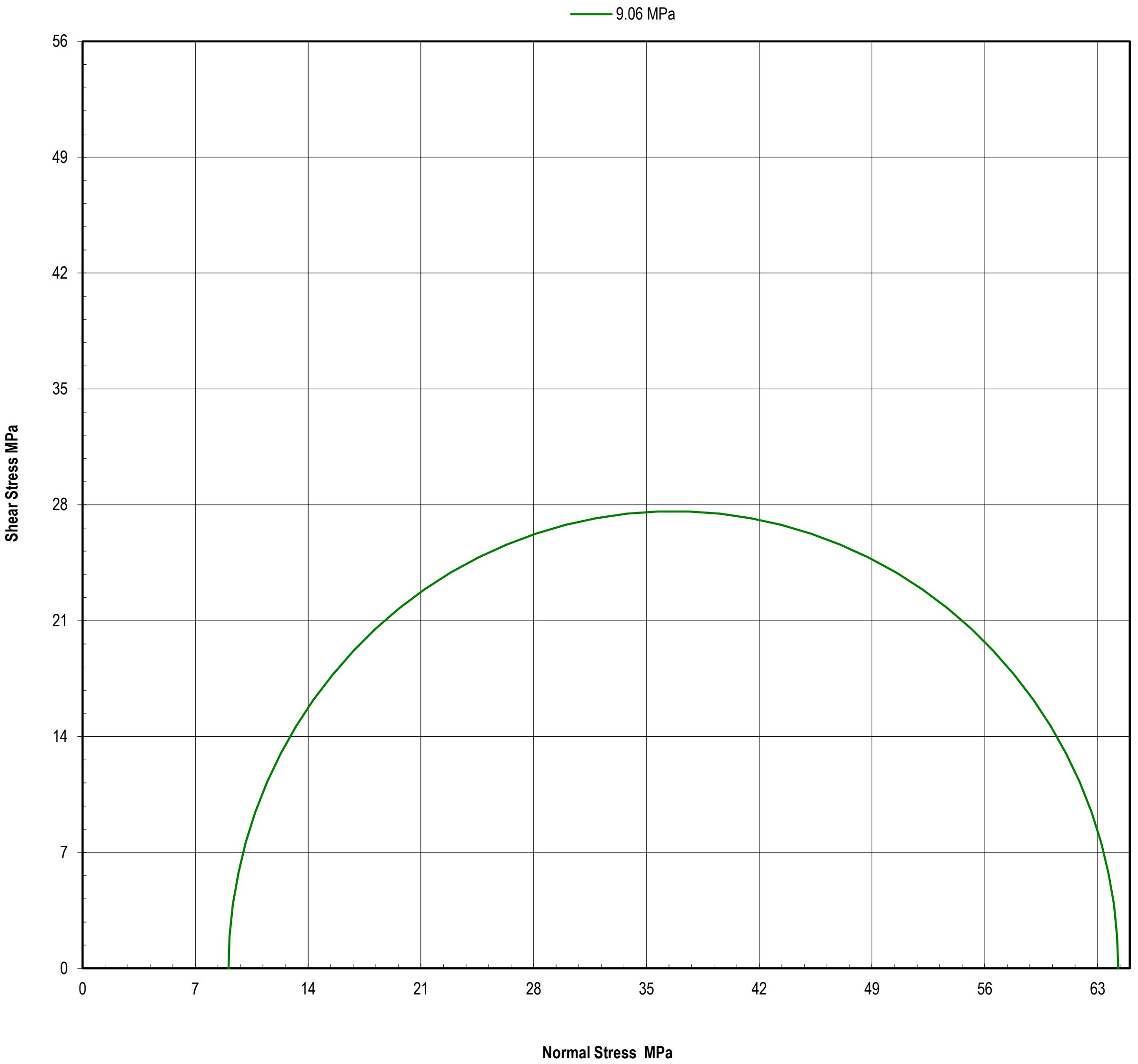
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Peak Stress Mohr Circle Plot



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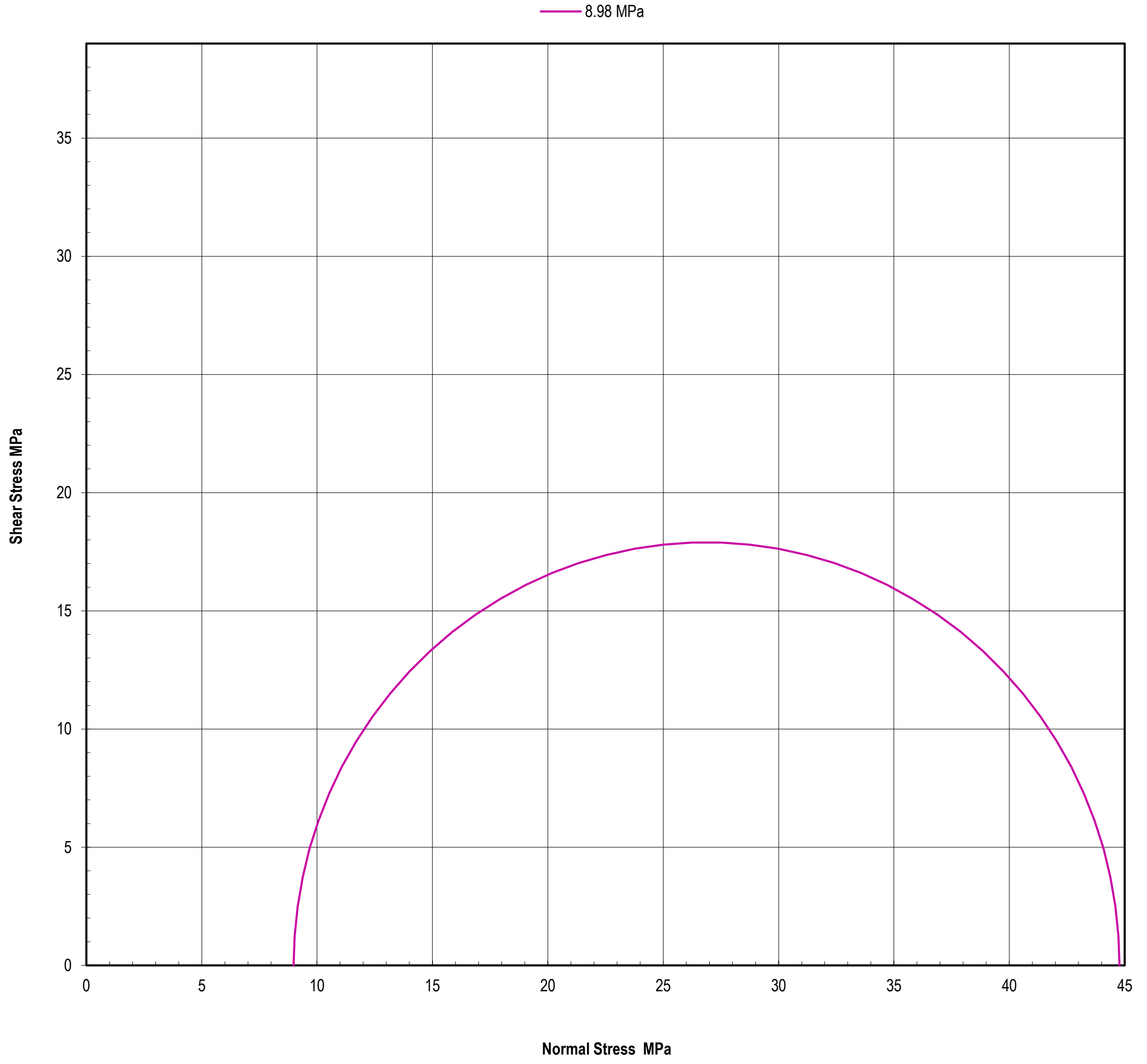
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Residual Stress Mohr Circle Plot



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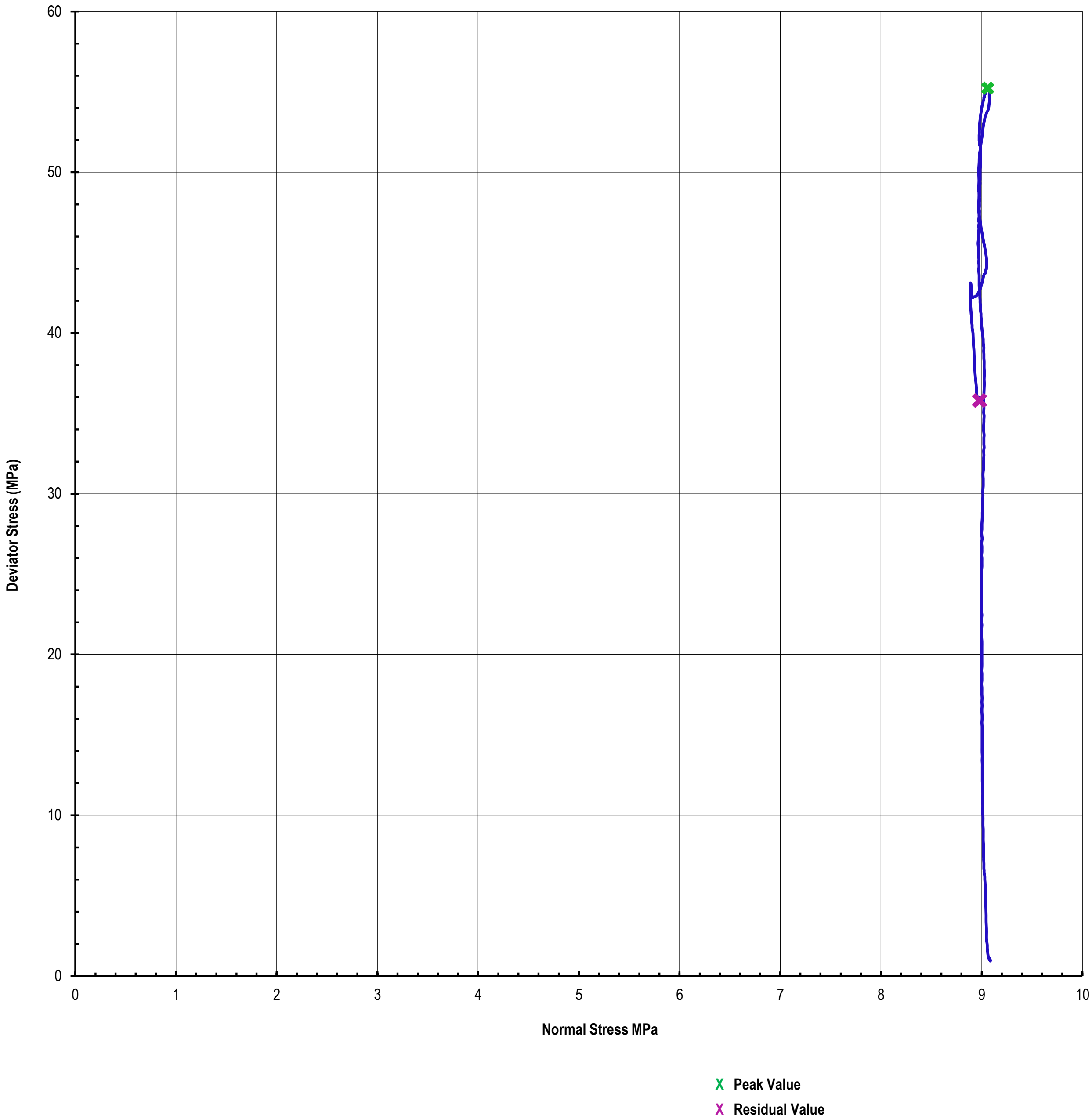
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110066-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.**	20110067-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 - 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:

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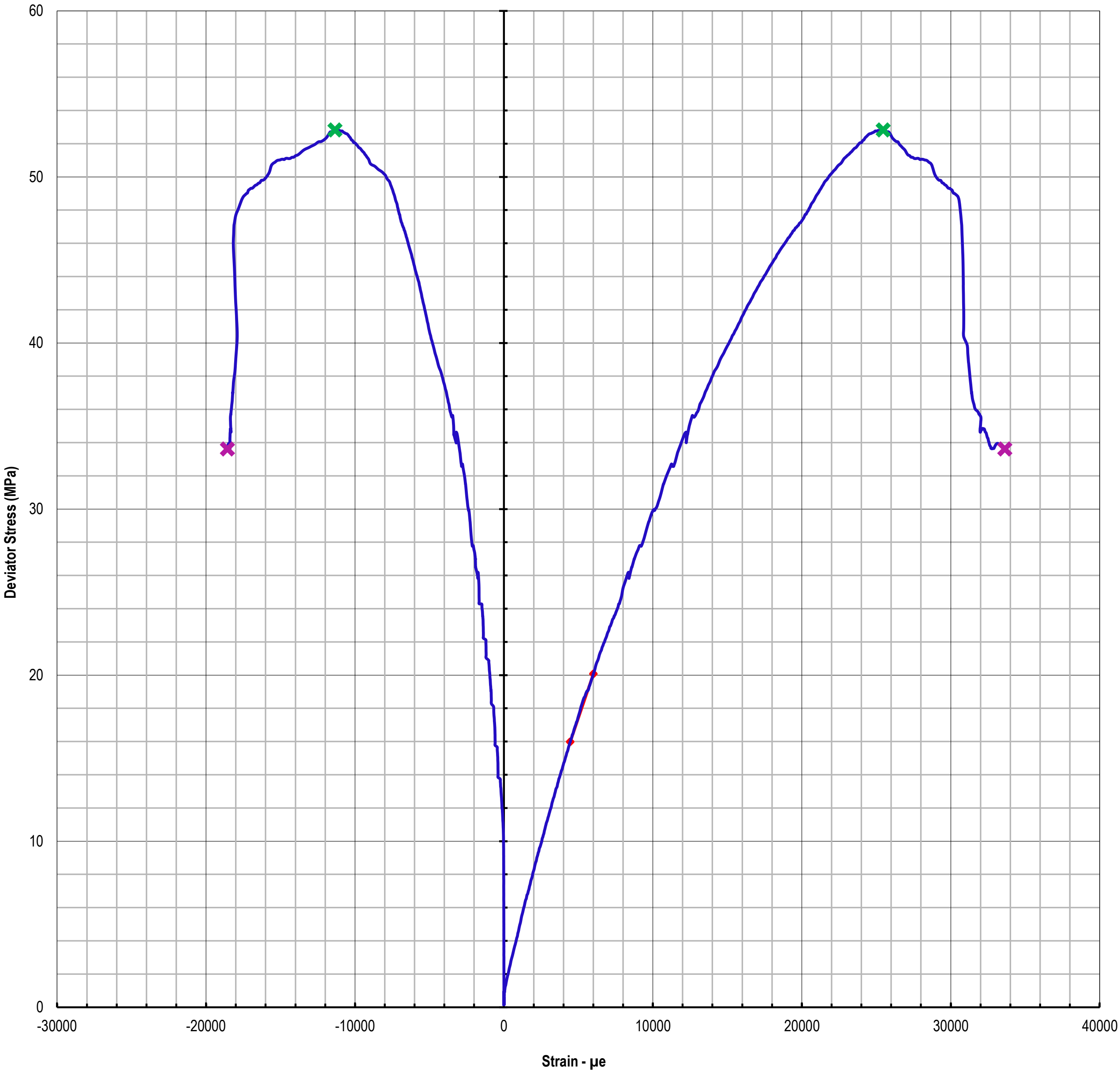
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110067-RTX

Deviator Stress vs Axial Strain Plots



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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

Notes/Remarks:

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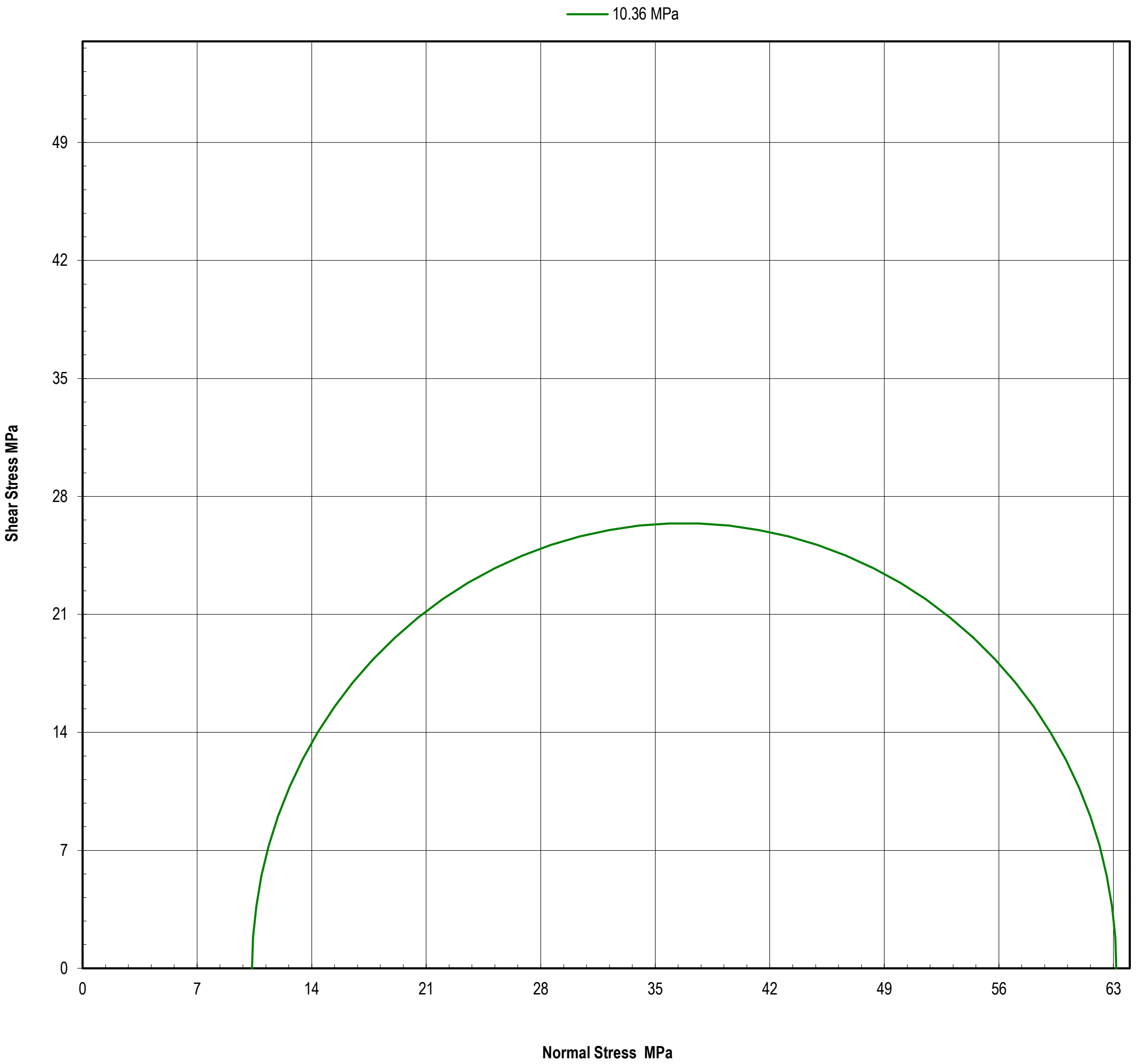
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110067-RTX

Peak Stress Mohr Circle Plot



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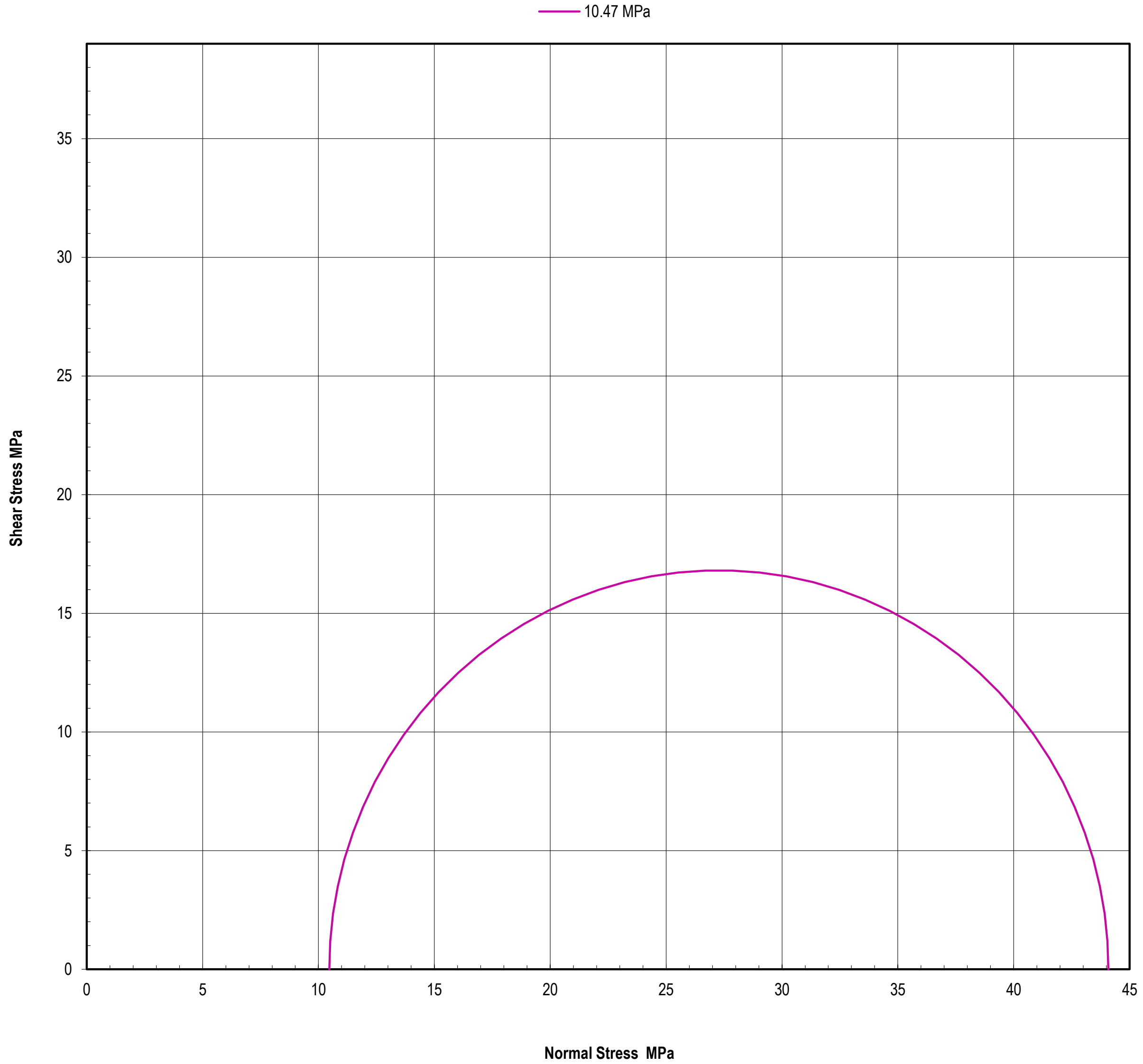
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110067-RTX

