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Providing Open-Access Data for Petrophysical Reservoir Characterization – the PetroPhysical Property Database P³

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ABSTRACT

Petrophysical properties are key to populate local and/or regional numerical models and to interpret results from geophysical investigation methods. Searching for rock property values measured on samples from a specific rock unit at a specific location might become a very time-consuming challenge given that such data are spread across diverse compilations and that the number of publications on new measurements is continuously growing and data are of heterogeneous quality. Profiting from existing laboratory data to populate numerical models or interpret geophysical surveys at specific locations or for individual reservoir units is often hampered if information on the sample location, petrography, stratigraphy, measuring method and conditions are sparse or not documented.

Within the framework of the EC funded project IMAGE (Integrated Methods for Advanced Geothermal Exploration, EU GA No. 608553), an open-access database has been developed. This database aims at providing easily accessible information on physical rock properties relevant for geothermal exploration and reservoir characterization in a single compilation. Collected data include 'classical' petrophysical, thermophysical and mechanical properties and, in addition, electrical conductivity and magnetic susceptibility. Each measured value is complemented by relevant meta-information such as the corresponding sample location, petrographic description, chronostratigraphic age, if available, and original citation. The original stratigraphic and petrographic descriptions are transferred to standardized catalogues following a hierarchical structure ensuring inter-comparability for statistical analysis. In addition, information on the experimental setup (methods) and the measurement conditions are listed for quality control. Thus, rock properties can directly be related to in-situ conditions to derive specific parameters relevant for modelling the subsurface or interpreting geophysical data.

We describe the structure, content and status quo of the database and discuss its limitations and advantages for the end-user.

1. INTRODUCTION

The characterization and utilization of subsurface reservoirs generally relies on applying geophysical investigation/exploration methods and/or numerical models – both requiring, in turn, the knowledge of physical rock properties at depth. The strategy of populating numerical models with petrophysical properties can differ. For local scale models, laboratory measurements may exist that have been applied to samples directly taken from the volume of the unit of interest. In this case, it is reasonable to use this direct information together with sophisticated (physical and empirical) laws to populate the entire geological unit. For regional and continental-scale models, by contrast, parameters have to be generalized, for example by associating locally measured properties with the spatial distribution of corresponding lithological units. Prior to cost-intensive, maybe even cored, exploration wells and geophysical well logging, outcrop analogue studies are a cheap and common tool in most exploration concepts (e.g. Enge et al. 2007, Jahn et al. 2008, Howell et al. 2014). They allow for large-scale investigations of the fracture network, seismic properties, lateral and vertical facies associations as well as obtaining representative rock samples for lab measurements of petrophysical properties (Figure 1).

Individual rock types or petrographies typically exhibit a great variability in related properties due to heterogeneous mineral compositions, variable textures and different porosity distribution (Schön 2015). Existing collections of rock properties are proof for this high variability (e.g. Cermak and Rybach 1982, Clark 1966, Clauser and Huenges 1995, Landolt-Börnstein, PetroMod, Schön 2004, 2011, 2015, Hantschel and Kauerauf 2009, Aretz et al. 2015). Since the compiled properties are mostly complemented by limited meta-information, it is difficult to use these data for regional applications. This is aggravated by the limitations of such compilations as these are usually covering only certain rock types or geographic areas (e.g. Germany: FIS Petrophysik hosted by the LIAG, Great Britain: BritGeothermal hosted by the British Geological Survey, USA: National Geothermal Data System (NGDS) hosted by the USGS, Ireland: IRETherm) and not providing the same set of information on all samples.

To avoid (i) time-consuming literature research, (ii) problems arising from unwanted generalizations and (iii) missing complementary information needed for further interpretation of the measured values, the PetroPhysical Property Database P³ has been developed within the scope of the IMAGE project. This unique database is filled with data, both measured during and prior to the project by the IMAGE research partners as well as data collected from literature.

This proceedings paper only provides a short description of P³. A more comprehensive description as well as full access to the database if provided in the publication of Bär et al. (2020), see chapter 8.

