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Borehole Geology Data Update and Analysis with JIWA DBase

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ABSTRACT

Borehole geology data in the form of cuttings, cores, and formation logs are observed during drilling, as well as advanced analysis and data integration afterward. The aforementioned data collected after drilling is used to update information about subsurface geology, including lithology characterization, geological structure interpretation, and hydrothermal alteration identification. By utilizing this information, a comprehensive understanding of the geothermal system can be attained. This knowledge leads to well-informed decisions in geothermal projects, such as well targeting strategy. To support this work, a fit-for-purpose database is needed to ensure the data is properly curated, accessible, and useful for further geological interpretation. In this study, the applications of JIWA DBase are elaborated for updating and analyzing borehole geology data to support geologists in geothermal drilling.

1. INTRODUCTION

Borehole geology data in the form of core sampled and cutting returns treated as the "hard" geological data and geophysical well logs are analyzed to update the information about the geothermal system. The aforementioned data acquired after drilling serves the information about subsurface geology, including lithology and stratigraphy characterization, geological structure interpretation, and hydrothermal alteration identification. This knowledge is incorporated for fine-tune geothermal reservoir characterization and resource estimation that leads to well-informed decisions in a well-targeting strategy.

The analysis of a borehole geologic static data sample can be frequently conducted using different methods. Consequently, the accuracy level of an analysis result can be impacted. For instance, the accuracy of data results is analyzed during drilling and post drilling. The aforementioned qualitative-based static data is prone to inconsistencies/not standardized in a uniform format as defined by company standards (Darnet et al., 2020). For example, unit measurement (for instance, meter/feet-MD and gAPI/cpm-Gamma Ray) and nomenclature placement (lithology or formation name column) are immensely difficult to unify into the database. Furthermore, the challenge is related to storage management. Because of the frequently analysis, some data are stored in disseminated repositories/report, for example the result of analysis on the drill site (core and mud log report) and in the laboratory (petrography, x-ray diffraction, permeability, and stress measurement report, etc.). There will exist time taken to access the disseminated data to further analysis (Hanton et al., 2019).

In response to all challenges as mentioned above, a fit-for-purpose database is needed to ensure the data is properly curated, accessible, and useful for further geological interpretation. In this study, the applications of JIWA DBase, a web-based database application are elaborated for updating and analyzing borehole geology data. This application also enables the collaboration in data management and analysis among geologists, subsurface & production engineers, and related stakeholders of geothermal developers and regulators (Sidqi et al., 2024).

2. METHODS

The present study adopts a case study approach and aims to showcase the step-by-step process of handling borehole geology data using JIWA DBase. The case study will employ Utah FORGE data to allow readers of this study and future users of JIWA DBase contextualize into the realistic geothermal data. Figure 1 show the process of using JIWA DBase and will be elaborated as follows:

2.1 Data Collection

Geological data in the geothermal industry is generally classified into two types of data, which are structured and unstructured data. The unstructured data would be collected from many different sources, such as digital or non-digital reports. In regard to borehole geology data, some reports which are commonly collected are End of Well Report (EOWR), core/cutting summary report, core testing report, mud log report, petrography report, XRD report, and geophysical log report. JIWA DBase allows users to turn an unstructured database into a structured database. In the transformation process, the data is prepared according to the types of module and properties within it. For instance, if the user is going to store data into the Core and Cutting module, it is suggested to prepare the dataset according to the properties inside the Core and Cutting module first. The users need to be aware that some properties might be retrieved from different sources of report.

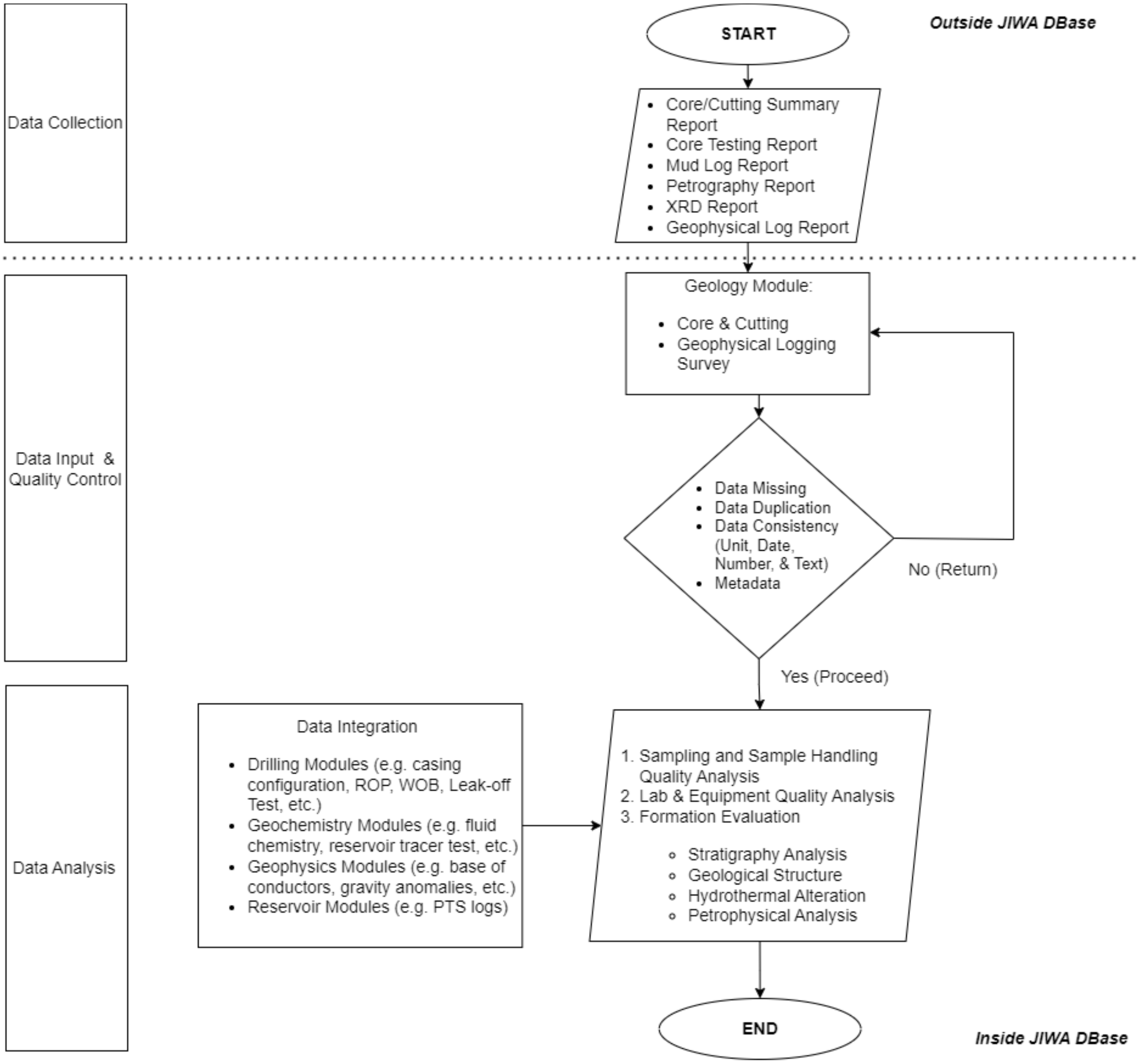


Figure 1: The workflow process of the borehole geology data management and analysis with JIWA DBase.

