PROCEEDINGS, Thirty-Eighth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 24-26, 2014
SGP-TR-202

# Outcrop Analogue vs. Reservoir Data: Characteristics and Controlling Factors of Physical Properties of the Upper Jurassic Geothermal Carbonate Reservoirs of the Molasse Basin, Germany

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**Keywords:** outcrop analogue, reservoir properties, carbonates, Upper Jurassic, Molasse Basin.

## ABSTRACT

In the early stages of reservoir exploration, the characterization of the reservoir is mainly accomplished by evaluating drilling data and seismic surveys. Especially in carbonate reservoirs the distinction of different facies zones is very challenging. For reservoir predictions density, porosity, permeability, thermal conductivity/diffusivity, and specific heat capacity have to be quantified as precisely as possible. Outcrop analogue studies enable the determination and correlation of facies related thermo-physical and petrophysical parameters. As these parameters show facies related trends, applying a thermofacies classification on the carbonate formations is helpful to understand the heterogeneities and to identify production zones. In combination with drilling data from a 1,600 m deep research drilling and a 4,850 m (total vertical depth, measured depth: 6,020 m) deep geothermal well (bottom hole temperature of around 170°C) the reservoir property prediction can be validated and consequently the exploration becomes more precise. The outcrops of the Swabian and Franconian Alb represent the target formations of Upper Jurassic carbonate reservoirs in the adjacent Molasse Basin. The hydraulic conductivity of these carbonate formations is mainly controlled by tectonic elements and karstification. The type and grade of karstification is also facies related. The rock permeability has only a minor effect on the reservoir's sustainability except for some grain- and dolostones with higher porosities and permeabilities. The overall rock permeability ranges from $10^{-18}$ m² to $10^{-14}$ m² (0.001 – 10 mD). A high variation of thermo-physical parameters is recognized within facies zones. Mud- and wackestones show typical thermal conductivities of around 2 $Wm^{-1}K^{-1}$. Mudstones have lower thermal conductivities than wackestones due to their clay content. The permeability range of mud and wackestones is about the same. Reef structures show the highest values of thermal conductivity (up to 4.8 $Wm^{-1}K^{-1}$), due to secondary silicified sponge layers and dolomitization processes. Also in the dolomitized areas higher permeabilities can be observed.

Most parameters are determined on oven dried samples. These values have to be corrected via transfer models for water saturated and according reservoir temperature and pressure conditions. To validate these calculated parameters a Thermo-Triaxial-Cell simulating the temperature and pressure conditions of the reservoir is used. Under reservoir conditions a decrease of 2-3 magnitudes in permeability is observed due to the thermal expansion of the rock matrix. From laboratory tests and analyzed drilling data can be concluded that in tight carbonates the matrix permeability is temperature controlled. The thermo-physical matrix parameters are density controlled. Density increases typically with depth and especially with dolomite content, therefore thermal conductivity increases but also decreases with increasing temperature, which is the dominant factor. Specific heat capacity increases with depth and temperature in a range from 790 to 1230 $Jkg^{-1}K^{-1}$.

In general the facies related characterization and prediction of reservoir properties proves to be a powerful tool for the exploration and operation of geothermal reservoirs.

## 1. INTRODUCTION

To assess the potential and productivity of a hydrothermal or petrothermal reservoir a comprehensive and detailed knowledge of the thermo-physical, the hydraulic and mechanical rock and formation properties of the system is mandatory. In general, the determination of these reservoir properties is limited to time and cost-consuming exploration drillings, which reflect only a small portion of the whole reservoir. Especially in terms of carbonates it is difficult to evaluate the heterogeneity of different facies zones in seismic sections (Chilingarian et al. 1992), which applies to the Jurassic (Malm) target formation of multiple planned geothermal power plant projects in the southern German Molasse Basin. These carbonates are characterized by a karst-fractured aquifer system (Schulz et al. 2012) located in 3,500 to 5,500 m below surface in the southern part of the Molasse Basin.

Outcrop analogue studies enable the determination and correlation of thermo- and petrophysical parameters as well as structural geology data with regional facies patterns. The outcrop analogues of the Swabian and Franconian Alb represent the reservoir formations and can be used for detailed facies and thermo- and petrophysical investigations on a low cost basis. The integrated analysis of lithology, facies, and corresponding thermo- and petrophysical rock properties as well as the application of relevant reservoir transfer models, lead to an improved prognosis of the reservoir properties. An outcrop analogue study of the target formation Malm (Upper Jurassic) which is the most promising formation for deep geothermal projects in the German Molasse Basin has to include facies studies following a thermofacies concept (Sass & Götz 2012).

