AI Driven Image-Based Digital Twin Rock Properties — Fast, Consistent, and Cost-Effective

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Abstract /

Rock properties derived from core analysis have been used as references for formation evaluation and integrated reservoir studies for decades. Some of the challenges in obtaining core data are that it is time-consuming to perform measurements, results may not be consistent from one laboratory to another, and it can be costly to acquire cores if many analyses are required. The main objective of this study is to test a new innovative method of extracting probability-based analog rock properties, the digital twin, from high-resolution images (HRIs) of thin sections by leveraging the power of artificial intelligence (AI).

The method is based on a proprietary AI technology, advanced rock typing, which includes two components. The first is to create a database, consisting of the measured rock properties of multiple rock types, each of which has been thoroughly quality controlled, and an associated thin section HRI. Such a database forms the foundation of this technology. The second part of the process is to develop an image recognition AI model comprised of the thin section HRI of the core analysis samples from the component one.

Once created and validated, such an AI model can be used to analyze, in instances where conventional cores are unavailable, the HRI is sourced from alternative formation representative samples such as oddly shaped rotary sidewall cores or even drill cuttings. In these situations, the HRI of the thin sections are prepared and compared, through the AI model, to images in the database. If a match is obtained, the rock properties associated with the matched image in the database, which can be thought of as its pore geometry digital twin, would be retrieved and serve as probability-based analog data for that sample. This unique combination of a conventional core database and image recognition technology is at the core of this analytical process. This methodology was applied to a database of 100 samples of core analysis data with associated thin section HRIs, and a customized AI model was developed, tested, and verified with satisfactory results.

In addition, we are pushing the envelope of further developing this technology by extending it to drill cuttings and studying the effect of cutting sizes and sample heterogeneity on the performance of the AI model built using data generated from core plugs. Twenty sets of synthetic cuttings in 5 mm, 4 mm, and 2 mm size fractions, created from core plugs, which had previously been used in the creation of the AI model, were prepared.

A thin section of each cutting size fraction was scanned, and each scan was then submitted to the AI model for analysis and analog matches were identified. Preliminary results demonstrate the potential of applying this technology to estimate rock properties as part of advanced mud logging, thereby expanding the capabilities of mud logging to estimate rock petrophysical properties from the thin section HRI analysis in near real-time while drilling.

Introduction

It would be ideal and desirable if formation rock properties could be obtained in situ at reservoir conditions and reservoir scale[1-4], but as extensively discussed in the Special Session 8 at the 2022 SPE Annual Technical Conference and Exhibition in Houston, technical challenges still prevent those developed methods from practical applications. Consequently, until today, rock properties are still routinely derived from laboratory core analysis and used as references or calibrations for formation evaluation and integrated reservoir studies[5, 6].

In obtaining core data, however, some of the challenges are that it could be expensive to acquire cores, time-consuming to perform laboratory measurements, results may not be consistent from one laboratory to another and may not even be representative[7], and can be costly if many analyses are required. In cases where measured core data are unavailable, analog core data are often used in reservoir characterization projects.

Analogs provide a probabilistic alternative and are a valuable tool for geological and engineering studies. The basic input in any petrophysical analog selection process is the rock type, either derived from drainage capillary pressure measurements[8] or more commonly estimated visually from rock samples (conventional cores, sidewall cores, or even drill cuttings) under a microscope[9-11]. A comprehensive review on conventional methods of pore structure characterization is available[12].

Visual rock typing has historically been a manual, time-consuming, and subjective process based on a limited number of observed parameters[13]. In sandstones for instance, the visually estimated parameters may include: porosity, grain size, sorting, degree of consolidation, argillaceous content, and cements.