Residual Stress Mohr Circle Plot



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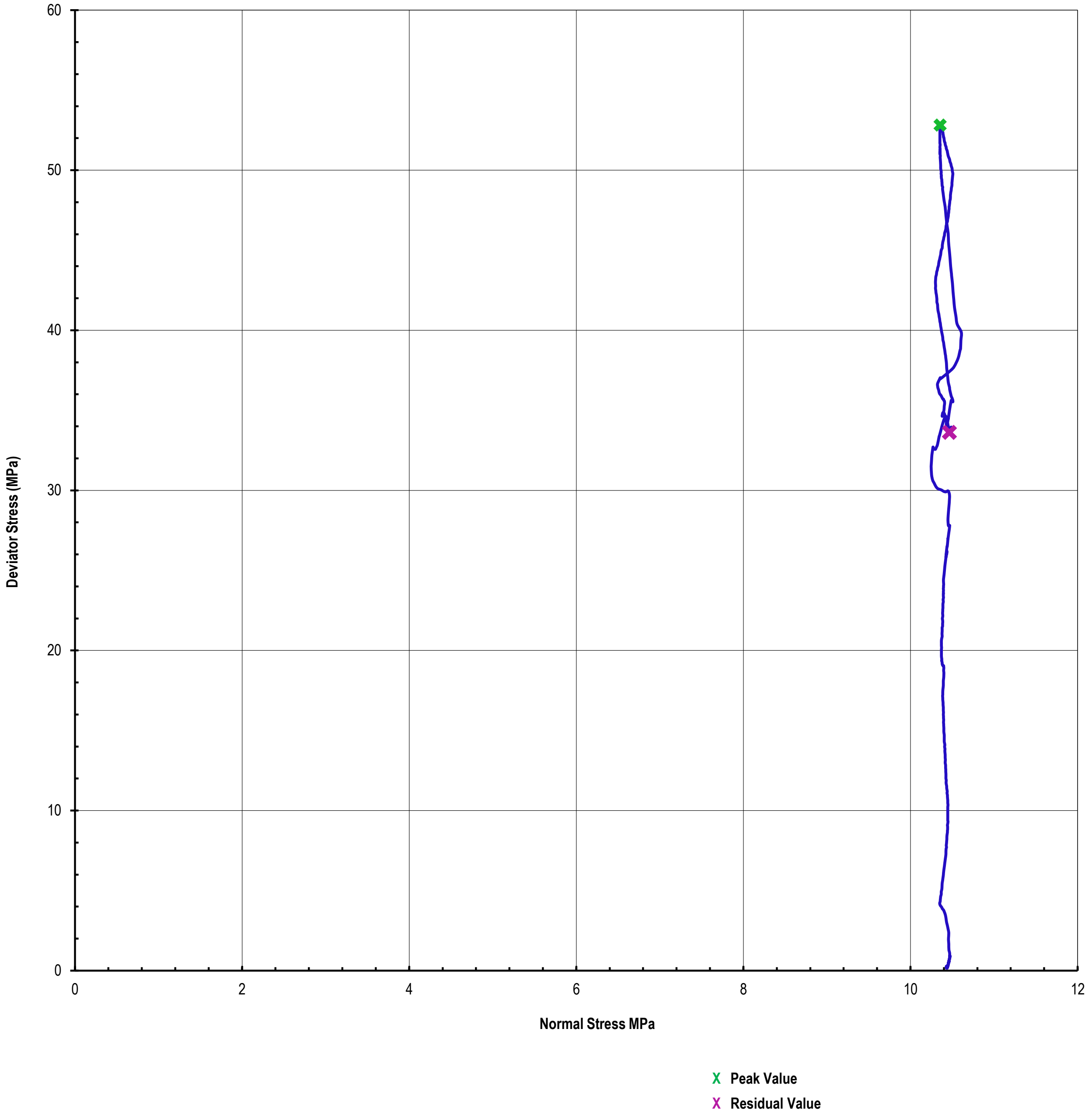
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	20110067-RTX

Deviator Stress vs Normal Stress Plot



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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 (με)	25950				
Diametral Strain (με)	-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 (με)	32932				
Diametral Strain (με)	-29167				

Notes/Remarks:

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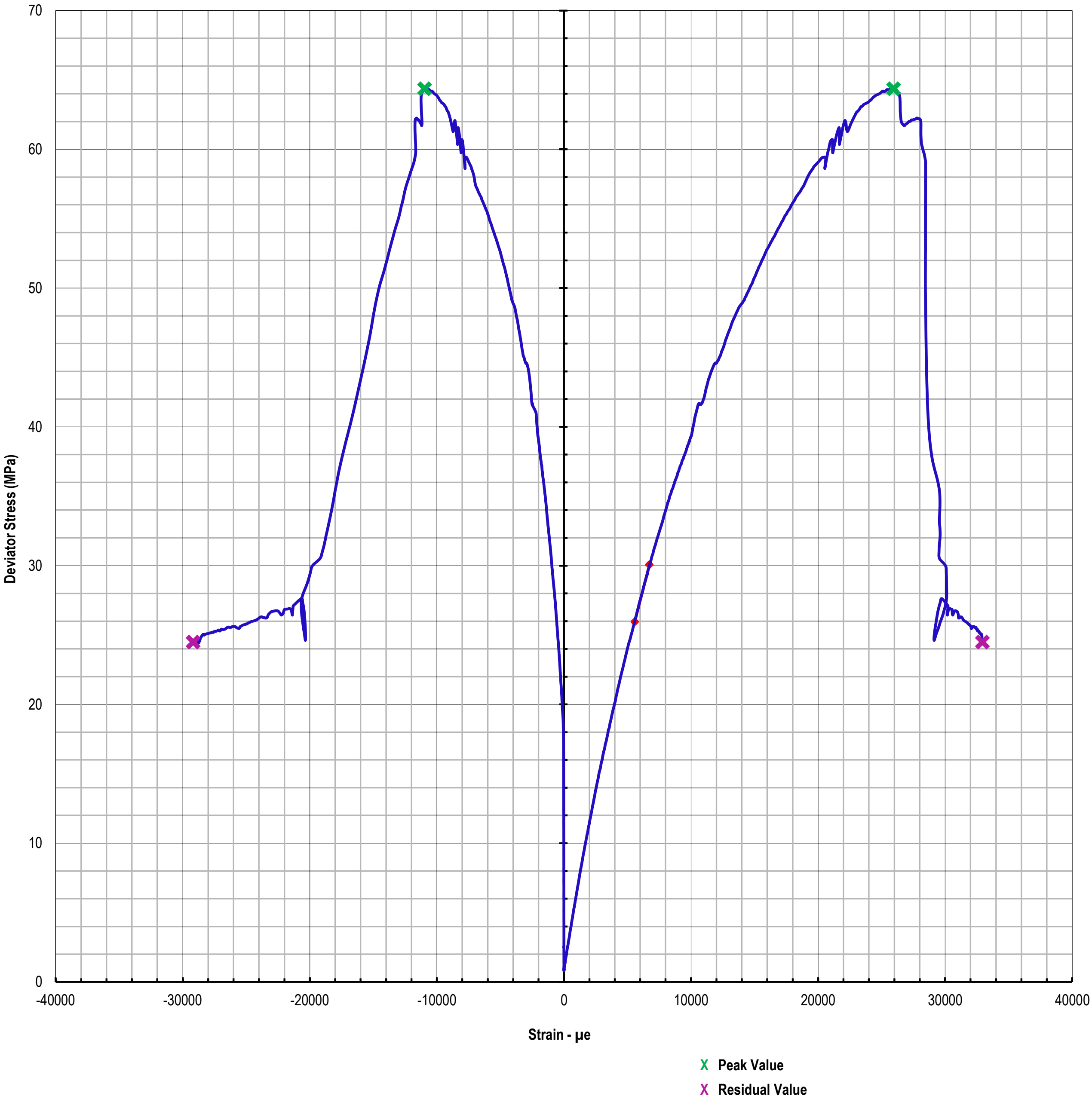
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Deviator Stress vs Axial Strain Plots



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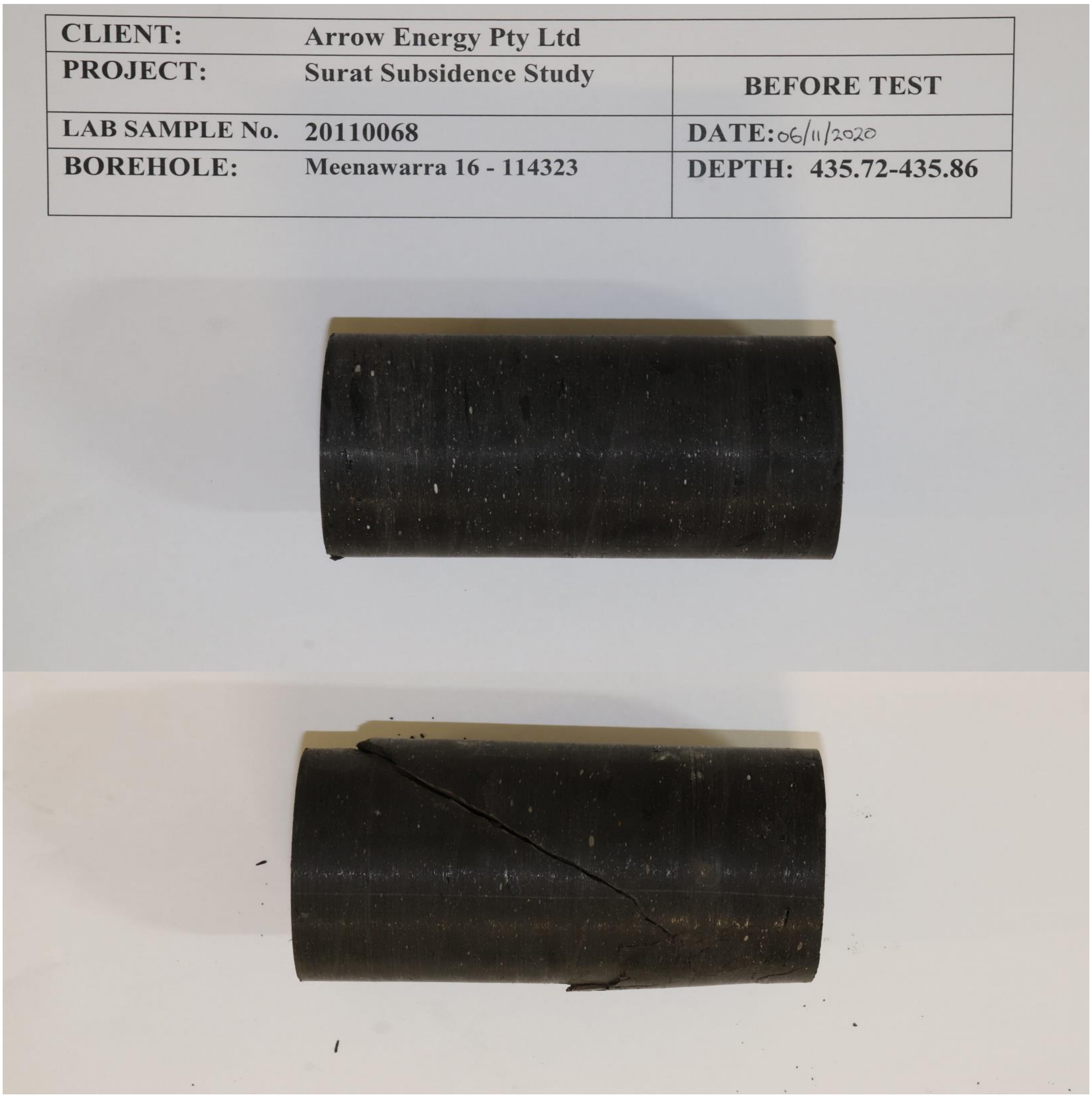
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos



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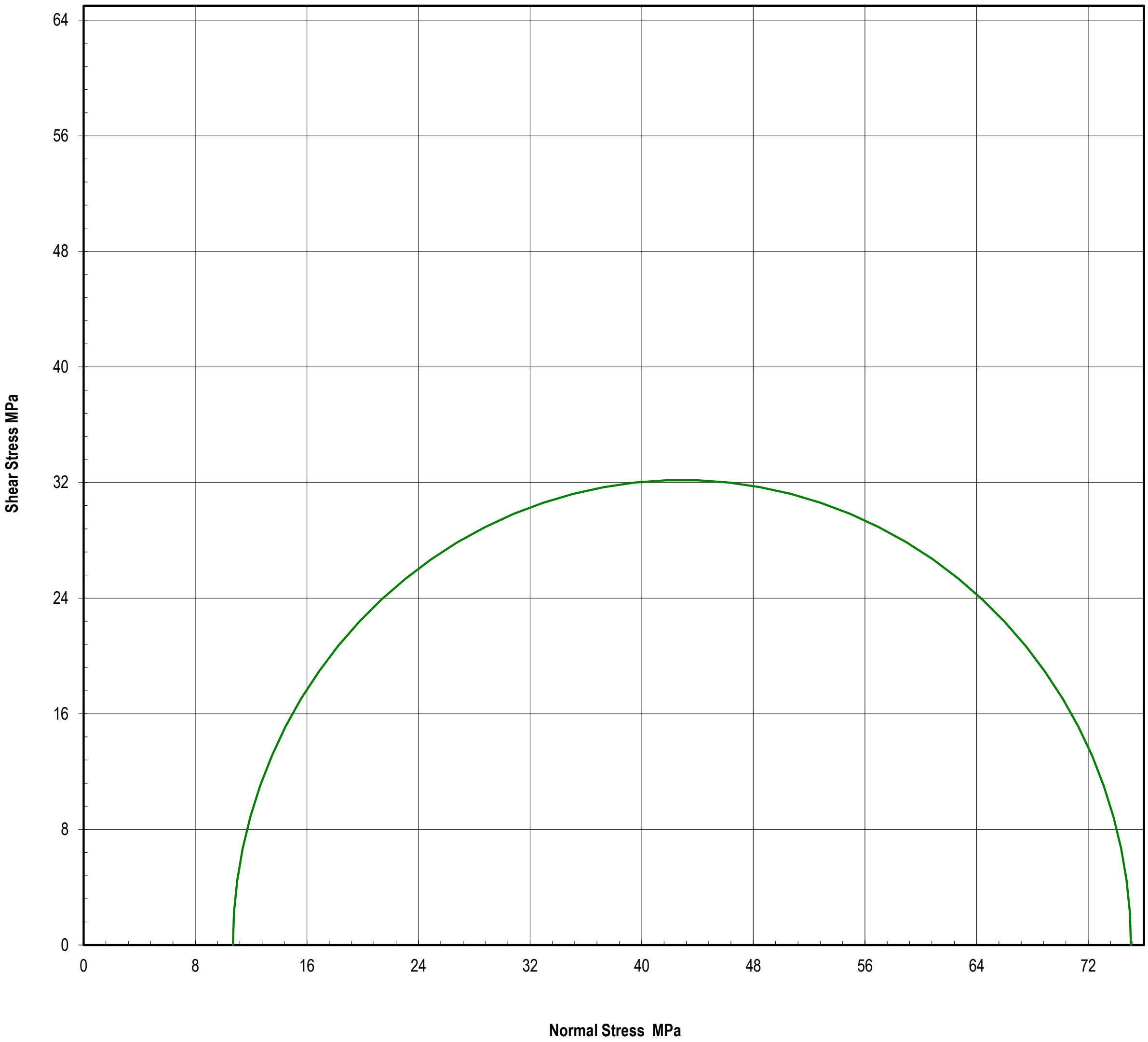
Peak Stress Mohr Circle Plot



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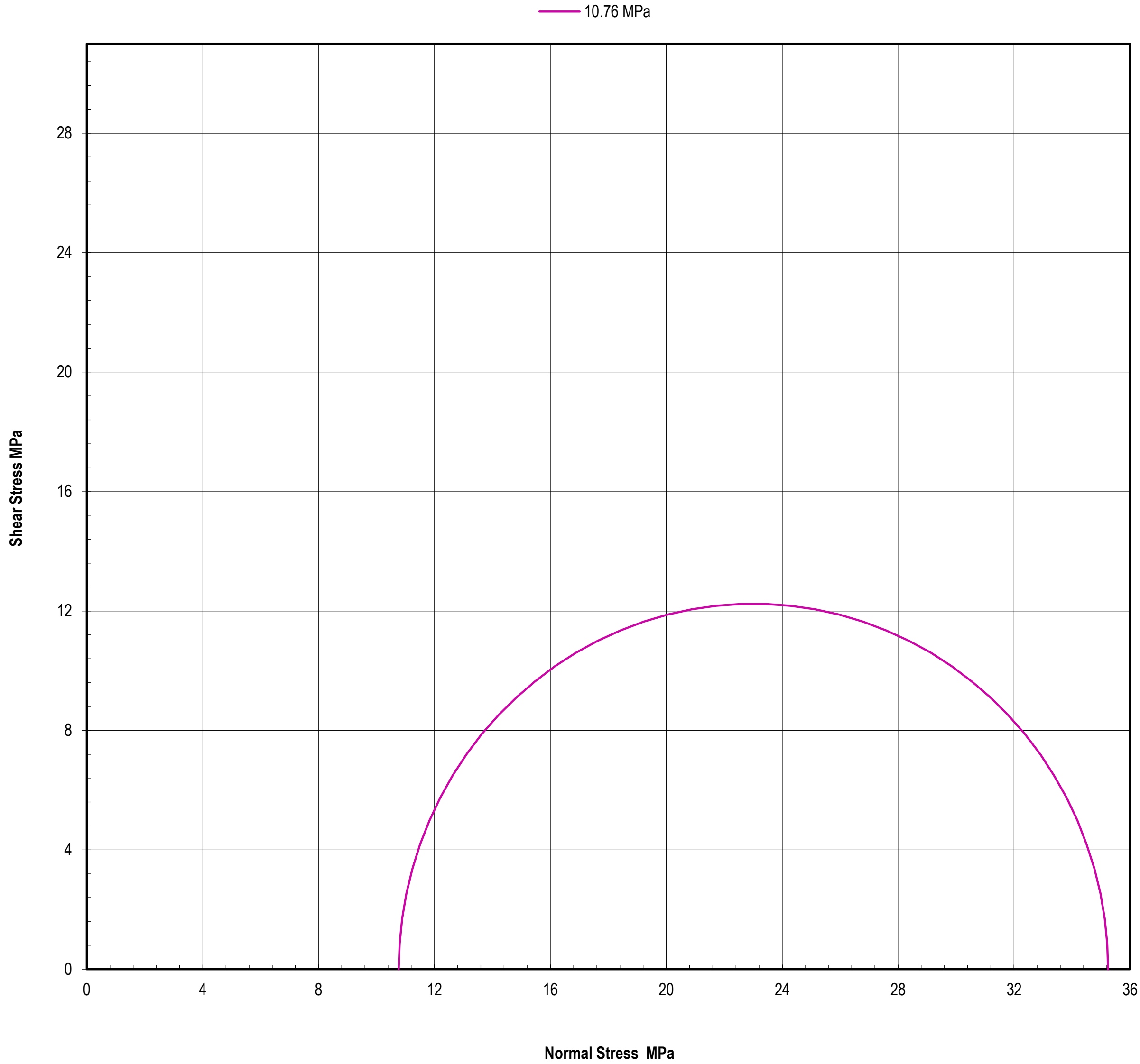
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

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

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

Residual Stress Mohr Circle Plot



Notes/Remarks:

Graph not to scale

Sample/s supplied by client

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Authorised Signatory

C. Purvis

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STRENGTH OF ROCK MATERIAL IN TRIAXIAL COMPRESSION

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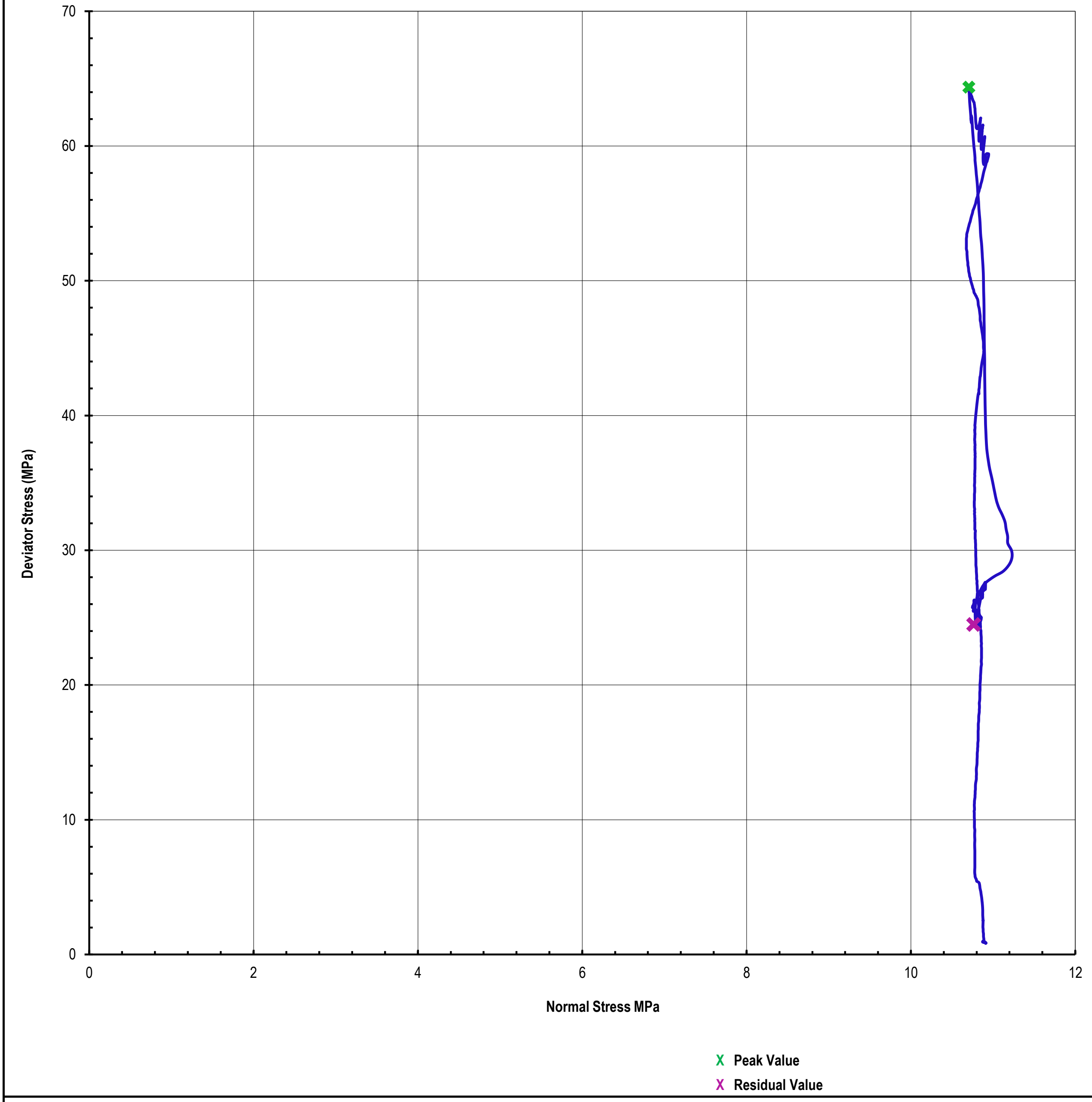
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client	Arrow Energy Pty Ltd	**Report No.**	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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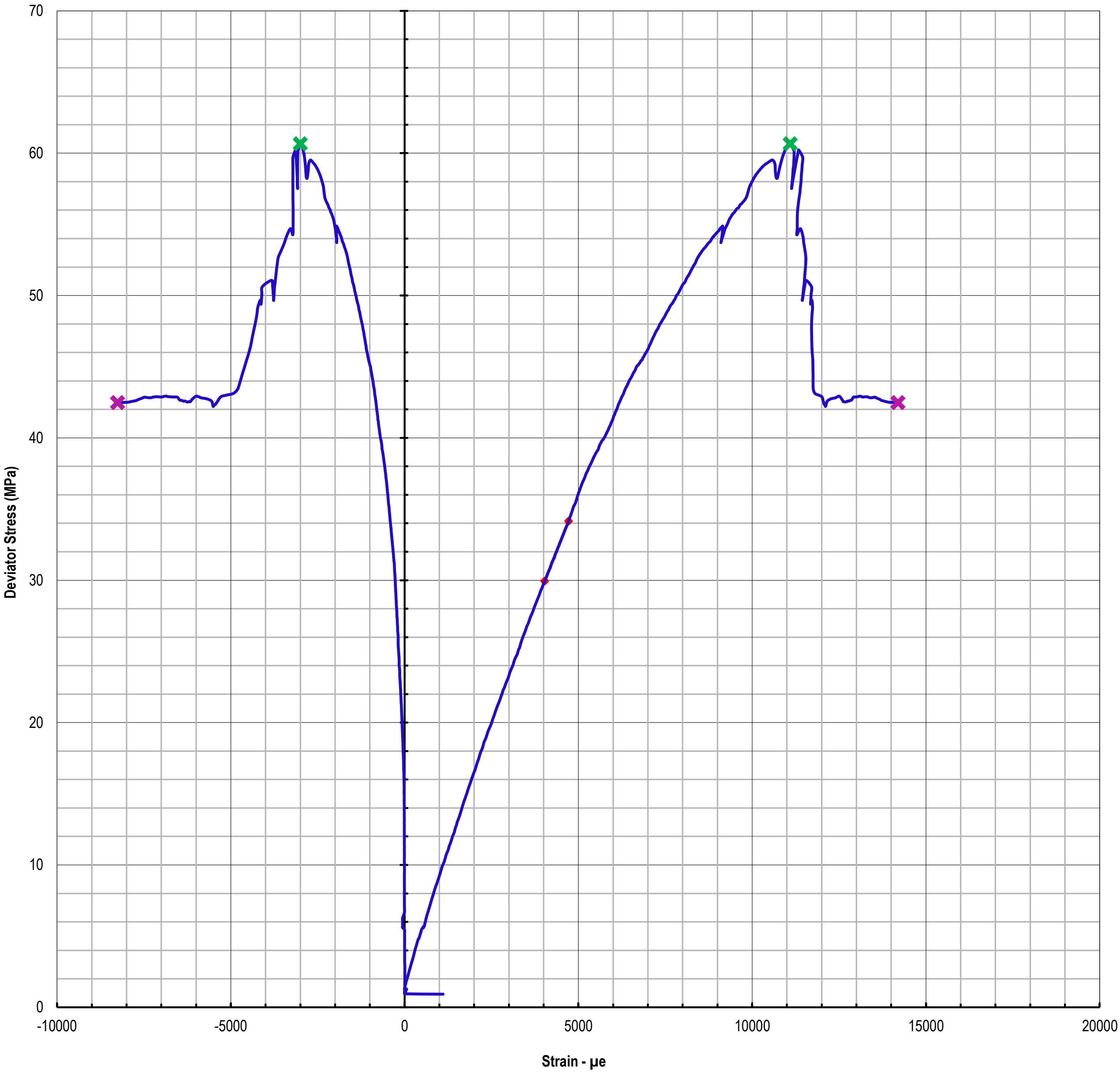
Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

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



Notes/Remarks:

Graph not to scale

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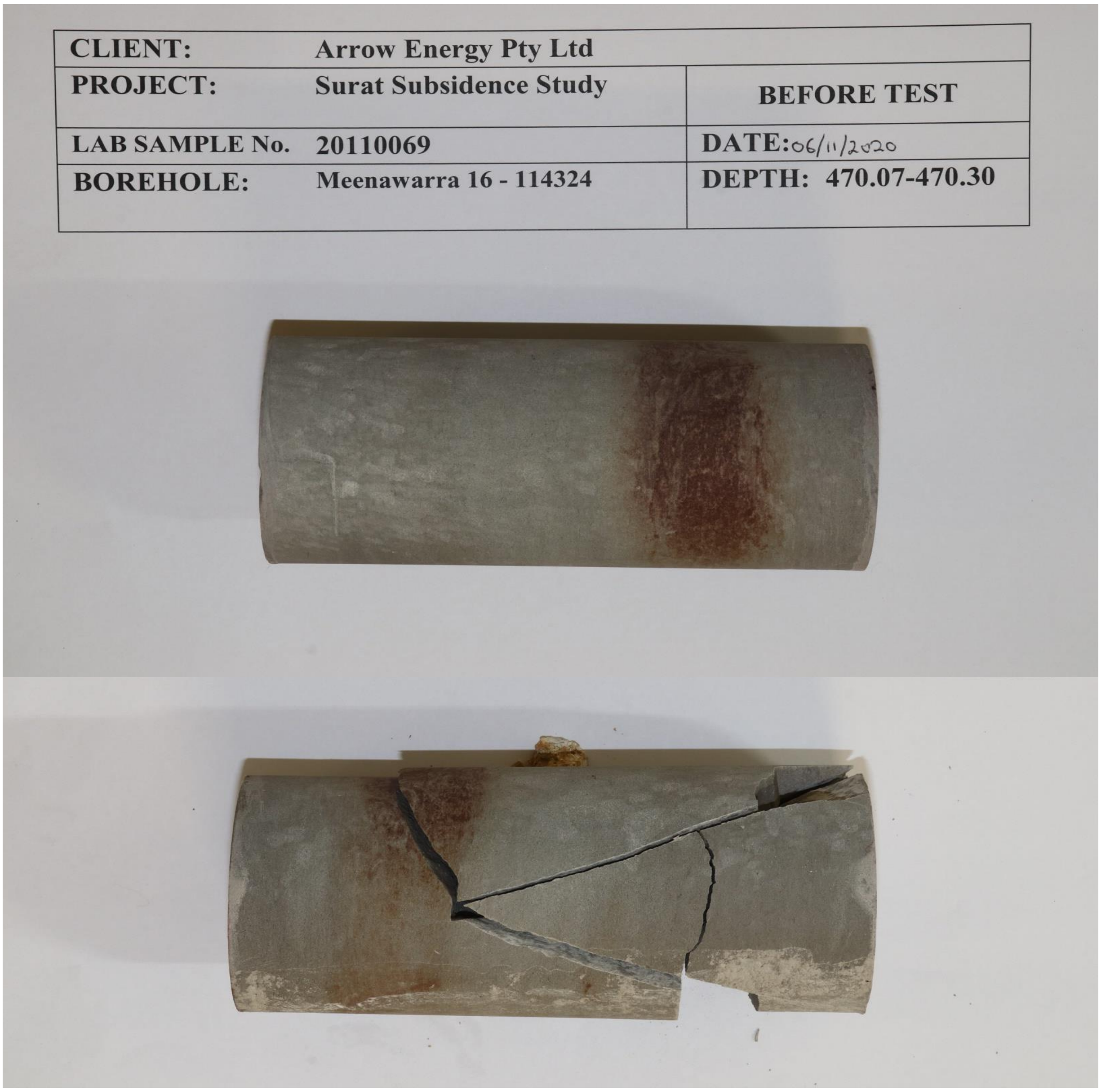
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos



Notes/Remarks:

Photo not to scale

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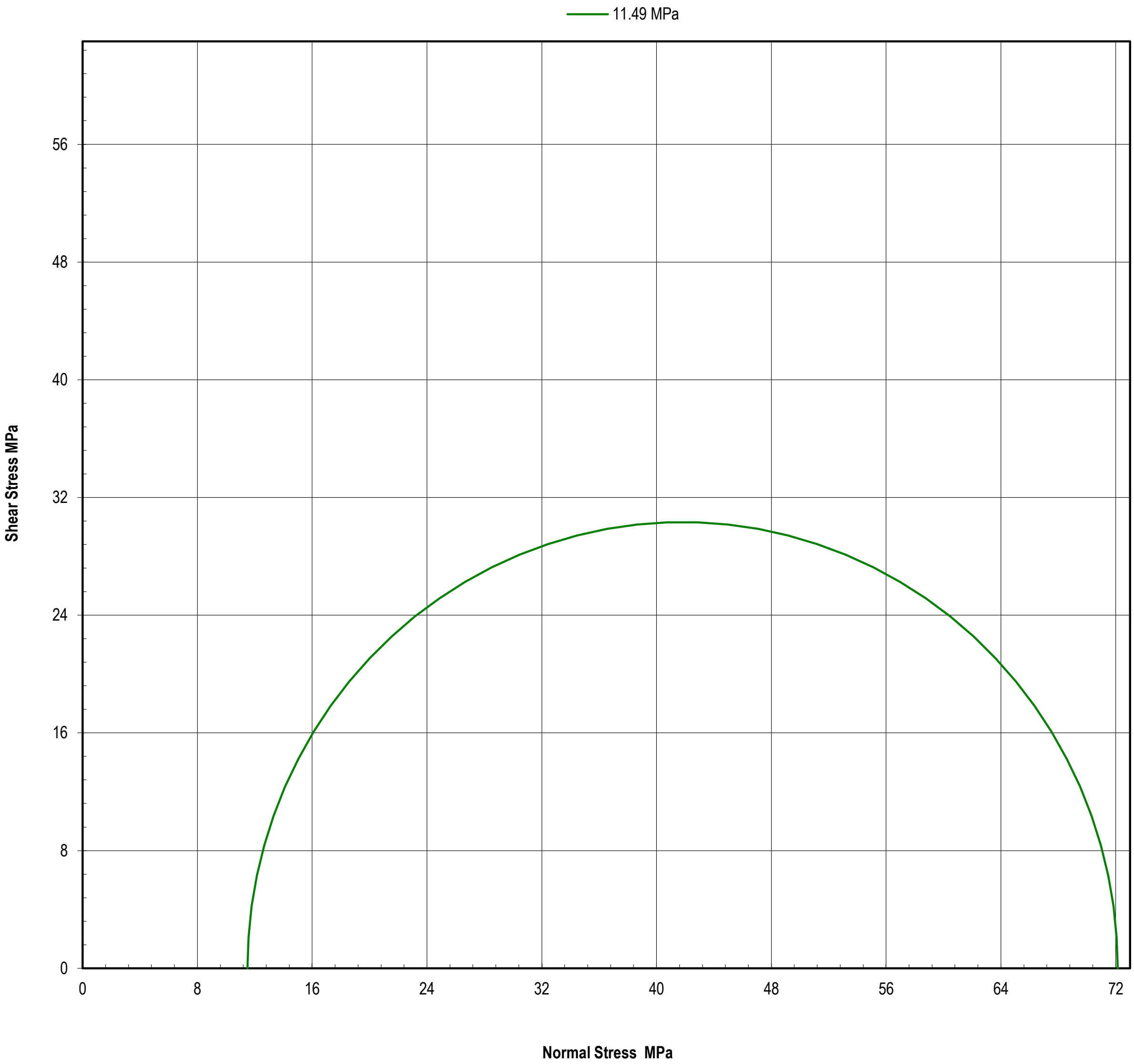
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110069-RTX

Peak Stress Mohr Circle Plot



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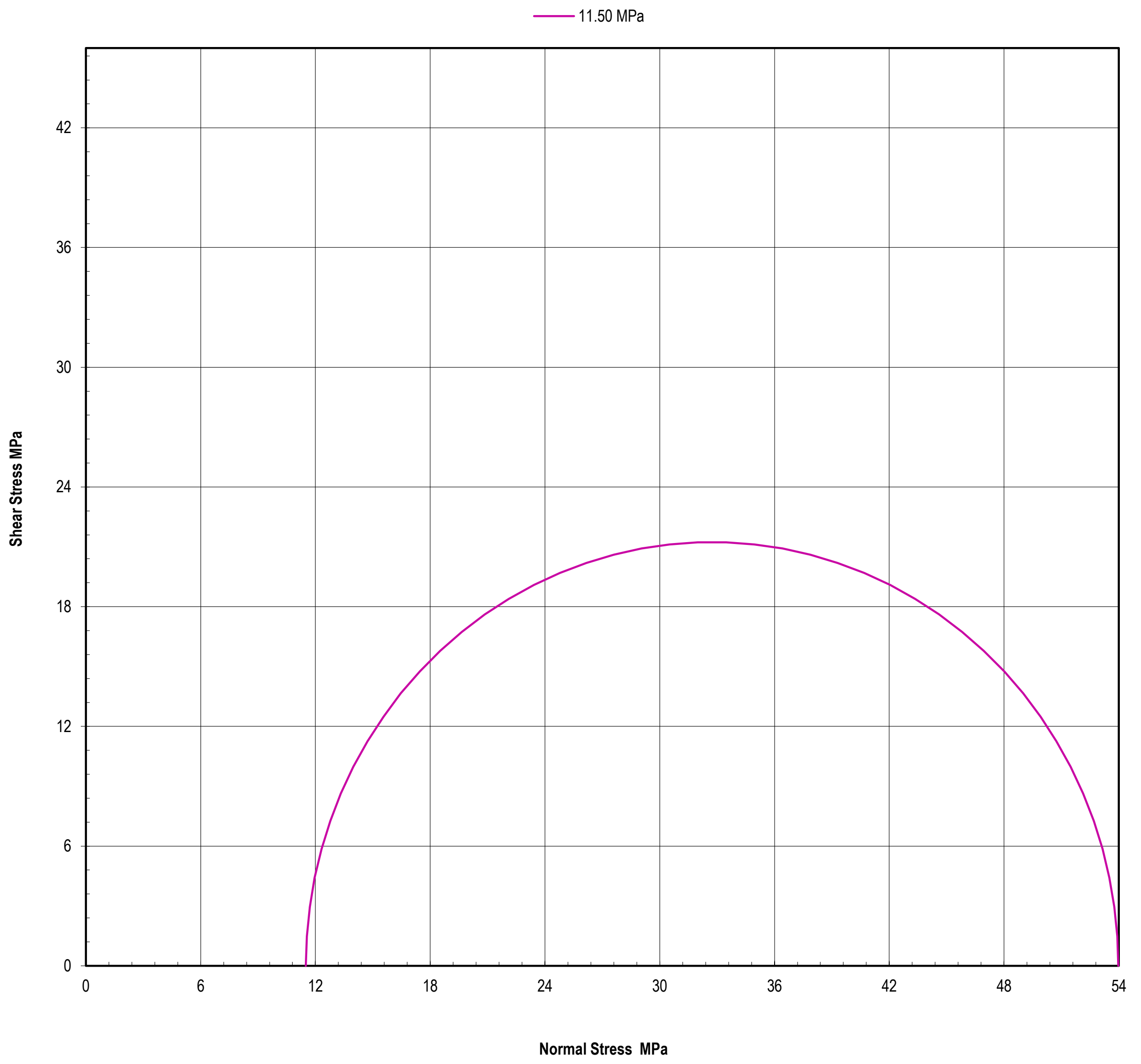
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

Client Arrow Energy Pty Ltd

Report No. 20110069-RTX

Residual Stress Mohr Circle Plot



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Graph not to scale

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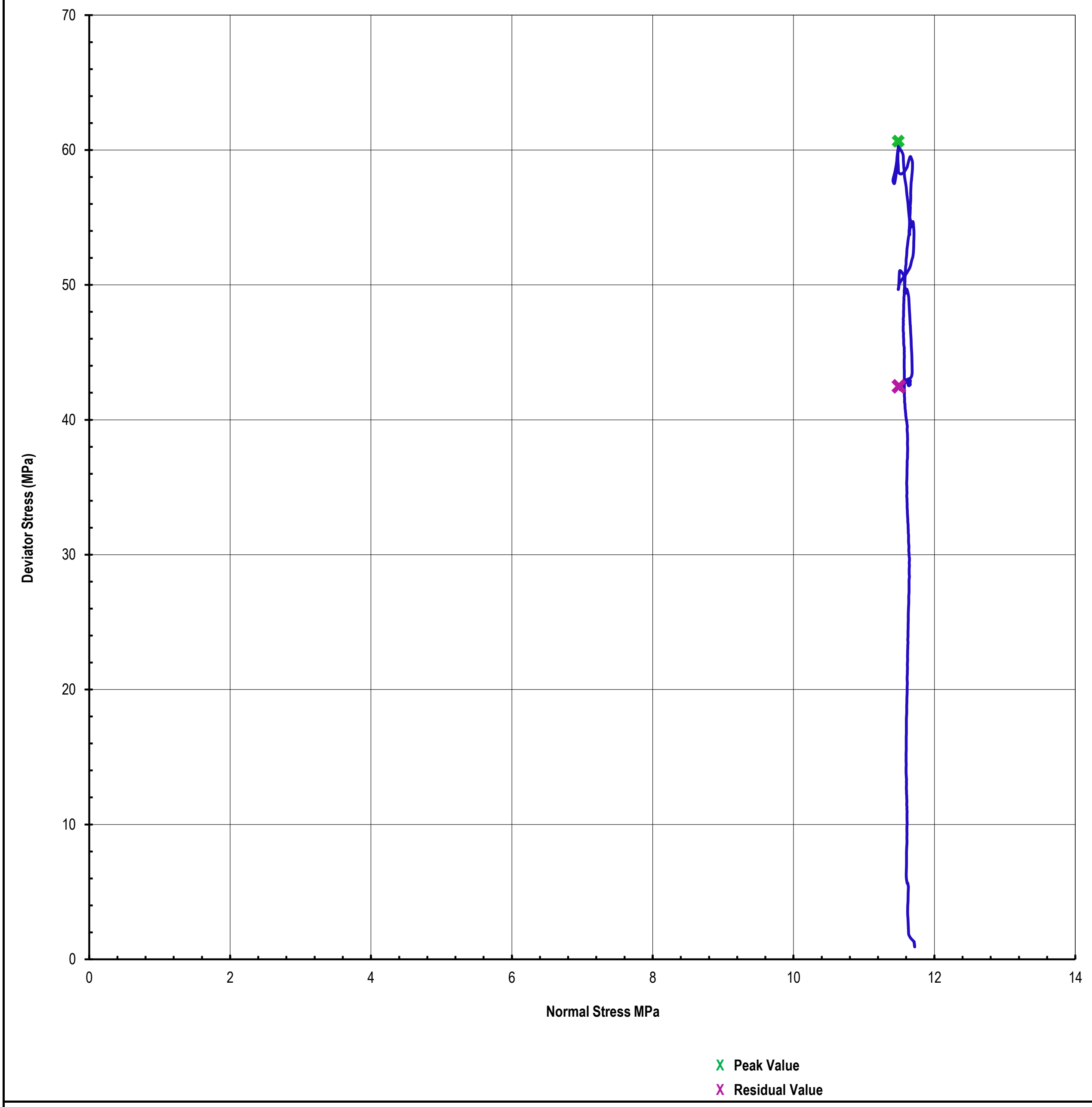
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

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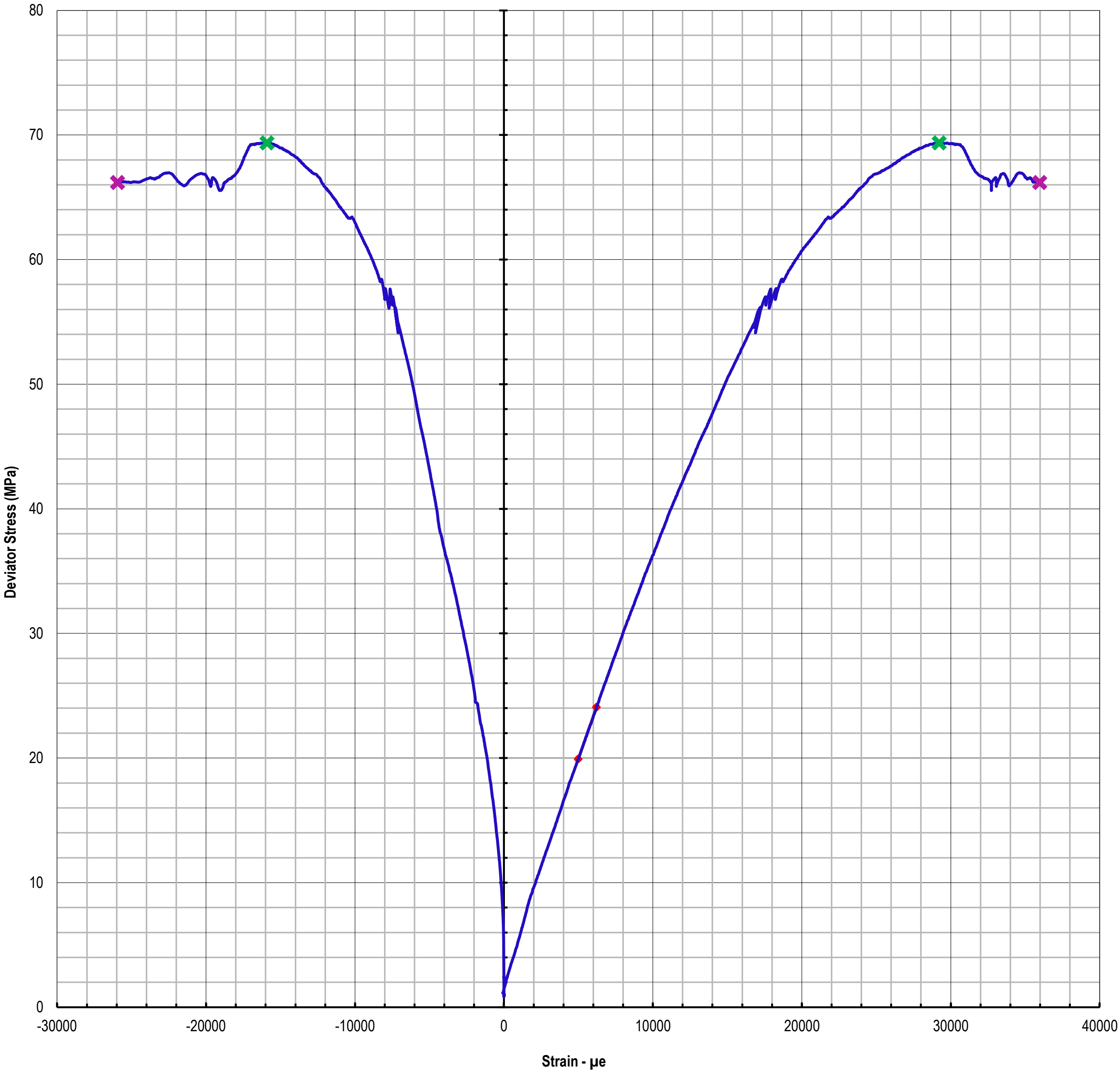
Method B : Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements

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

Before and After Test Photos

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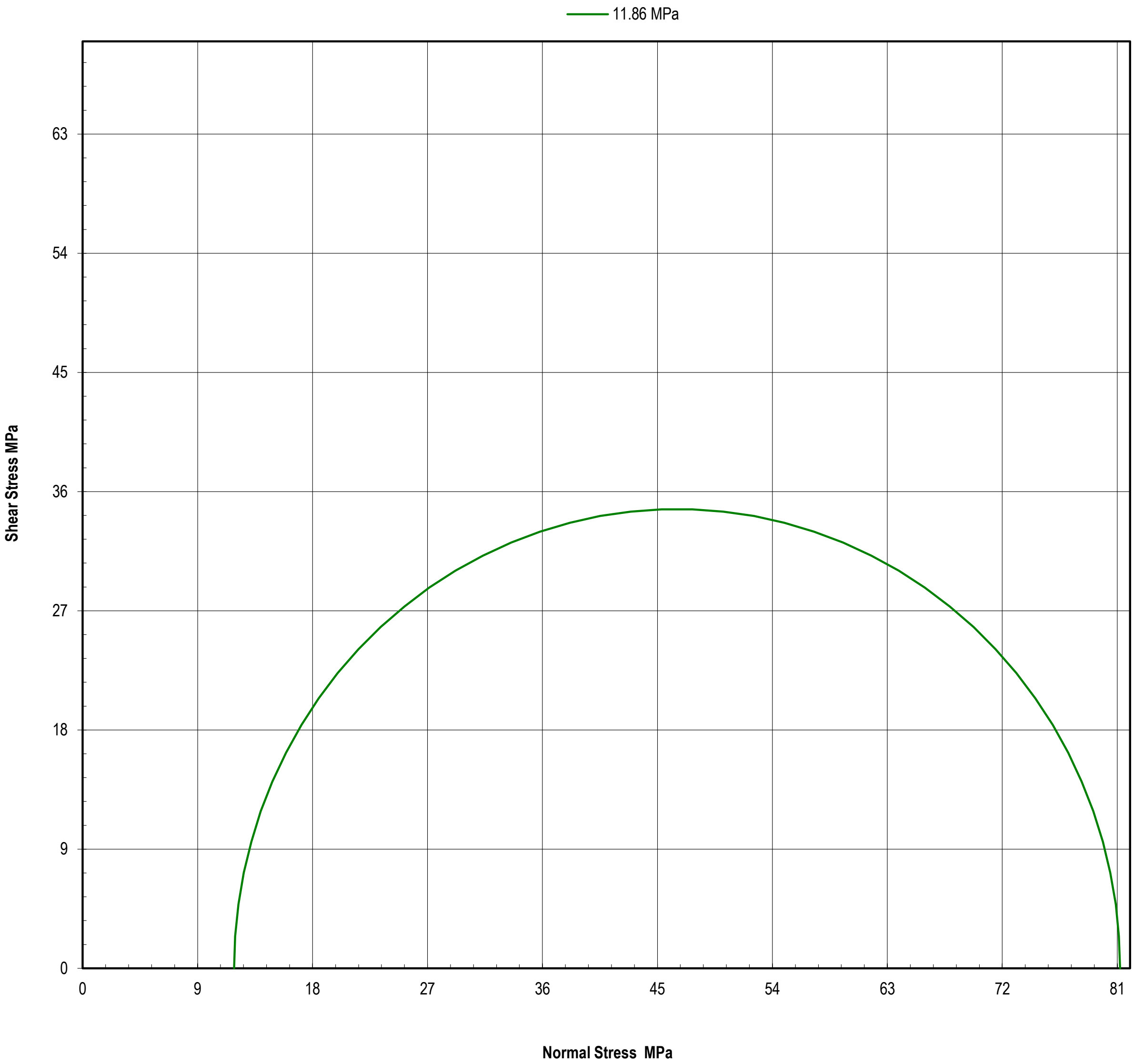
Client Arrow Energy Pty Ltd	**Report No.** 20110070-RTX

Peak Stress Mohr Circle Plot



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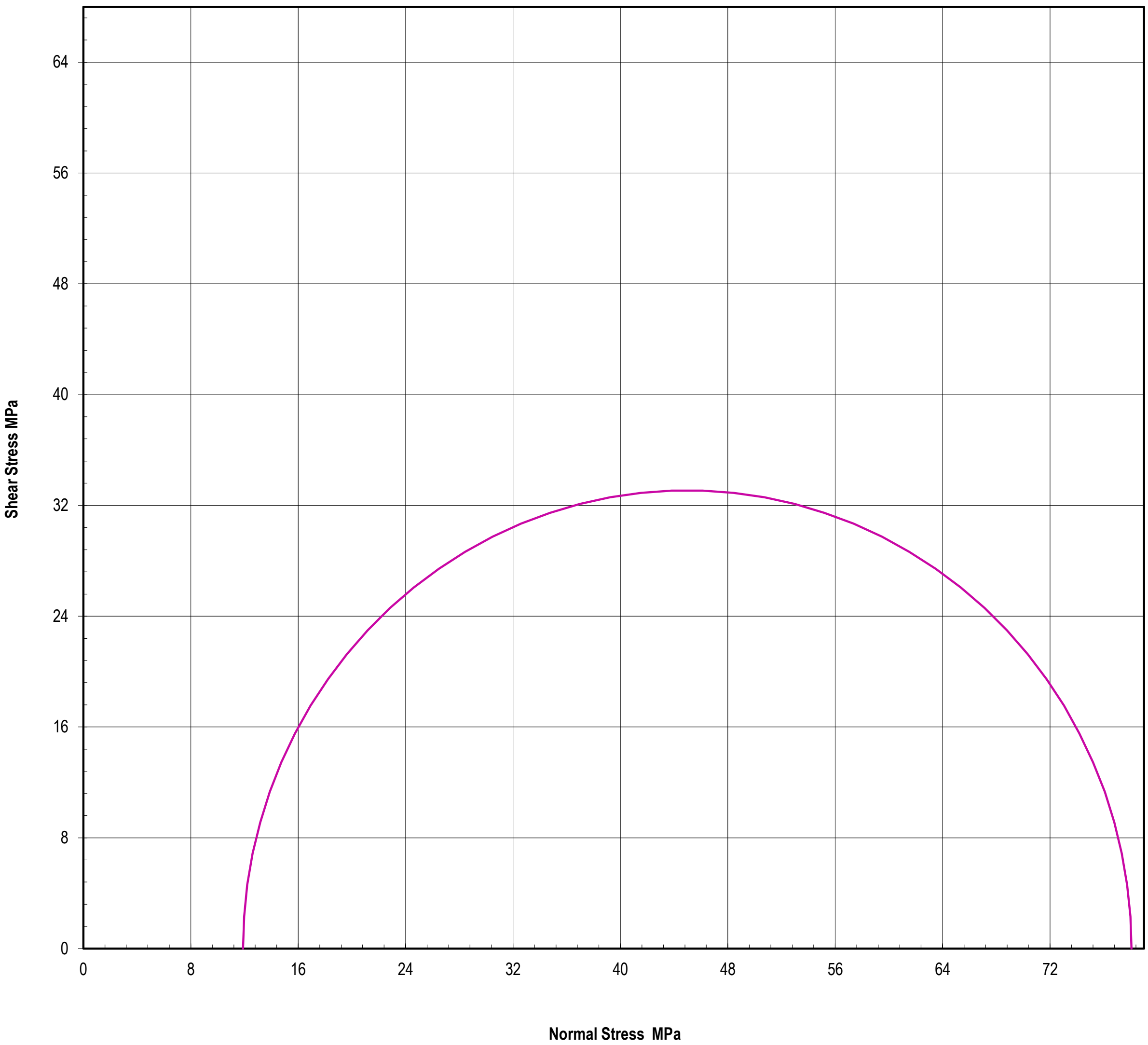
Residual Stress Mohr Circle Plot



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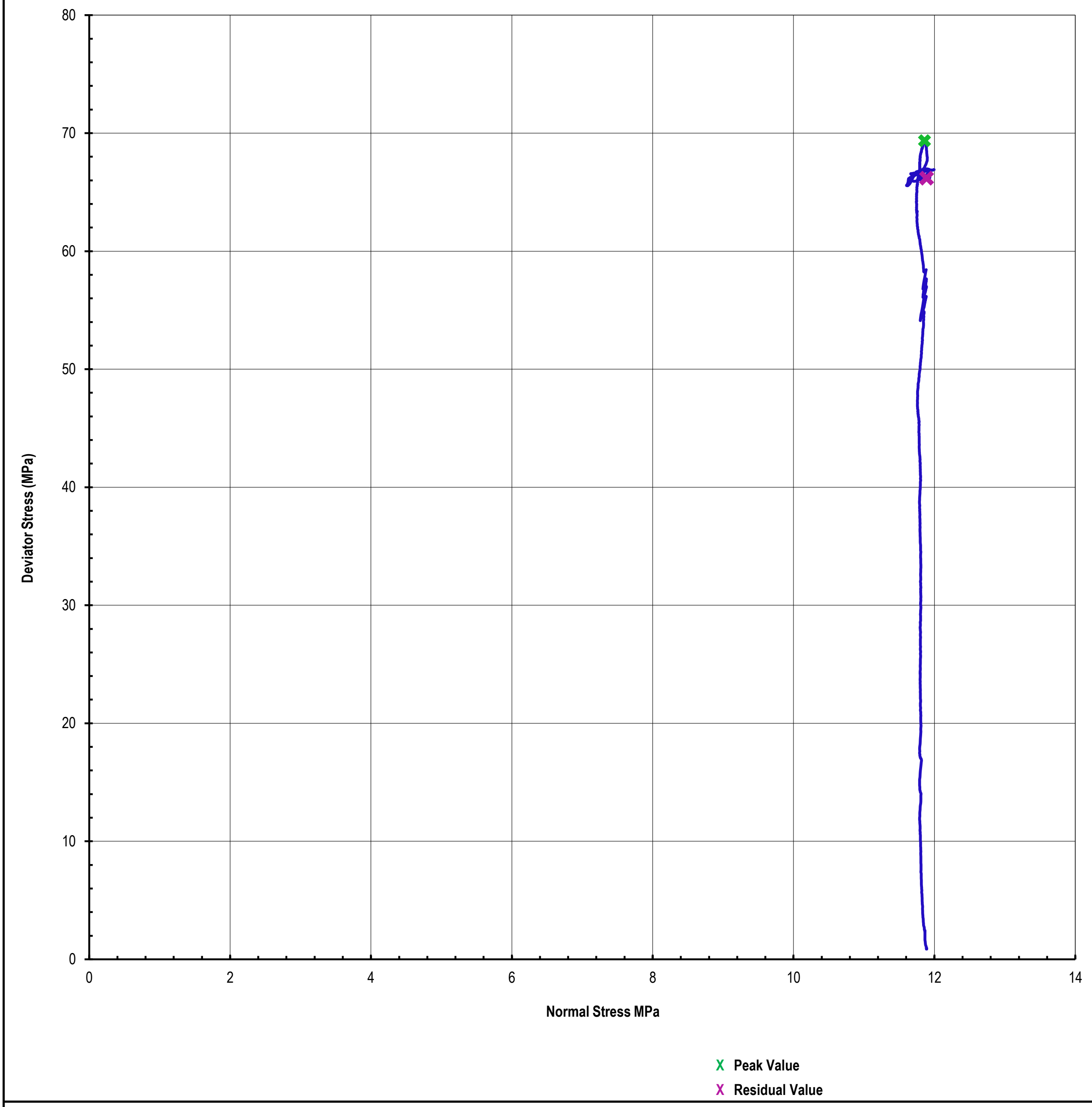
Client	Arrow Energy Pty Ltd	**Report No.**	20110070-RTX

Deviator Stress vs Normal Stress Plot



Notes/Remarks:

Graph not to scale

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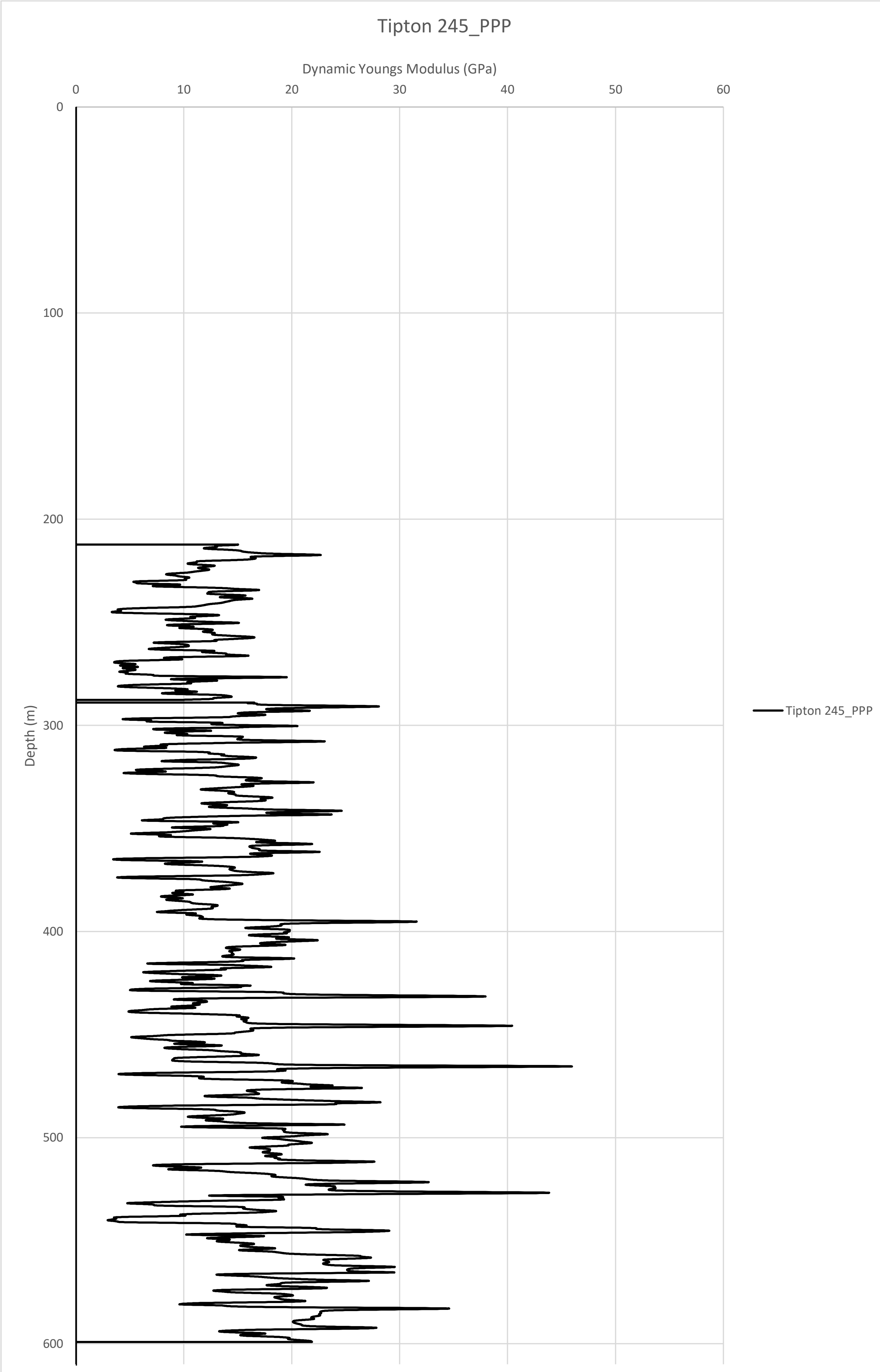
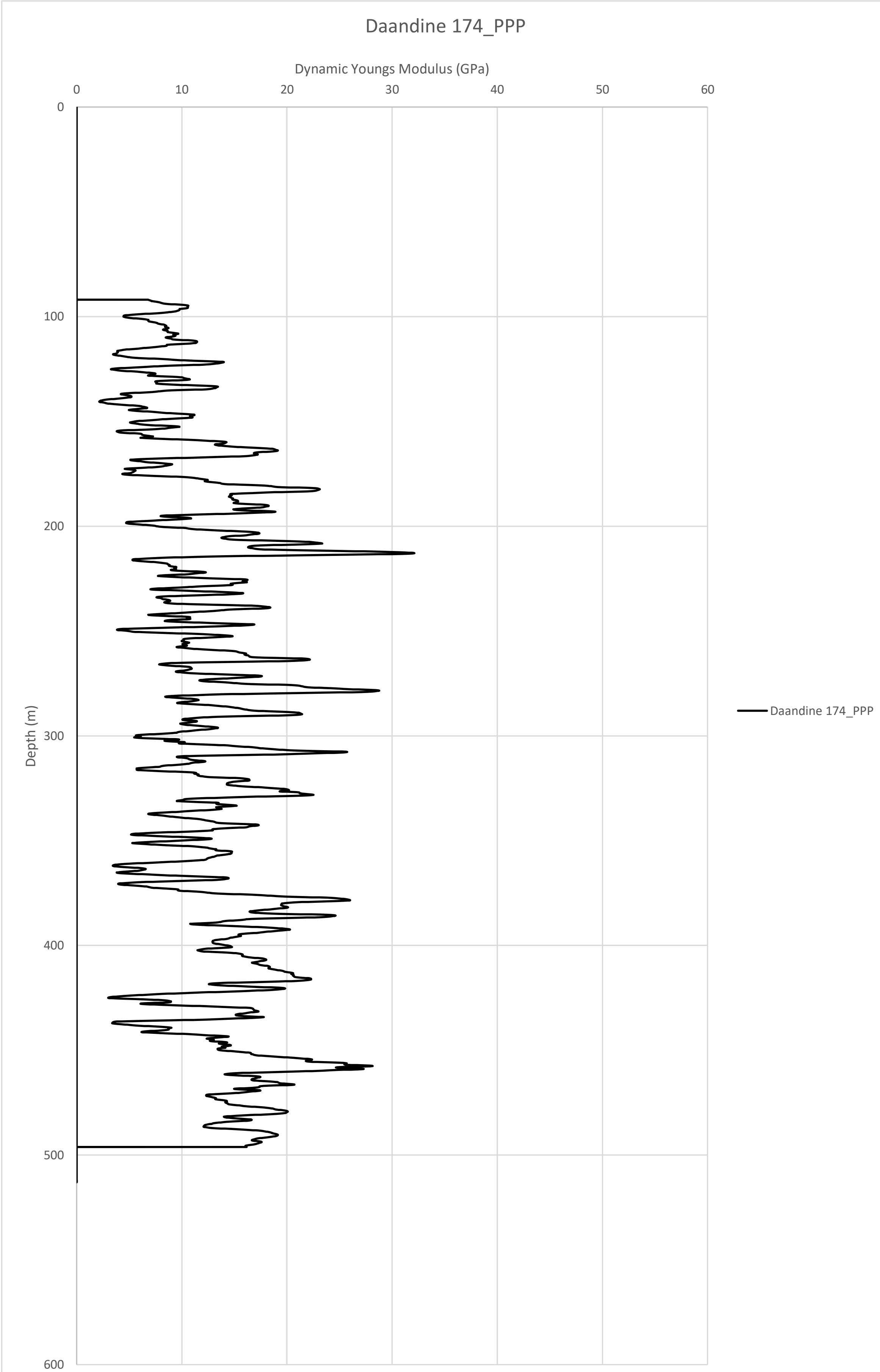
Tested as received