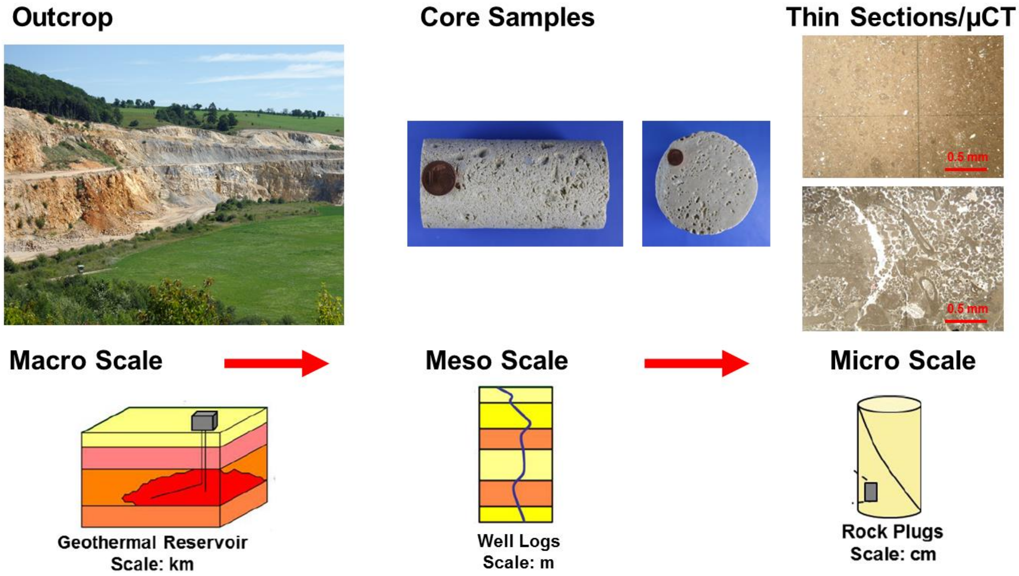


**Figure 1: Scales of Investigation.**

The investigations are carried out on three different scales (Fig. 1): (1) The macro scale including an outcrop mapping to detect the lithotypes, structural elements and facies patterns in the outcrop; (2) the meso scale, to determine thermo- and petrophysical properties of different lithotypes in the laboratory of representative rock samples; and (3) the micro scale, to analyze microstructures, cements, porosities, etc. in thin sections.

## 2. GEOLOGY

The shallow-water areas of inner carbonate ramps are generally well known from a larger number of case studies (e.g. compilation of Wright and Burchette 1998), partly because of the availability of actualistic analogs (Kirkham 1998, Pawellek & Aigner 2003) studied especially for the hydrocarbon exploration. In contrast, the deeper-water zones of outer carbonate ramp systems received comparatively little attention and are now in the focus of the geothermal exploration in the Molasse Basin in south Germany.