All data are selected to represent the characteristic scale of rock samples of few centimetres to decimetres, depending on the mostly standardized laboratory measurement methods (ISRM, EN, ASTM and many more) of the different properties (Figure 1). Larger scale data from geophysical well logging, hydraulic well testing, integrating geophysical methods or other field measurements, which integrate over larger rock volumes or several rock types are not included in the database. This is intended to ensure that the values only represent the properties of the rock matrix itself and not of larger geobodies including open or partly open discontinuities like fissures, fractures, bedding or schistosity. Neither included are data from smaller scale samples, where the sample volume investigated is in doubt to meet the minimum representative elementary volume (REV), based on the lithological description.

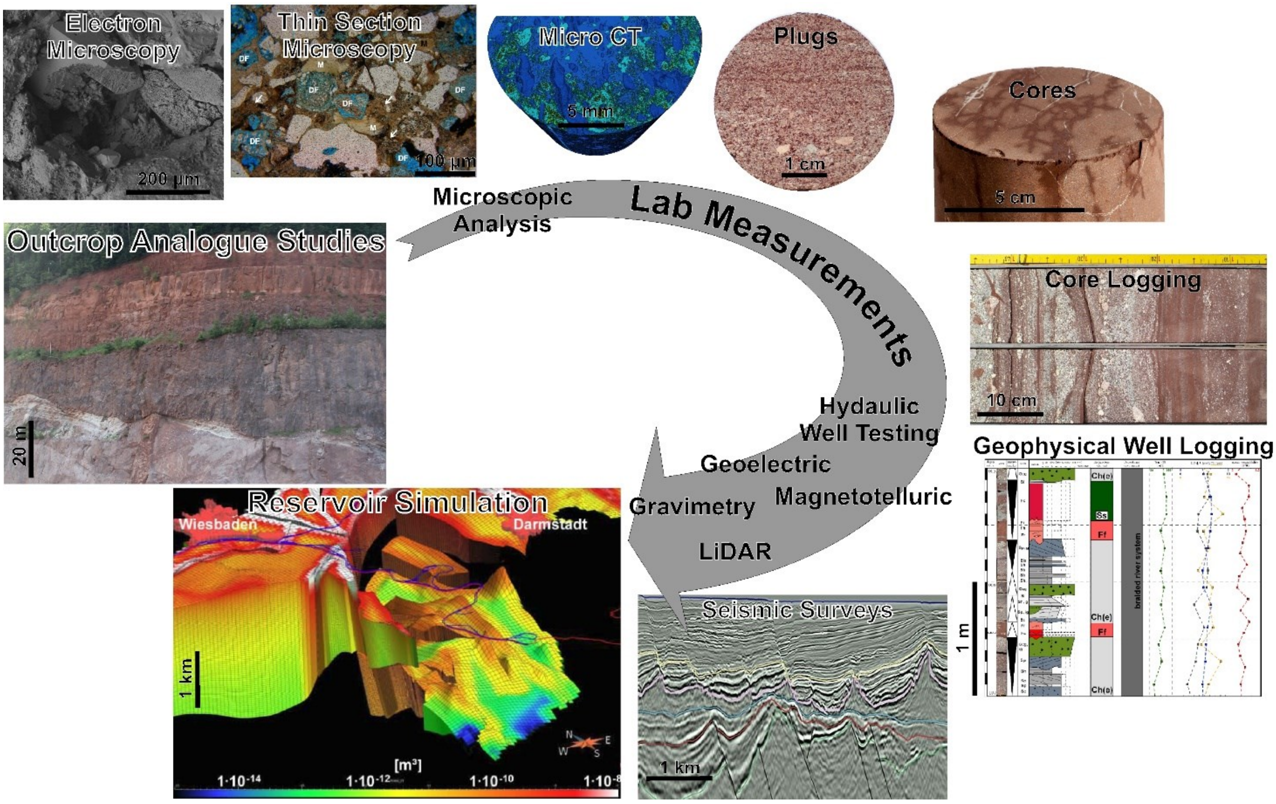

Figure 1: Concept of multiscale characterization of geological reservoirs with (examples of) integrated petrological, petrophysical or geophysical methods leading from outcrop analogues to reservoir simulations.