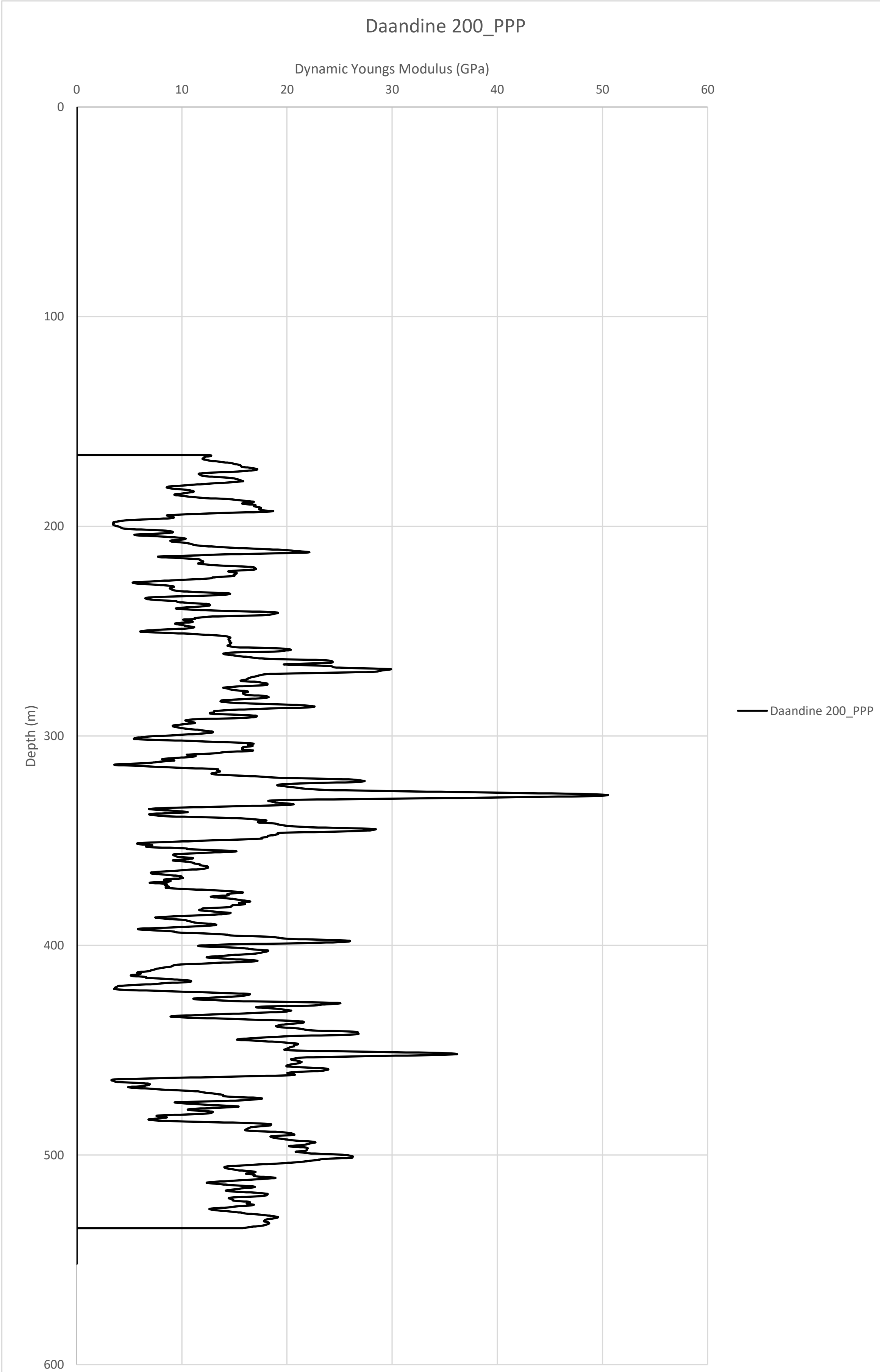
Subsidence

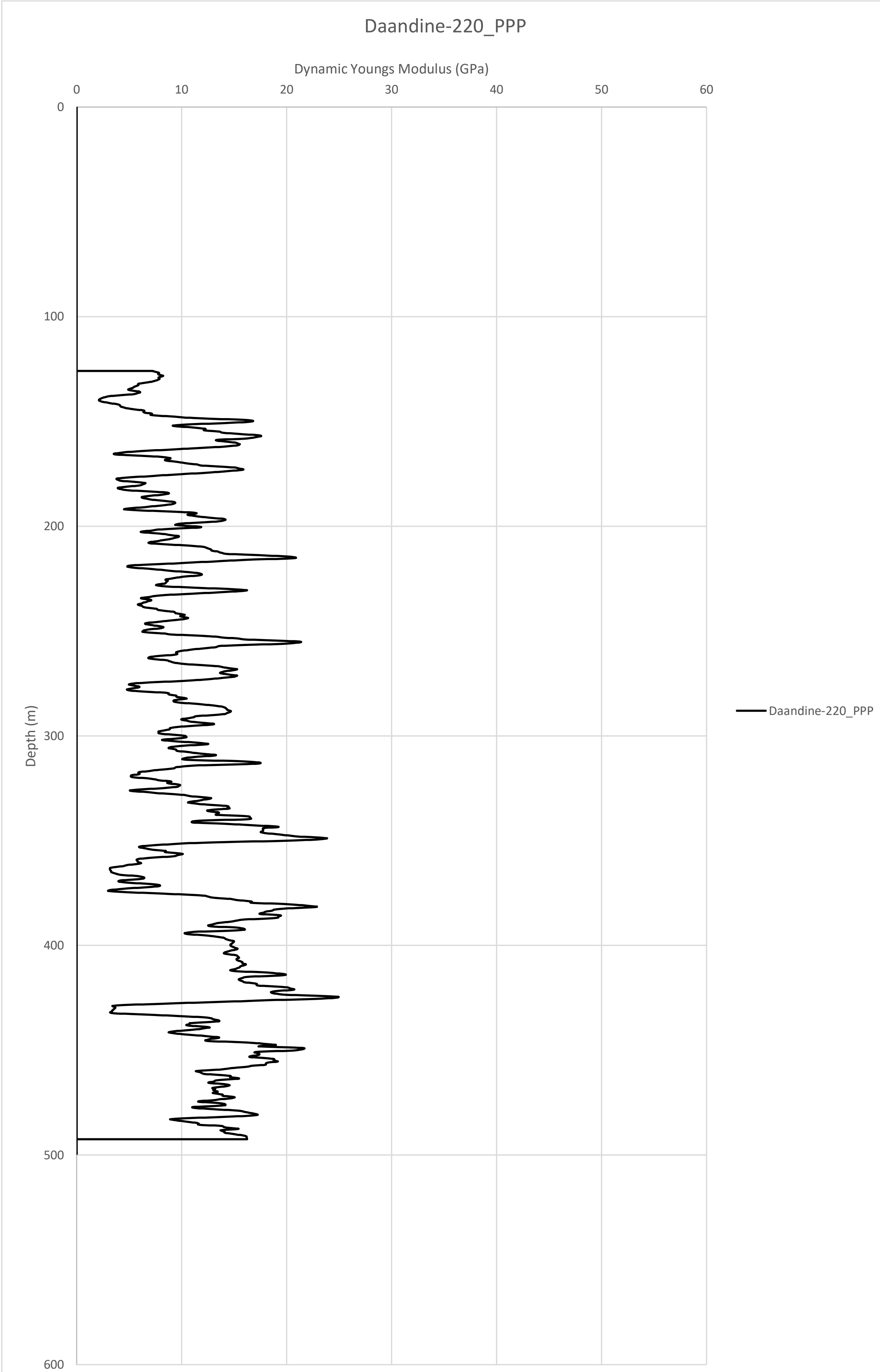
Appendix B Dynamic Young’s modulus from wireline logs for 22 boreholes


Tipton 245_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Tipton 245_PPP



Daandine 174_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Daandine 174_PPP


Daandine 200_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
Depth (m)
0
100
200
300
400
500
600
Daandine 200_PPP



Daandine-220_PPP
Dynamic Youngs Modulus (GPa)
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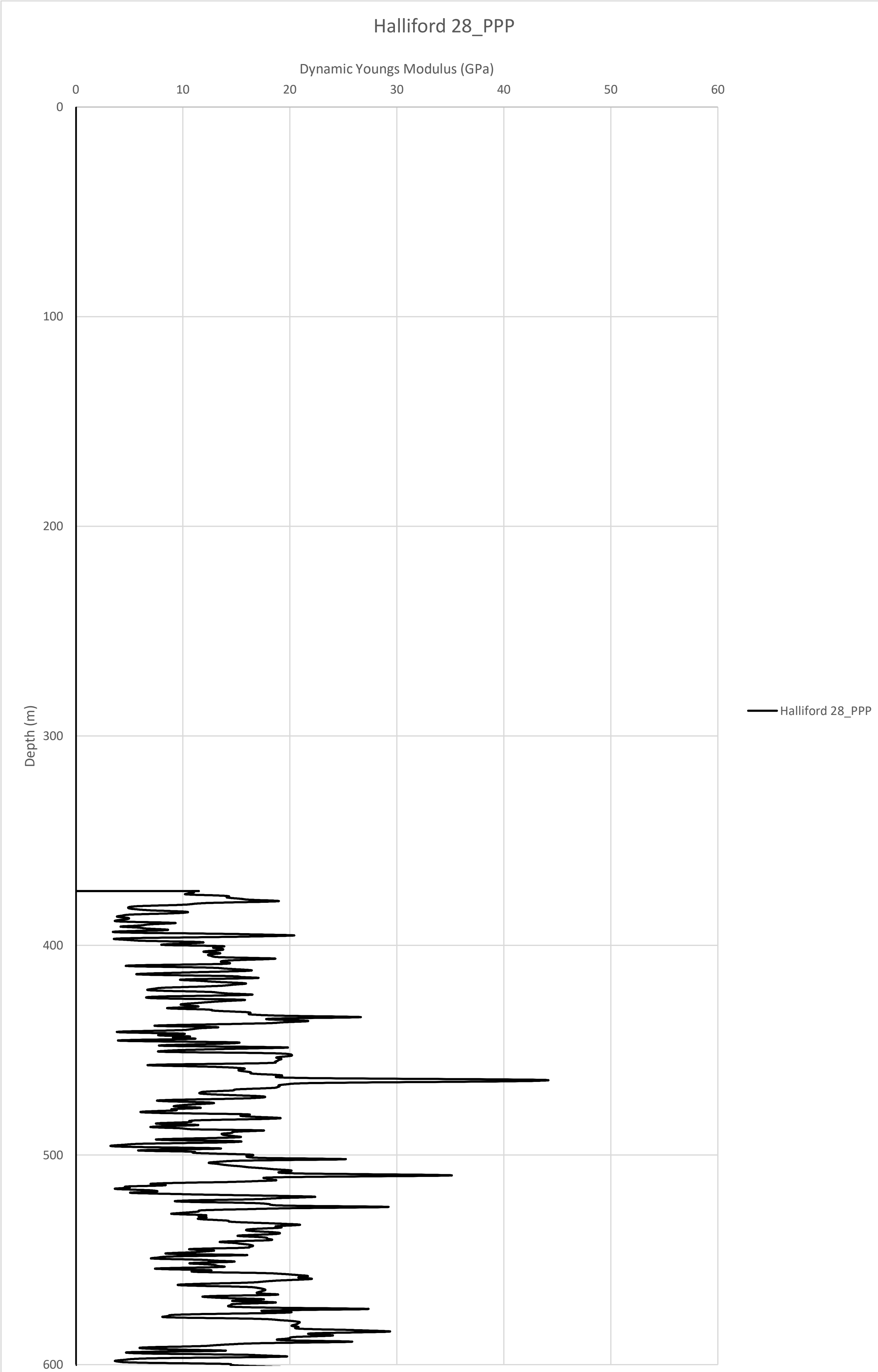
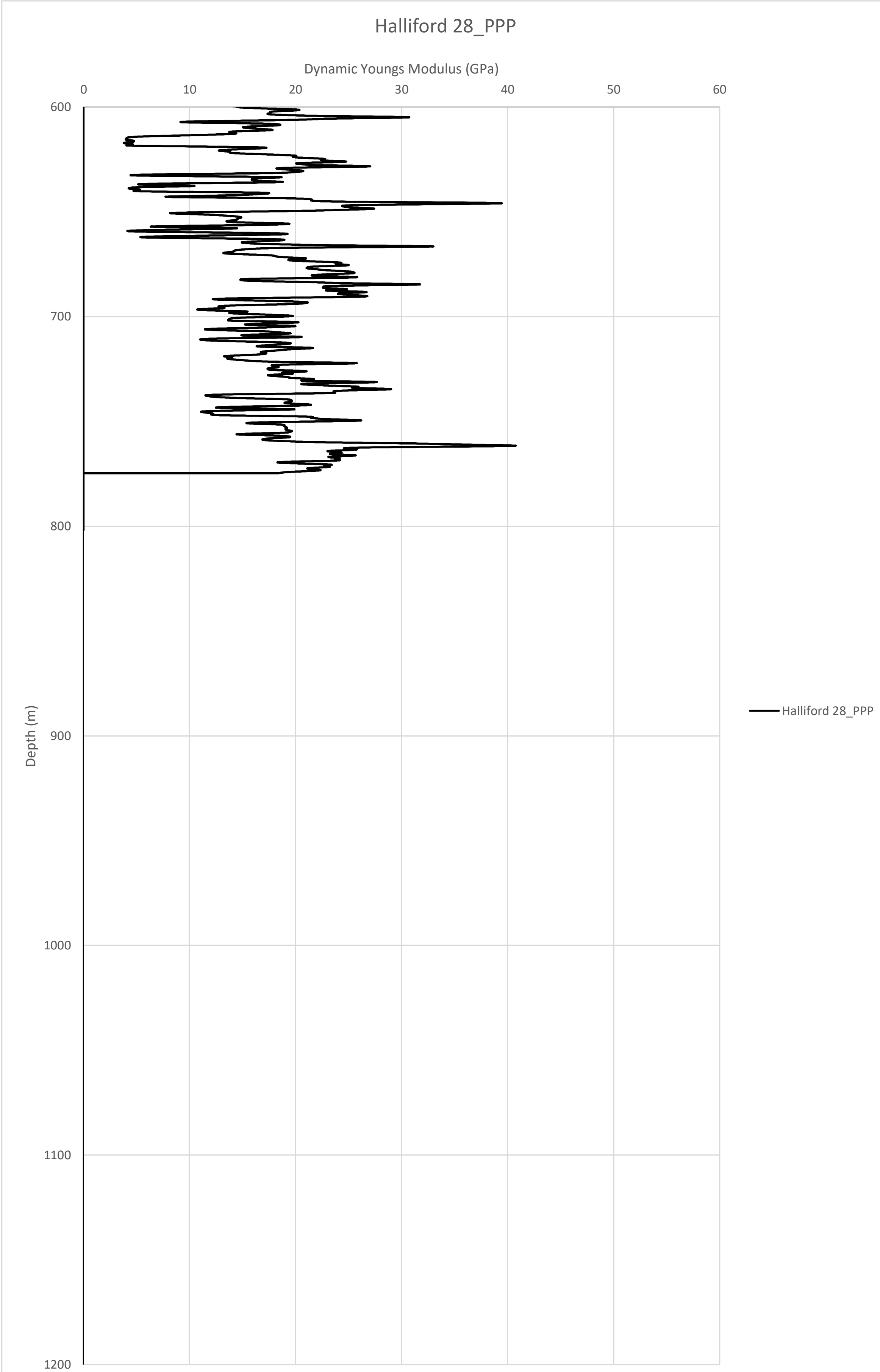
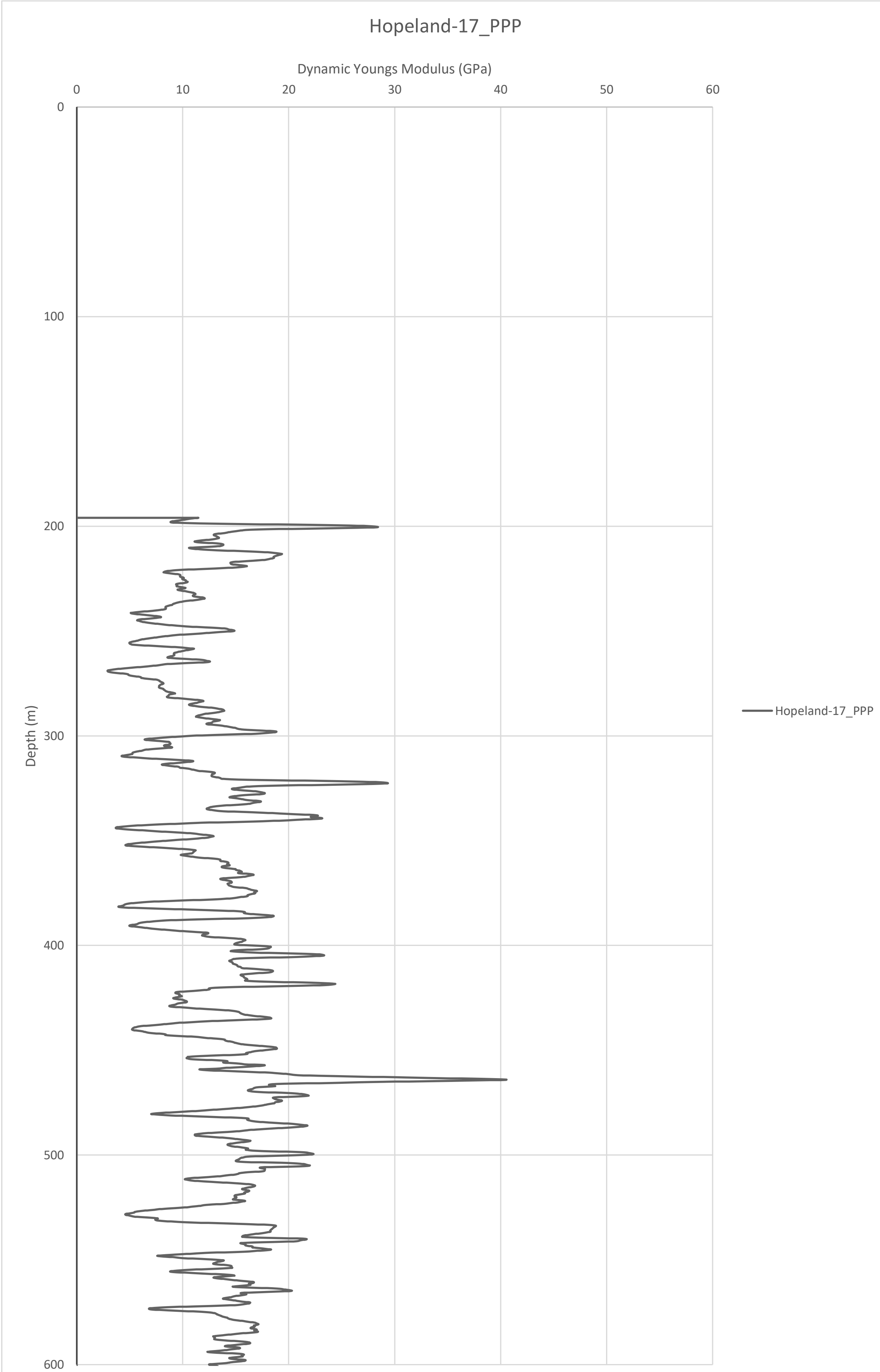
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Daandine-220_PPP



Halliford 28_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Halliford 28_PPP



Halliford 28_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
600
700
800
900
1000
1100
1200
Depth (m)
Halliford 28_PPP



