Centre for Computational Geostatistics (CCG)
Guidebook Series Vol. 3

Guide to SAGD (Steam Assisted Gravity Drainage) Reservoir Characterization Using Geostatistics

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Centre for Computational Geostatistics (CCG)
Guidebook Series

Volume 1. Guide to Geostatistical Grade Control and Dig Limit Determination

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Volume 3. Guide to SAGD (Steam Assisted Gravity Drainage) Reservoir Characterization Using Geostatistics

Volume 4. Guide to Recoverable Reserves with Uniform Conditioning

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ABSTRACT

The application of SAGD will become increasingly important in northern Alberta because of the vast resources/reserves accessible with this production mechanism. Quantitative reservoir characterization of McMurray formation facies and petrophysical properties is required for uncertainty assessment, well placement and production performance prediction. This guidebook was launched to address this need. We plan on expanding this documentation and the associated programs to ultimately provide a comprehensive toolbox for characterizing McMurray-type formations. At present, this is just a "taste" of what is to come. Members of the Centre for Computational Geostatistics (CCG) have full access to the report and associated presentations, programs and some help. All others are encouraged to join the CCG.

1 INTRODUCTION

Conventional crude oil reserves in Canada have been declining since the late 1960's. At the same time, Canadian offshore ventures are very costly to develop. Canada, threatened with a growing requirement for funds to purchase foreign oil, became more reliant on Alberta's immense heavy oil and bitumen resources, in particular, the Athabasca oil sands deposit (also referred to as the McMurray formation). Located in Northern Alberta, the Athabasca oil sands deposit spans 40,000 square kilometers and contains 140 billion cubic meters or one trillion barrels of original bitumen-in-place. This amount comprises two-thirds of Alberta's total oil reserves and 20% of Canada's.

In the past thirty years, oil sands have gone from 2% to 30% of Canada's total annual oil production. Syncrude Canada Ltd. and Suncor Inc., using surface mining techniques up to depths of approximately 130 meters, are currently extracting and producing approximately 22% of this 30% just North of Fort McMurray. However, a mere 10% of the Athabasca oil reserve, that is, only 14 billion cubic meters, is located sufficiently close to the surface to allow the continued use of economical surface mining methods. The demand for innovative oil sands extraction technology to recover the deeper oil sands is high. Expanded production of oil sands bitumen will be essential in maintaining Alberta's role as the major Canadian source of crude oil in the 21st century.

1.1 TIMELINE

Government, researchers and industry have undertaken many steps since the late 1960's to meet the demand for new oil sands extraction processes. Refer to Figure 1.1 for an illustration of an applicable timeline. In 1974, the Alberta government created a crown corporation with the specific mandate of, in cooperation with researchers and industry, developing new oil sands exploitation technologies: the Alberta Oil Sands Technology and Research Authority (AOSTRA). One of the main targets of AOSTRA was that part of the Athabasca oil sands that could not be recovered using surface mining techniques. In 1986, the Alberta Department of Energy (ADOE) took over AOSTRA's role in developing oil sands technology; then, in August 2000, ADOE's oil sands research initiatives and programs were consolidated by the Alberta Energy Research Institute (AERI).

In 1978, Dr. Roger Butler, Chemical Engineering Ph.D. from the Imperial College of Science and Technology (1951) and holder of the Endowed Chair of Petroleum Engineering at the University of Calgary from 1983 to 1995, introduced the concept of Steam Assisted Gravity Drainage (SAGD). AOSTRA, the Alberta petroleum industry and government quickly supported SAGD as a promising innovation in oil sands extraction technology. Today, it is proposed that more than one-third of the Athabascan oil sands' bitumen-in-place can be recovered using SAGD.

In 1984, the Underground Test Facility (UTF) was initiated by AOSTRA as an in-situ SAGD bitumen recovery facility. The facility was owned and operated by ten industrial participants and received ample government support. The SAGD process and its commercial viability have been confirmed at this site. Currently, at least 20 oil companies are invested in SAGD pilot and commercial projects across the world that total near $1 billion.

