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Geothermal energy extraction from sedimentary basins in Mediterranean and Caspian areas

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NOMENCLATURE

Units and Symbols	
km	kilometres
m.y	million years
b.d	barrels per day
tcf	trillion cubic feet
mmcf	million cubic feet
bcf/d	billion cubic feet per day
btu	British thermal units
GWh	Gigawatt hour
MWh	Megawatt hour
mW/m^2	milliwatts per square metre
m^3/h	cubic meter per hour
kW	kilowatt
℃	Celsius
%	percentage

ABBREVIATIONS

OPEC	Organization of the Petroleum Exporting Countries
IOC	International Oil Company
LNG	Liquefied natural gas
ACG	Azeri–Chirag–Gunashli
JCPOA	Joint Comprehensive Plan of Action
GMT	Generic Mapping Tools
WBHX	Wellbore Heat Exchanger
IRENA	International Renewable Energy Agency
GGA	Global Geothermal Alliance
AK	Apsheron Kobystan Periclinal Through
ATFS	Alborz Thrust Fold System
AG	Alborz Gorgan Foredeep
AP	Apsheron Balkhan Zone
GC	Greater Caucasus Foredeep
KR	Karpinsky Ridge
TCF	Terek Caspian Foredeep
WK	West Kopet Dagh Zone

ABSTRACT

There are geothermal resources beneath the earth's surface that have the potential to contribute significantly to world energy demand while also being environmentally beneficial. Although it appears to be an infinite resource, it has the potential to replace other energy sources if properly managed. The introduction of abandoned petroleum wells is of relevance because one of the industry's primary challenges is the high capital expenditures of drilling geothermal wells.

This thesis provides by retrofitting a double pipe heat exchanger in an abandoned petroleum well, we hope to examine the potential amounts of heat collected from under the surface.

The case study shows how working fluid characteristics, wellbore architecture, and operational factors (circulation rate, intake temperature, etc.) all play a role in geothermal energy production.

The resulting information can be utilized to improve data interpretation and develop more optimal solutions. For the economic aspect and the performance of wells in geothermal projects, detailed knowledge of heat transport is critical. Our research shows that providing cost-effective ways to improve heat extraction from geothermal wells is a solid strategy.

CHAPTER 1: INTRODUCTION

Geothermal energy is heat derived from the earths subsurface. The geothermal energy is carried to the Earth's surface via water and/or steam. Geothermal energy can be used for heating and cooling or for generating clean electricity, depending on its features. For electricity, however, high or medium temperature resources are required, which are typically found near tectonically active areas.

In countries such as Iceland, El Salvador, New Zealand, Kenya, and the Philippines, this important renewable source meets a considerable portion of energy need, as well as more than 90% of heating demand. Geothermal power facilities can produce baseload electricity while also providing ancillary services for short and long-term flexibility in some instances.

Different geothermal technologies are at different stages of development. Direct-use technologies, such as district heating, geothermal heat pumps, greenhouses, and other applications, are widely utilized and established. The technology for generating power from naturally high permeability hydrothermal reservoirs is equally mature and reliable, having been in use since 1913. Many of today's power plants are dry steam or flash plants (single, double, and triple) that operate at temperatures of over 180°C. However, because to the advent of binary cycle technology, which uses geothermal fluid to heat a process fluid in a closed loop via heat exchangers, medium temperature fields are increasingly being employed for electricity generation or combined heat and power. New technologies are also being developed, such as Enhanced Geothermal Systems (EGS), which are now being demonstrated.

International Renewable Energy Agency (IRENA) organizes and encourages the activities of the Global Geothermal Alliance (GGA), a platform for better communication and knowledge sharing for coordinated action to expand the share of installed geothermal electricity and heat generation around the world.

1.1 Main Advantages of Geothermal Energy

In addition to being almost limitless, like many other renewable energy sources, geothermal energy is constantly accessible. Unlike solar energy, it is not impacted by the time of day or night, and unlike wind, it is not impacted by the season, climate, or weather conditions. While solar power plants generate energy on average for 2,000 hours per year, geothermal power plants generate electricity on average for 8,600 hours per year [1]. Therefore, at least in the short and medium term, the rate of geothermal energy generation can be defined as constant. It is easier to predict and plan as a result.