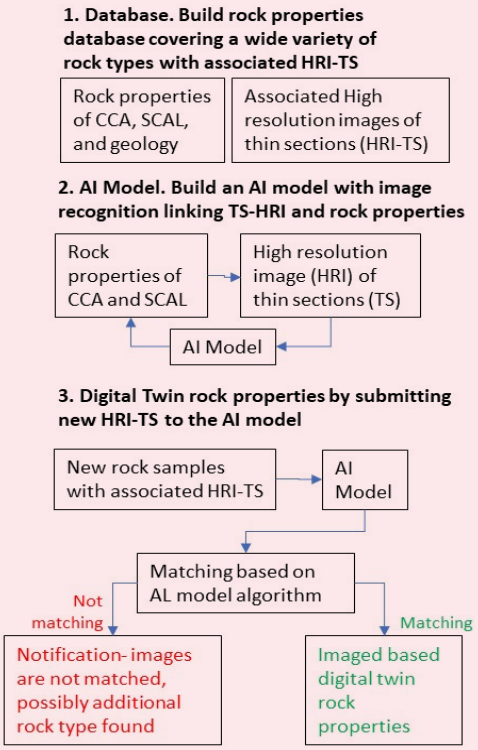
Once rock typing for a sample is complete, the estimated rock type parameters are used to find matching parameters in an established database. When a match is found, the associated rock properties represent the digital twin rock properties. The main objective of this study is to test a new, innovative, rapid, and objective artificial intelligence (AI) based method of extracting probability-based analog rock properties, the digital twin, from high-resolution images (HRI) of thin sections.

Methodology

The method of AI driven image-based digital twin rock properties is innovative, and yet straightforward[14]. As outlined in Fig. 1, it consists of the following steps:

1. **Database:** Build a rock property database covering a wide variety of rock types and associated thin section HRI.
    a. Collecting data consists of various conventional and special core analysis rock properties, derived from a variety of rock types, combined with representative and standardized thin sections scanned in transmitted and polarized light at a resolution of 0.44 microns/pixel to produce the HRI.
    b. Clean and quality control the collected data using conventional methods[7] or data analytics methods[15].

Fig. 1 *The workflow of estimating AI driven image-based digital twin rock properties.*



2. **AI Model:** Build an AI model with image recognition linking the thin section HRI and associated rock properties.
    a. As routinely done in machine learning[16], divide the database into two sets; one for model building and testing, and another for model validation.
    b. Once the model is established using the model building data set, the testing data set is used to test the robustness of the model and further any fine-tuning. The remaining data would be used to validate the robustness of the built model.
3. **Digital Twin Rock Properties:**
    a. Once the AI model is built, it may be used to estimate rock properties in situations where a thin section is made and imaged (similar as those used in constructing the database), but rock properties are not measurable or not available, due to reasons such as:
        - Certain rock properties, such as some special core analysis properties, are not measured.
        - Irregular rock samples, such as misshaped sidewall cores.
        - Limited rock material, such as wells with only drill cuttings.
    b. The newly acquired thin section HRIs would be matched by the AI model with a thin section HRI in the database. Note that pattern recognition probabilistic-based image matching and the mathematical criteria used to determine image similarities are at the core of the technology presented in this study and will be detailed later.
    c. Once a match is found, the associated rock properties would be, by definition, the digital twin rock properties of the new sample.
    d. On the other hand, if no match is found, it merely indicates that the rock type is not covered in the database; information important for future improvement of the database and then enhancement of the AI model.

It should be noted that since this methodology is image based, pore structure and matrix sensitive rock properties may be estimated, such as: porosity, permeability, mineralogy, Archie cementation exponent m, and drainage capillary pressure.

On the other hand, pore surface roughness[17] and degrees of pore surface properties' alteration, due to changes in wettability[18, 19] may be difficult to be observed and examined under a normal microscope. The end user should be cautious when using this type of technology to estimate rock pore surface roughness and wettability sensitive properties, unless special images such as surface property sensitive images of an environmental scanning electron microscope[20] are used in construction of the AI model for potential wettability related studies.

