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Geothermal Play Typing – Current Development and Future Trends of a Modern Concept for Geothermal Resources Assessment

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ABSTRACT

The play type is a common concept to streamline the exploration for subsurface natural commodities and is a fundamental part of the resource assessment practice. A play type describes the generic geological environment that might host an economic accumulation of a given commodity. The identification of a certain play type has therefore implications for exploration and extraction strategies. In geothermal exploration, a systematic worldwide play type concept has been recently published. The aim of geothermal play typing is to economize the exploration process, to define the play risk, and the chances of reservoir discovery by appropriate targeting and exploration methods, which are ideally geosystem specific. However, the play type concept needs further definitions and specifications to integrate geothermal plays into the assessment process for geothermal resources. A worldwide usable language for the geothermal assessment process remains elusive. First attempts have been made on a geothermal play type workshop under the umbrella of the IEA-Geothermal meeting in Vienna in May 2018. The recent nucleus for systematic research and development of a conceptual framework is the research project PlayType that aims to find a standardized and broadly applicable methodology for play typing (funded by the German Federal Ministry of Economy and Energy – BMWi). Preliminary results reveal the common interest in geothermal play type concepts but also the lack of clear definitions and play sub-categories. The play based assessment process requires the integration of surface criteria including user demand, infrastructure and land access, and subsurface criteria such as geosystem, play focus and prospect scale play levels. Ultimately, play based exploration as a goal of geothermal resources assessment can only be achieved by continuous efforts on an international level.

1. INTRODUCTION

The concept of geothermal play typing follows a modern approach to categorizing geothermal resources according to geological controls specific for particular geologic and plate tectonic settings. The first geothermal play type catalogue was introduced by Moeck (2014) and contrasts former classification schemes for geothermal resources that were based on depth, or temperature or fluid thermodynamic properties (e.g. Benderitter et al., 1990; Hochstein, 1988; Haenel et al., 1988; Nicholson, 1993; Sanyal, 2005). Since these formerly and still used criteria seem to be insufficient for a worldwide applicable geothermal resources assessment procedure (Lee, 2001), the geothermal play type concept offers an alternative, straightforward definition on the geological interplay in a geothermal system between heat source, heat transport mechanism, fluid chemistry, structural geology/tectonics and reservoir rock (Moeck, 2014). The play type approach aims to streamline the geothermal exploration phase and enable the comparison of exploration processes for geological-geothermal play analogues. This goal is different and not comparable to the goals of the IGA document on the "Specifications for the application of the UNFC-2009 to geothermal energy resources" (Falcone et al., 2016). The specification document aims to provide application rules of terms in conjunction with the UNFC-2009 application specifications on renewable energy resources and to normalize the reporting process for geothermal energy resources to improve the global communication in the geothermal sector.

The BMWi (German Federal Ministry of Economy and Energy) funded project PlayType commenced researching the concept of systematic geothermal play typing in 2018 with the aim of improving the economics and internationalisation of German geothermal developments by cataloguing geothermal provinces in Germany using the play type concept of Moeck (2014). The PlayType project collaborates in the activities of the *IEA Geothermal working group 13 Exploration* on the newly defined *Task A1 – Geothermal Play Types*. The IEA workshops and executive meetings are international and held biannually, so that the Task Workshops on geothermal play typing have met three times: (I.) in May 2018 in Vienna/Austria with the topic *Geothermal play types: their fundamental characteristics, key workflows and recognition of uncertainties, risk and opportunities*; (II.) in November 2018 in Daejeon/Korea with the topic Play based geothermal resources assessment; (III.) in April 2019 on Canary Islands/Spain with the topic *Definitions and play based geothermal use*. The topic of the fourth play type workshop under the umbrella of the IEA will be held in Costa Rica in November 2019 with an emphasis on geothermal use in play types with convection dominated heat transport.