Geothermal power facilities only require moderate amounts of space, in contrast to the majesty of enormous wind turbines and solar panels. The majority of the parts (including the heat exchangers) are buried underground, with very little remaining above ground, whether it is a small-scale system or a large-scale facility. The heat pump is roughly the size of a household appliance in a home, whereas at larger plants, cooling towers and turbines are the largest building blocks. In some circumstances, the plants may have an aesthetic impact on the landscape, but more recent architecture designs have lessened this problem.

Because of its consistent delivery, geothermal energy can operate at full capacity at all times (maintenance aside). This means that the amount of energy used will be equal to the power multiplied by the number of hours used. Photovoltaic, hydroelectric, and wind systems, on the other hand, rarely operate at full capacity. As a result, for the same nominal power, more energy is produced.

1.2 Thesis Objectives

The high investment costs of geothermal wells are a major concern in geothermal exploration. The idea of using abandoned petroleum wells to harvest geothermal resources is a novel one. The temperature profiles of wells aid in estimating how much heat can be transmitted and produced. Literature research was conducted in this paper to look into the current applications of geothermal energy extraction using abandoned petroleum wells. The oilfields in the Mediterranean and Caspian regions serve as a case study for the importance of working fluid characteristics, wellbore architecture, and operational parameters (circulation rate, inlet temperature, and so on) in geothermal energy production. In geothermal projects, a thorough understanding of heat transport is critical to the project's economic viability and well performance. Our research shows that providing cost-effective ways to improve heat extraction from geothermal wells is a solid strategy.

CHAPTER 2: SEDIMENTARY BASIN THAT HOSTED HYDROCARBONS

2.1 Sedimentary basin that hosted hydrocarbons in Mediterranean area

The Mediterranean Sea is one of the world's most mobile zones, dividing the Eastern European, Sino-Korean, Siberian, and South China platforms from the Indian and African-Arab platforms. Mediterranean Sea is a semi-enclosed sea. Analysing the geographical configuration of this sea more closely, we find that it is composed a number of seas: the Aegean Sea, the Tyrrhenian Sea, the Adriatic Sea, the Ionian Sea, the gulf of the Lion, and the Alboran Sea (Figure 1) [2].

Figure 1: Mediterranean Sea [2]

The Mediterranean Sea is divided into two primary basins, each of which is subdivided into smaller basins. Eastern Mediterranean basins and Western Mediterranean basins are the two primary basins. The Levantine basin, Aegean Sea basin, Adriatic Sea basin, Ionian Sea basin, Tyrrhenian Sea basin, Alboran Sea basin, and Algerian basin are the sub-basins.

2.1.1 Source of hydrocarbon in Eastern Mediterranean basin

The Ionian Sea and Levantine sub-basins are the main zones for hydrocarbon reserves in Eastern Mediterranean basin [3].

IONIAN SEA BASIN

In Western Greece, the Ionian Zone is an area that may produce hydrocarbons. In the area, there are many oil seeps and the area is a continuation of tectonic Albanide areas with active oil fields.

There are three principal lithological components for the Ionian Zone (Figure 2):

- the Triassic evaporites and carbonates
- the Jurassic-Cretaceous carbonates
- Tertiary clastics (mainly flysch and molasses) and carbonates (mainly limestones).