Results and Discussions

The Database

To evaluate the methodology previously presented in Fig. 1, a feasibility study was conducted where a database of 100 core samples were selected with rock properties, Fig. 2, and associated thin section HRI, Fig. 3, of various lithologies of: sandstone, siltstone, limestone, dolostone, mudstone, and anhydrite.

Probabilistic-Based Analog Match

In conventional thin section image analysis, rock typing variables that can be characterized may include: grain size, sorting, cements, texture, and visible porosity.

The method presented in this study is AI-based, using image recognition technologies to evaluate pore geometry heterogeneity inherent in each thin section image submitted for analysis, and finding probabilistic-based analog matches to that range of heterogeneity in the database of rock types. Matching parameters in this probabilistic way is mathematically based, and therefore, many more parameters can be evaluated as compared to the five variables noted.

Figure 4 illustrates the matching concept. With modern computing power, this matching process can be completed rapidly, i.e., in seconds.

Factors affecting image matching may include the number of rock types contained in the database used to build the AI model and how well the rock types in the model represent the pore geometry variability of the formation modeled. Having a wide range of core-based rock types in the model allows for a more robust AI interpretation of the formation being evaluated.

Note that in the probabilistic approach to validation, while the image of a child will have similarities with an image of its parent and thereby a probabilistic match, it may not be an exact match. Likewise, matches based on rock images with varying cements, grain shapes, and sizes will never be an exact match, even though their petrophysical attributes are very similar.

Results and Digital Twin Rock Properties

The results of this study show that the model was 99% accurate in verifying the training set used to create the model, i.e., 99 out of the 100 model samples matched, based on image recognition

Fig. 2 *An example of data used to evaluate the AI driven image-based digital twin rock properties methodology in Fig. 1.*