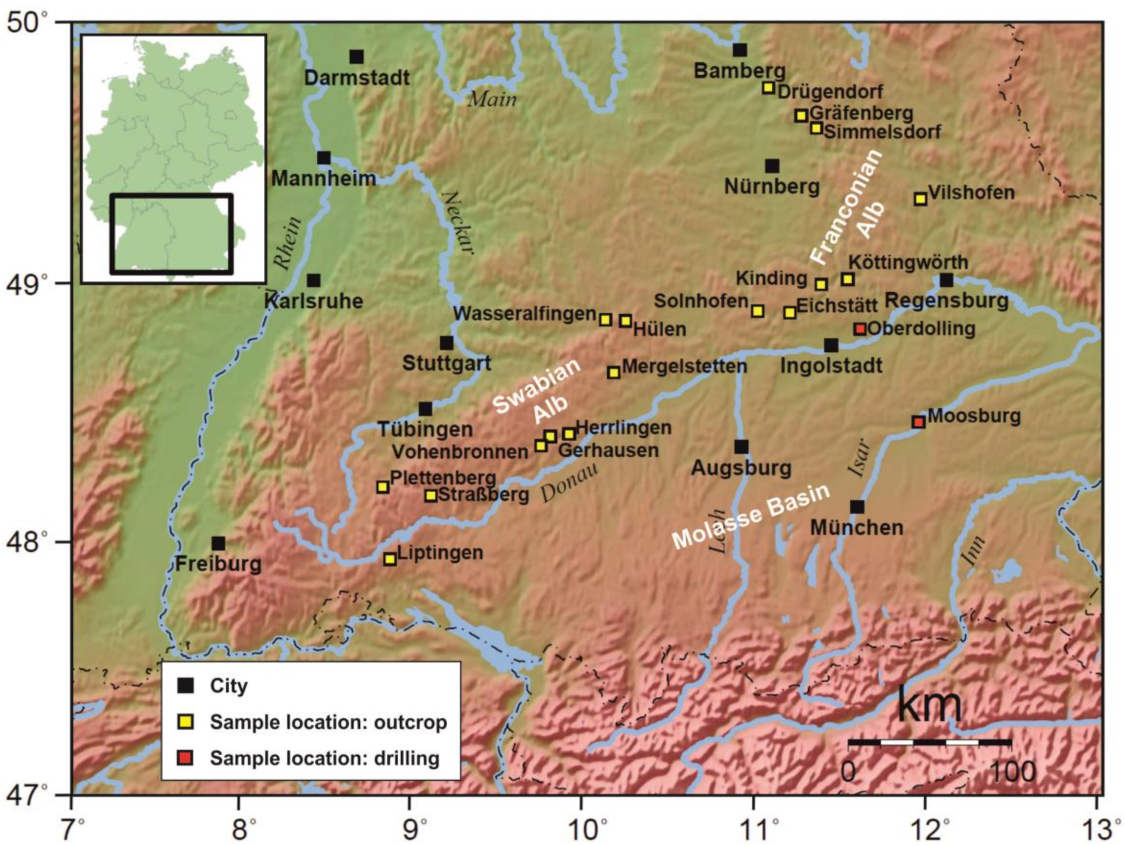


**Figure 2: Study area and sample locations in the Swabian and Franconian Alb and adjacent Molasse Basin.**

During the Mesozoic, large parts of the European craton were covered with a shelf sea marginal to the Tethys Ocean in the South. In the North, this shelf sea was separated from the boreal sea by an island archipelago of changing dimensions, an extensive siliceous sponge–microbial reef belt developed. With the burial of the Vindelician Ridge a direct connection of the south German Jurassic Sea with the Tethys Ocean was established (Meyer & Schmidt-Kaler 1989). During the entire Upper Jurassic a high carbonate production on the shallow shelf resulted in thick limestone series (Selg & Wagenplast 1990). In the southern, deeper part of this epicontinental shelf sea, a reefal facies, established in the Middle Oxfordian, was part of an intensive facies belt characterized by frequent silicious sponge reefs spanning the northern Tethys shelf (Pieńkowski et al. 2008). In addition, clay-rich sediments from the Mid German Swell were shed into the shelf area. During times of low carbonate production, the clay content of the sediments increased which resulted in the sedimentation of marl (Meyer & Schmidt-Kaler 1990). These differences in facies are reflected in the different development of the carbonate successions of the Swabian and Franconian Alb and their southern adjacent buried sections in the Molasse Basin. According to Meyer and Schmidt-Kaler (1989, 1990), the Swabian facies as the central part of the reef belt formed a deeper-water area between the shallower Franconian–Southern Bavarian platform in the East and the Swiss platform in the West. To the South, the Swabian facies passed into the Helvetic Basin. The Helvetic facies is characterized by dense typically dark and bituminous limestones with in places interbedded oolith layers. This facies describes the transition of the Germanic facies into the Helvetic facies, which is considered as sediments of a deeper shelf area of bedded limestones with very low permeabilties. Also karstification is not observed, so the northern boundary of the Helvetic facies is considered as the southern boundary of the Malm aquifer of the Molasse Basin (Villinger 1988).

In general 400 to 600 m of carbonate rocks were deposited during the Upper Jurassic. Two major lithofacies-types can be distinguished (Geyer and Gwinner 1979, Pawellek & Aigner 2003):

(1) a basin facies, consisting of wellbedded limestones and calcareous marls (mud-/wackestones), and

(2) a reefal or massive facies, when bedding is either absent, indistinct or very irregular (rud-/float-/grainstones).

The massive limestones are built by microbial crusts (stromatolites and thrombolites) and siliceous sponges that have been interpreted by various authors as relatively deep and quiet water ‘‘reefs’’, mounds or bioherms (Gwinner 1976, Leinfelder et al., 1994, 1996, Pawellek & Aigner 2003). The normal facies may either interfinger with the reefs or onlap onto the reefs (Gwinner, 1976; Pawellek 2001). In the upper parts of the Upper Jurassic, a coral facies developed locally upon the microbial crust–sponge reefs. The abundance of reef facies differs regularly through time. Reef expansion phases correlate with an increase in the carbonate content within the basin facies, while phases of reef retreat correlate with increasing abundance of marls within the basin facies (Meyer and Schmidt-Kaler 1989,1990, Pawellek 2001).

## 3. METHODS

Reservoir characterization based on thermo-and petrophysical parameters including permeability and thermal conductivity data is rarely available measured at the same sample. For direct correlation in this study all parameters are determined at the same sample. More than 350 rock samples from 19 outcrop locations as well as shallow and deep core drillings in Baden-Wuerttemberg and Bavaria (Fig. 2) are collected and analyzed. For statistical purposes on each rock sample 3 to 10 single measurements of different rock properties were conducted, i.e. in total over 1150 measurement pairs or triples are collected.

According to the Dunham classification of carbonate rocks the following lithofacies types are detected in the study area: mudstones, wackestones, grain-/packstones and float-/rudstones. The rock classification is also based on previous studies of the Malm formations in Southern Germany by Schauer (1998) and Pawellek (2001).

To determine the thermo-physical properties of the sampled formations and to generate reproducible results the samples were dried at 105°C to mass constancy and afterwards cooled down to 20°C in an exsiccator. A thermal conductivity scanner (optical scanning method after Popov et al. 1985) and a gas pressure permeameter (Jaritz 1999, Hornung & Aigner 2004) and porosimeter are used. With a thermal conductivity scanner the thermal conductivity and diffusivity are determined. The measurement is based on a contact free temperature measurement with infrared temperature sensors (Bär et al. 2011). The measurement accuracy is stated by the manufacturer of about 3 %. The determination of the grain and bulk density as well as the porosity was done by measuring the grain and bulk volume of the samples, using a helium pycnometer and a powder pycnometer. The specific heat capacity $c_p$ was calculated with the measured thermal conductivity λ, density ρ and thermal diffusivity α (converted Debye-Equation):

$$c_p = \frac{\lambda}{\rho \cdot \alpha} \tag{1}$$

For the determination of the rock permeability a combined column and mini permeameter was used. The method offers either the measurement of the apparent gas permeability which afterwards is converted in permeability or the direct measurement of the intrinsic permeability. The basis for the gas driven permeameter is the Darcy law which is enhanced by the terms of compressibility and viscosity of gases.

To simulate geothermal reservoir conditions, temperature and pressure depending parameters must be considered. It is possible to calculate these values for water saturated rocks under reservoir pressure and temperature conditions for relevant depths (e. g. Vosteen & Schellschmidt 2003, Popov et al. 2003). These parameters can be validated in a Thermo-Triax-Cell simulating the existing temperature and pressure conditions in the target horizon of a geothermal reservoir and furthermore induces a pore pressure on the rock sample. Therefore the device offers the opportunity to determine permeabilities from outcrop samples under realistic reservoir conditions. Figure 3 illustrates the principle of the Thermo-Triax-Cell.