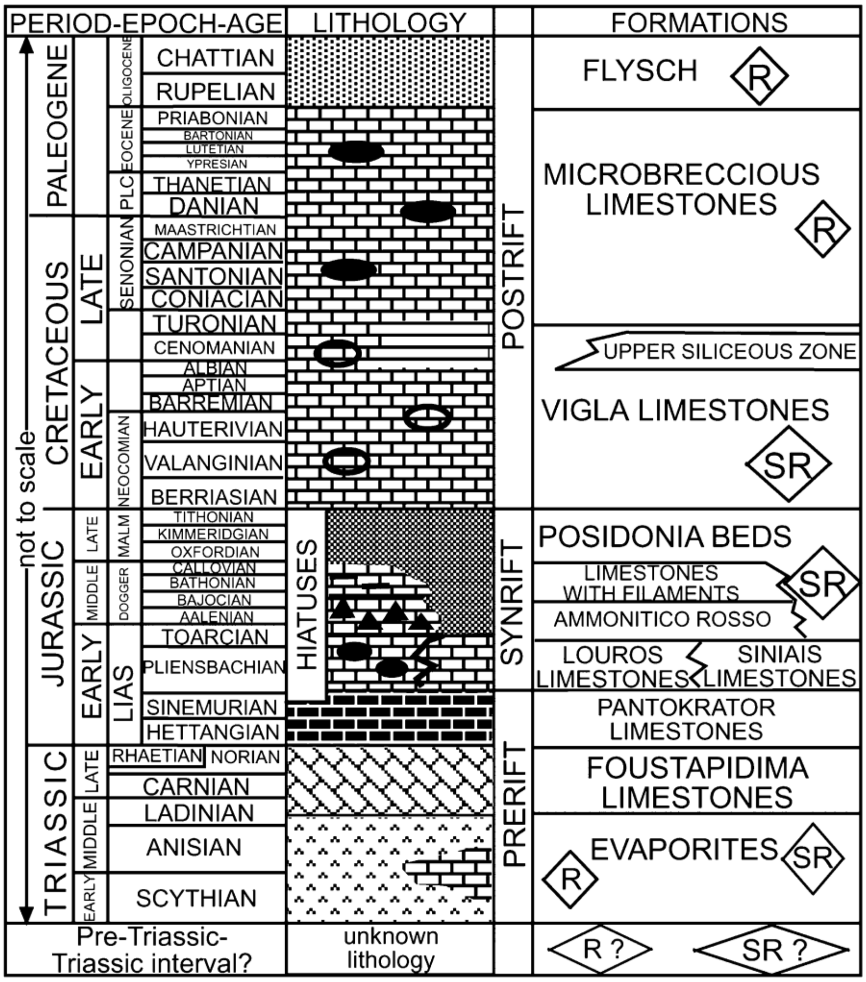

Figure 2: Stratigraphic column of Ionian Zone [3]

Triassic evaporites and carbonates are deposited on Jurassic-Cretaceous carbonates and Cretaceous-Tertiary clastics to form the Ionian Zone. The oldest sediments are Triassic evaporites. Because the evaporites have never been penetrated, the stratigraphy beneath them is unknown. The structural style affects evaporites, and they can form hydrocarbon seals. Hydrocarbons are efficiently preserved in traps beneath evaporites.

We can see 5 horizon of possible source rocks that have hydrocarbon potential in Ionian Zone:

- the Vigla shales (Cenomanina-Turonian)

- the Upper Posidonia Beds (Callovian-Tithonian)

- the Lower Posidonia Beds (Toarcian-Aalenian)

- the marls at the base of Ammonitico Rosso (Lower Toarcian)

- some Triassic breccia horizons containing shale fragments.

The carbonate source rocks beneath the evaporites produce late mature oils and gas, while the source rocks in the evaporitic sequence produce early mid-mature oil.

A maturity modelling model is used to check the source of hydrocarbons produced in this zone as well as the structural model of the area. The area cannot be completely modelled due to structural and stratigraphic complexity [3].

LEVANTINE BASIN

The Levantine Basin is a broad wide and deep sedimentary basin that contains Triassic and modern materials [1]. It has displayed passive margin processes and sedimentation for over a hundred million years. Throughout this time span, subsidence, uplift, and tectonic processes have created a favourable environment for hydrocarbon formation and entrapment.

The Levantine Basin is situated between Cyprus and Egypt's Nile Delta marine cone in the Eastern Mediterranean. This zone has seen a lot of hydrocarbon discoveries. The Levantine basin is an exploration frontier region, notwithstanding the discoveries made in Egypt and offshore areas in the south-eastern Mediterranean Sea.

The stratigraphy of Levantine basin is show in Figure 3. It shows that the basin was established since the Middle Jurassic.