2. CONTENTS OF THE DATABASE

According to our motivation, the PetroPhysical Property Database is intended to be publicly accessible and only contains rock properties measured in laboratory experiments. Furthermore, it only contains measurements that are associated with lithological or petrographic descriptions of the corresponding sample and a proper reference to the original citation. The data thus has to be publicly available for all researchers, meaning that only data from scientific publications (books or peer reviewed journals) or proceedings (e.g. IGA Geothermal Papers/Conference Database) as well as published research reports (e.g. dissertations or publicly available student's theses) have been included.

To ensure that the data can later on be used for interpretations, generalizations or simulations, a set of meta-information on the sample is regarded essential for each measured value. The minimum associated input is the reference to the original source (citation), the location of the sample (including a radius of uncertainty) and information on the petrography for the allocation of a possible lithotype. If available, additional meta-data on the type of sampling location (e.g. natural outcrop, quarry, vertical or deviated well), affiliation to a registered sample set (e.g. International Geo Sample Number (IGSN, cf. Devaraju et al. 2016, Lehnert et al. 2006)), stratigraphy, sample dimensions, measurement method or device and measurement conditions (pressure, temperature, stress) including degree of saturation or type of saturating fluid can be included.

3. STRUCTURE OF THE DATABASE

The database is structured into three main sections (Figure 2). The first, named "sample information", contains all the meta-information on the sample including the sampling location, the sample type and dimensions as well as information on its petrography and stratigraphy. The second section contains the actual measured property value(s), the information on the measurement (parameter, method, conditions etc.) and a field for specific remarks. Finally, the third section named "quality control" includes all information relevant for the quality assessment of a dataset. The properties included in the database are displayed in Figure 2 and were chosen due to their high relevance for geothermal exploration (including the fields of geophysical exploration techniques and subsurface numerical simulations).