During the mid 1990's, many organizations worked to bridge the gap between industrial challenges and research and development (R&D) involving innovative bitumen-in-place extraction and treatment technology. For example, the Canadian Oil Sands Network for Research and Development (CONRAD) was created in 1994. The Petroleum Technology Alliance of Canada (PTAC) was founded in 1996. Similarly, the CANMET Western Research Centre (CWRC), the Advanced Separation Technologies institution (AST), the National Centre for Upgrading Technology (NCUT) and the Alberta Department of Energy (ADOE)/Alberta Research Council (ARC) Core Industry (AACI) were also created in the 1990's. SAGD is a major part of all of these organization's transactions and goals.

1.2 THE STEAM ASSISTED GRAVITY DRAINAGE (SAGD) PROCESS

SAGD is a thermal in-situ heavy oil recovery process. The procedure is applied to multiple well pairs. The well pairs are drilled horizontal, parallel and vertically aligned with each other; their length and vertical separation are on the order of 1 kilometer and 5 meters, respectively. The upper well is known as the "injection well" and the lower well is known as the "production well". The process begins by circulating steam in both wells so that the bitumen between the well pair is heated enough to flow to the lower production well. The freed pore space is continually filled with steam forming a "steam chamber". The steam chamber heats and drains more and more bitumen until it has overtaken the oil-bearing pores between the well pair. Steam circulation in the production well is then stopped and injected into the upper injection well only. The cone shaped steam chamber, anchored at the production well, now begins to develop upwards from the injection well. As new bitumen surfaces are heated, the oil lowers in viscosity and flows downward along the steam chamber boundary into the production well by way of gravity. Figure 1.2 illustrates the concept with a typical well pair.

Steam is always injected below the fracture pressure of the rock mass. Also, the production well is often throttled to maintain the temperature of the bitumen production stream just below saturated steam conditions to prevent steam vapor from entering the well bore and diluting oil production – this is known as the SAGD "steam trap". The SAGD process is able to economically recover 55% of the original bitumen-in-place. There are many other engineering considerations for SAGD such as recovery rate, thermal efficiency, the capability and economics of drilling horizontal well pairs, steam quality, steam injection rate, steam pressure, minimizing sand production, reservoir pressure maintenance and water intrusion; however, their importance is not key to the purpose of this report, which is to describe how to characterize a potential SAGD reservoir using geostatistics.

SAGD offers a number of advantages in comparison with conventional surface mining extraction techniques and alternate thermal recovery methods. For example, SAGD offers significantly greater per well production rates, greater reservoir recoveries, reduced water treating costs and dramatic reductions in SOR.

1.3 THE UNDERGROUND TEST FACILITY (UTF)

The Underground Test Facility (UTF) was initiated in 1984 by AOSTRA, later known as ADOE and currently the AERI. The UTF site is located approximately 60km North-West of Fort McMurray, Alberta, Canada, see Figure 1.3. This is just a few kilometers West of Syncrude Canada Ltd. and Suncor Inc.'s surface mining operations. Drilling the horizontal wells and conducting the SAGD tests from underground meant less capital cost and minimal environmental impact. The purpose of this facility is to validate SAGD's physical process, commercial viability and ancillary operations, e.g., drilling horizontal wells. The UTF consists of two vertical shafts 3.3m in diameter penetrating 140m of overburden, 20m of oil sands and 15m of limestone. Within the solid limestone formation, a horseshoe-shaped horizontal tunnel 5m wide and 4m high was excavated. From these tunnel walls, horizontal wells were drilled upward through the limestone sequence then horizontal through the lower pay zone of the oil sands. Figure 1.4 illustrates the setup.