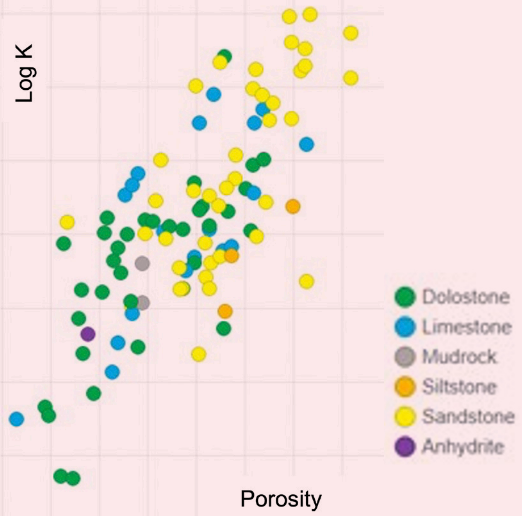


Fig. 3 *An example of a thin section HRI and associated rock properties.*

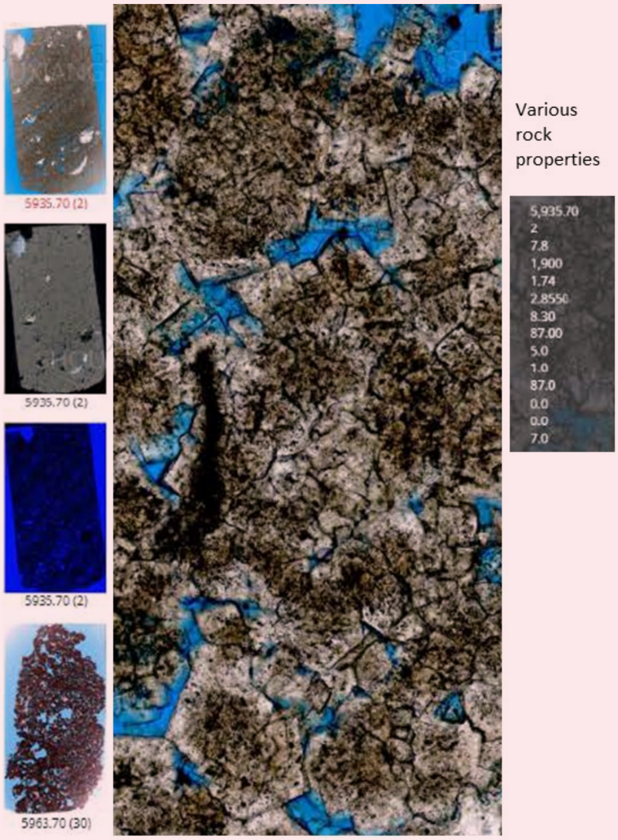
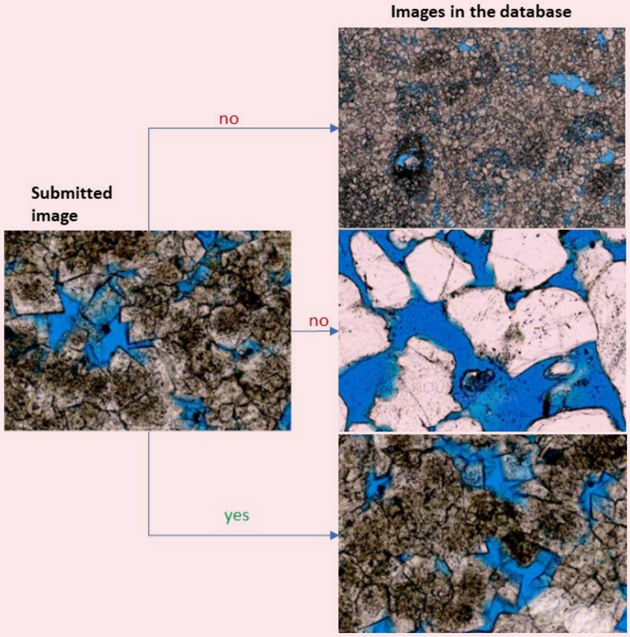


Fig. 4 *An illustration of a probabilistic match with image recognition.*



parameters during model validation, demonstrating the robustness of the built model for practical applications. The one sample that did not match itself found a similar sample with similar properties within the same well, Fig. 5.

Results of the built AI model to predict various digital twin rock properties is illustrated in Fig. 6 for porosity, grain density, permeability, and Archie porosity exponent *m*. The robustness of its performance will be further tested with a much larger database.

Extension to Drill Cuttings

Cutting Data Sets

With the core plug-based digital twin rock property model tested and established, its application is naturally extended to drill cuttings with the ultimate goal of deriving rock petrophysical properties as part of advanced mud logging[21, 22]. To realize that ambitious Archie's dream of Loermans et al. (2005)[23], the effects of the sample heterogeneity and cutting size on the performance of the plug-based digital twin rock property model needed to be evaluated. Therefore, the following feasibility study was conducted:

1. Twenty sets of synthetic cuttings were created from conventional core plugs, which had previously been used in the creation of the model.
2. A thin section of each cutting sample was scanned.
3. Each scan was submitted to the core plug digital twin rock property model for analysis and analog match determination.

Fig. 5 *An example of the one model validation sample that did not match.*

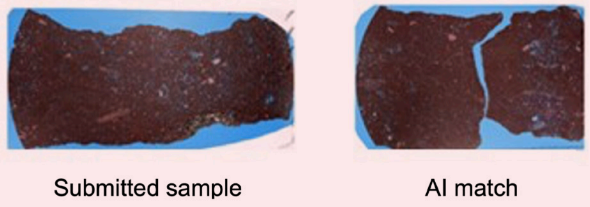
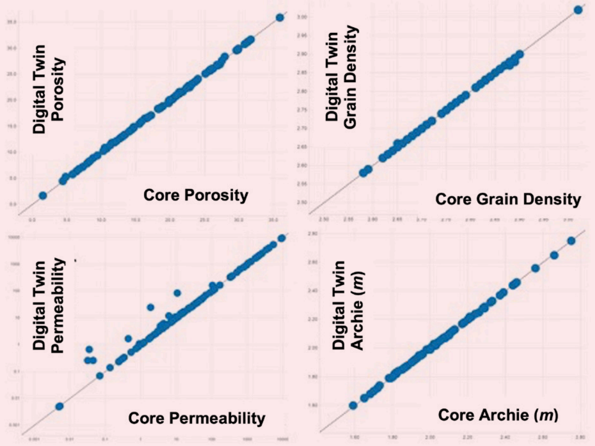