The first workshop in Vienna emphasised - among other sub-themes - comparisons between play based geothermal exploration and hydrocarbon resources, and tried to delineate play based geothermal exploration similar to the three-level approach (basin, play, and prospect) in play based hydrocarbon exploration. In contrast to hydrocarbon resources, geothermal resources are not characterized by accumulations in the subsurface. The methodology and adoption of play-based exploration to geothermal resources is presented in the next chapter. Geothermal resources can be utilized in manifold ways from the use of ground source heat pumps to borehole heat exchangers to direct use and deep geothermal well doublets. A geothermal province may contain multiple geologic formations that can be used as a resource, from shallow to deeper levels and hence, the energy or heat demand may determine how deep wells will be drilled and what technology is employed to exploit the most suitable resource.. More terms describing the levels and system components of a geothermal play seem to be necessary. First attempts on specific terminology for a systematic geothermal play typing were discussed during the second workshop in Daejeon and are presented in the third chapter. The scalability of geothermal utilization in a play province with conduction dominated heat transport is presented in the fourth chapter. The value of a geothermal resource is not only dependent on the heat accumulation in the subsurface but also on the energy demand at the surface and the existing infrastructure. The decision whether to start a geothermal project or not is not only driven by the likelihood of finding a geothermal resource in a certain geologic environment as the play type concept aims but is also driven by conditions at surface. The criteria with a geologic technical focus for the subsurface conditions and with a societal technical focus for the surface conditions were discussed in the Daejeon workshop and are introduced in the fifth chapter.

2. METHODOLOGY OF PLAY BASED EXPLORATION ADOPED FROM HYDROCARBON PLAYS

In the style of exploration play typing for hydrocarbon resources, the assessment process starts with the geosystem-scale basin focus, followed by the regional-scale play focus and ends with a local-scale prospect focus (Royal Dutch Shell, 2013). At the scale of geothermal systems, geothermal plays can be broadly separated into two types related to the mechanism by which heat is transported into the reservoir: the heat transport is dominated by either convection or conduction. Whether convection or conduction dominates depends primarily on the characteristics of the heat source and the distribution and range of permeability within the host rocks at the system scale (Bogie et al., 2005; Lawless et al., 1995; Smith & Chapman, 1983; López & Smith, 1995 and 1996; Zech et al., 2016). It is important to recognize that convection and conduction are end-members of a heat transfer continuum. Conductive intervals always exist in localized parts of a convective regime (frequently, for example, on the outer margins of convective systems) while minor convective intervals can sometimes exist within conductive systems. For example, gravity-driven convection (i.e., forced convection) might occur within a discrete aquifer within a conduction-dominated system in steep mountainous terrain where recharge zones are at a higher elevation than discharge sites (Deming, 1994; Tóth, 2009). Alternatively, buoyancy variations due to different concentrations of fluid salinity can result in local convection (i.e., free convection) within sedimentary aquifers.

Play based exploration passes through different scales from geosystem to local scale. When a stratigraphic unit is analysed for exploration, it becomes obvious that the play type at the geosystem scale as hitherto defined by Moeck (2014) is not precise enough to describe likely reservoirs or promising drilling targets. We suggest, therefore, a scale-dependent play based geothermal exploration adapted and modified from hydrocarbon play based exploration (The Royal Dutch Shell, 2013). Play based exploration passes from broad to local scale and can be described by a three-level pyramid (Fig. 1), which starts with a broad geosystem focus where the geological boundary conditions of a geothermal play type are described. The aim of this first step is to sort the geosystem into one of the geothermal play type categories. The second step focuses on the more specific identified play and analyses levels and elements to better understand the play, namely the geologic controls on porosity and permeability, and ultimately to delineate exploration targets and prospect areas. In the third step, one play level and one or more play elements are analysed on the local prospect scale (Fig. 1).

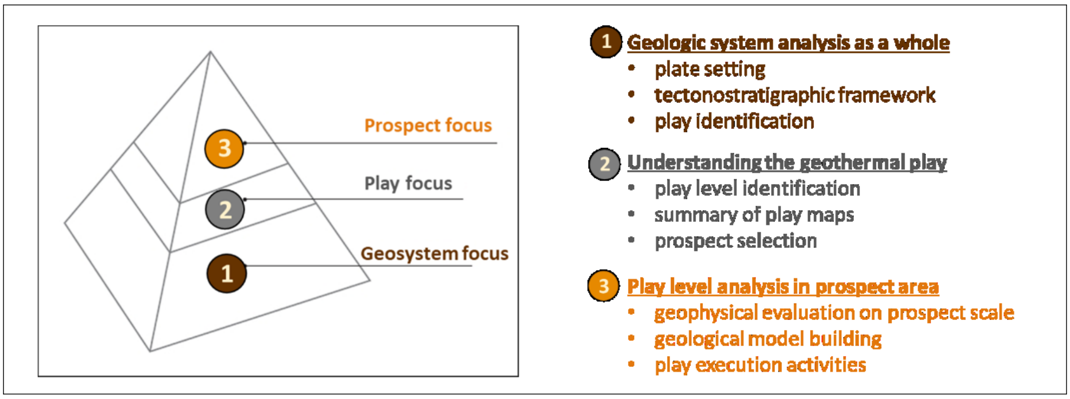

Figure 1: The exploration play pyramid, illustrating the steps of play-based exploration (modified from Royal Dutch Shell, 2013).