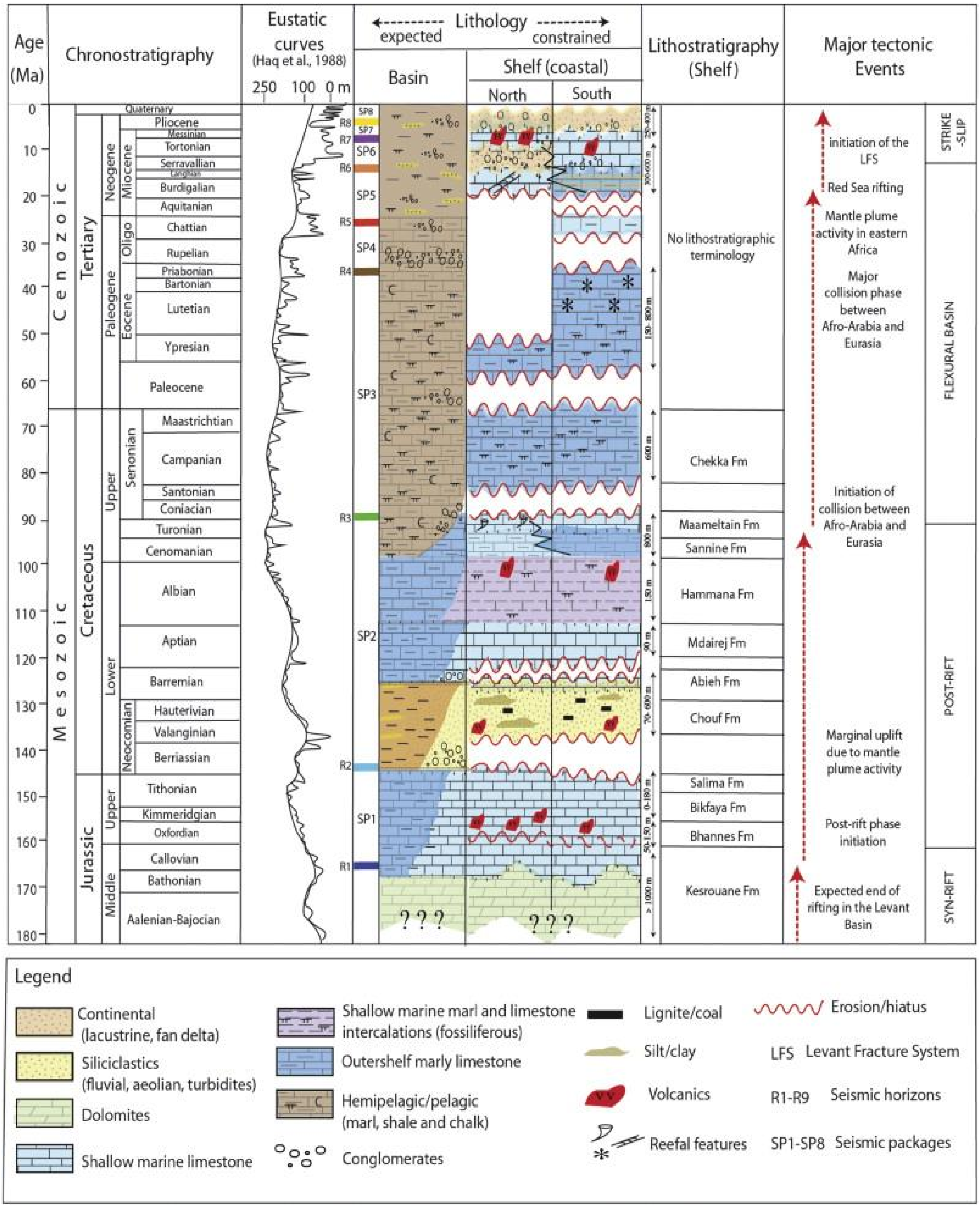

Figure 3: Stratigraphy of Levantine Basin [1]

Limestones and sandstones, as well as fractured dolomites, make up Jurassic reservoirs. Probably the oldest reservoirs are in the Triassic sandstones.

The Levantine Basin contains multiple source rocks. The most common source rocks are Mesozoic-era rocks. Upper Cretaceous source rocks are oil-prone, while Triassic-Jurassic source rocks are gas-prone.

The Mesozoic hydrocarbon system discovered in Lebanon was abundant in organic material and is thought to have been deposited in an anoxic basin.

2.1.2 Source of hydrocarbon in Western Mediterranean basin

The western Mediterranean is the youngest part of the Mediterranean, being the late Oligocene basin. The Alboran, Valencia, Provençal, Algerian, and Tyrrhenian Seas are some of the sub-basins in the western Mediterranean.

The geological evolution of the Western Mediterranean shows complicated interplay of orogenic processes with broad tectonics. The transformation of these basins is occurring in tandem with Africa's continued integration with Europe [4].

The Alboran and Algerian sub-basins are the main zones for hydrocarbon reserves in Western Mediterranean basin.