Fig. 6 *The results of the predicted digital twin properties (porosity, grain density, permeability, and Archie porosity exponent* m*) vs. measured core data.*



The 20 sets of cuttings were selected to cover a range of geological and petrophysical properties, including the porosity, permeability, and lithology of:

1. Clastics:
    a. Siltstone
    b. Argillaceous sandy siltstone
    c. Sandstone
    d. Argillaceous sandstone
    e. Argillaceous dolomitic sandstone
    f. Organic argillaceous sandstone
2. Carbonates:
    a. Limestone
    b. Dolomitic limestone
    c. Dolostone
    d. Calcareous dolostone
    e. Celestine dolostone
    f. Bituminous dolostone

Synthetic cuttings from each selected sample were created by carefully disaggregating each core plug and sieving the resulting size fractions into three size classes of diameters of 5 mm, 4 mm, and down to 2 mm, i.e., a total of 60 samples.

A thin section of each cutting sample was created and subsequently scanned in transmitted light and polarized light at 0.44 microns/pixel, Fig. 7, same as that of core plug thin section HRI.

Child-Parent Matching

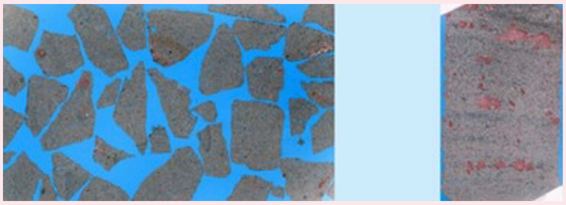
Matching results indicate that 60% of the cutting images match their analog parent, Fig. 8, while the remaining 40% match a non-parent analog sample better, Fig. 9. Further examination reveals that the primary reason for the non-matching was due to pore geometry heterogeneity, which is especially prevalent among the carbonate samples analyzed.

Fig. 7 *An example of a thin section HRI of the synthetic cutting sample.*

In some cases, the level of heterogeneity was reduced as the sample size becomes smaller, i.e., macroporosity in the parent thin section disappeared in the analyzed cutting's thin section.

Fig. 8 *An example of a good match between the cutting image and its parent plug image.*

Fig. 9 *An example of a mismatch between the cutting image and its parent plug image.*



To comprehensively address these effects of sample size and heterogeneity on model performance, a larger data set covering a wide range of geological and petrophysical properties would be required to have a better understanding of the issue, statistically.

Child-Parent Matching Comparison

Identification of rock properties associated with each analog match from the established AI model allows for the comparison of the measured parent core plug properties with analog properties of child cutting samples, after proper averaging. Figure 10 shows examples of permeability and porosity comparisons in the clastic samples; in the case where multiple analogs are returned by the AI model, analog cutting permeability and analog cutting porosity values are weight averaged based on each analogs' areal match percentage in the thin section image that was analyzed.

Figure 11 shows the results of the carbonate samples. Visually, it can be seen that the performance of the core plug-based AI model in predicting rock properties of rock cuttings is better for clastic samples compared to that of carbonate samples, most likely due to the carbonate samples exhibiting more heterogeneity than the clastic samples, as previously explained.

Figure 12 is a combination of both clastic, Fig. 10, and carbonate samples, Fig. 11.