2.2 Data Input & Quality Control

Entering JIWA DBase interface, users will find several sections of data input, including Head Data (job description, job type selector, and others), detail properties comprise method selector, spreadsheet table, quantitative value lookups, and image attachment, and Original File to accommodate digital reports appendix. The design of the input features which collaborate both text-form and look-up input allows users to be agile in data input as well as keeping the consistency of descriptive information as it is commonly found in the borehole geology data.

Along with the data input, quality control (QC) is an indivisible step in the flow process of using JIWA DBase. There are at least three types of QC process suggested in this study.

2.2.1 Prior to Data Submission

The system in JIWA DBase enables users to record their data into a structured database which consist of mandatory and non-mandatory properties to fill. Besides, the system will also check the conformity of the data by giving pop-up information. These steps of quality-checking are included in the data validation mechanism (Figure 2). After inputting data in the available properties of JIWA DBase, users are advised to check upon the possibility of data missing, duplication, and its consistency, including when the parameter might require unit conversion. In order to assist users for this QC process, JIWA DBase is equipped with plotting features, specifically for tabular data (Figure 3).

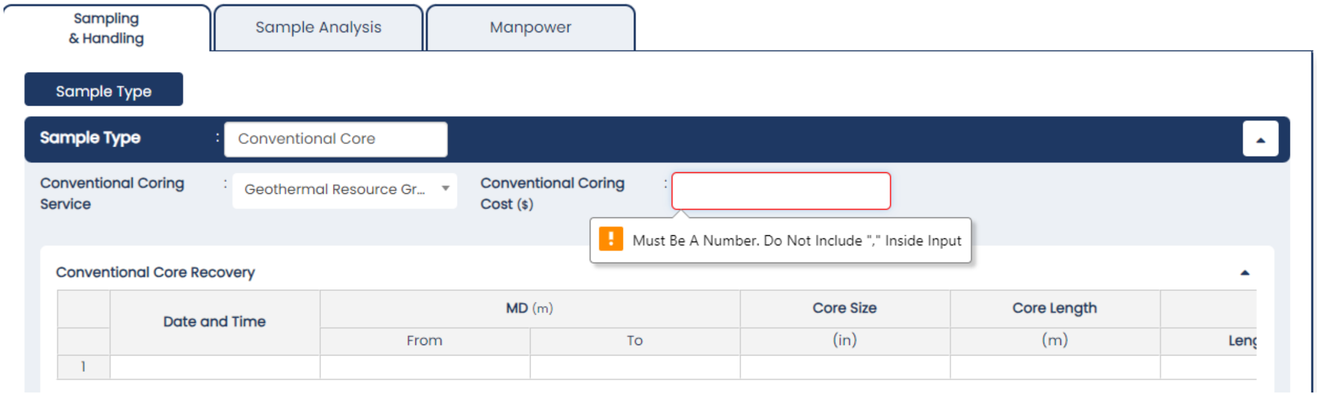


Figure 2: The example of validation quality check in core and cutting sub-module JIWA DBase.

Figure 3: The example of QC plotting to check data duplication.

2.2.2 After Data Submission

JIWA DBase is strategically designed to facilitate users in discerning the methodologies or procedural approaches employed in relation to specific datasets. For instance, the users would like to quality-check which methods applied in the designated "X" core sample, both during the drilling stage and post-drilling stage. By utilizing the plotting feature in JIWA DBase, it empowers users to scrutinize the appropriateness and adequacy of the employed methodologies at each stage, thereby augmenting confidence in the subsequent data analysis.

2.2.3 Metadata Coverage

As the database which covers comprehensiveness of the data, JIWA DBase exhibits a capacity to present metadata pertaining to specific reports through the utilization of plotting features. Its significance is particularly pronounced within the geothermal industry, where diverse stakeholders participate in the lengthy timeline. Users, through this database, are seamlessly empowered to ascertain the entities involved, temporal and spatial dimensions of project execution, financial implications, and access the original documentation of project reports. This plotting feature is purposefully designed to enhance user proficiency in comprehending data for evaluative purposes, thereby optimizing accuracy in analyses.

2.3 Data Analysis

Following the quality-checking process, JIWA DBase allows users to integrate several datasets from different modules to establish multidisciplinary comprehension, such as but not limited to conceptual model update, top of reservoir's depth estimation, and permeability characteristics. Moreover, JIWA DBase is aimed to support users in comprehending borehole geology data and principally aid in formation evaluation process, from stratigraphy, geological structure, hydrothermal alteration, to the quality of respective samples, personnel, and laboratory equipment.

3. FIELD CASE AND DATA

Utah FORGE area is a subsurface research project; conducted by Utah Frontier Observatory for Research in Geothermal Energy (FORGE) for developing Enhanced Geothermal System (EGS) technology. Figure 4 show this area situated ~350 km south of Salt Lake City and 16 km north of Milford, Utah, United States (Kirby et al., 2018). The geologic framework indicate the Utah FORGE site is located in a part of the great basin that is tectonically quiet (Simmons et al., 2019). Moore et al. (2020) mentioned the stratigraphy units in Utah FORGE area are divided into two rock types: basin fill (sedimentary and volcanic deposits) and crystalline basement rock group.

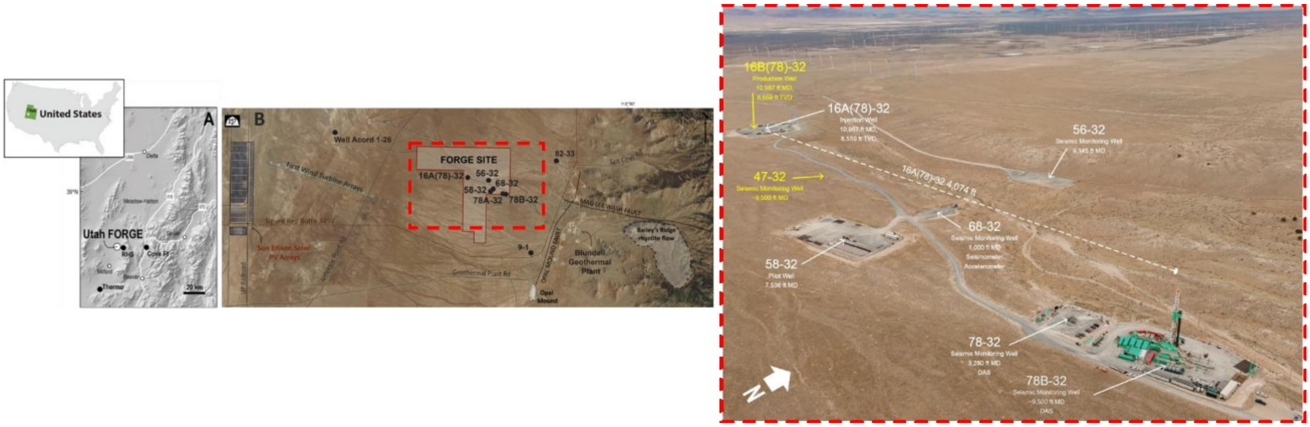
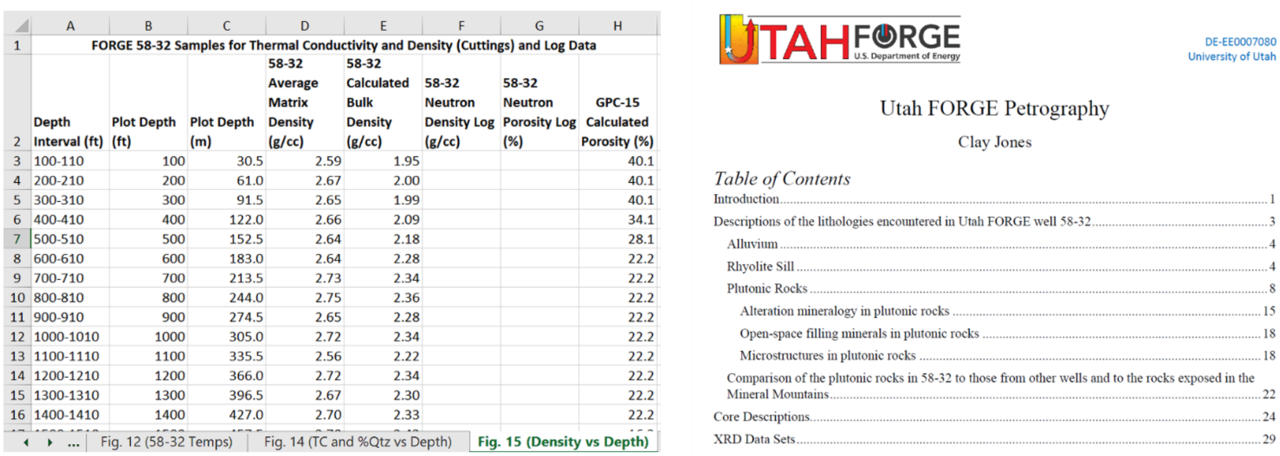