There were multiple phases to the UTF operation. The first phase in 1987, "Phase A", sought to validate only the physical process of SAGD. Three horizontal well pairs, horizontally separated by 25m and 60m in length, were drilled for this phase. The test was successful. The second phase, "Phase B", aimed to prove the SAGD process on a commercial scale. For this phase, three well pairs, horizontally and vertically separated by 70m and 4m, respectively, and 600m in length, were drilled from underground into the base of the oil sands pay zone. These wells were successfully operated for approximately 10 years at better than predicted production outputs. UTF's "B Wells" also successfully exhibited the steam trap mechanism. By the mid 1990's, horizontal well drilling and completion had gained much experience in drilling from the surface; "Phase D" involved drilling two horizontal SAGD well pairs 650m in length and 6m in vertical separation from the surface with a slant-drilling rig. This phase was only partially successful. One well pair was successfully completed to its specifications; but problems were encountered in placing the liner in the second well pair. However, the two SAGD well pairs were still put into operation successfully. In 1997, the second well pair was repaired and production significantly improved.

1.4 GEOLOGY OF THE ATHABASCA OIL SANDS

About 100 million years ago, streams containing sand and mud, flowed from the Rocky Mountains in the West and from the Precambrian Shield in the East into the Prairie Provinces such as Alberta and Saskatchewan. The stream runoff formed a massive inland sea. The sand and mud was spread relatively flat throughout the sea, except on the shores where sand preferentially accumulated. These sediments were covered by other sediments, buried and lithified. Although there is debate, popular opinion among geologists suggests that the oil came from somewhere else, more specifically, highly organic Cretaceous shale in the southern portion of the Alberta Sedimentary Basin. The deposit's cap rock consists mostly of marine shale, and at times tidal flat sediments, known in the Athabasca region as the “Cleanwater Formation”.

The Athabascan oil sands are composed of approximately 70% sand and clay, 10% water and anywhere from 0 to 18% heavy oil or bitumen. Unlike conventional oil, the oil sands contain a mixture of bitumen, sand, clay and water. A thin film of water, which contains trace amounts of clay, iron, vanadium and titanium, surrounds each sand particle. The viscous oil called bitumen then surrounds the water skin and sand particle. The oil sands must be specifically treated in order to remove the bitumen from the sand. Syncrude, for example, first removes the majority of the sand and clay via a hot water washing process, and then the resulting froth is diluted with a hydrocarbon mixture that settles water and solids and suspends the viscous bitumen.

Figure 1.5 shows a few of the geological specifications and statistics applicable to the UTF region. There are several companies that have invested in the Athabasca oil sands deposit, each with a different lease property and, therefore, slightly different geological specifications.

1.5 Geostatistical Characterization of Potential SAGD Reservoirs

Geological heterogeneities are impossible to exactly predict between wells. Uncertainty is an unavoidable characteristic of any geological model, that is, the unique true distribution of lithofacies and petrophysical properties between wells will remain unknown. Geostatistics allows the construction of multiple realizations that can be combined into a model of uncertainty. This geological uncertainty is transferred into production uncertainty, that is, uncertainty in production variables such as the cumulative SOR and oil production rate over time.

The main advantage of using geostatistics is the capability to access production uncertainty on the basis of geological uncertainty. Multiple geostatistical realizations of lithofacies and petrophysical properties, conditional to exploratory core hole data, are constructed to assess geological uncertainty. These realizations are then input into the “transfer function”, that is, flow simulation, which provides realizations of SOR and oil production rate. Access to production uncertainty allows better SAGD developmental decisions to be made such as the number and location of horizontal well locations. The value of additional delineation information such as infill wells or seismic data can also be assessed.

Using geostatistics, it is possible to identify regions of a reservoir with the greatest SAGD potential, aid in selecting the optimal number of SAGD wells to put into production and assess the value of additional delineation information. A geological ranking system that is correlated to production variables such as SOR and oil production rate can be used to choose optimal well locations. An analysis of production uncertainty, derived from geological uncertainty and flow simulation, will aid in the selection of the optimal number of SAGD wells. The entire process can be repeated with more or different conditioning data to assess the value of additional or different information.