Hopeland-17_PPP
Dynamic Youngs Modulus (GPa)
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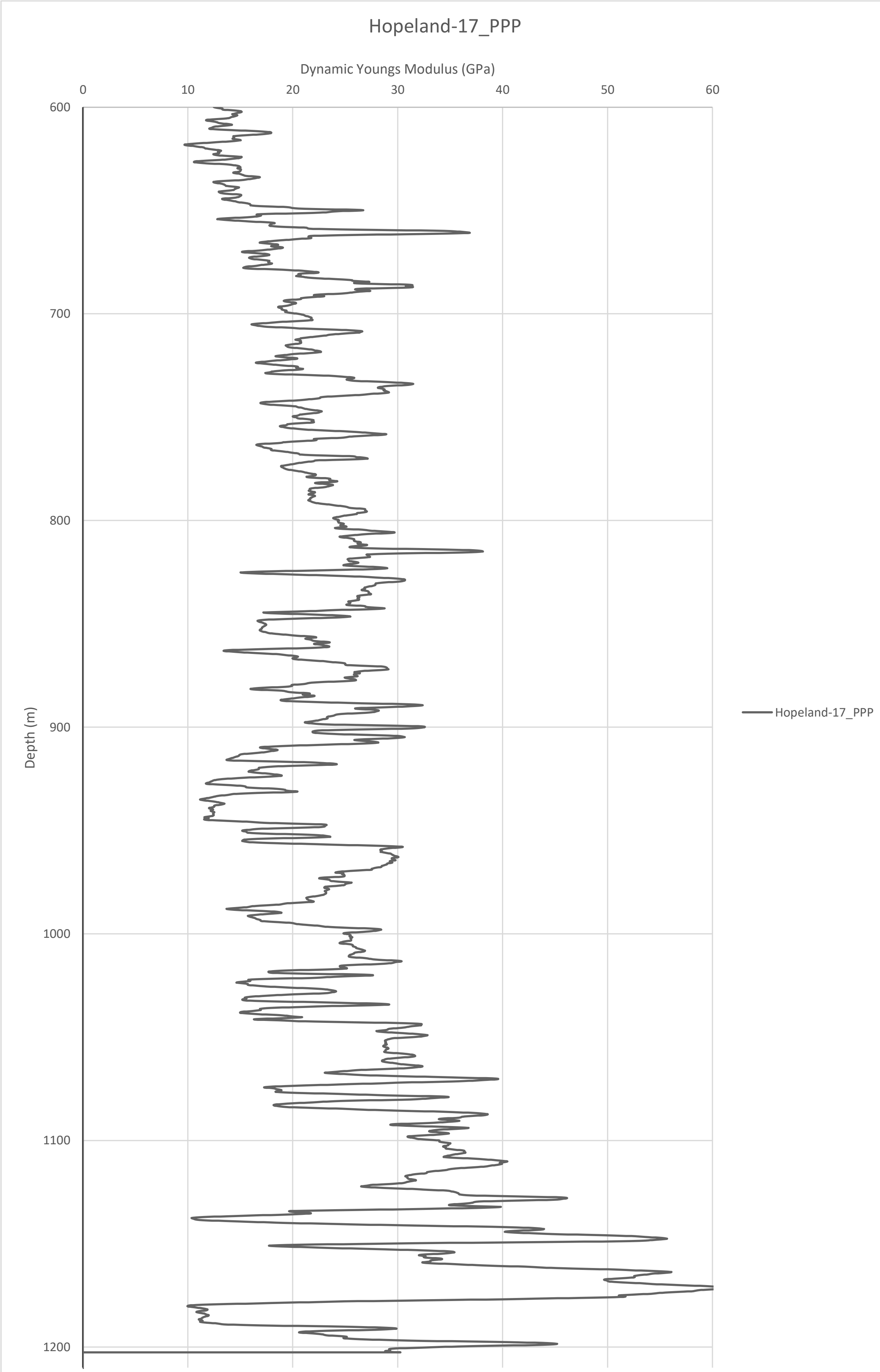
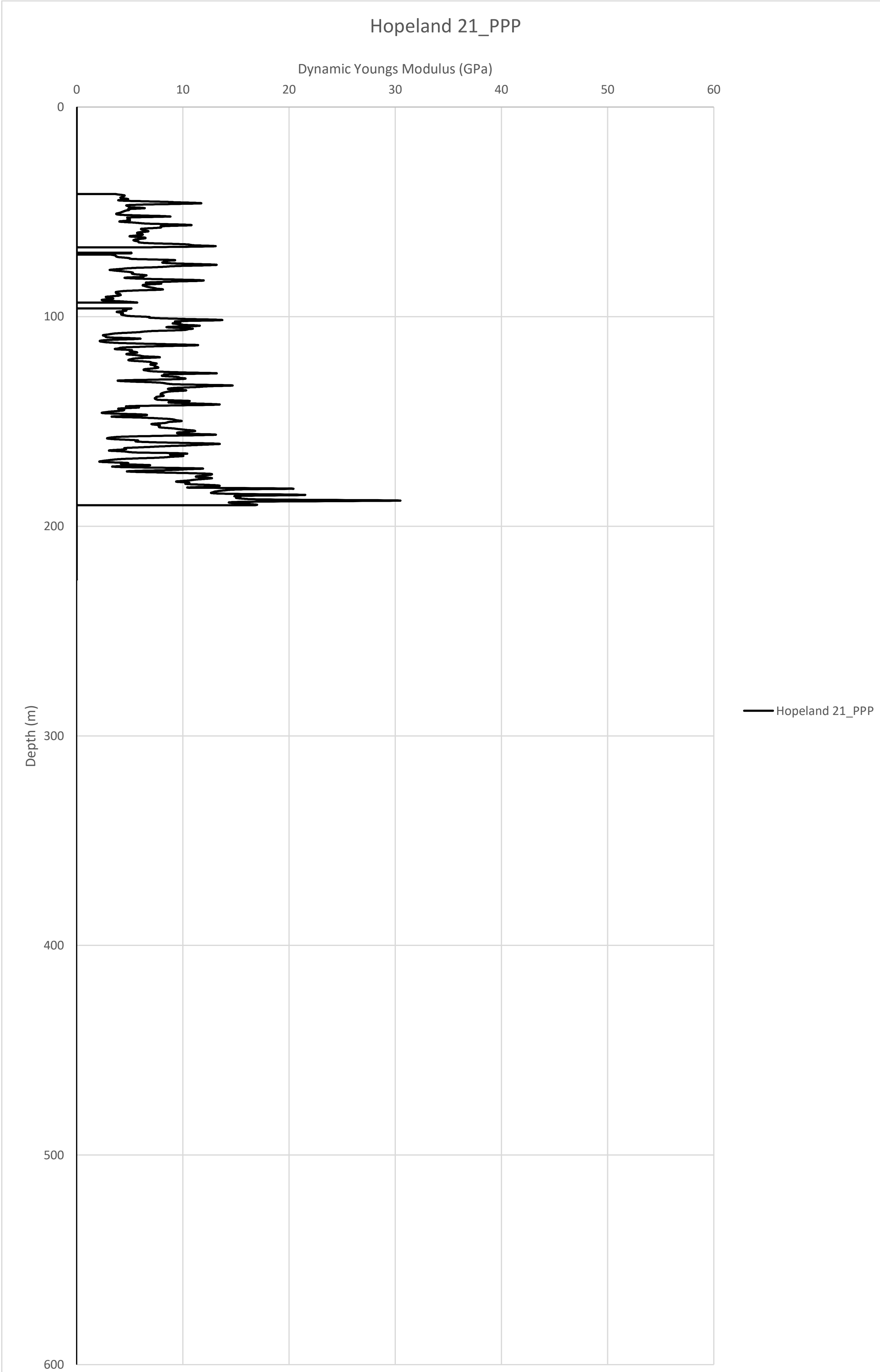
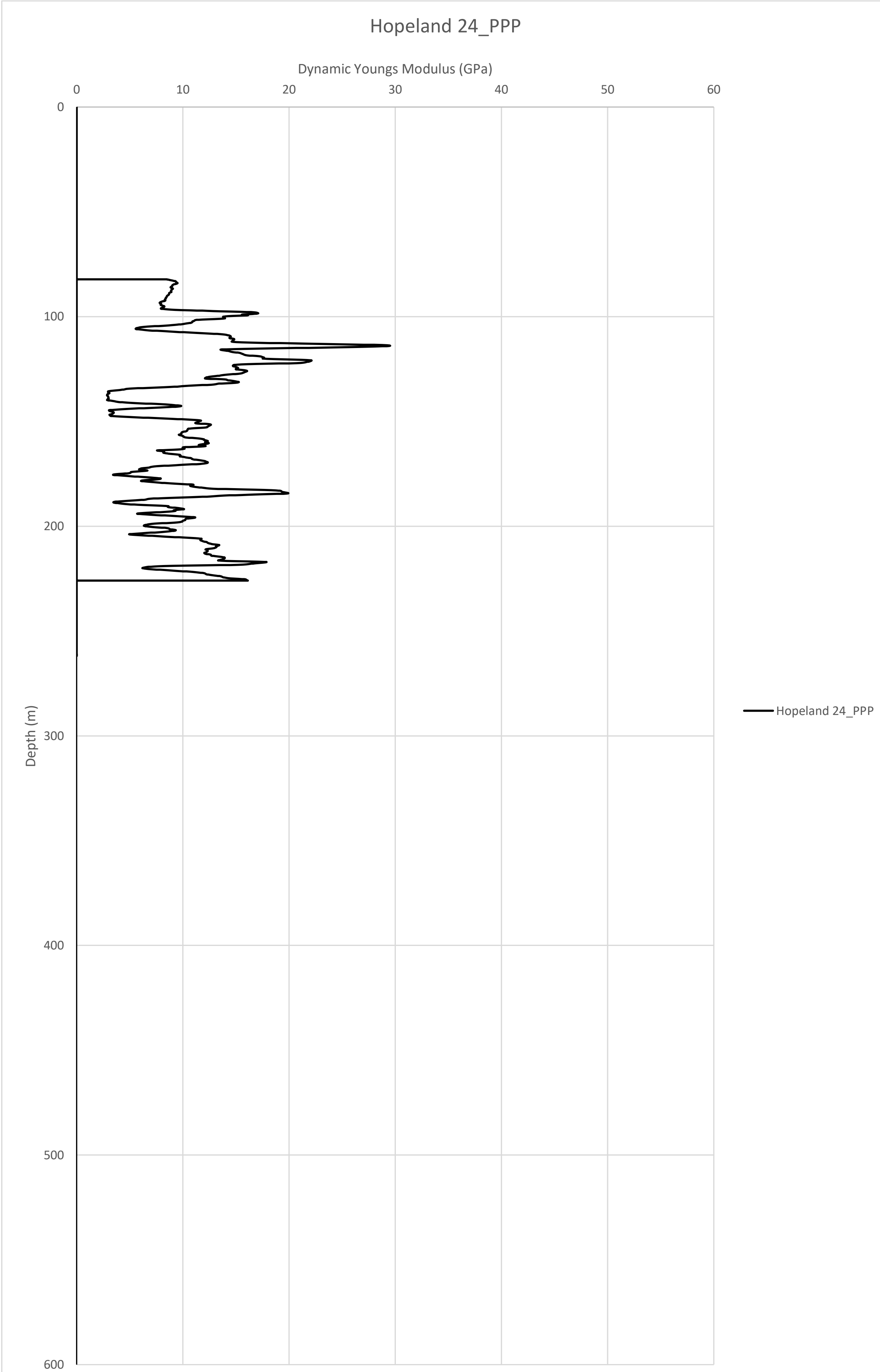
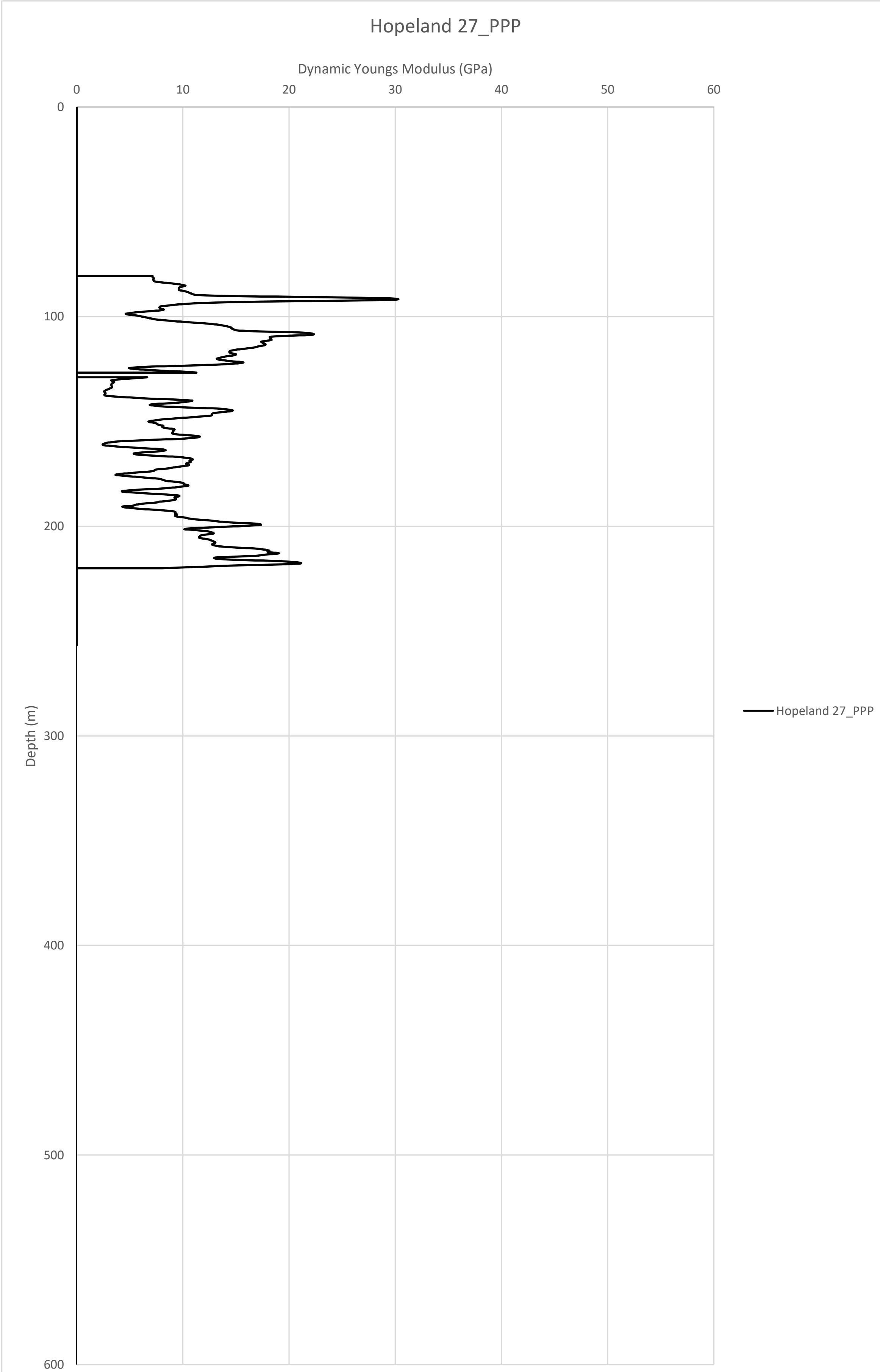
30
40
50
60
Depth (m)
0
100
200
300
400
500
600
Hopeland-17_PPP



Hopeland-17_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
600
700
800
900
1000
1100
1200
Depth (m)
Hopeland-17_PPP


Hopeland 21_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Hopeland 21_PPP


Hopeland 24_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
Depth (m)
0
100
200
300
400
500
600
Hopeland 24_PPP



Hopeland 27_PPP
Dynamic Youngs Modulus (GPa)
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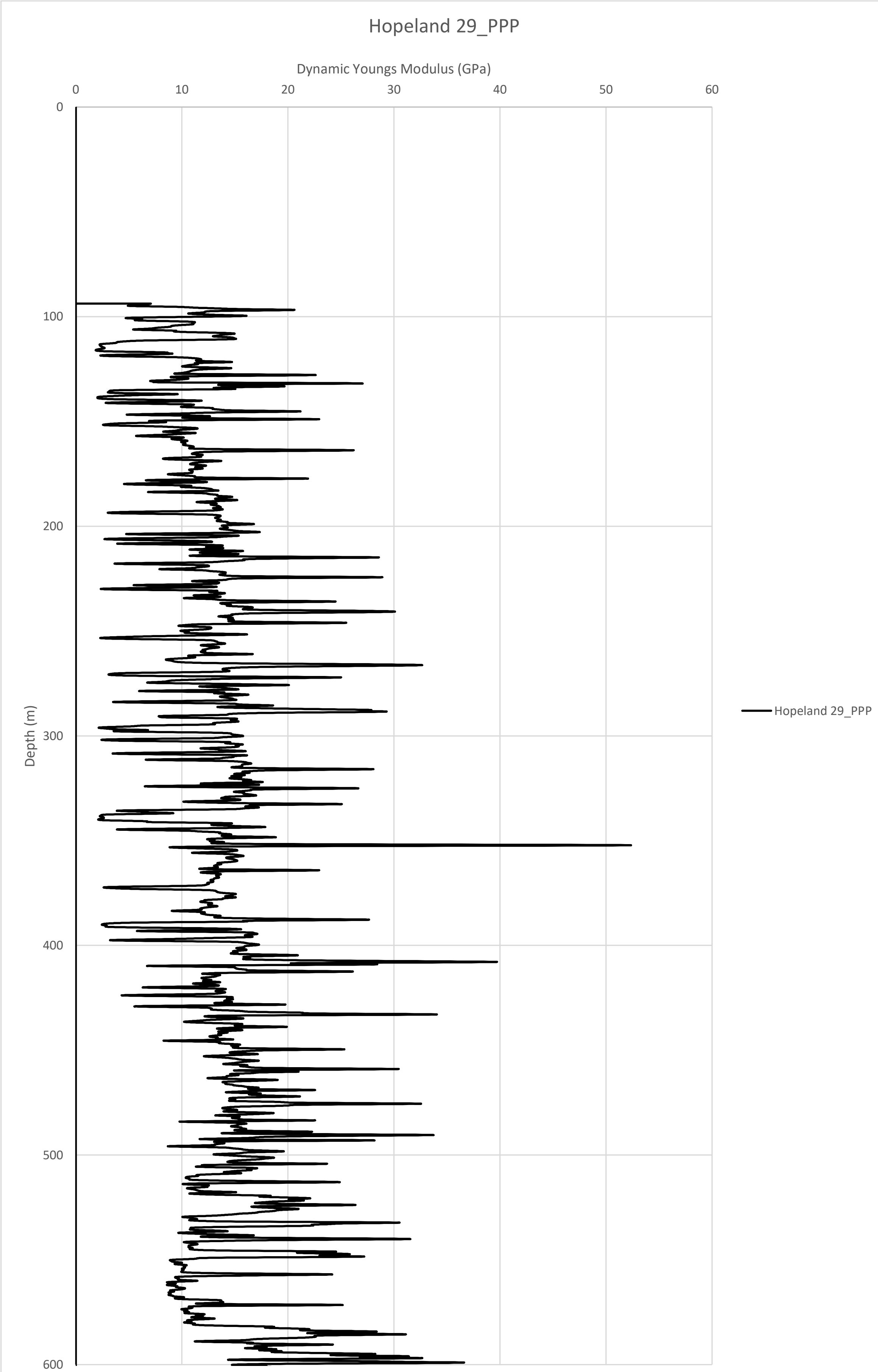
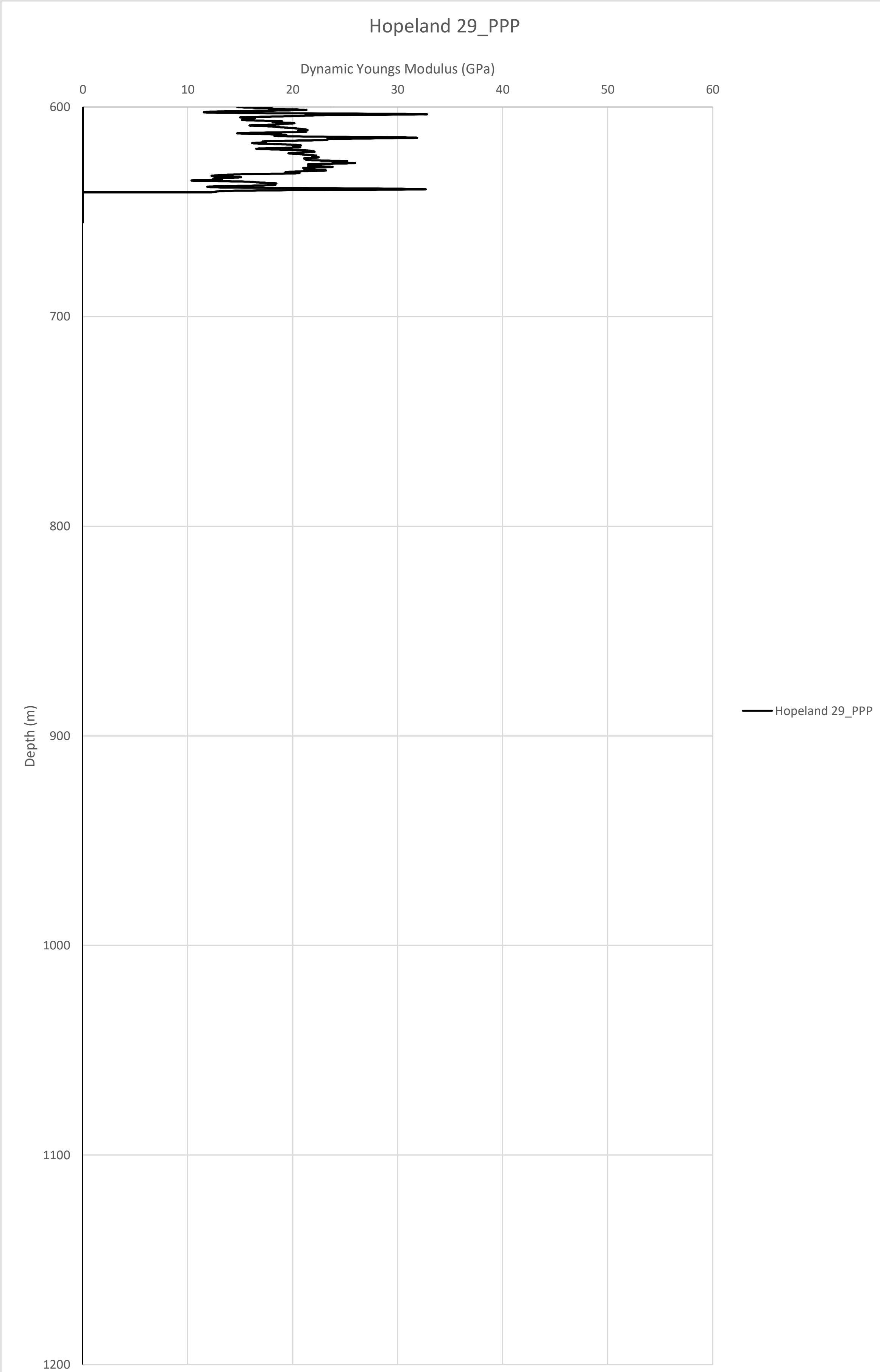
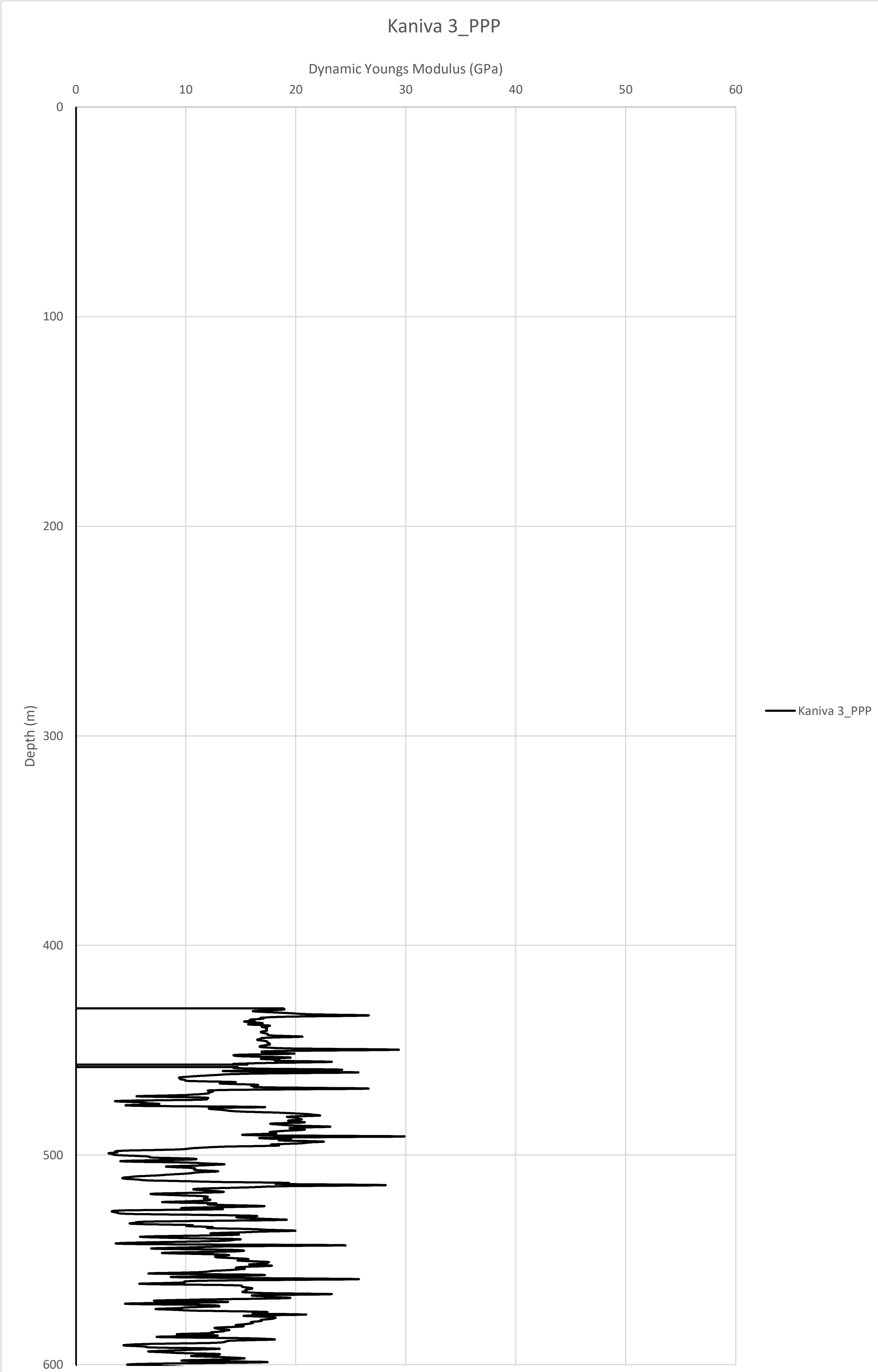
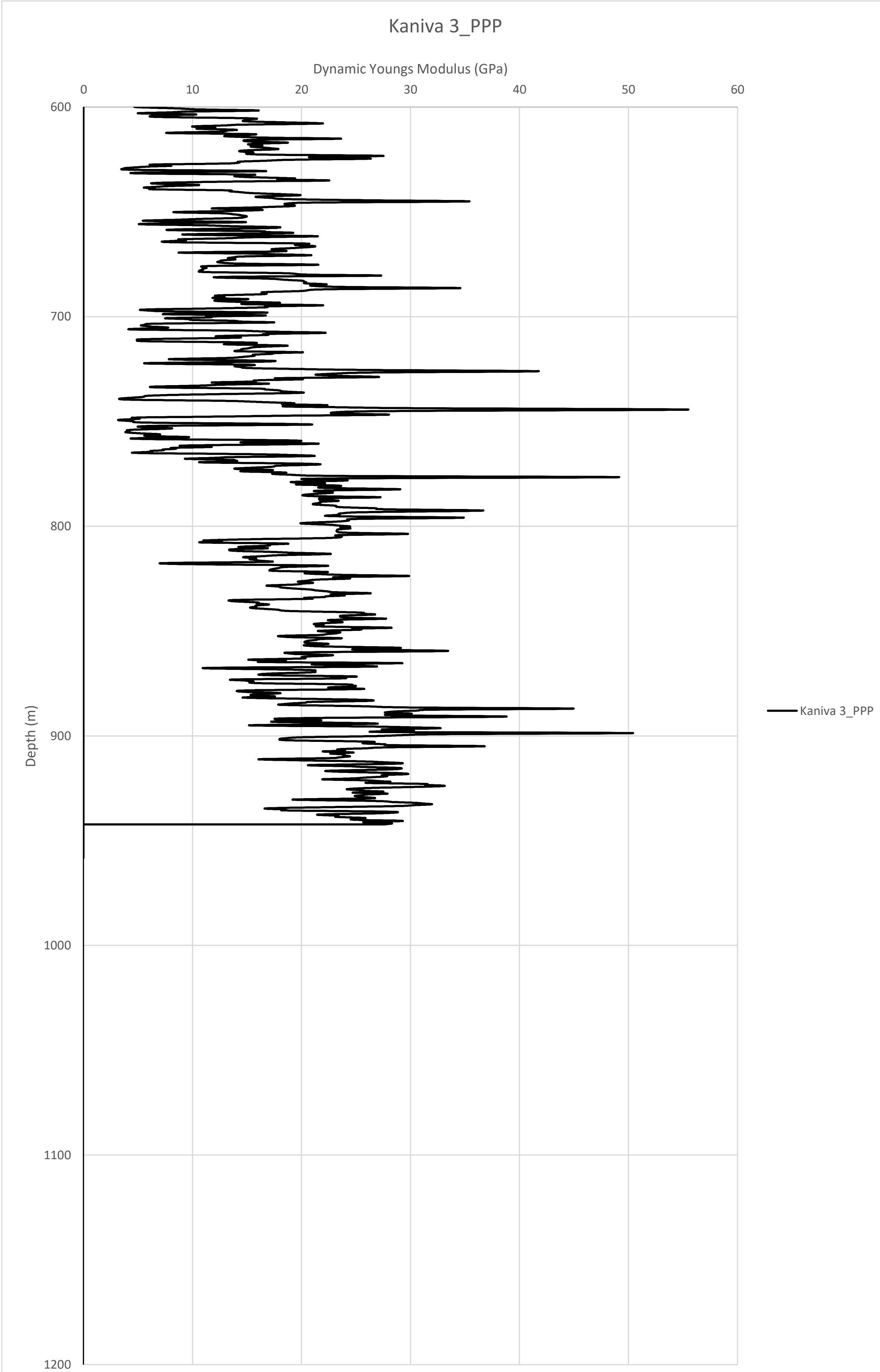
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Hopeland 27_PPP