The western Mediterranean Sea's southern boundary includes the Algerian offshore. In the western half of this offshore area, the transitional edge between the South Algero-Balearic Basin and the Alboran Basin may be found. The Yusuf-Habibas Ridge connects the eastern and southern sections of the Alboran Basin with the South Algero-Balearic Basin. There are three main reservoirs in the Habibas well sedimentary section: (1) Pliocene sandstones above Messinian evaporites; (2) Middle-to-Upper Miocene sandstones beneath Messinian evaporites; and (3) earlier allochthonous carbonates and sandstones.

The region has source rocks from the Miocene, Paleogene, and Cretaceous periods. Potentially produced hydrocarbons travelled vertically into anticlinal traps, then laterally into stratigraphic traps, from Langhian and Serravallian source rocks. Gas chimneys or pockmarks can be seen on some of the anticlines.

2.2 Sedimentary basin that hosted hydrocarbons in Caspian Area

The Caspian Sea is the world's largest inland body of water, commonly referred to as the world's largest lake or a full-fledged sea. It lies east of the Caucasus, west of Central Asia's huge steppe, south of Eastern Europe's rich plains, and north of Western Asia's steep Iranian Plateau. It has a 371,000 km² surface area and a volume of 78,200 km³. Kazakhstan to the north, Russia to the west, Azerbaijan to the southwest, Iran to the south and adjacent corners, and Turkmenistan to the south along the eastern coast (Figure 4) [5].

Figure 4: Caspian Sea [5]

2.2.1 Source of hydrocarbon in South Caspian basin

The massive oil reserves of the Caspian Sea region are well-known. Azerbaijan, Iran, and Turkmenistan currently border the South Caspian Sea. The South Caspian Basin Province encompasses the southern part of the Caspian Sea as well as adjacent narrow strips of land, with Azerbaijan accounting for 45 percent, Turkmenistan for 35 percent, and Iran for 20 percent [6]. The water has 12–13 percent saline. Although the water level is 25 meters below sea level, it has changed over time.

The principal petroleum system of the South Caspian Basin is the Oligocene–Miocene Maykop/Diatom Total Petroleum System, which encompasses the whole basin region. Secondary hydrocarbon sources in western Turkmenistan could include Jurassic and Cretaceous carbonates, Eocene shales, and Pliocene mudstones. In total 620 oil and gas fields have been discovered in rocks dating from the Miocene to the Quaternary.

The depositional system of the South Caspian Basin is unique in several ways:

- sediment accumulated at an alarmingly rapid rate (as high as 4.5 km/m.y.)
- sediment compaction is very low
- gradients of geothermal energy are relatively low (1.5°C/100 m)
- in some basin areas, abnormally high pressures exist.

Early Pliocene hydrocarbon generation was connected to tectonic activity in the Caucasus Mountains and contemporaneous subsidence of the Lower Kura Depression in the marine source rocks of the Oligocene–Miocene Maykop and Diatom Suites in the Baku Archipelago (Table 1). The basin's strong sedimentation and burial rates contributed in the generation of hydrocarbons throughout the middle Pliocene. Since the late Apsheronian age of the early Pleistocene in western Turkmenistan, thick sedimentary cover and modest temperature gradients south of the Apsheron-Pribalkhan Ridge indicate that probable Pliocene source rocks have been in the oil-producing window.

Throughout the South Caspian Basin, different types of sediment were deposited in Pliocene–Pleistocene reservoir rocks. The best reservoir properties are found in quartz-rich rocks deposited in the Volga paleo delta and derived from the Russian platform, which sits north of the Turan continental block.