Although there are many sources of production uncertainty, geological uncertainty is perhaps the most significant contributor.

This report is intended to be a guide to SAGD reservoir characterization using geostatistics. The main steps of the geostatistical study are (1) geological structure and gridding analysis, (2) preliminary statistical analysis, (3) variography, (4) construction of multiple realizations, (4) post-processing and ranking these realizations for flow simulation. Further work entails flow simulation on selected realizations, calibration of flow responses to geological ranking and an uncertainty analysis. These main steps are very clear and unambiguous; however, there are several details that need to be addressed along the way.

Each detail and step of the geostatistical procedure will be described and carried out on some data in this guidebook. The guidebook will grow in time to become more comprehensive.

1.6 FIGURES

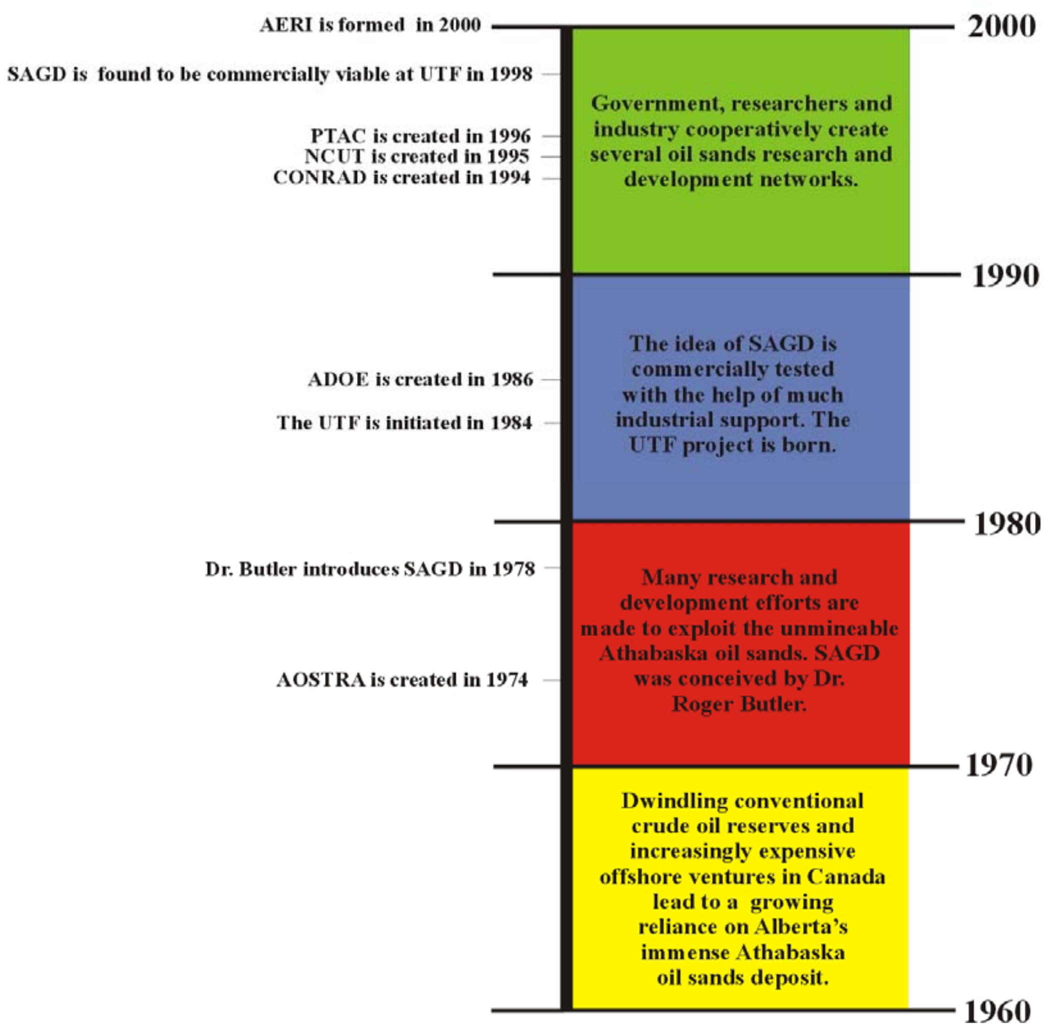

Figure 1.1 – SAGD Timeline. Highlights concerning the growth of SAGD technology. The colored right side of the vertical bold line describes four 10 year decades from 1960 to 2000. On the left are some specific dates within the decade blocks.