3. DEFINITIONS AND TERMS REQUIRED FOR PLAY BASED GEOTHERMAL EXPLORATION

As reports from hydrocarbon or mineral exploration show, play based exploration requires more terms than only the generic description of a geologic system that is likely to contain *exploitable* – or in case of geothermal exploration *usable* - resources. There are several stratigraphic units within one play type. A group of stratigraphic units could be defined as geothermal plays within a play type, which is a region of a geologic system encompassing different plays either in a horizontal or vertical direction. For example, in carbonate plays, the geological controls on permeability and hence future well productivity can be fault systems, depositional systems such as reef and laminated facies, and karst. Similar to the definitions for hydrocarbon exploration plays, we define these geological controls on geothermal reservoir productivity as play segments (Tab. 1), while one singular stratigraphic unit is a play level (Tab. 1). Several play levels within a play type make a play. Besides the primary geological controls such as deposition or faults, compaction and diagenesis, and hence episodes of basin subsidence and burial have a strong effect on reservoir productivity (Mountjoy et al., 2001; Mraz et al., 2019). This is relevant in foreland basins or faulted regions like horst-graben or basin and range plays, where one play level is located in increasing or variable depth (e.g. Mraz et al., 2018; Sinclair & Allen, 1992). We consider these depth related, different porosity and permeability domains as play elements (Tab. 1).

Table 1. Definitions of terms required for play based exploration of geothermal resources

Term	Definition
Geothermal play type	Patterns in the heat charge system, permeability structure and fluid type related to a specific geological setting, that resemble each other closely geologically, allowing world-wide analogue comparison.
Play	Group of lithologically related stratigraphic units with potential for heat charge and suitable reservoir conditions within a play type.
Play segment	Subdivision of a geothermal play. Fields and prospects that share common geological controls and thus a common probability of success profile.
Play level	Structural or stratigraphic level of a play; portrays plays at different depths.
Play element	Geological controls on a play segment bounded by a significant change in the play elements.

4. SCALABILITY OF GEOTHERMAL APPLICATIONS

A generic geological model for geothermal play types with conduction dominated heat transport contains sedimentary layers as formed in intracratonic or foreland basins, and granitic or basement segments. Critical differences between geothermal resources and hydrocarbon resources are the scalability of geothermal energy and the fungibility of hydrocarbons. The geothermal play concept integrates a suitable local user demand/infrastructure aspect at surface, which is far more critical in geothermal developments than for hydrocarbons, which can be transported over long distances. The wide range of geothermal applications are intimately dependant on resource depth and user demand. Geothermal resources range from near-surface geothermal energy for single homes, to mid-depth geothermal energy for neighbourhoods and individual districts as well as deep geothermal energy for the supply of district heating networks in entire metropolises and power production (Fig. 2). The depths of geothermal resources ranges from a few metres to several kilometres. The applications and utilization depths presented below (Fig. 2) are typical for an average geothermal gradient.