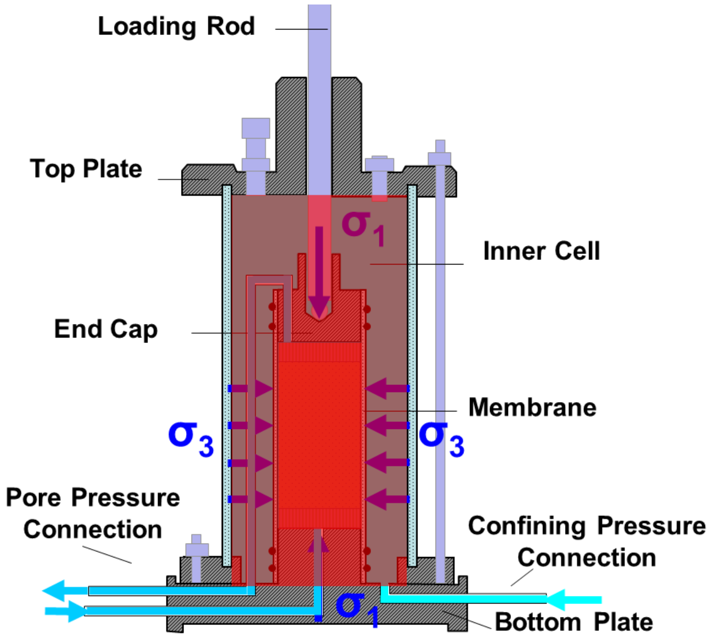


**Figure 3: Schematic sketch of the Thermo-Triax-Cell; σ1: litho static pressure, σ3: confining pressure, red area: heated up to reservoir temperature (Pei et al. 2013).**

The unique design allows experiments with tempered rocks and fluids up to about 170 °C by applying up to 500 MPa litho static pressure and 70 MPa confining pressure. Built of V4A premium steel, the cell can be operated with highly aggressive (corrosive) fluids. Both fluid and rock can be individually tempered, thus allowing a wide range of testing setups to simulate reservoir conditions. Shear tests can be conducted on dry and saturated samples. Additionally, fluids can be pumped through the sample during shear tests, thus allowing permeability measurements and monitoring under reservoir conditions.

**4. RESULTS**

The matrix permeability of all measured carbonates is quite low except for some grain- and dolostones with higher permeabilities and porosities (Fig. 6). Thick-bedded and platy limestones show thermal conductivities around 2 W/mK, characteristic of limestones. Permeabilities range from $10^{-18}$ to $10^{-13}$ m² (0.001 – 10 mD) (K in [m²] = K in [D] • 9.8692 $10^{-13}$). Marly limestones have lower thermal conductivities than thick-bedded and platy limestones, showing the same range of permeabilities as the thick-bedded limestones. It seems that the higher clay content of the marly limestones is decreasing the thermal conductivity by insulating the heat conduction and at the same time showing only minor effects on permeability which shows the same range for mud- and wackestones. The thermal conductivities of different reefal limestones have values of 1.8 to 3.9 W/(mK), related to the higher content of secondarily silicified reef bodies and due to dolomitization of reefal structures. The layers with increased silica content are identified as silicified sponge layers (Leinfelder et al. 1994, 1996). The dolomitized carbonates show the highest values of thermal conductivity of all investigated carbonates in this study. The herein presented thermal conductivity and porosity values were in good accordance to results reported from a limited number of samples in recent works (Koch et al. 2007). However, this study focuses on the facies relation of thermo- and petrophysical rock parameters of Malm carbonates with respect to geothermal reservoir characterization. Figure 4 shows that for some stratigraphic units trends are detectable (increasing thermal conductivity from Malm α to Malm ζ, due to decreasing clay content and increasing dolomitization (the maximum of the dolomitization is also found within the Malm δ by Schauer (1996, 1998)). The peak of thermal conductivity observed in the Malm δ also correlates with increased silica content supplied by silicified sponge layers). Thermo-physical correlations between different reservoir properties are controlled by lithofacies types.

Based on the Debye-Equation (eq. 1) and the results of measurements on deep drill cores from a 1,600 m deep research dore drilling and a 4850 m deep production well (cuttings sampled), it can be inferred that the thermophysical properties for tight carbonate rocks are density controlled (results will be presented in the presentation but for legal reasons cannot be shown in this paper). Density itself is strongly dependent on the lithofacies of the carbonate rock, so the massive and basin facies has direct influence on the formations' hydraulic conductivity. In the transition zone of basin facies to reef facies sub-vertical fractures caused through differential compaction between massive facies and adjacent basin facies can also be observed in the studied outcrops. Due to the increased fracture density in this zone, the karstification process is favored, which results in dissolution of carbonate. The increased hydraulic conductivity results (Fig. 5) in the disintegration into dolomite sand or in the process of de-dolomitization (re-calcification) either. In this context it is important to consider that zones of dolomites due to their primary facies interfingering and genesis also on a small scale are laterally variable and developed across fractures and porous zones into adjacent facies (Koch 2011). Therefore, the identification and location of dolomitized areas is of special interest for the geothermal reservoir prognosis in terms of hydraulically prospective reservoir formations.