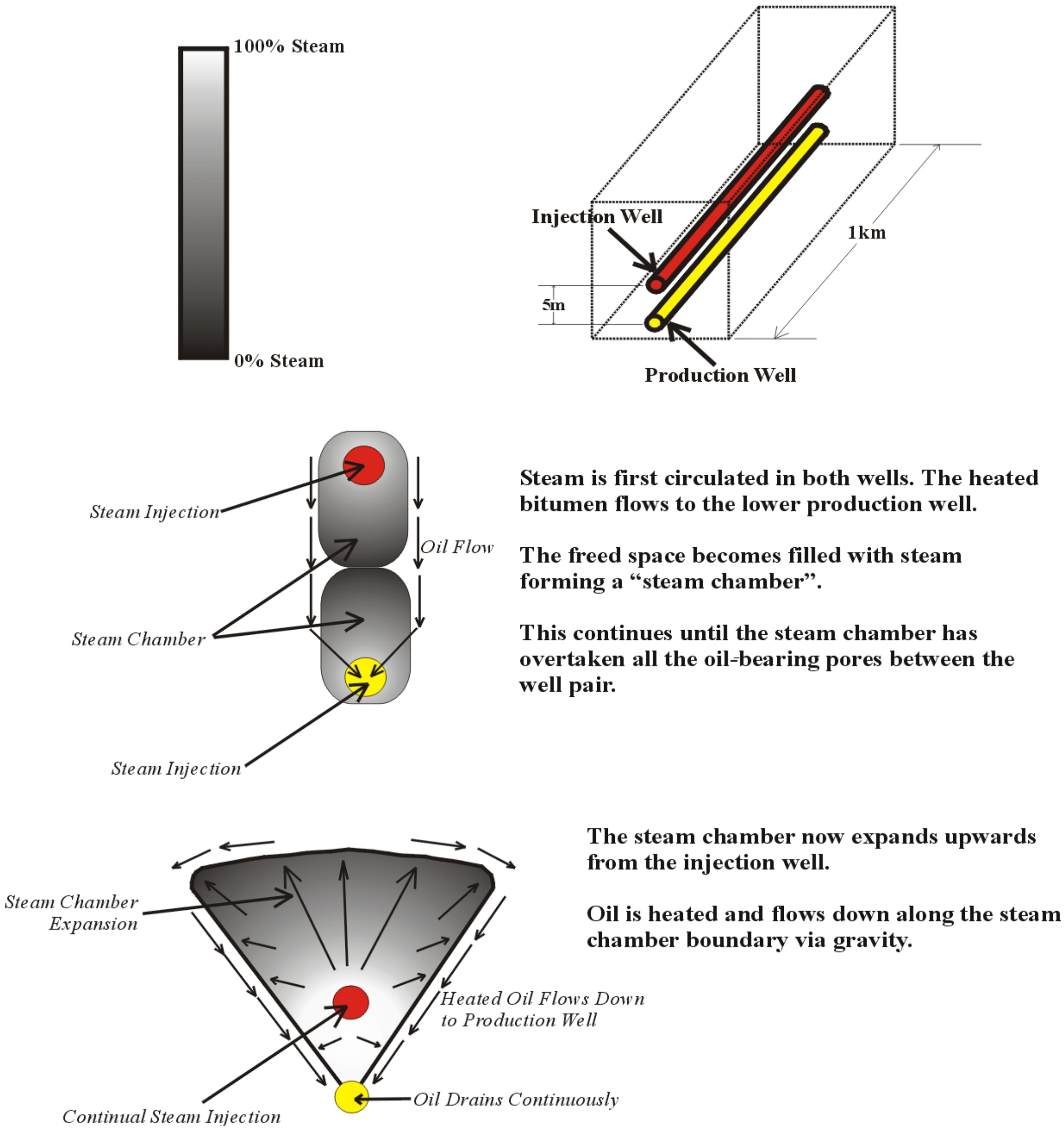

Figure 1.2 – The Steam Assisted Gravity Drainage (SAGD) Process. Schematic illustration of the physical SAGD process. Steam concentration is depicted on the grayscale shown in the top left; the setting, including the horizontal well dimensions, is shown in the top right. The middle illustrates the initial stage of SAGD when steam is injected into both wells and the steam chamber begins to form. The bottom shows the overriding SAGD mechanics when steam is injected into the injection well only and a cone shape steam chamber develops from the injection well anchored at the production well.