Figure 4: A detailed map of the Utah FORGE study area from aerial with all the wells clearly marked and label; modified from (Moore et al., 2020).

In this study, two vertical well data are acquired from open-source data: Geothermal Data Repository (GDR) or the Utah FORGE website. The well data has been collected from core and cuttings of wells 58-32 and 78B-32. The drill cuttings of the well were mainly collected mainly at over 3 meters and 30 meters intervals (Gwynn et al., 2018). Well 58-32 and 78B-32 are drilled to a measured depth of 2297 and 2896 meters respectively (Moore et al., 2023). The wells are being used for seismic monitoring (78B-32) and pilot well for testing (58-32). As shown in Figure 5, the data and information are documented in two format types of report: spreadsheets (X-Ray Diffraction analysis and rock properties measurement) and portable documents (petrography analysis, core recovery run, and lithology).



FORGE 58-32 Samples for Thermal Conductivity and Density (Cuttings) and Log Data

Depth Interval (ft)	Plot Depth (ft)	Plot Depth (m)	58-32 Average Matrix Density (g/cc)	58-32 Calculated Bulk Density (g/cc)	58-32 Neutron Density Log (g/cc)	58-32 Neutron Porosity Log (%)	GPC-15 Calculated Porosity (%)
100-110	100	30.5	2.59	1.95			40.1
200-210	200	61.0	2.67	2.00			40.1
300-310	300	91.5	2.65	1.99			40.1
400-410	400	122.0	2.66	2.09			34.1
500-510	500	152.5	2.64	2.18			28.1
600-610	600	183.0	2.64	2.28			22.2
700-710	700	213.5	2.73	2.34			22.2
800-810	800	244.0	2.75	2.36			22.2
900-910	900	274.5	2.65	2.28			22.2
1000-1010	1000	305.0	2.72	2.34			22.2
1100-1110	1100	335.5	2.56	2.22			22.2
1200-1210	1200	366.0	2.72	2.34			22.2
1300-1310	1300	396.5	2.67	2.30			22.2
1400-1410	1400	427.0	2.70	2.33			22.2

Fig. 12 (58-32 Temps) | Fig. 14 (TC and %Qtz vs Depth) | Fig. 15 (Density vs Depth)

UTAH FORGE U.S. Department of Energy

DE-EE0007080
University of Utah

Utah FORGE Petrography

Clay Jones

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Figure 5: The example of the report format that is managed in JIWA DBase. Particularly, spreadsheet (.xls) and portable document (.pdf) formats are used in this study (Moore et al., 2018).

Table 1 shows the data usage value of this study. The values and information would then be used for data management and analysis in the study area. Well survey data is limited to 3D visualization of lithology/stratigraphy in the study area. Casing data is limited to geology log and interpreted plotting. Then, X-Ray diffraction & petrography data analysis dominantly focuses on plutonic rock samples.

Table 1: Data usage of this study. The data is compiled from various data source on geothermal data repository website. *FMI= Fullbore Formation Microimager.

Well	Data Analysis Result	Raw Data					Data Source
	Subsurface Lithology (Core & Cutting)	Core Run	Drilling (Well Survey & Casing)	Fracture (from FMI* log) Data	Porosity, Density, and Permeability (Core & Cutting)	Spectral Gamma Ray Measurements (Cutting)	
58-32	Yes: Macroscopic and Petrography	No	Yes: UTM Coordinate (X & Y), Depth, Inclination, and Azimuth	Yes: Azimuth, Dip, and Type	Yes: Bulk Density, Neutron Porosity, Klinkenberg Permeability	Yes: Potassium, Thorium, and Uranium Element	Gwynn et al. (2018); Nash and Jones, (2018); Nash and Moore, (2018)
78B-32	Yes: Macroscopic, Petrography, and XRD	Yes: Core Length and Recovery Percentage		No	No	No	McLennan (2021)

4. RESULT AND DISCUSSION

The following subsection presents the results and discussion based on representative of well data. These represent a dataset for analysis, visualized within JIWA DBase.

4.1 Coring Run Operation (Core Recovery)

Four coring runs were performed by the 78B-32 well at a total depth 2600 meters (Figure 6). It can be implied that the 78B-32 well can be considered as adequate for the core recovery. It is proved by the core recovery quality for the cores (except core run#1) averaged ~82%.