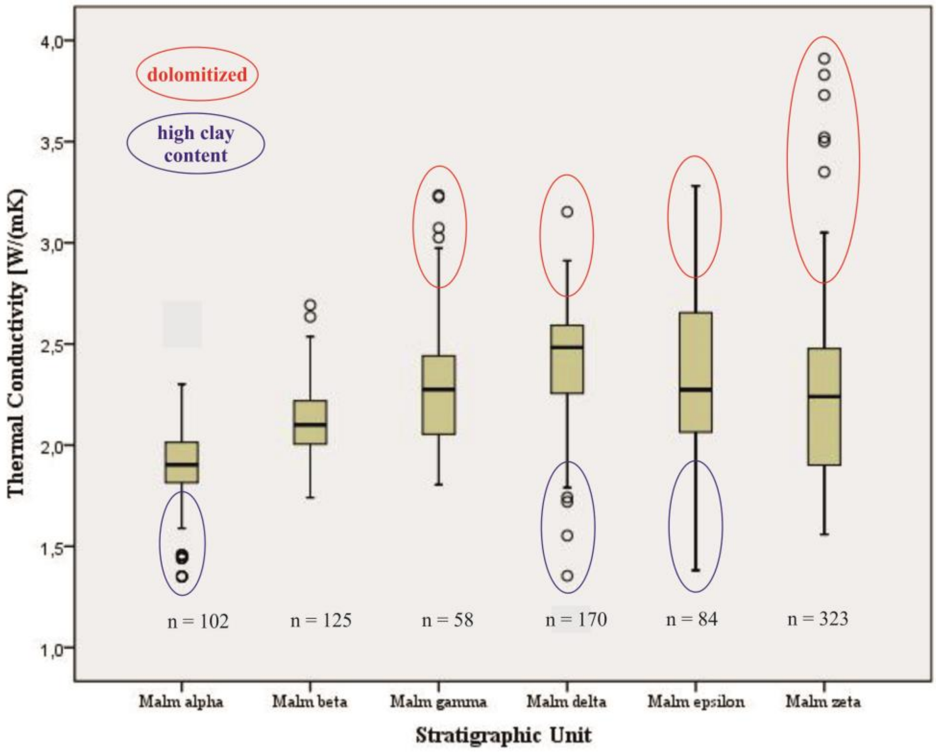


**Figure 4: Stratigraphic trend of thermal conductivity depending on clay and dolomite yield.**

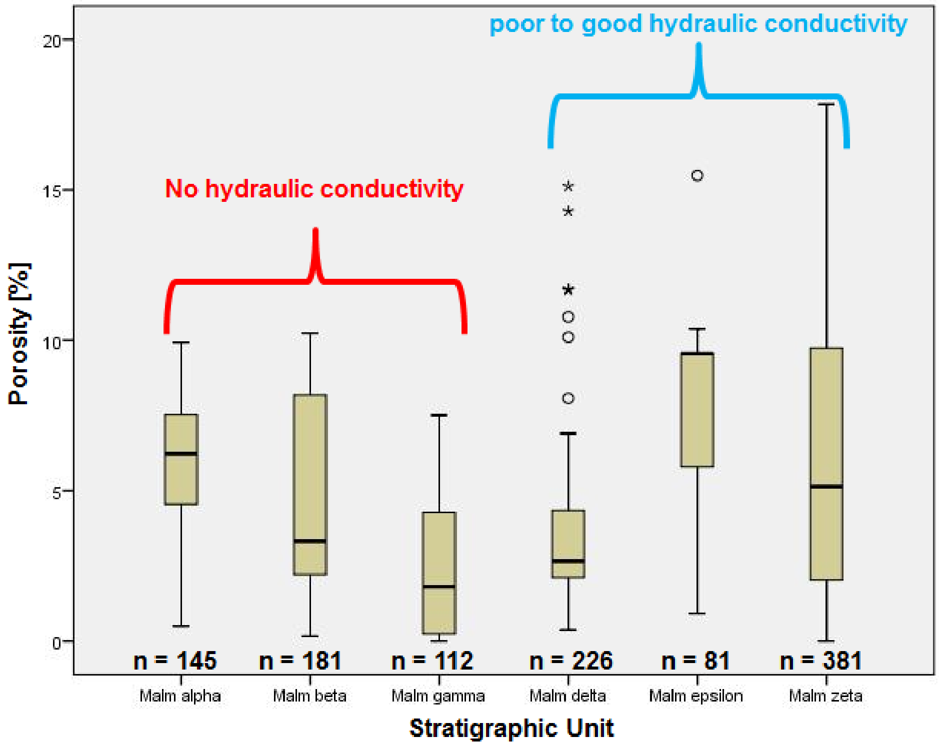


**Figure 5: Porosity trend in dependence of stratigraphy.**

The grain density of the outcrop samples ranges between 2.59 and 2.80 g/cm³, the bulk density is between 2.31 and 2.75 g/cm³. The porosity calculation based on these values is accordingly less than 15%. The massive limestones have porosities less than 8%, grainstones and dolomitized zones showing increased porosities up to 18%. The permeability measurements state in general very low matrix permeabilties. Only grainstones, reef/coral debris limestones and dolomitized zones show higher permeability ranges up to $10^{-14}$ m² (10 mD). A comparison of permeability and porosity indicates that high porosities occur in grain- and dolostones and also cause higher permeability. But for all other lithofacies types no correlation between porosity and permeability in regard to interconnected porosity can be inferred (Fig. 6).

