Effects of Stratigraphy on Geothermal Reservoir Performance
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ABSTRACT

Geothermal reservoir performance is critical to successful production of energy from geothermal resources. It is highly dependent upon a variety of factors, including reservoir types, fluid properties, rock properties, temperature, structural geology, stratigraphy, and others. Drilling of the well field and construction of the associated fluid collection and processing system is one of the largest costs of developing a geothermal resource. Proper conceptual modeling of the geothermal resource is necessary to optimize the design of the subsurface and surface geothermal energy production system. When done correctly, we can maximize the return on investment of our development dollars. Furthermore, we can use this information to better maintain the 'health' of our reservoirs and wells. We can also improve and optimize well and reservoir productivity, providing additional return on our geothermal investments. This paper outlines some of the interactions between geothermal reservoirs and their associated stratigraphies. The resultant effects upon reservoir performance as seen at the wellhead are discussed in detail.

INTRODUCTION

Many factors influence the performance of geothermal reservoirs, including reservoir types, fluid properties, rock properties, temperature, structural geology, and stratigraphy.

Geothermal reservoirs can be broadly classified as follows:

- Vapor (vapor-dominated reservoirs)
- Two-Phase (flashing liquid-dominated, natural two-phase, and condensing vapor-dominated reservoirs)
- Liquid (liquid-dominated reservoirs)

At present, there are 5 vapor-dominated reservoirs in production in the world; these systems are generally considered anomalous, and more of them are not likely to be found.

Two-phase reservoirs are somewhat more common in nature than vapor-dominated, but not much more common. However, the exploitation of a liquid-dominated reservoir typically results in a producing two-phase reservoir, so it is important to be aware of this behavior under exploitation.

Since liquid-dominated reservoirs are by far the most commonly found in nature, this paper focuses on them. In addition, they are the most complicated, and two-phase and vapor reservoirs can be analyzed by the same methods that are used for liquid-dominated reservoirs.

Although the properties of water are very well known and identical in all reservoirs, dissolved gases and solids (such as CO_2 and NaCl, respectively) cause variations in the behavior of aqueous fluids in the reservoirs. While there can be wide variations in fluid compositions and properties, most geothermal reservoirs tend to have low concentrations of dissolved gases and solids, and they are usually neutral in pH. This paper focuses on pure water reservoir fluids.

Prior to resource development, reservoir rock properties are not well known. In addition, rock properties can vary more than the properties of aqueous reservoir fluids. However, since we have over 100 geothermal reservoirs in production world wide, we can make some general assumptions about the properties of rocks that are likely to be found in geothermal reservoirs until properties of the specific reservoir rocks are better known. This paper focuses on the typical rocks that we could expect to encounter and their properties.

Temperatures can vary from one reservoir to the next. In addition, they vary with both horizontal and vertical locations within the same reservoir. In general, these temperature differences cause density differences that interact with gravity to be the main driving forces in geothermal reservoir fluid flow. The rock matrix, structural geology, and stratigraphy tend to resist these driving forces and their resulting flows. This paper focuses on high-temperature geothermal systems that are suitable for electric power production, generally taken to be 150^{o}C or higher.

Structural geology is a very broad subject, and it varies widely from one reservoir to another. It comprises faults, intrusions, plate tectonics, and other large-scale structures. Faults can facilitate or impede reservoir recharge. Intrusions and plate tectonics are often the sources of heat. Other structural features are less common in geothermal systems, but they can be influential, too. This paper focuses on reservoirs with minimal effects from structural geology.

Stratigraphy can also vary widely from one reservoir to another. However, certain stratigraphic features are typical of high-temperature geothermal systems: basement rock, reservoir rock, and cap rock. Heat, rocks, and fluids interact in a stratigraphic column to produce a geothermal system that can be exploited. This paper focuses primarily on the effects of stratigraphy.

Due to time availability, the scope of this paper is limited to liquid-dominated reservoirs, pure water reservoir fluids, the typical rocks that we could expect to encounter, and their properties. In addition, the scope has been limited to high-temperature geothermal systems that are suitable for electric power production. Finally, the scope has been limited in ways that minimize the effects of structural geology on reservoir performance and emphasize the effects of stratigraphy.

Specifically, this paper explores the effects of caprock (and its thickness) on geothermal reservoir performance (and its existence). The importance of caprock in geothermal systems is still contentious. Analytical methods and reservoir simulations are used to analyze the absence, presence, and thickness of caprock as a major component of stratigraphy and its effects on geothermal reservoir performance, and the results are summarized in this paper.

Understanding of the effects of stratigraphy can increase the knowledge of a particular geothermal system and the confidence in the conceptual model of it. In addition, this is a major input to the exploration effort, the resultant resource assessment, and the conceptual design of a geothermal power system that can be developed to exploit the resource. Furthermore, since these systems evolve under exploitation, understanding of the effects of stratigraphy can contribute to long-term, sustainable power generation from the geothermal system after it is in production.