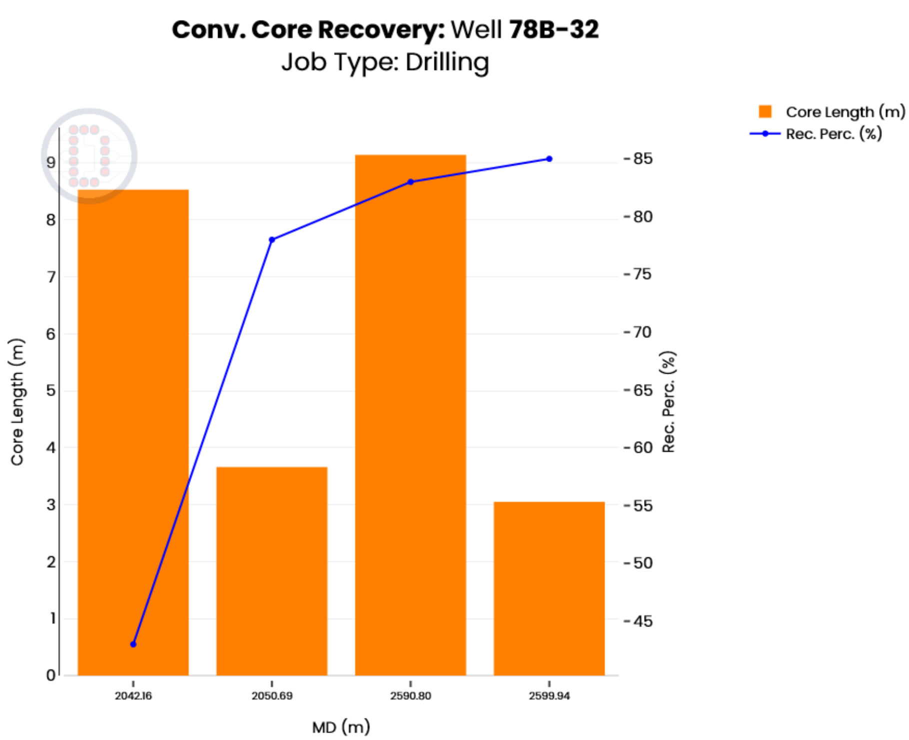

Figure 6: The summary core recovery chart from the core runs of 78B-32 well using JIWA DBase.

The trend of core recovery percentage tends to be increased with depth. The first run from 2042.16 m to 2050.69 m, core length 8.53 m, recovering 3.66 m (43% recovery). In the second run, cored from 2050.69 to 2054.35 m, core length 3.66 m, recovering 2.87 m (78% recovery). In the core run #3, cored from 2590.80 m to 2599.94 m, core length 9.14 m, were core with a recovery 7.57 m (83% recovery), and on core run#4 from 2599.94 m to 2602.99 m, core length 3.05 m, and recovered 2.59 m (85% recovery). The core recovery data can be integrated with drilling parameter data, i.e. penetration rates and weight on bit learned in order to more effectively plan and execute future rock formation coring operations (McLennan, 2021).

4.2 Lithology and Stratigraphy Analysis

By utilizing data from all wells, a plotting of lithology and stratigraphy was achieved by integrated analysis, primarily through detailed 3D visualization using JIWA DBase (Figure 7). In addition, JIWA DBase can visualize multiple charts of numerous datasets on a single dashboard from the several results of lithological analysis, i.e. macroscopic, petrography, XRD, etc. In this study, the charts are not shown due to data and research limitations. Figure 7 shows rock types distribution with depth. By analyzing the lithology distribution for all the wells, the stratigraphy of the study area is composed of alluvial and coarse grained-rock. The analysis of lithology and stratigraphy are explained in paragraph below.

The 78B-32 well stratigraphy consists of five rock types: alluvial, rhyolite, granite, granodiorite, and monzodiorite rock types. In the upper part, the 78B-32 well is alluvial to a depth of ~800 meters. This well encountered rhyolite and other rocks after penetrating alluvial deposits. The start occurrence of monzodiorite rock is encountered at ~930 meters depth. The granodiorite rocks were encountered at ~1600 meters.

According to Simmons et al. (2019), the top of reservoir is estimated at a depth of 2 km, at temperature 175±10ºC on integration with (PT) Pressure Temperature data. At these depths, the plutonic rock, granodiorite, are predominantly found in the reservoir zone. Furthermore, the result of lithology and analysis can also be correlated with drilling parameter data, i.e. penetration rates and weight on bit. According to Gwynn et al. (2018) the alluvial (soft rock) section has higher penetration rate average (>50 ft/hours) than basement (hard rock) section (<50 ft/hours).

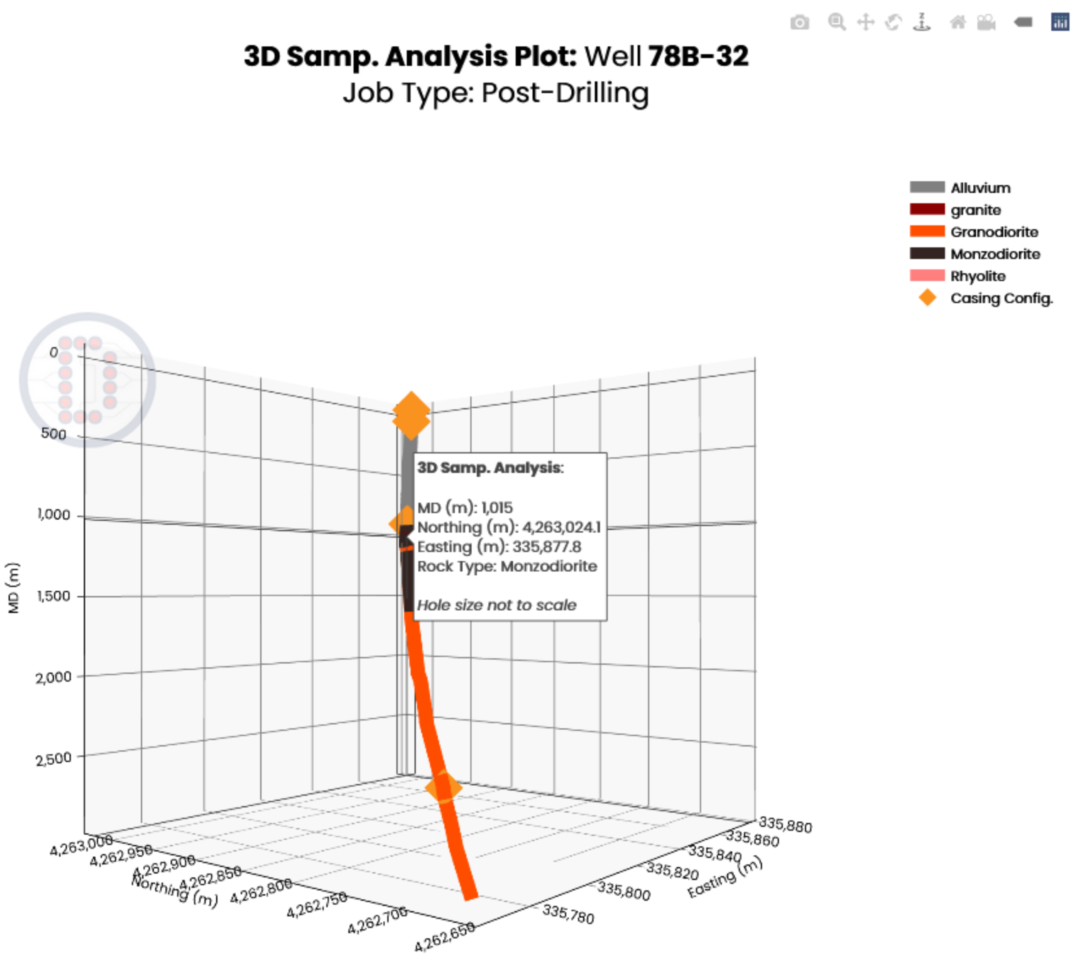

Figure 7: Three-dimension (3D) visualization of 78B-32 well using JIWA DBase.

4.3 Geological Structure and Borehole Breakouts

This subsection primarily represents fracture and in-situ stress identification within 56-32 and 58-32 well. The boxplot chart shows the average of dip between 56-32 and 58-32 well 47 and 43° respectively (Figure 8). The dip information helps determine the well targeting, particularly the direction of the wellbore.