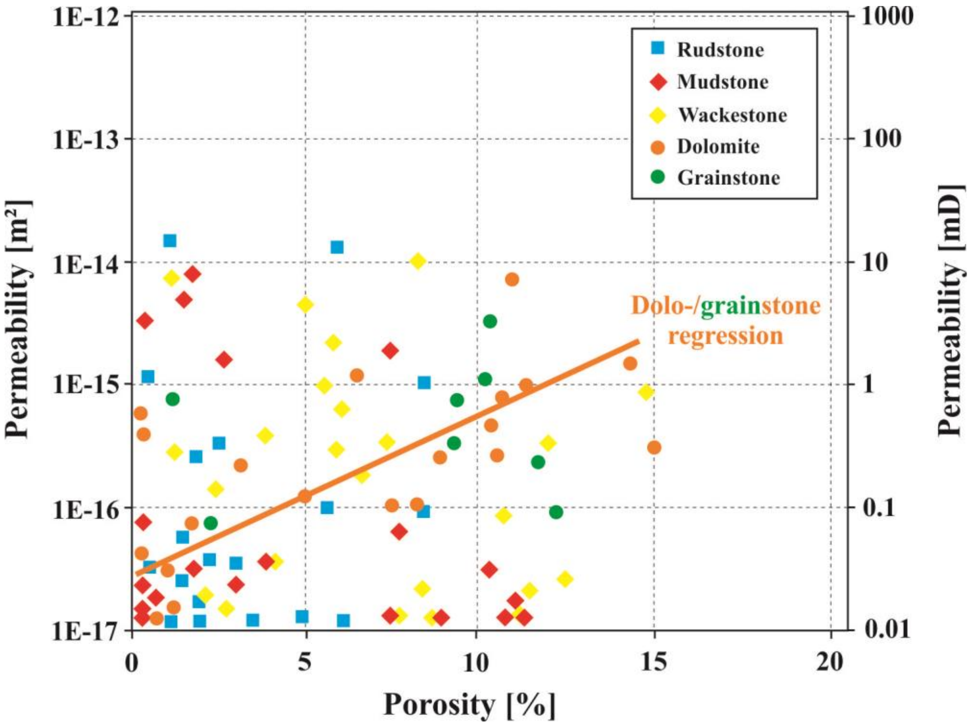


**Figure 6: Porosity/Permeability relation for different lithotypes (only mean values are displayed).**

Diagenetic processes caused dolomitization and de-dolomitization of reef structures and their adjacent transition zones to the basin facies, resulting in an increase of inter-crystalline porosity and therefore increased matrix permeability. On the other hand, if de-dolomitization led to the formation of saccharoidal limestone, permeability is decreasing due to reduced crystalline porosity. With increasing dolomite content an increase of thermal conductivity is observed due to the higher thermal conductivity of the dolomite crystal structure. The dolomitized areas related to the geometry of the massive reefal limestone complexes can span over several stratigraphic units of the Malm predominantly in vertical direction (Schauer 1998, Koch 2011).

N (proximal) — S (distal)

| Stratigraphy | Purbeck * | | | | Malm | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Facies type | Mudstone | Mud-/Wacke-/Grainstone | | | Float-/Rudstone | Mud-/Wacke-/Grain-/Rudstone | | | Mudstone | Helvetic |
| Dolomitization [%] | 0 - 50 | 0 - 20 | 0 - 30 | 20 - 80 | 70 - 100 | 0 - 20 | 20 - 100 | 0 - 50 | 0 - 10 | 0 - 10 |
| Permeability [m²] | n. d. | | | | 1,2E-18 - 5E-16 | 1,1E-18 - 5,2E-14 | | | 1,2E-18 - 5E-15 | n. d. |
| Porosity [%] | 0,15 - 12,6 | 1,6 - 16,2 | | 0,15 - 12,6 | 1,0 - 15,2 | 0,3 - 11,5 | 0,4 - 15,2 | 0,3 - 11,8 | 0,1 - 9,8 | n. d. |
| TC [W/(mK)] | 2,3 - 3,9 | 2,3 - 3,3 | | 3,3 - 4,9 | 1,8 - 4,9 | 1,6 - 2,9 | 1,6 - 4,9 | 1,4 - 3,0 | 1,4 - 2,6 | n. d. |
| $c_p$[J/(kgK)] | 2,03 - 2,56 MJ/(m³K) | | | | 0,55 - 0,99 | | | | | n. d. |

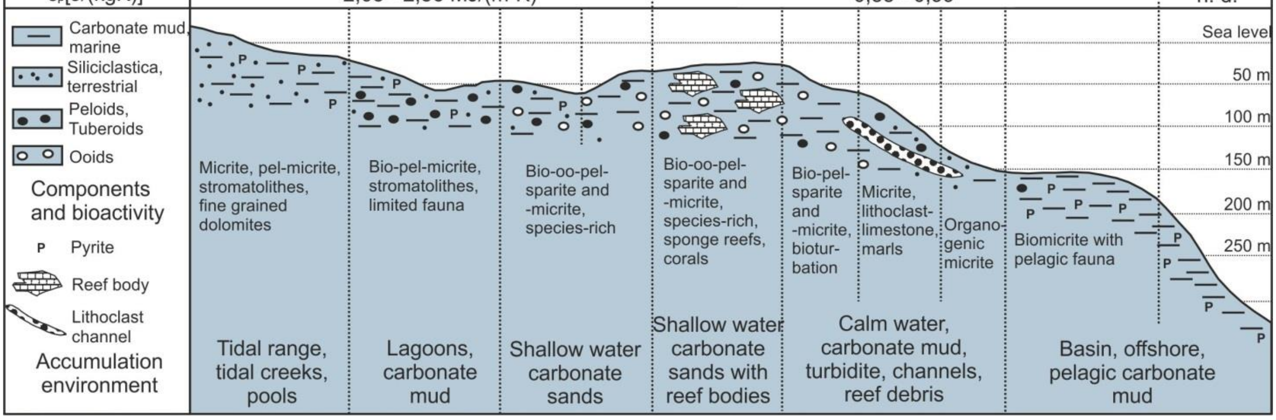


**Figure 7: Schematic sketch of the marine accumulation area of carbonates of the Purbeck and Malm and corresponding thermo- and petrophysical matrix properties; Estimation of dolomitization intensity is based on Wolfgramm et al. (2011); values marked with * of the Purbeck are from Koch et al. (2007, 2009); TC: Thermal Conductivity, $c_p$: specific heat capacity, n.d.: no data available.**