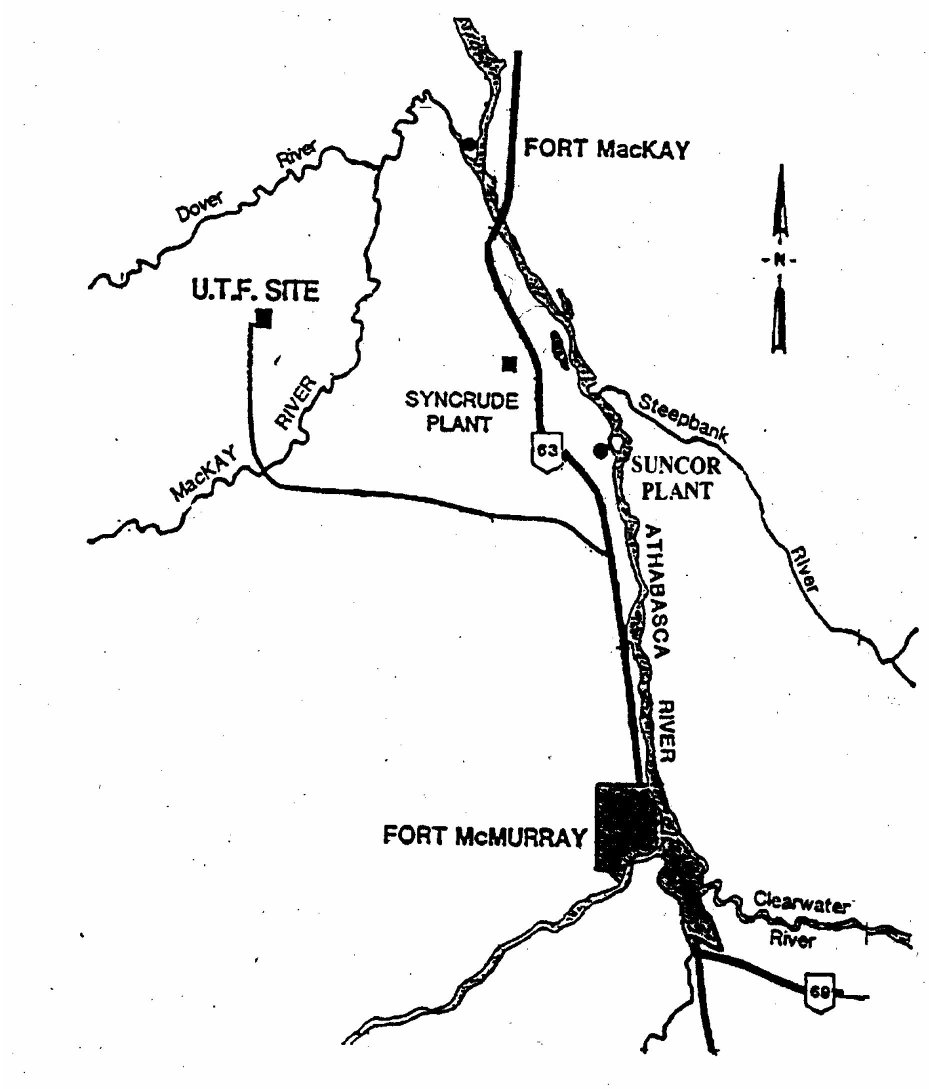

Figure 1.3 – UTF Location. Map showing the location of the Underground Test Facility (UTF). (Source: *Pilot Testing of Post-Steam Bitumen Recovery from Mature SAGD Wells in Canada*, 1998)

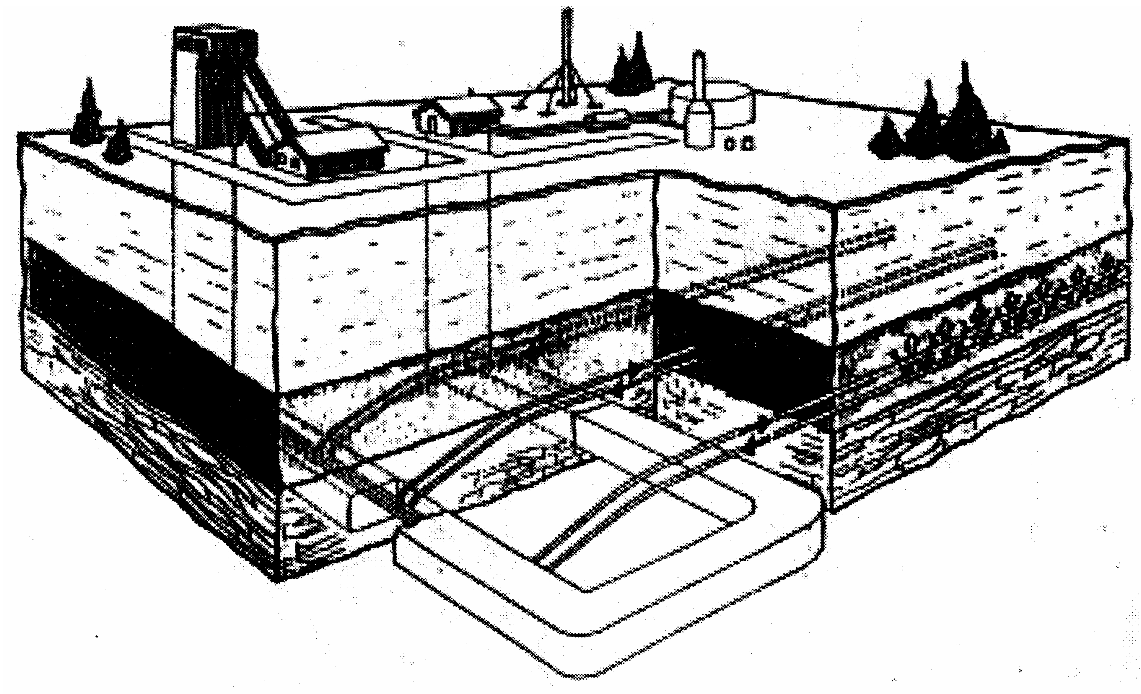

Figure 1.4 – UTF. Schematic illustration of the Underground Test Facility (UTF) in its preliminary stages. (Source: *Pilot Testing of Post-Steam Bitumen Recovery from Mature SAGD Wells in Canada*, 1998)

Parameter	Value
Depth from Surface	125 to 175m
Net Pay Thickness	15 to 20m
Sand Porosity	35%
Sand Permeability	5 to 12 Darcy
Bitumen Saturation	85%
Bitumen Viscosity (70^0C)	5×10^6 cp
Weight % Bitumen	16%
API Gravity	8^0

Figure 1.5 – UTF Geology. Summary of some important geological parameters applicable to the UTF site.