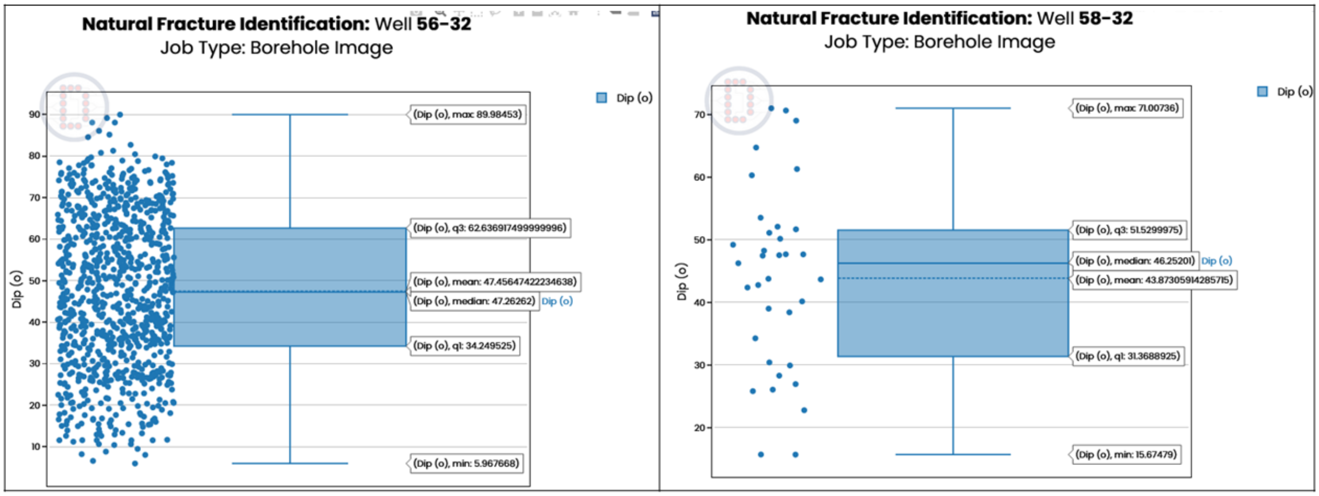

Figure 8: The boxplot chart of 56-32 (left) and 58-32 (right) well. The chart shows statistics analysis of conductive fracture dip data including max, min, mean, median, and quartile value.

Analysis of image log from 58-32 well revealed a fracture within the basement rock. The fracture characteristics are identified in Utah FORGE site reservoir crystalline basement rock amount to more than 2000 natural fractures azimuth and dip data (Figure 9). As depicted in Figure 9, the 58-32 well exhibited a significant presence of fractures, predominantly partial conductive fracture. The dip of this fracture is approximately 30º to 40º to the west. By combining with Pressure Temperature Spinner (PTS) logging data; afterward, effective fractures can be investigated. This data can be further analyzed for geomechanics modeling integrated with other data such as core lab tests, leak-off tests, etc.

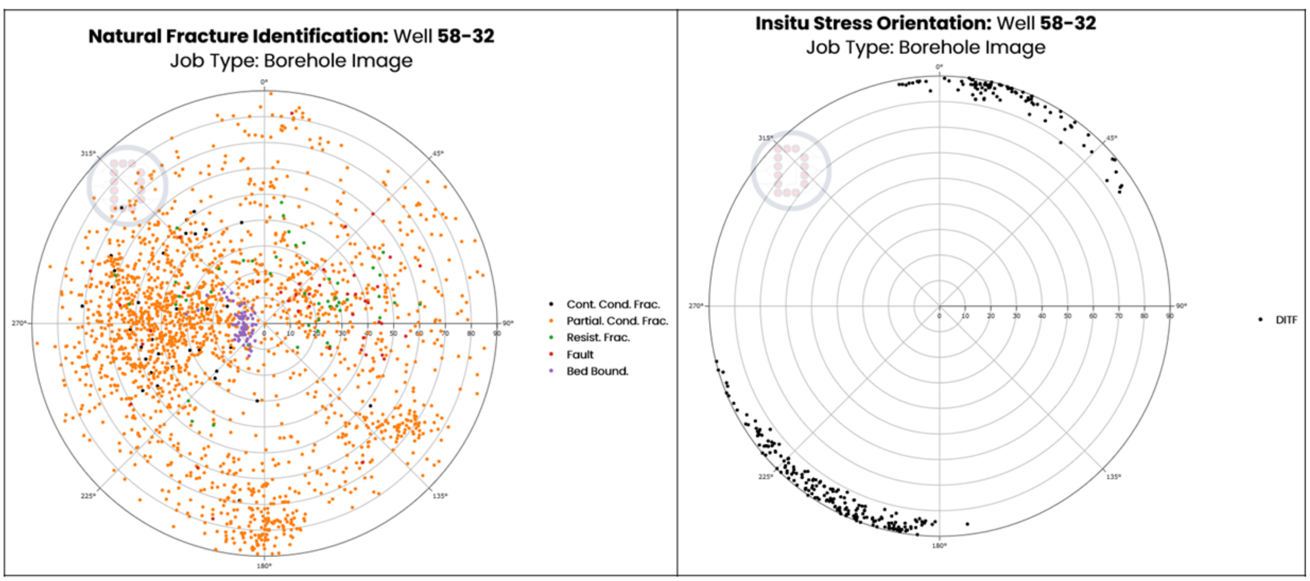

Figure 9: The left image shows the azimuth and dip of >2000 natural fractures in 58-32 well, especially in basement rock. The fracture is dominated by partial conductive fracture with azimuth. The right image shows the azimuth and dip of in-situ stress orientation, reflecting NNE-SSW orientation.

4.4 Mineralogy and Hydrothermal Alteration

As shown in Figure 10, quartz-plagioclase mineralogy composition (%) of 58-32 well indicates an inverse relationship; low quartz-high plagioclase (~950 to ~1500 m). At this depth, diorite rock types are revealed. In addition, the 58-32 well, rock types are determined from integrated analysis of cuttings and cores: alluvial in the upper part of the well (~0 to ~950 m) and coarse-grained plutonic rocks in the lower portion (~980 to ~2300 m). The major plutonic rocks at these depths are granite and monzonite with minor granodiorite, monzodiorite, and diorite. A thin layer of rhyolite (~970 to ~975 m) separates from alluvial and plutonic rock. Moore et al. (2020) mentioned that the rhyolite rock is marked as the top of the basement.