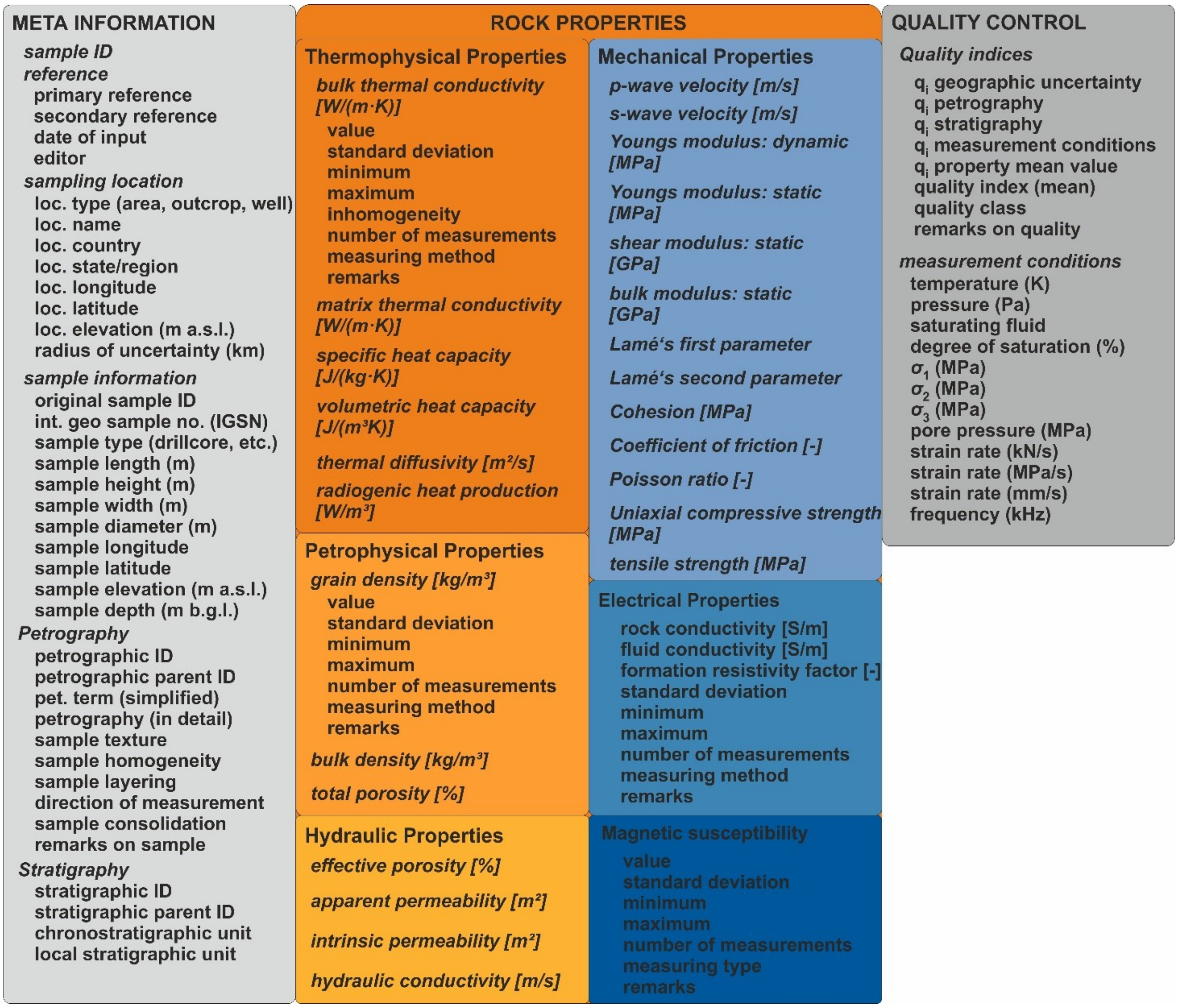

Figure 2: Schematic structure of the PetroPhysical Property Database illustrating the main three sections: sample information, rock properties and quality control. Different input parameters (small font) are grouped according to the property they belong to (italics) (Bär et al., 2019).

The petrography or rock type classification is defined in a separate database directly connected to the property database. Its internal structure is based on a hierarchical subdivision of rock types, where the rock description becomes more detailed with increasing rank of petrographic classification. This hierarchical subdivision is based on international convention (e.g. Bates & Jackson 1987, Gillespie & Styles 1999, Robertson 1999, Hallsworth & Knox 1999, Bas & Streckeisen 1991, Schmid 1981, Fisher & Smith 1991) and allows for the statistical analysis for specific rock types, where all available values of subordinate petrographies can be grouped into more generalized terms. The classification also corresponds to the subdivision used in existing property data compilations such as e.g. Hantschel and Kauerauf (2009), Schön (2011), Rybach (1984) and Clauser and Huenges (1995).

The stratigraphy of each sample can be inserted into the database in two complementary ways. The first way is to use the definitions of the international chronostratigraphic chart of the IUGS v2016/04 (Cohen et al. 2013, updated), which are also compiled in a directly linked hierarchical database ensuring that formations of a certain age are connected to the corresponding stratigraphic epoch, period or erathem. Alternatively, a more detailed description of local stratigraphic units can also be documented if provided in the primary reference.

4. STATUS OF THE DATABASE

Up to now, data included in the PetroPhysical Property Database are either from own measurements, published data collections or scientific papers (316 references including students' theses and scientific reports). So far, more than 75,000 data points from all over the world (Figure 3) have been collected. The amount of samples from different petrographies shows that all main rock types are represented: more than 13,500 samples from magmatic rocks, more than 7,500 samples from metamorphic rocks, more than 12,700 samples from sedimentary rocks and more than 1,300 samples from unconsolidated clastic sediments. Since this database has been filled to follow the goals of the IMAGE project and it is supposed to always represent work in progress, its data entries are unevenly distributed among the different properties and among the different regions of the world. Moreover, the entries for some properties derive from only one single source, such as e.g. the values of radiogenic heat production that are taken from the compilation of Vilà et al. (2010).