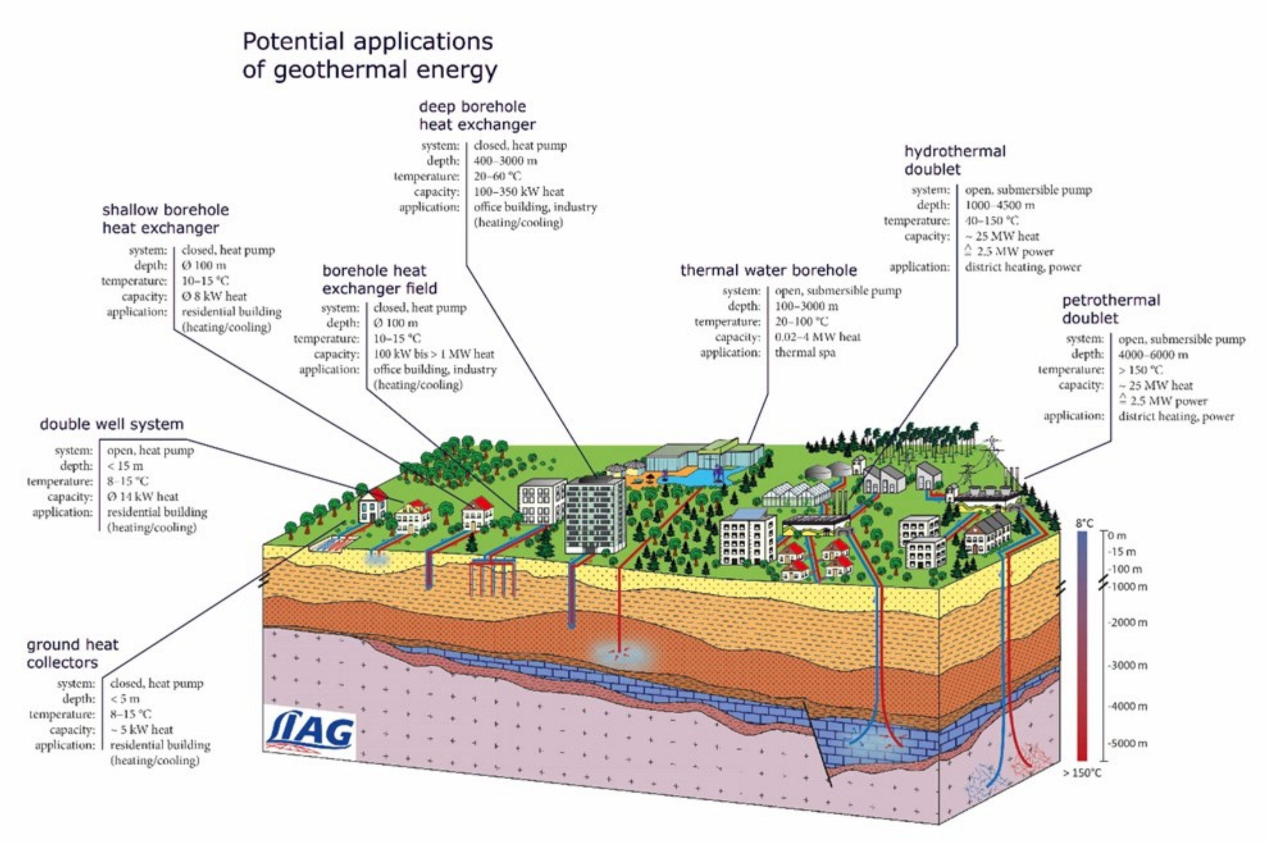

Figure 2: Range of possible geothermal applications from shallow to deep resources in a play province with conduction dominated heat transport (adopted Weber & Moeck, 2019).

As opposed to hydrocarbon resources with continental (gas) and global (oil) commodity prices, the value of a specific geothermal resource is tightly controlled by local and regional surface factors. Therefore, dependent on the surface infrastructure, geothermal resources in shallow or mid-range depth can be economic.

The efficiency of the geothermal energy use increases with a cascade operation (i.e. utilization of residual heat from high to low high demand) as illustrated by the hydrothermal well doublet scenario in Figure 2. In this case, geothermal energy is first used for industrial applications requiring high enthalpy, then lower temperature waste heat from that facility is successively distributed through various other infrastructure such as greenhouses, aquaculture, and district heating and cooling networks. Other renewable energy resources can generate electricity for well pumps such as from biomass in rural areas encircling a city.

5. DECISION MAKING PROCESS BASED ON GEOTHERMAL PLAY EXPLORATION

Ideally, geothermal exploration should be conducted with a portfolio approach, where several geothermal prospects form the exploration portfolio. Play based geothermal exploration intends to assist the decision making process in ranking which of the prospects carry the least risk and most potential for reward, and hence should be matured further. As described above, the subsurface conditions can be analysed by the play based exploration approach, starting with field reconnaissance and reinterpretation of existing data at the geosystem scale, narrowing down to the play scale, and finishing with technical risk evaluation at the prospect scale, ultimately leading towards target selection and a decision to drill. (Fig. 1). This progressive analysis of the geological subsurface can be described in a geologic-technical focus pyramid leading towards a drilling and development decision (Fig. 3). The description and cataloguing of the plays (i.e. the play typing) and the mapping-out of the play fairway (i.e. the play fairway analysis) (Moeck & Beardsmore, 2014; Nash & Bennett, 2015) belongs to the essential tasks geologic-technical focus pyramid. A relevant difference to hydrocarbon or mineral resources is the scalability of geothermal application and the potential to use geothermal plays for multiple infrastructure applications. Hence different play segments of more than one play level in one play can be developed for use in a range of surface applications.