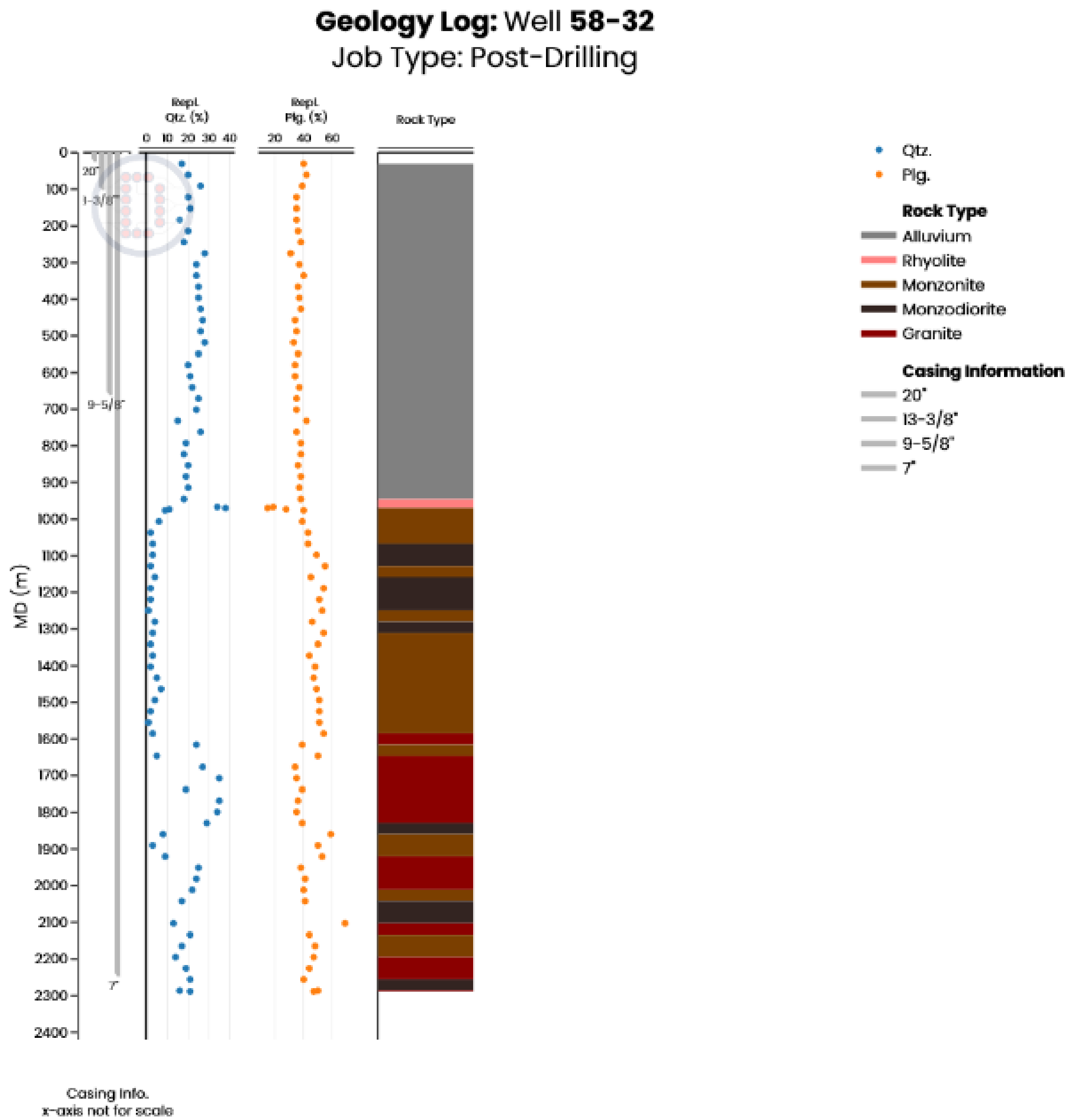

Figure 10: Quartz and plagioclase in drill cuttings at 30 meters intervals show an inverse relationship, with low quartz and high plagioclase and vice versa being predicted of more dioritic rock types (plot on right). Abbreviation: qtz= quartz, plg=plagioclase.

In terms of hydrothermal alteration, Figure 11 shows secondary and clay minerals abundance determined in the plutonic rock sample of 58-32 well. These explain the secondary minerals abundance in the plutonic rock of well 58-32 is generally low and the proportion decreases with depth. Moore et al. (2023) mentioned the low abundances of alteration minerals impacted the low permeability of these rocks. The Utah FORGE site reservoir (at a depth of ~2 km) has low abundances of total secondary minerals (2 to 6%) with an average of 4% include clay minerals (smectite, interlayered chlorite/smectite, chlorite, illite and kaolinite), as well as calcite and epidote. According to petrography analysis from Jones et al. (2018), the clay mineral of 58-32 well replacing primary minerals through hydrothermal alteration process; plagioclase alters to illite and/or smectite; ferromagnesian minerals alter to chlorite, interlayered chlorite/smectite and/or smectite. Calcite, anhydrite, and epidote are also observed replacing plagioclase in low abundances (Jones et al., 2018).

Clay mineral abundance chart shows trace amounts (<1%) of smectite were observed within the Utah FORGE site reservoir (Figure 11). According to temperature data, the smectite and epidote in Utah FORGE reservoir zone at temperatures ranging from 180 to 197℃ (Jones et al., 2018). Henley and Ellis (1983) mentioned that the expected temperature stability ranges of the clay minerals are as follow: at <180℃ smectite is stable; at >180℃ and <220℃ interlayered clays are stable; at 240 to 260℃ epidote is typically forms or stable, and at >220℃

chlorite and illite are stable in geothermal system. Hence, the smectite and epidote in the Utah FORGE site reservoir is found outside of the expected stability range; indicates low permeability rock and remnants of an older episode of hydrothermal alteration.