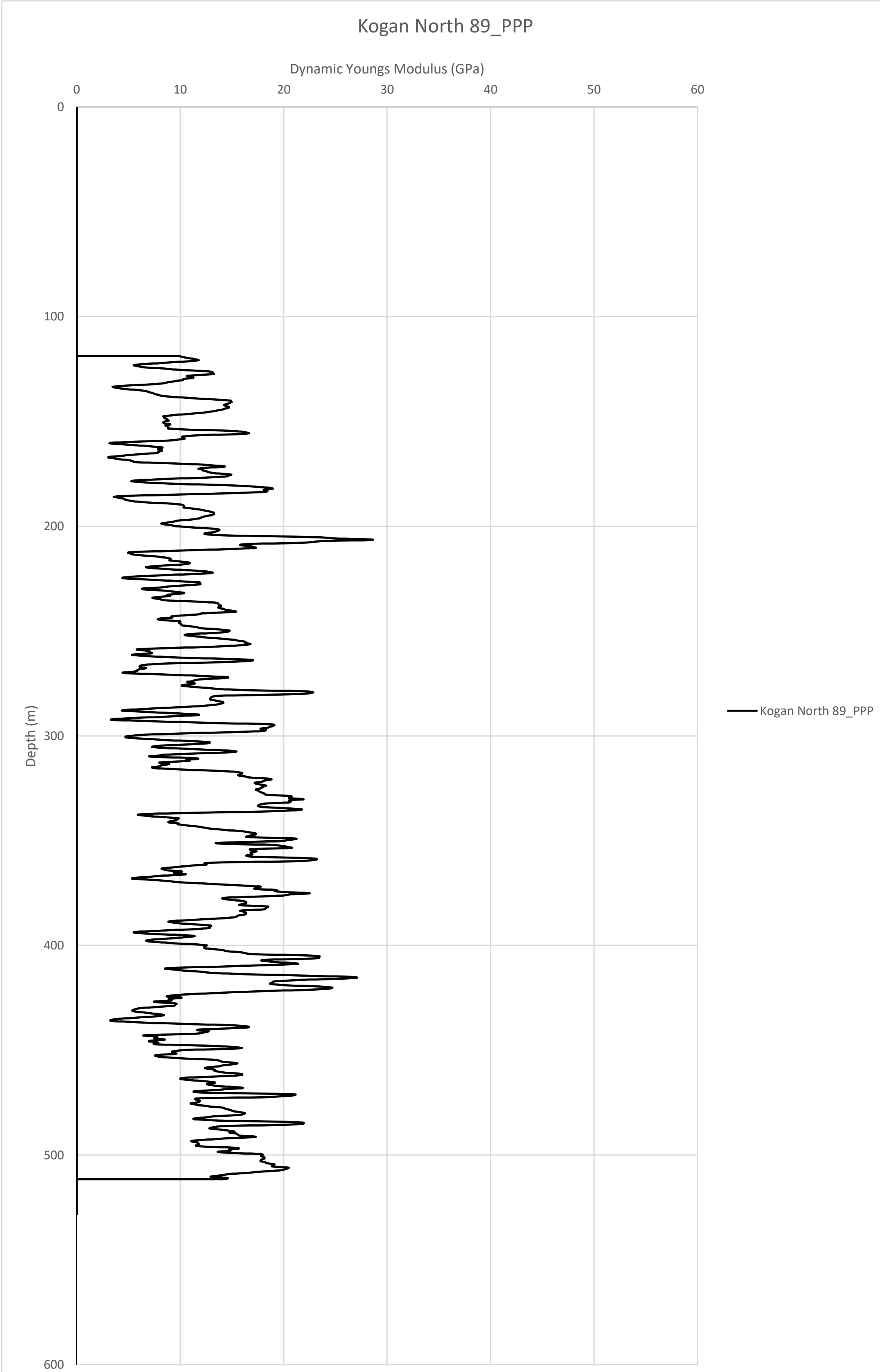
Hopeland 29_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Hopeland 29_PPP


Hopeland 29_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
600
700
800
900
1000
1100
1200
Depth (m)
Hopeland 29_PPP

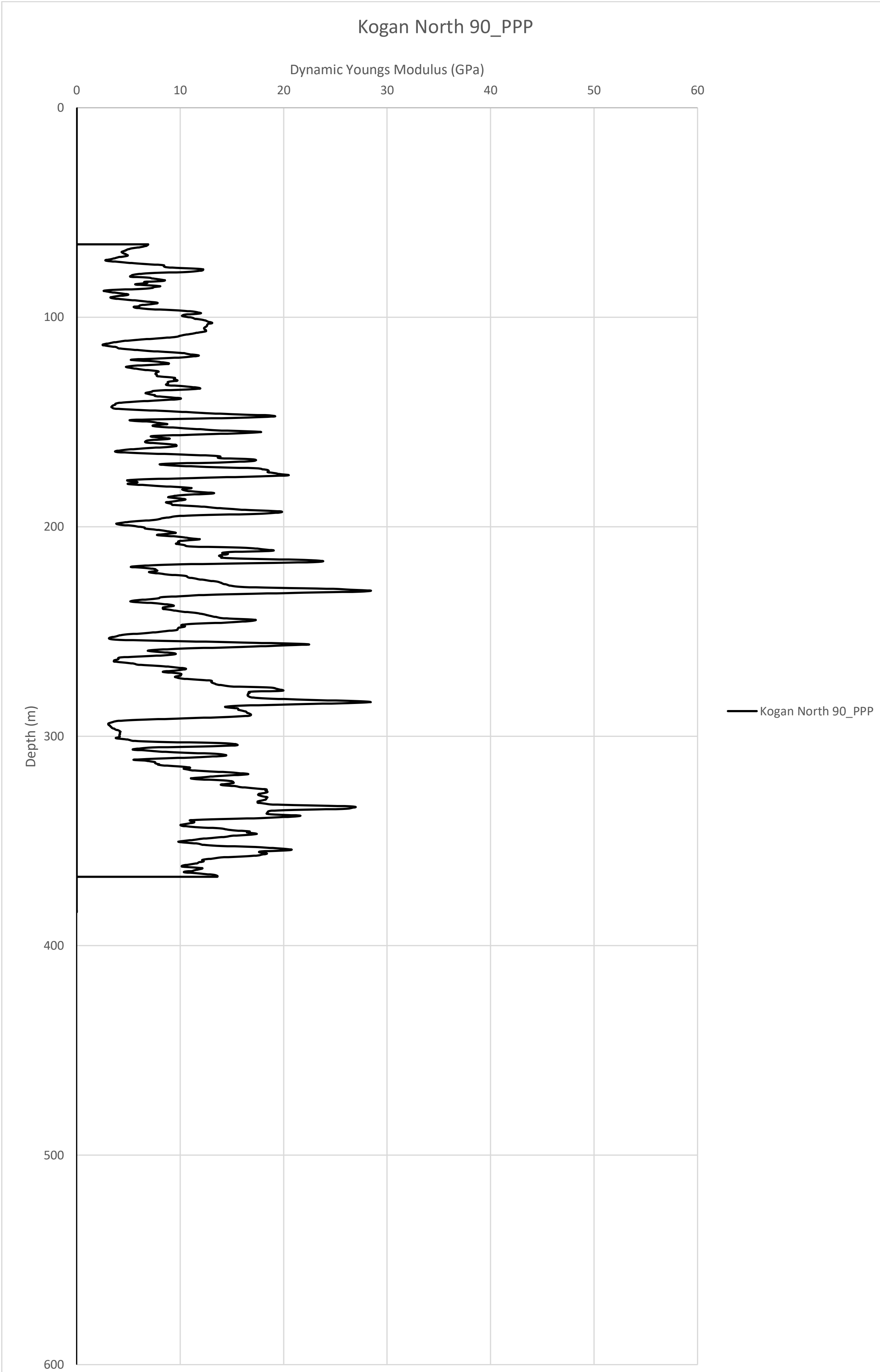

Kaniva 3_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Kaniva 3_PPP

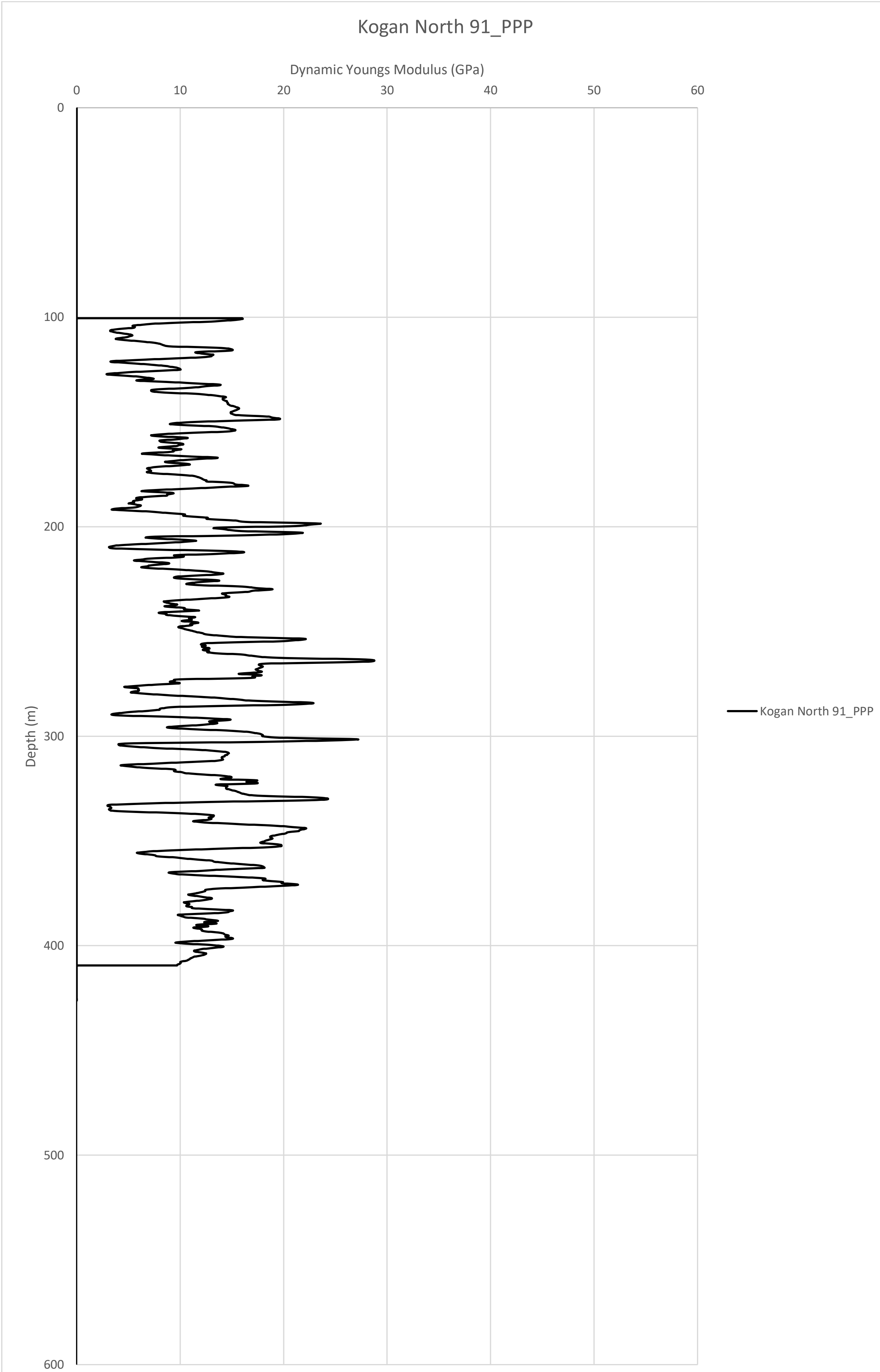


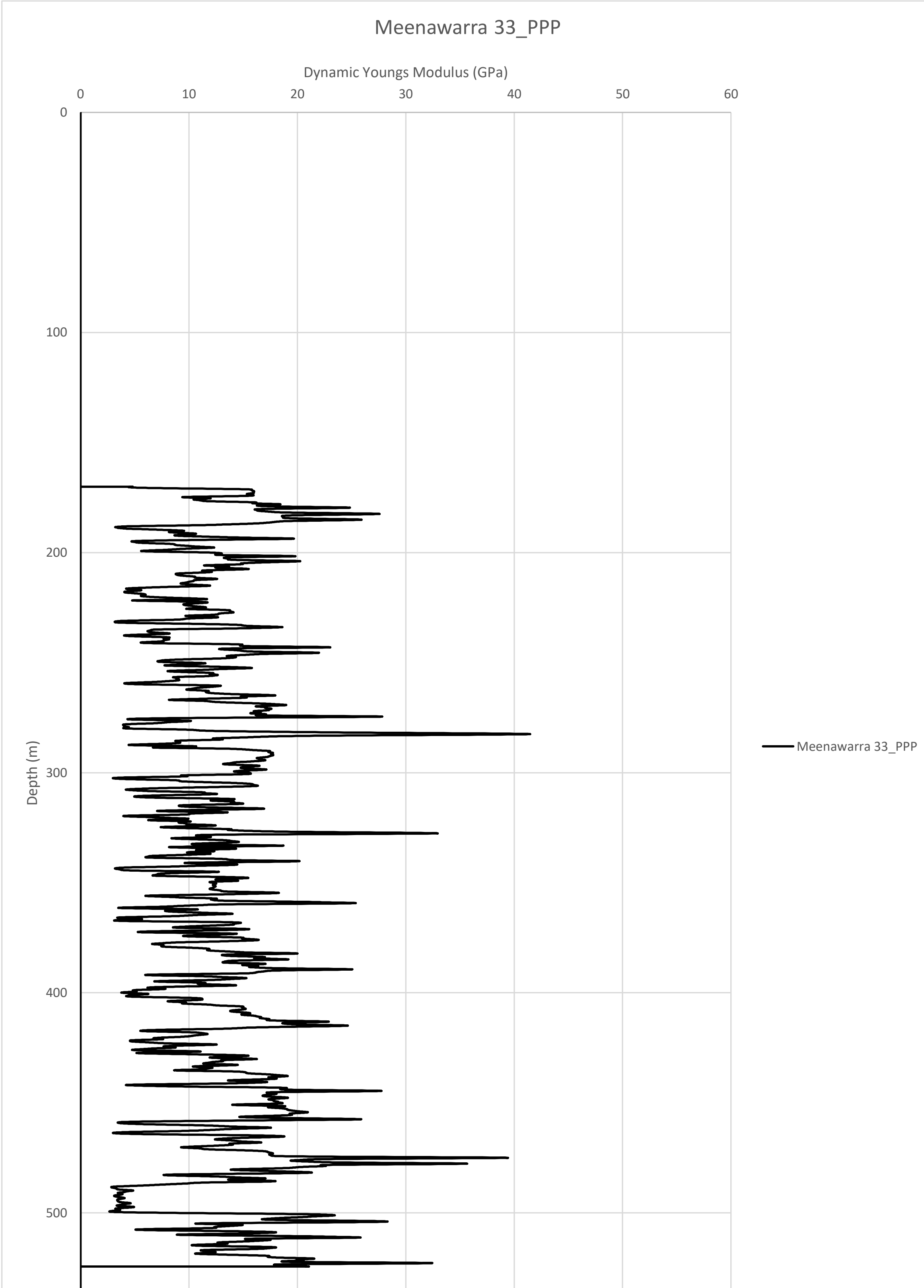
Kaniva 3_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
600
700
800
900
1000
1100
1200
Depth (m)
Kaniva 3_PPP



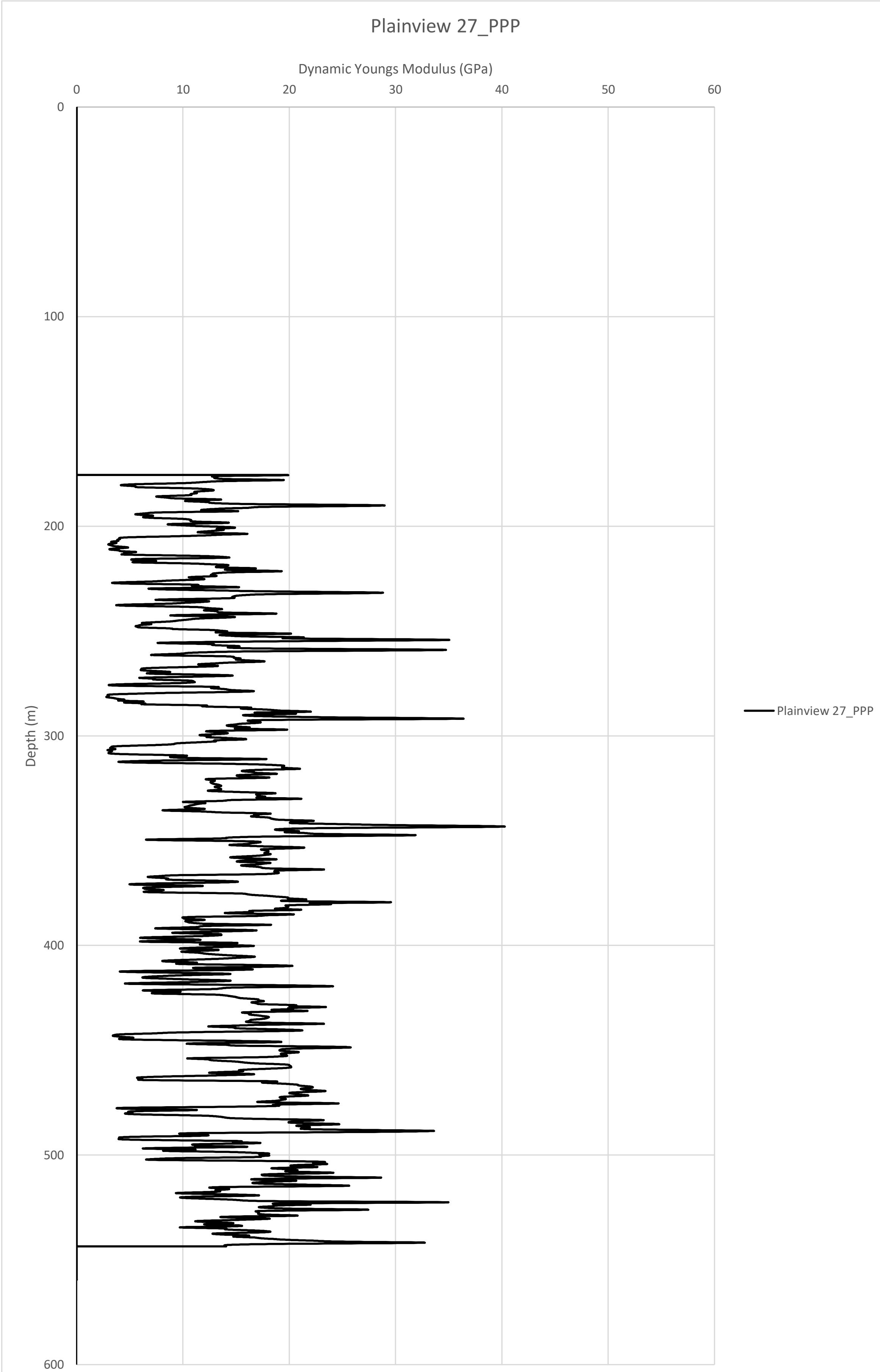
Kogan North 89_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
Depth (m)
0
100
200
300
400
500
600
Kogan North 89_PPP