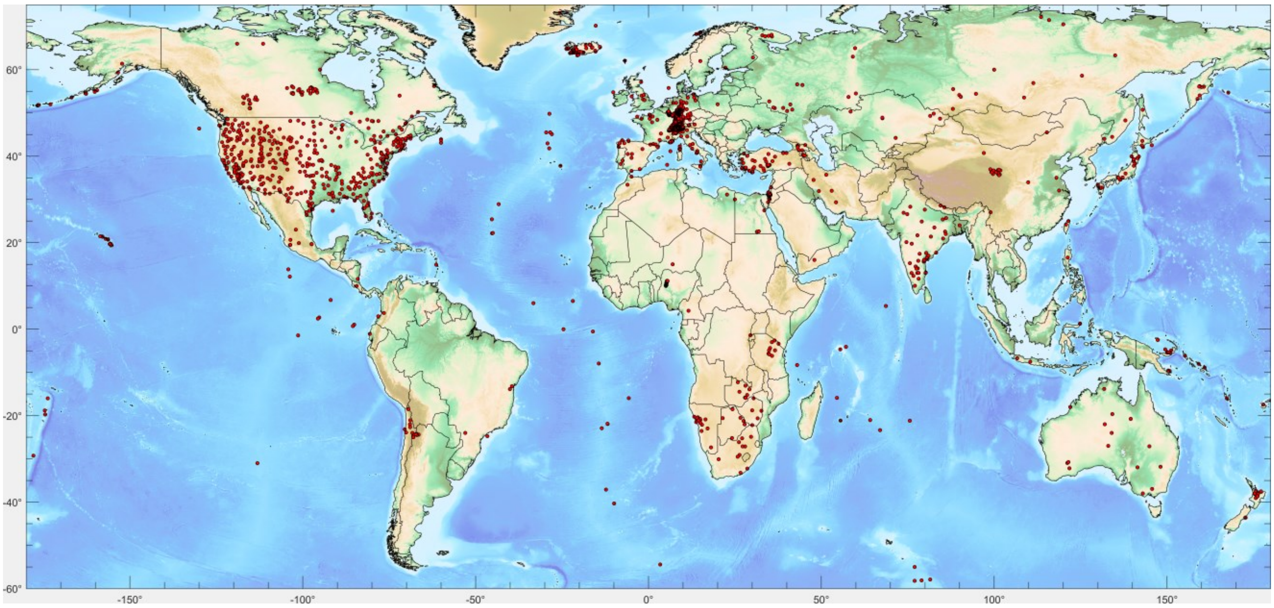

Figure 3: Locations of all data points currently included in P³ (Bär et al. 2019). Topographic map is the ETOPO1 map (Amante and Eakins, 2009)

5. QUALITY CONTROL

To provide a quality estimate for each data entry in terms of provided meta-information, a set of key criteria is automatically analyzed: (i) uncertainty of the geographic location, (ii) the rank of petrographic classification, (iii) the rank of stratigraphic classification, (iv) the completeness of information on measurement conditions and, (v) the statistical type of a value (e.g. single value, mean value etc.). For each key criterion, four different quality classes (excellent =1, average =2, poor = 3; and minimum) are defined and computed to numerical quality indices (q_i, cf. Figure 2). A bulk quality index is calculated according to the arithmetic mean of the quality indices of the different criteria, where values < 1.5 are considered excellent, values ≥ 1.5 < 2.5 are considered average and values ≥ 2.5 are considered poor.

6. DISCUSSION

The current status of the database already shows a lot of benefits that such a compilation has, but also some limitations, which have to be topics for future amendments.

The defined minimum requirements for a datum to be integrated in the database guarantee its usability in terms of statistical, spatial, petrographic and stratigraphic analyses. Since it also contains multiple properties measured on one sample, direct correlations with other data and properties are facilitated, which may help identifying new relationships (formal, causal or statistical correlations) and, on the other hand, contribute to a better understanding of the limitations of generalization or possibilities for upscaling approaches. Thereby, the partly automatic quality assessment allows for a quick evaluation of single data within a group of selected entries. The possibility of correlating data also simplifies and accelerates the identification of key references for rock parameters in specific regions, for specific rock types, or stratigraphic units. Furthermore, the database allows to systematically analyze the dependency of property values on the corresponding measurement conditions, which enables to transfer parameters measured on outcrop analogue samples to in situ reservoir conditions. Thus, the most important added values of this compilation compared to existent databases are its dimensions (large number of entries corresponding to a large number of petrophysical properties) and the abundance of given meta-information.