In the study of Wolfgramm et al. (2011) an overview and estimation in percentage of the dolomitized areas of the Purbeck and Malm is given. Figure 7 includes the measurement ranges of different thermo- and petrophysical matrix properties to improve the reservoir assessment. Compared with other carbonate reservoirs mainly explored for hydrocarbons (Ehrenberg und Nadeau, 2005), the rock permeability and porosity of the Malm carbonates of the Molasse Basin is rather low. The dolomitization and de-dolomitization processes can have a significant influence on rock permeability, meaning that it can either increase or reduce the average rock permeability. Including fracture network, dolomitization and karstification, a positive shift of the permeability-porosity relationship across several magnitudes can be observed. This shift identifies a high hydrothermal potential of the deep Malm aquifer system in the Molasse Basin. The assumption of a positive 2-3 magnitude reaching permeability correction is based on pump test data and comparisons of matrix and formation productivity from different deep drilling locations in the Molasse Basin (Böhm et al. 2011, Schulz et al. 2012).

### 4.1 Transfer to reservoir conditions

The presented data of outcrop analogue studies are based on rock measurements on oven dried cores, which are conducted under laboratory conditions with atmospheric pressure and room temperature of 20°C. This approach guarantees a very good reproducibility of the results but also requires a correction of the measured data for reservoir conditions. It is assumed that the reservoir is completely saturated. For the following analyses the temperature and pressure conditions of a 5000 m deep and 150°C hot reservoir, which are realistic values for the Molasse Basin, are estimated.

The thermal conductivity of water saturated rocks can be calculated following the model of Lichtenecker and numerous other authors (Pribnow 1994, Clauser & Huenges 1995, Pribnow & Sass 1995, Williams et al. 1995, Schoen 1996, Popov et al. 2003, Hartmann et al. 2005). Temperature dependency models of thermo-physical properties of different rock types can be found in Tikhomirov (1968), Huenges et al. (1989), Somerton (1992), Pribnow (1994), Vosteen & Schellschmidt (2003), and Abdulagatova et al. (2009). In general the thermal conductivity decreases with increasing temperature and increases with increasing pressure (Clauser & Huenges 1995). The fundamental effects are the reduction of pore space and the increasing temperature with increasing depth (Clauser et al. 2002). Both parameters control the fluid and matrix conditions, although in terms of tight carbonates the temperature depending porosity reduction is the dominant factor. Also for tight carbonates the lithostatic pressure has only minor influence on the porosity-permeability relation (Schmoker 1984, Bjørkum et al.1998).

**Table 1: Facies types and associated thermo-physical properties at laboratory (measured values) and reservoir temperatures (calculated values) according to different transfer models; matrix dominated: Mud-/wackestone, grain-/component dominated: Rud-/floatstone, grain- and dolostone.**

| Parameter | Facies type | Value range at 20°C, dry | Value range for saturated conditions at 20°C | Value range at 150°C, saturated | Transfer model |
|---|---|---|---|---|---|
| **Specific heat capacity [J/kgK]** | Matrix dominated | **613 - 1045** | **645 - 1081** | **806 - 1227** | Vosteen & Schellschmidt (2003) |
| | Grain/component dominated | **547 - 1167** | **565 - 1184** | **711 - 1330** | |
| **Thermal conductivity [W/(mK)]** | Matrix dominated | **1.35 - 2.62** | **1.60 - 2.79** | **1.80 - 2.46** | Zoth & Hänel (1988) |
| | Grain/component dominated | **1.72 - 4.87** | **1.85 - 4.94** | **1.92 - 3.53** | |
| | Matrix dominated | **1.35 - 2.62** | **1.60 - 2.79** | **1.83 - 2.51** | Sass et al. (1971) |
| | Grain/component dominated | **1.72 - 4.87** | **1.85 - 4.94** | **1.92 - 3.92** | |

In terms of matrix porosity and permeability it is concluded that the low rock porosity measured on the outcrop samples will not change significantly with increasing depth in regards to hydraulic conductivity. In terms of the mean reservoir porosity the temperature of the carbonate systems is the dominant factor with regard to the thermal expansion and carbonate chemistry and not the depth function of the reservoir (Schmoker 1984, Bjørkum & Nadeau 1998). A comparison with other carbonate reservoir data (Ehrenberg & Nadeau 2005) and a thermo-triax test series on outcrop samples confirms this approach. Different samples tested with the thermo-triax cell had initial permeabilities, measured under laboratory conditions with an air-driven permeameter of $3.5 \cdot 10^{-16}$ m². After complete water saturation of the samples an average decrease of permeability of about one magnitude is observed.

When applying reservoir pressure (vertical stress: 130 MPa, confining stress: 30 MPa, pore pressure: 1 MPa) and temperature (150°C) a total shift of permeability of about 2-3 magnitudes is measured (Fig. 8).