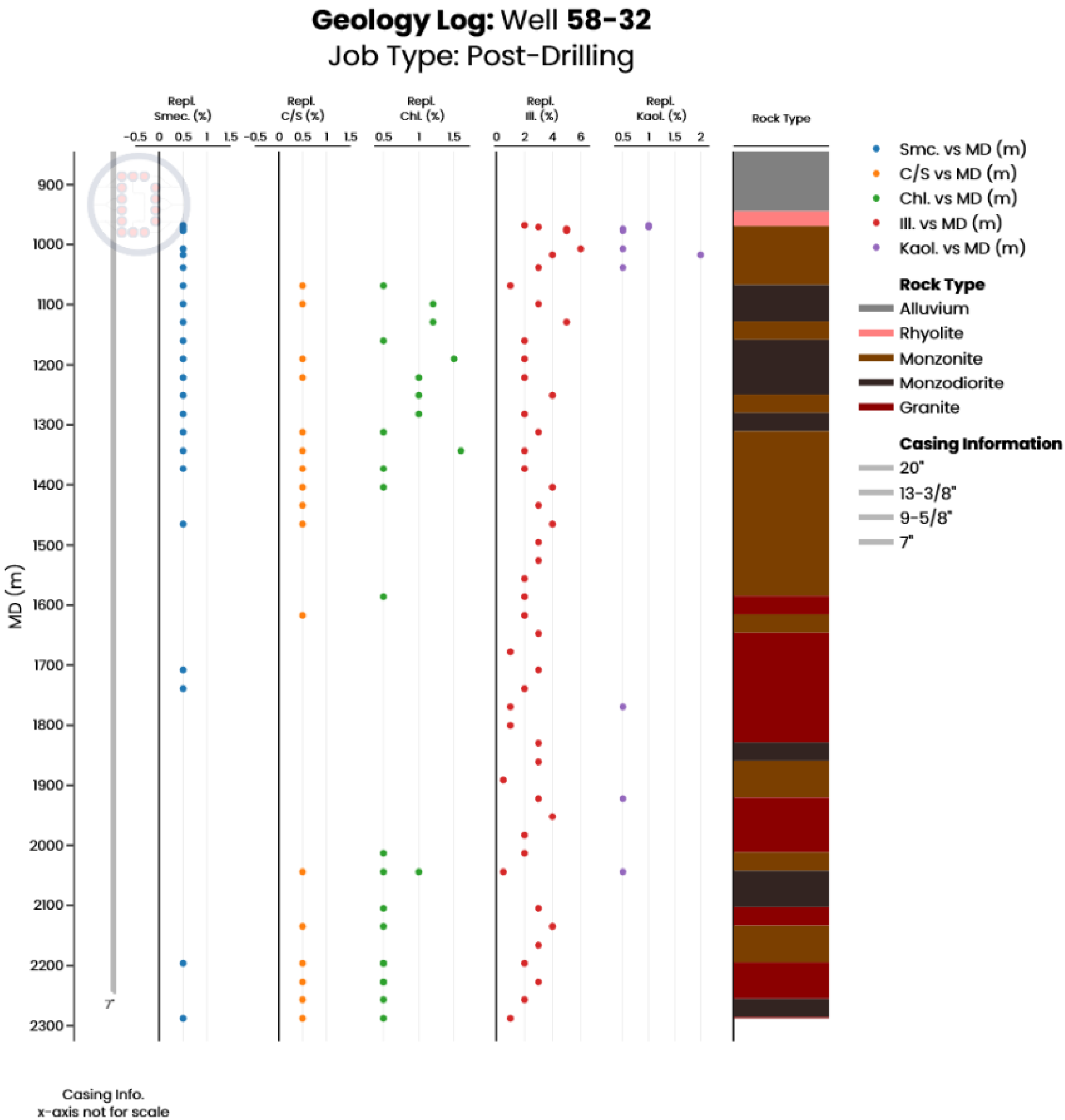

Figure 11: The abundances of secondary mineral & clay mineral in the basement rock of 58-32 well. Secondary minerals observed in trace amounts during petrographic observation are shown as 0.5% for visualization purposes. Abbreviation: smec= smectite, C/S=chlorite/smectite, chl=chlorite, ill=illite, and kaol=kaolinite.

4.5 Rock Properties

The rock properties are analyzed using sample data from 58-32 well. Many of the rock properties data established in geophysical logging and core testing report.

4.5.1 Porosity, Density, and Permeability

Figure 12 shows the distribution of porosity and density value into plutonic rock. There is a decrease trend in porosity value with depth through the alluvial section and the very uniform and minimal porosity deeper in the plutonic basement rock. Within the alluvial section, a gradual decrease in porosity was observed, ranging from approximately 15% to 11% between at about 1006 meters. A notable shift was observed below 1310 meters, where the rock porosity became relatively constant at low 1-2%. In terms of density, the value faces a pattern with the significant increase of about 1000 and 1280 meters as shown in Figure 12. This pattern directly relates to the occurrence of mafic minerals, which lithology data suggest is predominantly monzodiorite rock.

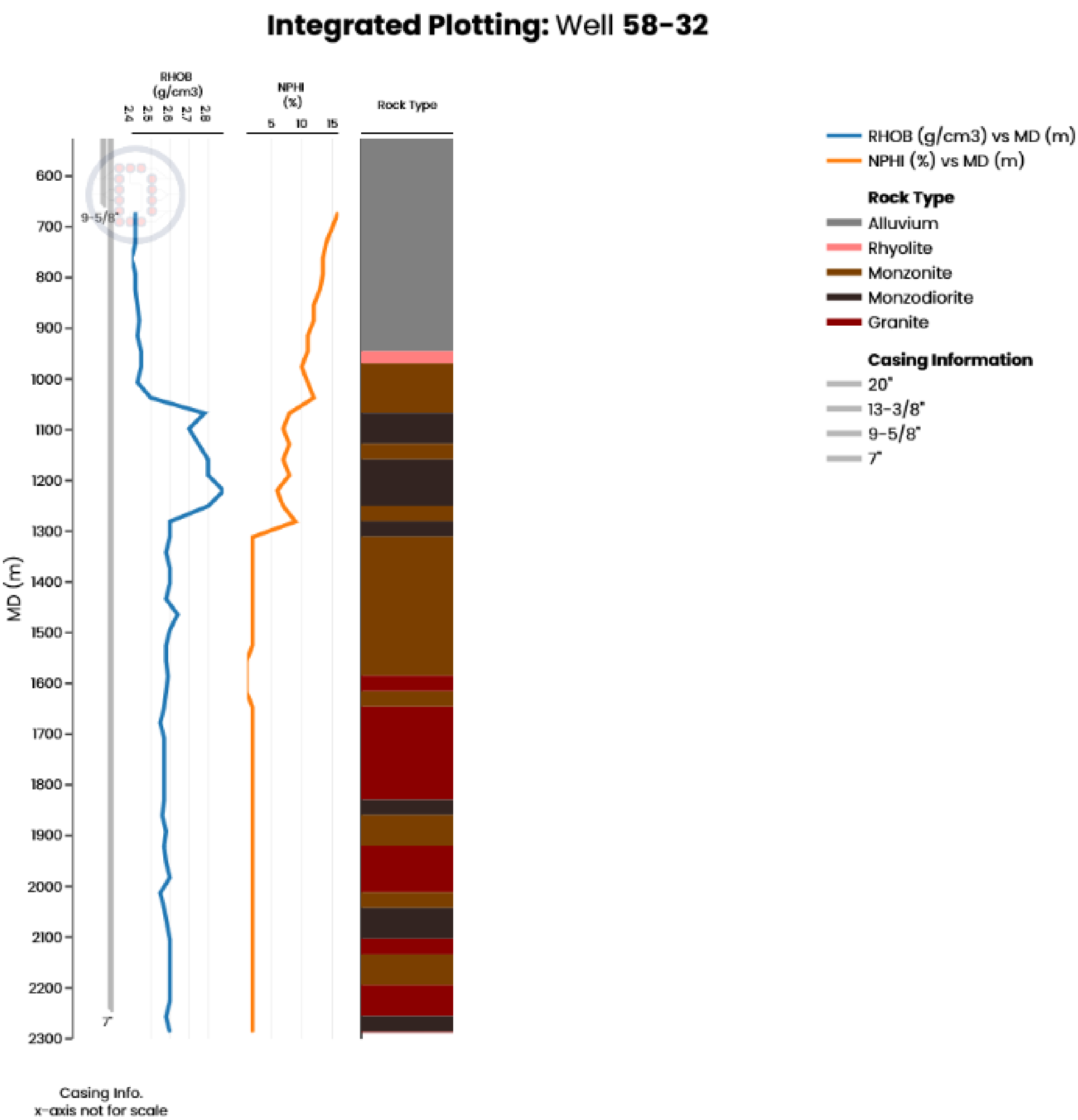

Figure 12: The measured bulk density (RHOB) from drill cuttings 58-32 well. These measurements compare well with the wireline neutron density data starting at 662 meters (bottom of the surface casing). Mafic minerals are the primary cause for density changes as shown by the dramatic increase between ~1000 and 1280 meters, which lithology data suggest is primarily dominated by monzodiorite. The plot of neutron porosity (NPHI) shows decreasing porosity value with depth through the alluvial section. Meanwhile, porosity is relatively constant in plutonic basement rock.