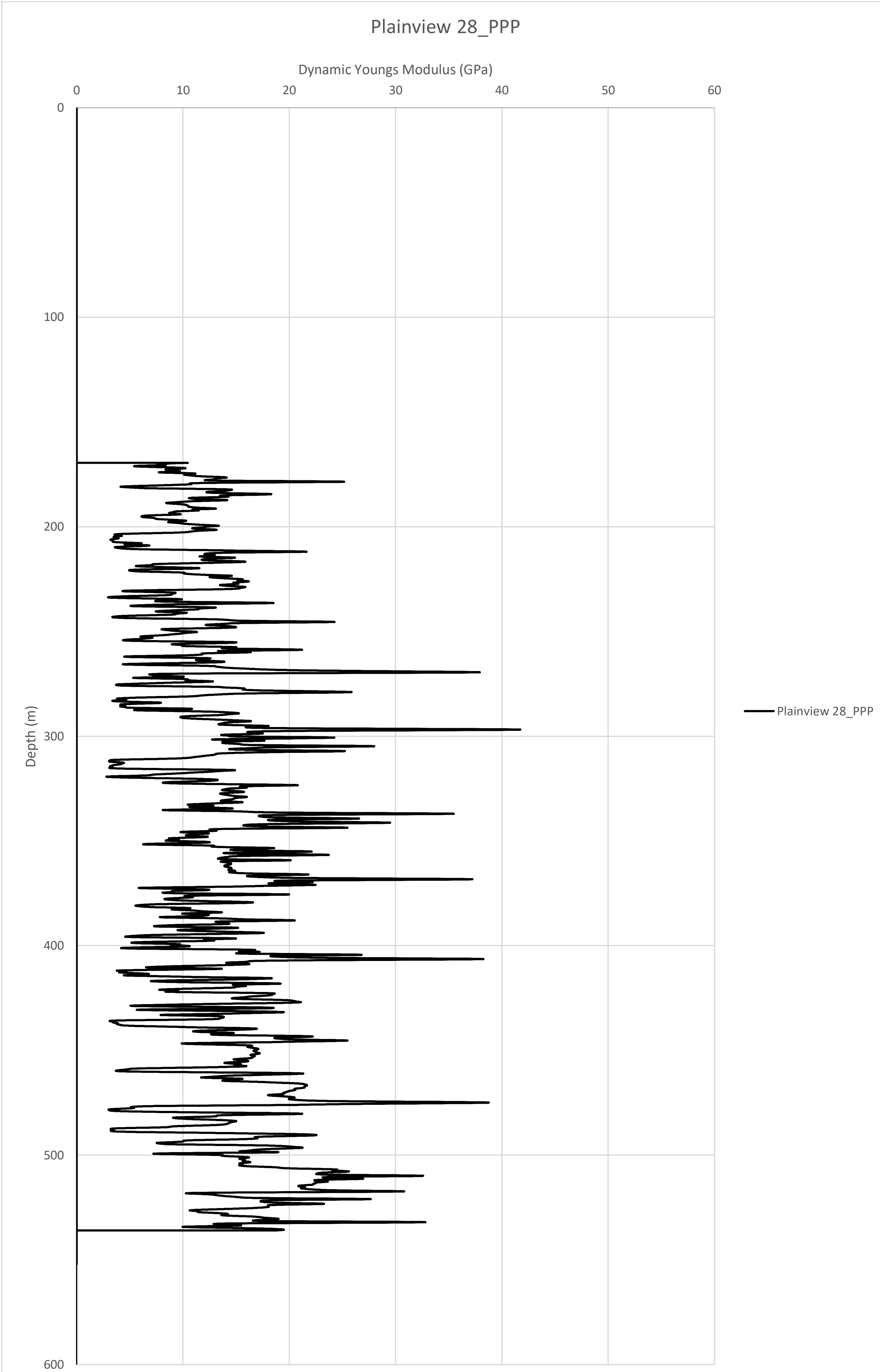

Kogan North 90_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Kogan North 90_PPP

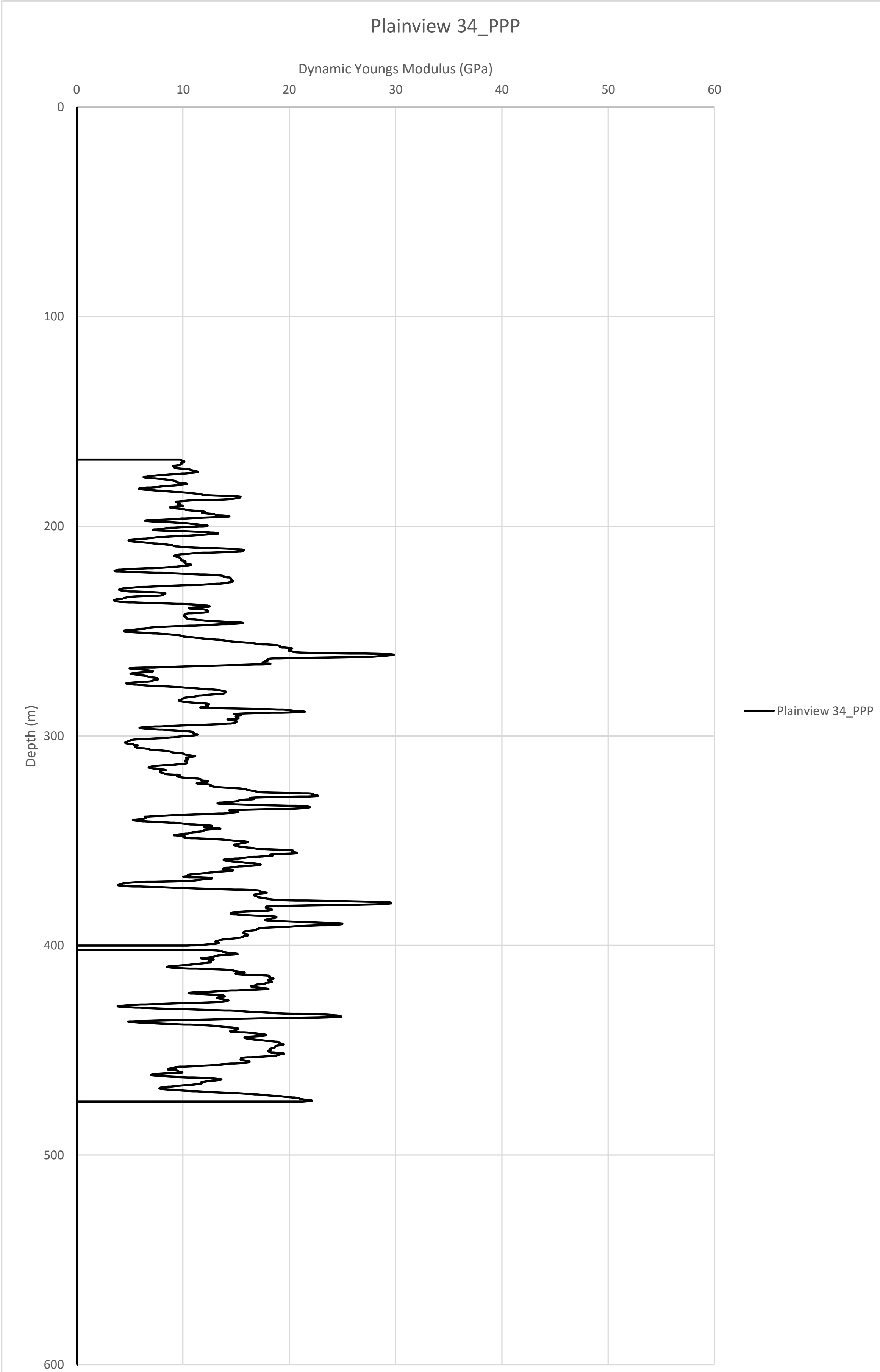

Kogan North 91_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Kogan North 91_PPP

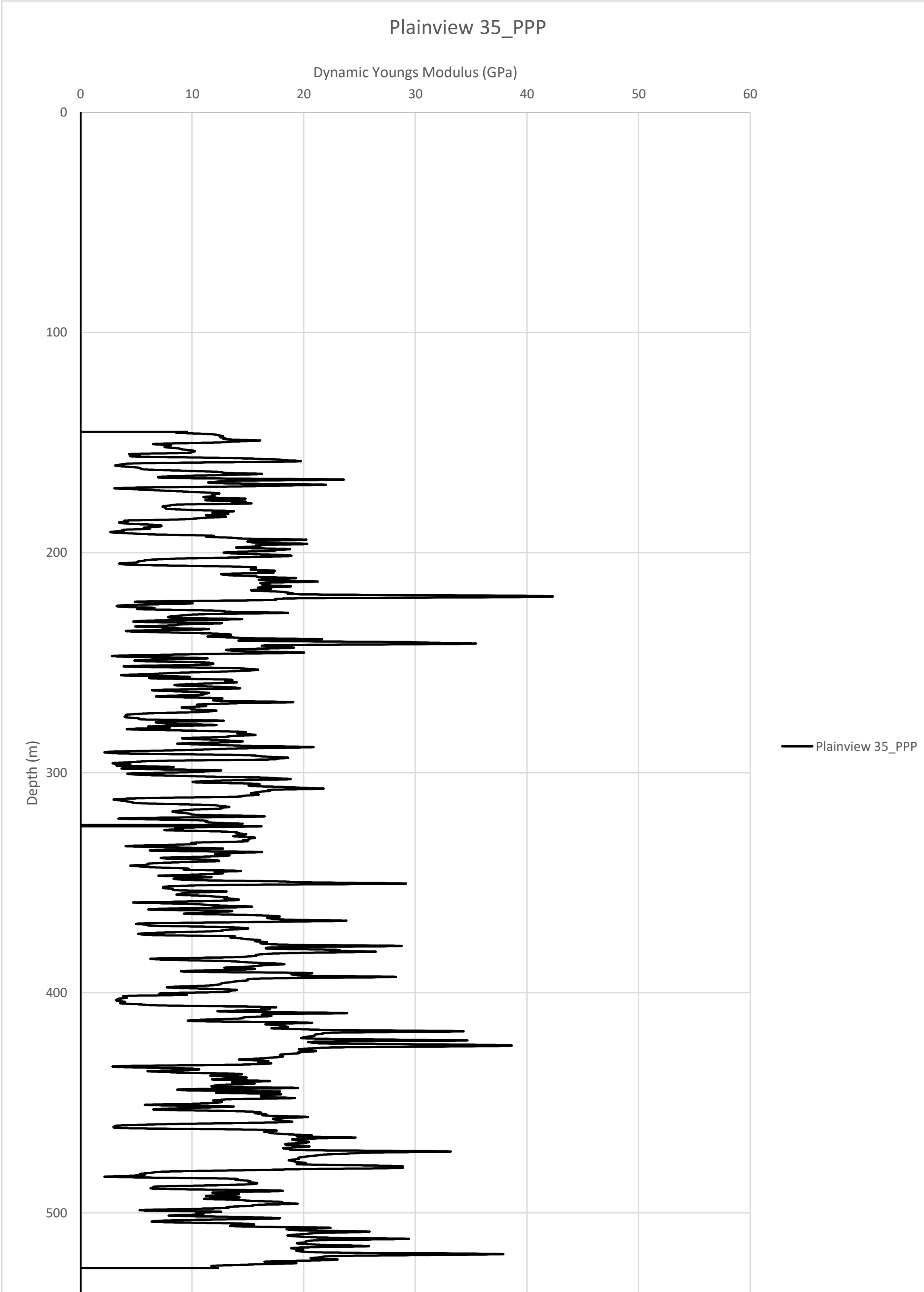


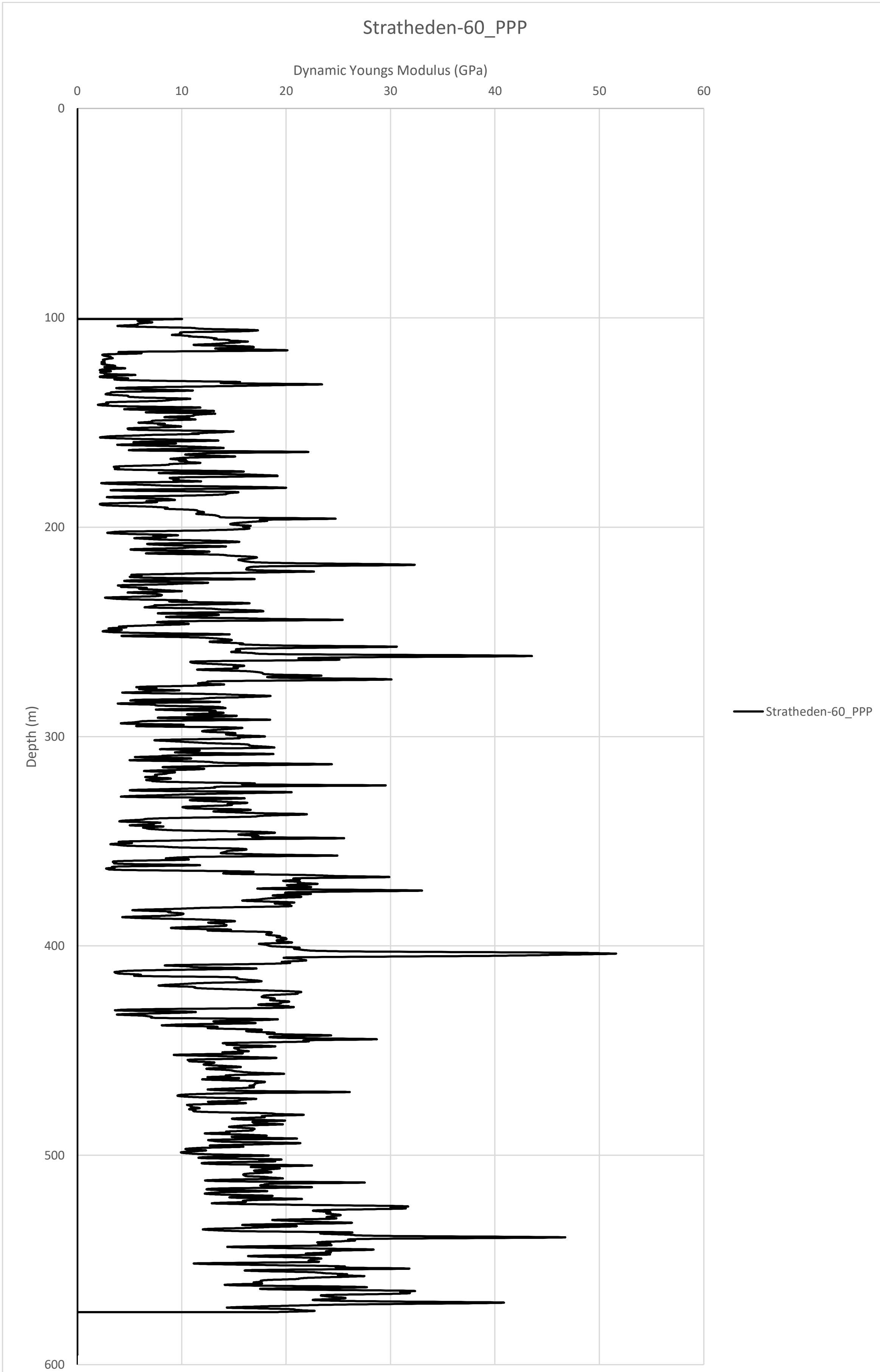
Meenawarra 33_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Meenawarra 33_PPP

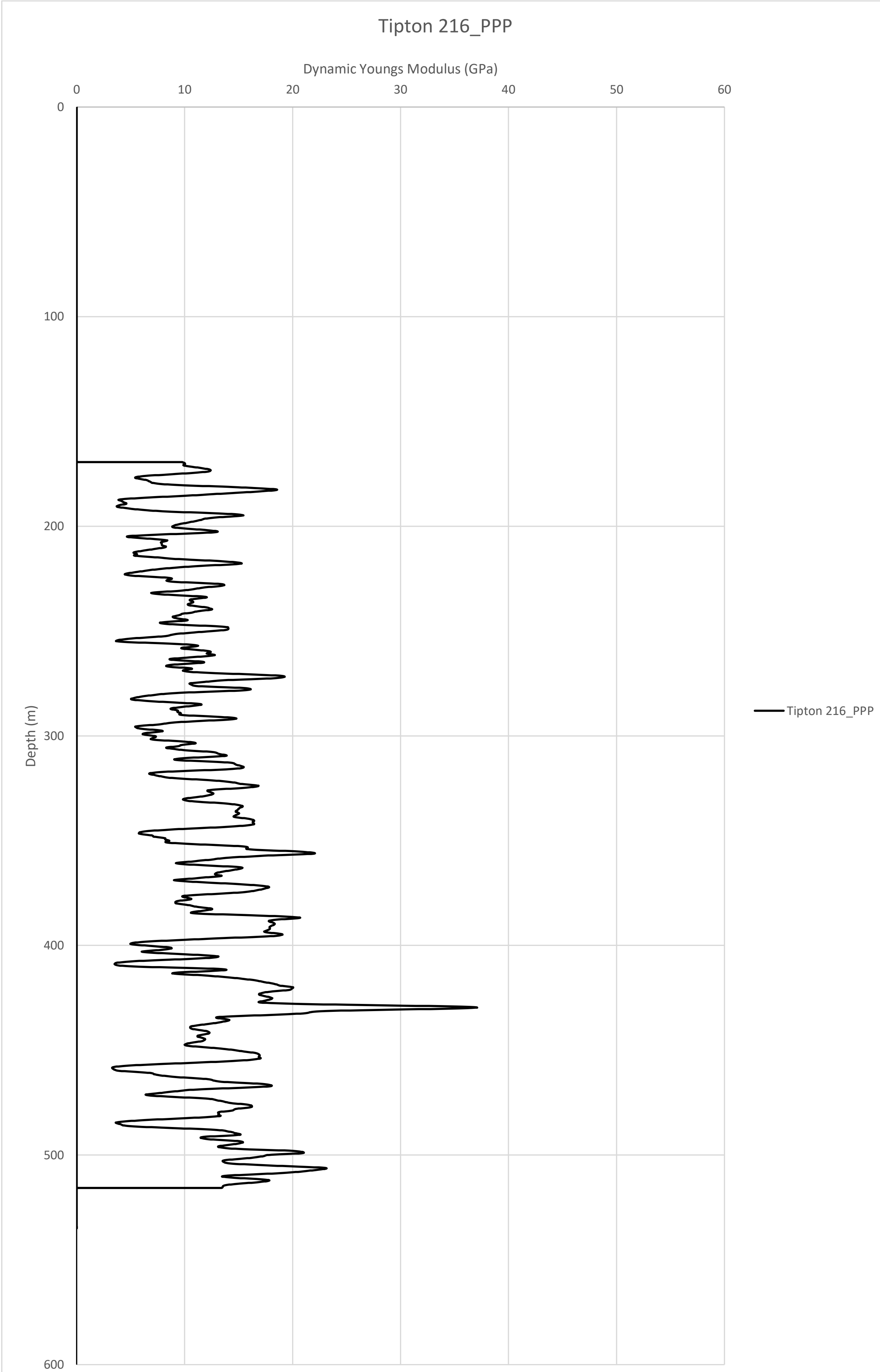

Plainview 27_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Plainview 27_PPP


Plainview 28_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Plainview 28_PPP

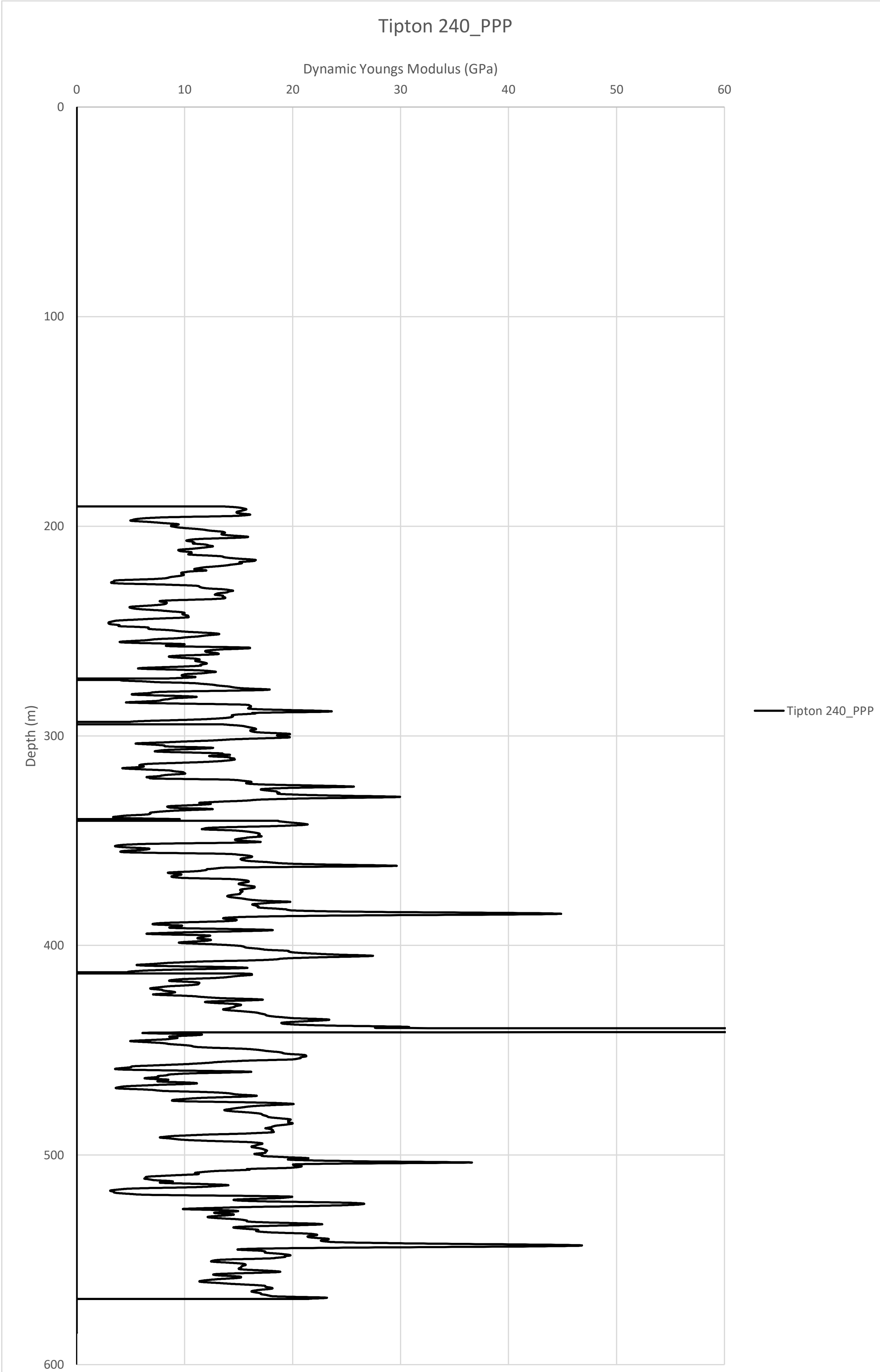

Plainview 34_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
Depth (m)
0
100
200
300
400
500
600
Plainview 34_PPP


Plainview 35_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Plainview 35_PPP


Stratheden-60_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Stratheden-60_PPP



Tipton 216_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
Depth (m)
Tipton 216_PPP


Tipton 240_PPP
Dynamic Youngs Modulus (GPa)
0
10
20
30
40
50
60
Depth (m)
0
100
200
300
400
500
600
Tipton 240_PPP