From the results of this feasibility study as demonstrated in Figs. 10, 11, and 12, the AI model shows very promising results in predicting well cutting rock properties. This is especially useful for qualitative applications, such as use of drill cutting analysis as part of mud logging for geosteering and

Fig. 10 *A comparison between digital twin and measured rock properties, clastic samples.*

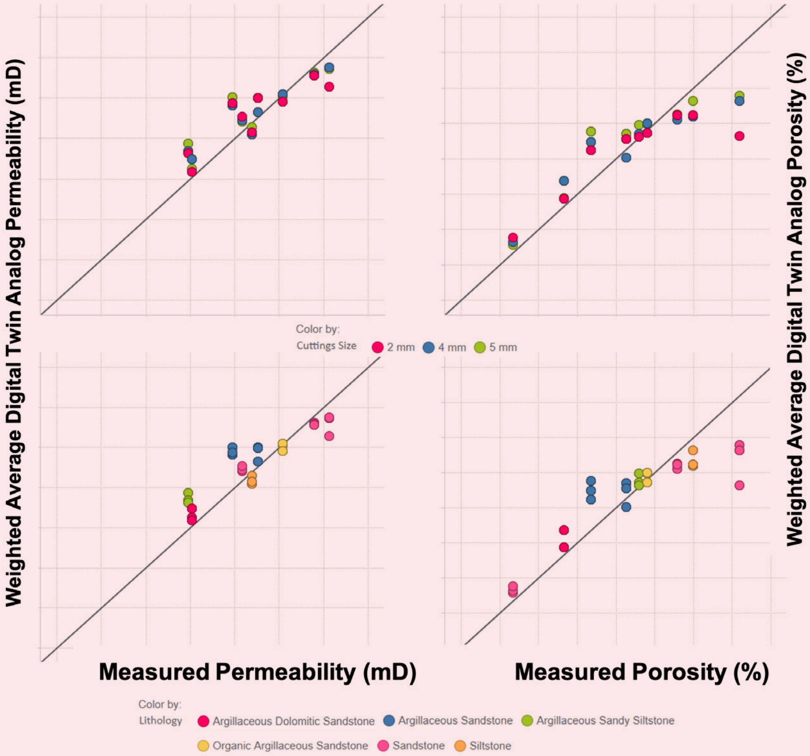
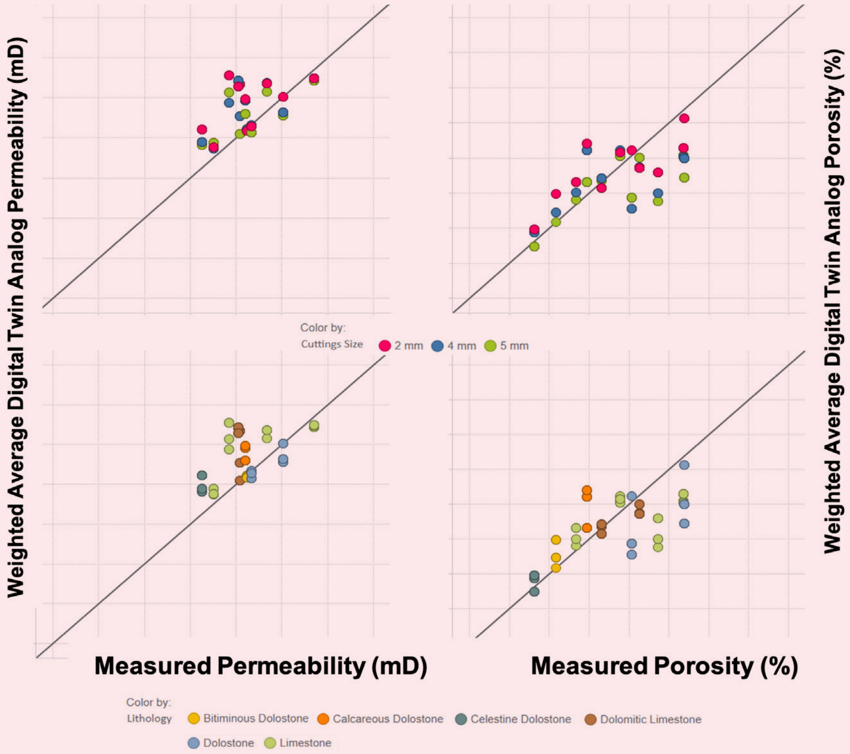