Figure 13 revealed the matrix permeabilities value near the reservoir zone are less than 30 micro-darcies according to core plugs testing. These values indicate that the proposed Utah FORGE reservoir has very low permeability. Combined with secondary mineral abundance, the low permeability value is associated with the decreasing proportion of secondary mineral in the reservoir zone of 58-32 well.

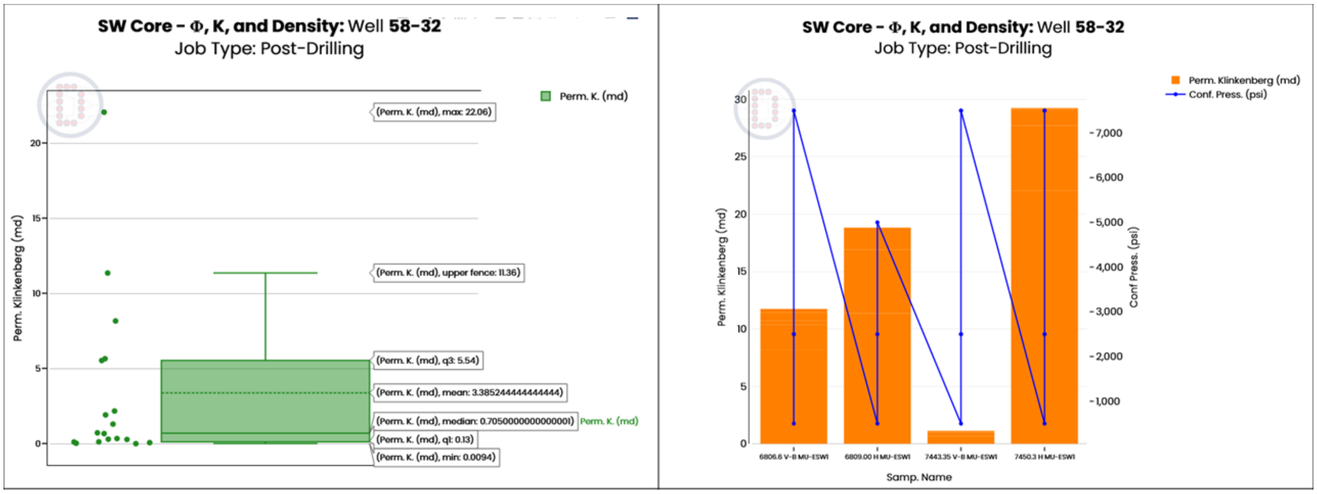

Figure 13: The left image shows statistics analysis in the form of boxplot chart. The average of permeability in this case is categorized as low permeability with 3 micro darcy. The right image shows permeability measured from sidewall core sample of 58-32 well. All the samples revealed the permeabilities value are less than 30 micro-darcies.

4.5.2 Radioactive Decay of Potassium, Thorium, and Uranium Element.

As shown in Figure 14, cutting measurement reveals a cutting of relatively low quantities of potassium (K) in the monzodiorite zone about (1052 to 1295 meters). Additionally, Figure 14 shows the enriched thorium (Th) and low to moderate potassium (K) in the granitic zone (about 1603 to 1814 meters and 1905 meters in total depth. The insight of this data can support the rock properties analysis as explained in the previous subsection.

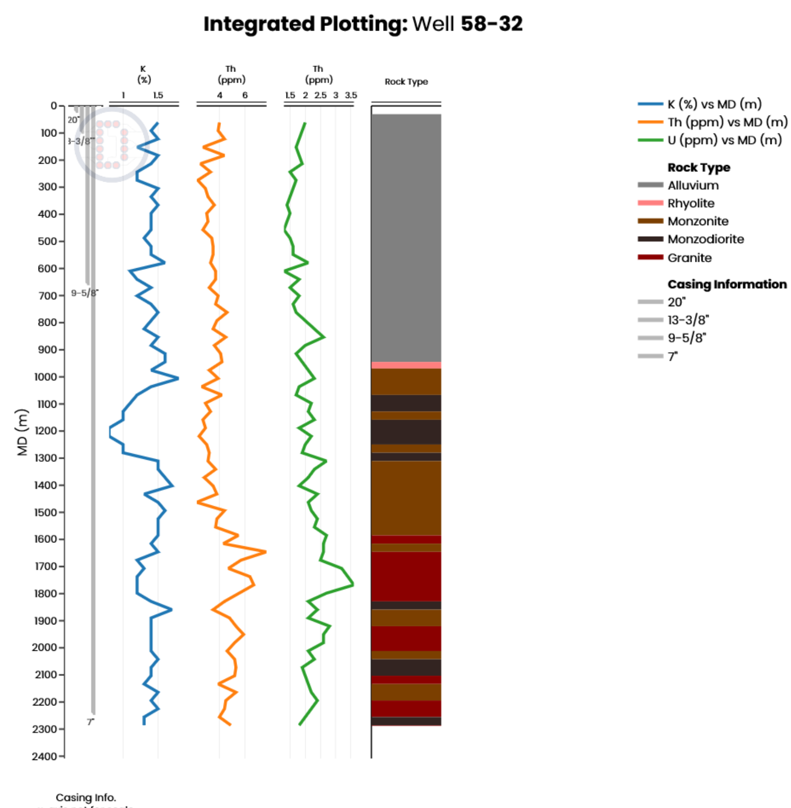

Figure 14: Spectral gamma ray data plotting from cuttings data of 58-32 well using JIWA DBase. Potassium (K) is measured as a percentage, while uranium (U) and thorium (Th) components are measured as parts per million (ppm).

5. CONCLUSION

Borehole geology data management update and analysis was conducted on dataset from Utah FORGE Site to showcase step-by-step process of handling using JIWA DBase. With this application, data collection helps convert unstructured data into structured data. The data input includes head data and detail properties in the form of text and look-up input. The quality control consists of validation quality check and plotting (data duplication, data missing, etc.). Data analysis aid in quality of respective samples, formation evaluation process, from lithology and stratigraphy analysis, geological structure, hydrothermal alteration, and petrophysical analysis. In 78B-32 well, core run is considered as adequate for core recovery and can be integrated with drilling parameter data. The lithology analysis through three-dimension visualization consists of alluvial and plutonic rock; can also be correlated with penetration rates and weight on bit. In 58-32 well, geological structure, mineralogy, hydrothermal alteration, and rock properties are analyzed. The 58-32 well exhibited a significant presence of fractures, predominantly partial conductive fracture. The integration of Pressure Temperature Spinner (PTS) with image log data facilitates the identification of effective fractures within the wellbore. The analysis of tensile-induced fracture reveals a dominant NNE-SSW. Furthermore, this data can be utilized for geomechanics modeling, incorporating additional data from core lab tests, leak-off tests, and other relevant data. Geology log chart shows the secondary minerals abundance in the plutonic rock of 58-32 well is generally low and the proportion decreases with depth. Clay mineral abundance chart shows trace amounts of smectite were observed within the Utah FORGE site reservoir. Integrated plotting of rock properties indicates bulk density and porosity value correlate with lithology or mineralogy changes. The insight obtained from the analysis can support decision making. Therefore, implementation of JIWA DBase for borehole geology data assists end users in various purposes of geothermal projects in resource assessment, conceptual model update, and well targeting.

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