The efficiency of a geothermal resource is not only related to geological-geothermal subsurface conditions but also to local energy demand, infrastructure and land access. A prime geothermal resource with low risk on the geological-technical front may lack existing infrastructure at surface so that the distribution of geothermal energy is difficult, cost-prohibitive and challenging. Logistic and legal access to the geothermal license area can be more challenging than the later access to the reservoir. In particular, the exploration and development of greenfields in remote areas can contradict environmental protection and native title aspects such as the felling of primeval forest or disturbance of culturally sensitive areas for access road construction. Therefore, geothermal resources with lower predicted temperature and productivity in densely populated areas with highly developed infrastructure may have higher development potential than high temperature and productivity resources in remote areas with no infrastructure.

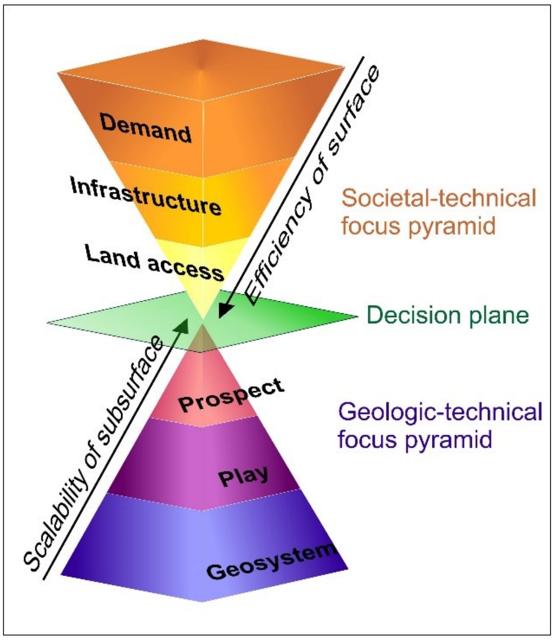

Figure 3: Efficiency criteria of surface conditions represented by the societal-technical focus pyramid and scalability criteria of the subsurface conditions presented by the geological-technical focus pyramid as driving decision-making factors to start a geothermal project.

Play based exploration also considers the consequences of surface influences such as the scenarios mentioned above. Therefore, the demand for energy (seasonal, end user types, population development), existing infrastructure and acceptance level should be scrutinized simultaneously with geosystem analysis. If the demand is tangible and the geosystem is likely to contain geothermal plays, play analysis together with infrastructure analysis can be conducted. At the same time, local stakeholders and populations can be educated about geothermal energy provision to increase or strengthen the acceptance. On the local scale, the prospect is analysed simultaneously with the land access situation, and appropriate decisions on where, and what geothermal technology should ideally be employed (e.g. multiple GSHP versus minimally deeper boreholes for direct use) can be made. This decision making process can be compiled in a societal-technical focus pyramid (Fig. 3).

6. CONCLUSION

Play based geothermal exploration is a systematic exploration approach adopted from the hydrocarbon industry that describes the different exploration steps from large to small scale; however, the concept requires adaptation with more specific terms needed to differentiate between groups, levels, segments and elements of geothermal plays. In contrast to hydrocarbon plays, geothermal plays can be developed for a variety of applications, from indirect to direct use, and shallow to deep play levels. We call this wide range of possibilities the scalability of geothermal use. Generic geological models help to illustrate the range of geothermal applications in convection or conduction dominated play types. A generic model for conduction dominated play types has already been developed within the research project PlayType and the IEA Geothermal working group 13 Exploration. The newly established task group A1-Geothermal Play Types of the IEA Geothermal Exploration group is currently preparing a generic model for scalable geothermal applications in convection dominated plays.

With geologic-technical and societal-technical foci, the decision of whether to develop a geothermal field is made by analysing both the scalable subsurface and efficient surface conditions, respectively. After these preliminary attempts to define and describe play based geothermal exploration, more efforts need to be taken to further develop this new concept. The ultimate goal is to facilitate communication, field development and acceptance amongst the international geothermal community for consistent and systematic geothermal resources assessment. The activities in the IEA Geothermal working groups in collaboration with other international groups such as the IGA might be the appropriate vehicle to reach this goal.

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