On the other hand, such a database can never be complete and is always prone to some uncertainties. To identify errors in the original publications (in terms of property values and meta-information) is beyond the scope of this compilation and rather a task for the skilled reviewers or editors of scientific journals, while data-input errors cannot be totally excluded. Additionally, this database includes values generated with different established or newly developed measurement methods usually delivering data of different quality and uncertainty. Thus, data comparability is not necessarily given. But due to the documentation of the original source, the according detailed information of a chosen sample set can be checked if in doubt. For example, due to diverse effects (such as temperature, pressure, weathering etc.), properties measured from outcrop analogue samples might differ considerably in quality from those of the same formation at in situ conditions of the deep reservoir.

7. CONCLUSIONS AND PERSPECTIVES

A database of diverse petrophysical rock properties derived from published results from lab measurements on rock samples has been developed. It has been designed to be as transparent and useful for various purposes as possible through the integration of multiple meta-information (including the original source) for each data point. The database already comprises a great variety of properties, petrographies, stratigraphies etc. from samples investigated all over the world. The current compilation of samples, however, largely reflects the project goals of the geothermal project IMAGE (Van Wees et al., 2015), while the applicability of the database certainly can be seen in various geoscientific fields focusing on subsurface utilization (e.g. oil and gas, ccs, hydrogeology etc.).

Compiling the data from various sources however has shown that the general documentation of measured petrophysical properties is very heterogeneous and often the minimum requirements defined for our database are not met. We therefore have to emphasize the responsibility of the reviewers and editors of scientific journals to ensure that any kind of publication containing original measurements of petrophysical properties are documented including all the helpful and necessary meta-information as described here. Only if these requirements are met, a published dataset is of added value for the scientific community and can be used for consecutive investigations or applications.

To broaden the applicability of the database, the integration of exploration methods aiming at the determination of petrophysical reservoir properties on smaller or larger scale would be beneficial to include in the future. This could include data from geophysical well logging, hydraulic testing in wells or other integrating geophysical exploration methods as well as additional information on the sample like their geochemical or modal composition from XRF, ICP-MS or ICP-OES analyses, point counting of thin sections or electron microscopic investigation of e.g. cementation or pore geometry.

A first release of the presented database is under preparation for peer-reviewed and open-access publication. Since such a database can never be complete, an ongoing extension through updated versions is foreseen. We also plan to develop a publicly accessible web-based interface to facilitate external users to perform specific queries on petrophysical properties. In addition, external users shall also be given the opportunity to complement the database for a better visibility of their own measured rock properties. Thus, the database will be continuously updated and at certain intervals released by the editors.

8. DATABASE AVAILABILITY

The extended database description is published by Bär et al. (2020) under https://doi.org/10.5194/essd-12-2485-2020.

The excel version of the P³ database (Bär et al., 2019b: P³ – PetroPhysical Property Database, V. 1.0, GFZ Data Services, Potsdam, https://doi.org/10.5880/GFZ.4.8.2019.P3) is available under the given DOI.

The petrographic classification table (Petrography), which is included in P³ (Bär and Mielke, 2019: Petrographic classification table (Petrography): P³ – Petrography, V. 1.0, GFZ Data Services, Potsdam, https://doi.org/10.5880/GFZ.4.8.2019.P3.p), is available under the given DOI.

The stratigraphic classification table (Stratigraphy), which is also included in P³ (Bär et al., 2019a: Stratigraphic classification table (Stratigraphy): P³ – Stratigraphy, V. 1.0, GFZ Data Services, Potsdam, https://doi.org/10.5880/GFZ.4.8.2019.P3.s), is available under the given DOI.

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