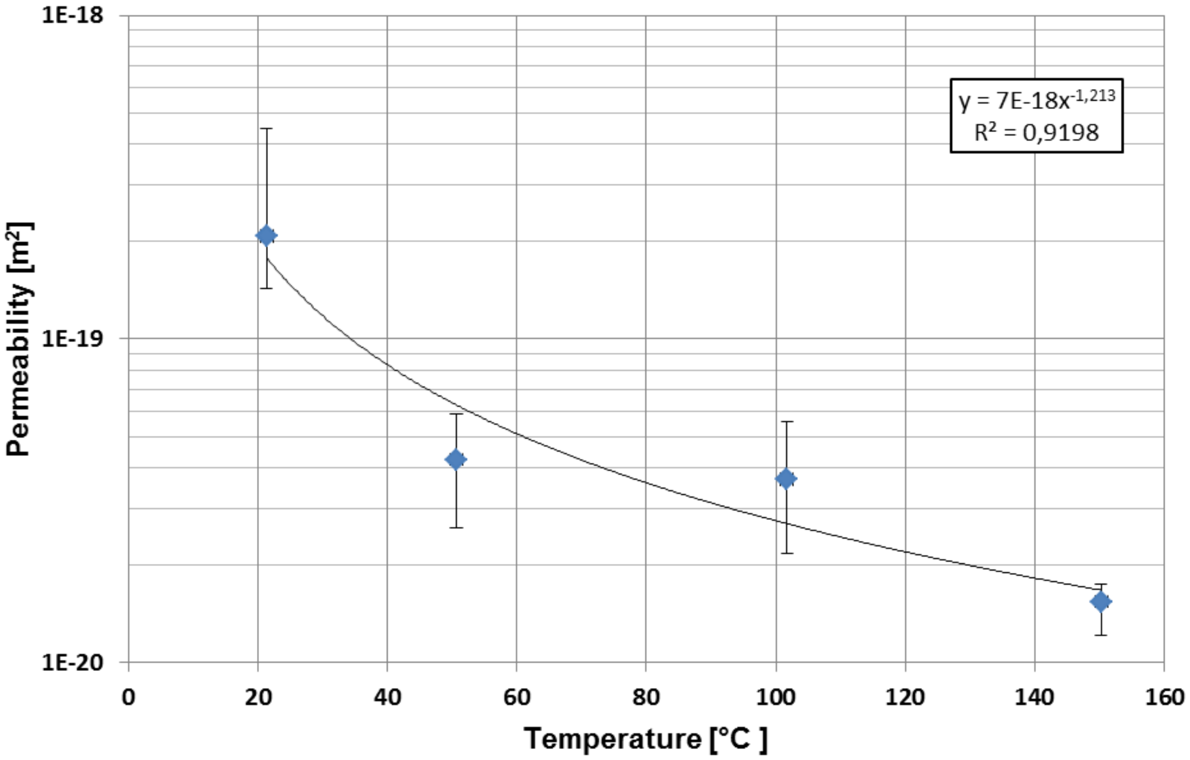


**Figure 8: Decrease of permeability of carbonate outcrop samples under reservoir pressure and increasing temperature regime starting at 20°C up to 150°C (reservoir temperature).**

## 6. CONCLUSIONS

The obtained data from the Upper Jurassic limestones of South Germany show that prognosis of reservoir properties by applying facies models to the deeper subsurface can be implemented as an additional exploration tool. The determination of geothermal reservoir properties serves in general to distinguish between petrothermal and hydrothermal systems (Sass & Götz 2012) and can also be used for optimized drilling and stimulation design purposes. Outcrop analogue studies offer effective opportunities to gain data to be predicted via reservoir transfer models to greater depths and higher temperatures, which lead to a better understanding of production capacities of geothermal reservoirs. Furthermore, these studies provide a sufficient data base to determine thermo-physical reservoir characteristics of the rock matrix of geothermal reservoir formations. Facies concepts are applied as exploration tool producing conservative results. Adding information on secondary porosities, karstification, dolomitization and stress field into a reservoir model will lead to realistic reservoir capacities.

The studied rocks of the Upper Jurassic are not a homogenous formation of limestones. Even on a small scale different facies zones and their interfingering, which can be differentiated in geometry, structure, fabric and composition, can be identified. These differences affect the thermo-physical properties of the rocks and show facies related trends. The hydraulic parameters vary in the order of 4 magnitudes within a stratigraphic unit or facies zone, but show in general a range of poor to very poor hydraulic conductivity. It can be inferred from the outcrop studies that hydraulic active pathways are bound to fracture networks, faults and adjacent karstification and/or dolomitized zones. The secondary reservoir permeability is strongly related to the tectonic setting and diagenesis, which also is facies controlled. It is additionally depending on the hydro chemical conditions of the carbonate reservoir to maintain open flow paths. Based on the investigation of the matrix parameters the sustainable heat transport into the utilized geothermal reservoir can be assessed. Thus, the long-term capacities for different utilization scenarios can be calculated more precisely. With the help of 3D seismic surveys the investigations on the lateral extension and possibly also facies heterogeneity will give insight on the transmissibility of different target horizons/facies. The thermofacies characterization and prediction of geothermal reservoir parameters is therefore a powerful tool for the exploration, operation and quality management of planned and existing geothermal power plant projects. The key to a reliable reservoir prognosis, reservoir stimulation, and sustainable reservoir utilization for the Malm in the Molasse Basin is to integrate statistically tested databases of tectonic, hydraulic and thermofacies models into 3D reservoir models.

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