Fig. 11 A comparison between digital twin and measured rock properties, carbonate samples.



well placement in challenging environments, such as that in slim hole underbalanced coil tubing drilling with limited logs available for geosteering.

Summary and Conclusions

A study specific to an AI driven image-based digital twin rock property model was established. This model can be used to estimate rock properties of core samples, which have high resolution thin section images, but where rock properties have not been acquired.

This core plug-based model was extended to drill cuttings, and a feasibility study indicates that the rock cutting properties may be estimated from its higher resolution images for homogeneous rocks.

While scale dependent rock heterogeneity may limit the extension of a core plug-based model to drill cuttings, further research is required to make the AI driven image-based digital twin rock property technology a deliverable for advanced mud logging.

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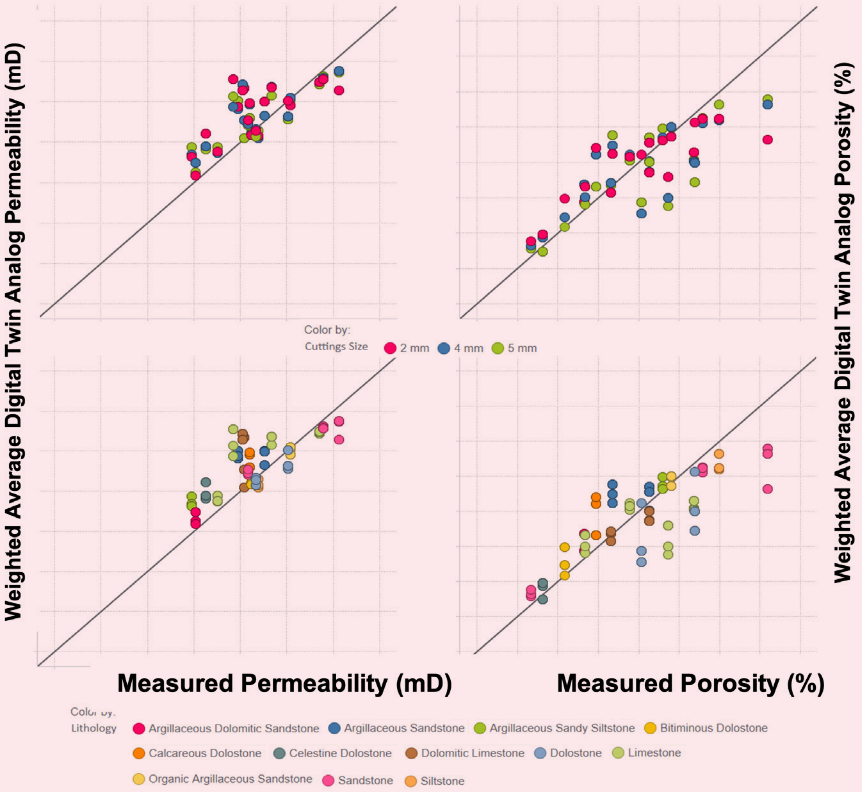
Fig. 12 *A comparison between digital twin and measured rock properties, all samples.*



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Katrina has probably looked at over 20K thin sections from all over the world. Recently, she joined the Digital Innovation Group at Core Laboratories to use her experience and knowledge to develop analytical programs and products. Katrina is using her petrologic knowledge to advise and advance artificial intelligence applications to address challenging and routine samples.

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