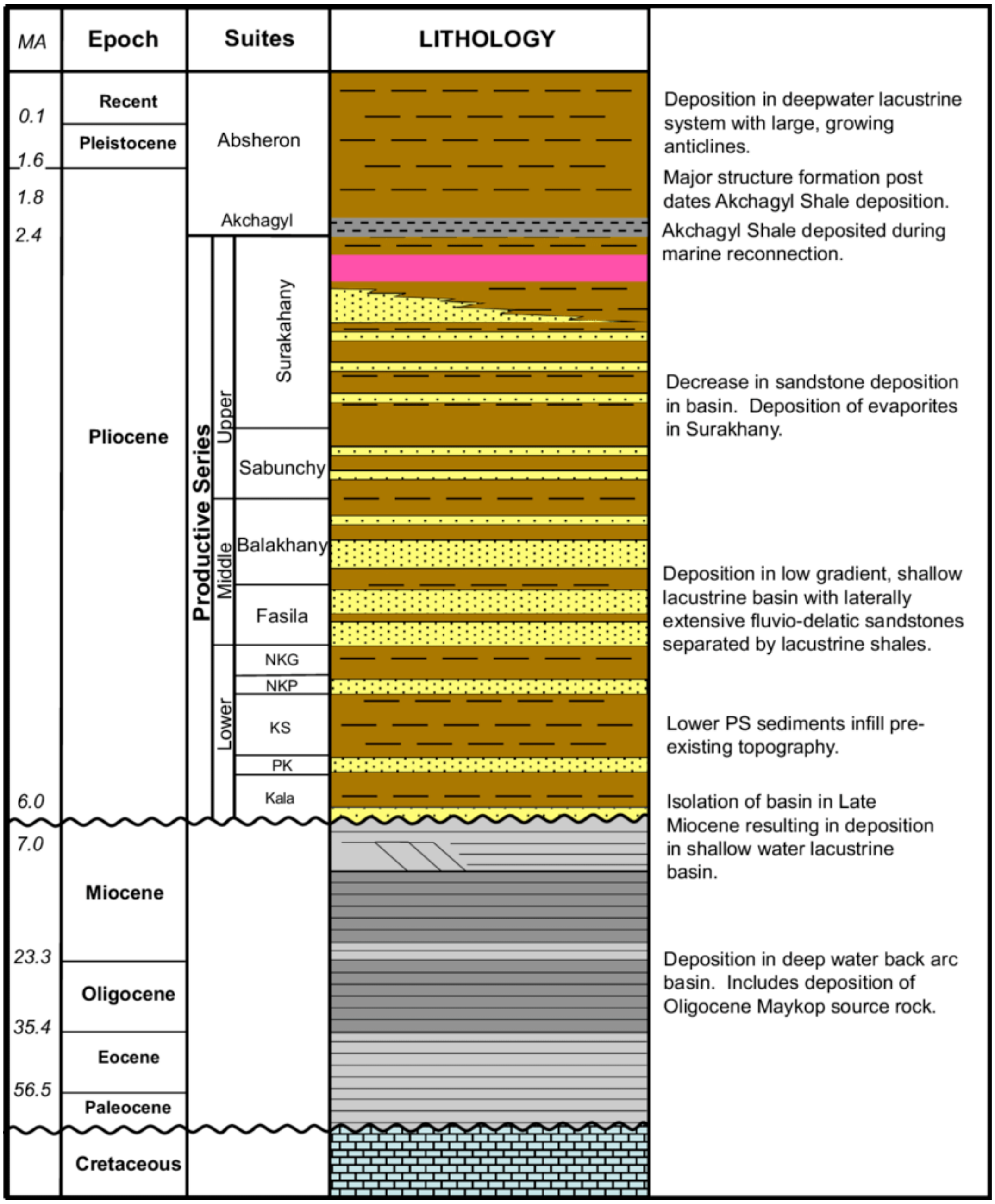

Figure 5: Stratigraphic column for South Caspian Basin [6]

2.2.2 Source of hydrocarbon in North Caspian basin

The North Caspian basin is a petroleum-rich basin that spans Kazakhstan and Russia. It encompasses the northern part of the Caspian Sea, as well as the wide plain between the Volga and Ural Rivers in the north, and the Mugodzhary highlands in the east, which are part of the Ural fold belt. The basin is surrounded on the north and west by the Volga-Ural province's Palaeozoic carbonate platform, and on the east and south by the Ural, South Emba, and Karpinsky Hercynian fold belts. During the pre-Late Devonian period, rifting and subsequent spreading uncovered the oceanic crust, forming the basin, but the exact chronology of these tectonic events is unknown. In the central areas of the basin, the sedimentary succession is more than 20 kilometres thick. A prominent thick Kungurian salt formation separates strata into the subsalt and suprasalt sequences and played an important role in the formation of oil and gas fields in the drilled Upper Devonian to Tertiary part of this succession[7].

There is a single comprehensive petroleum system in the North Caspian basin. There have been discoveries of 19.7 billion barrels of oil and natural gas liquids, as well as 157 trillion cubic feet of gas. Most of the reserves are concentrated in the supergiant Tengiz, Karachaganak, and Astrakhan fields.

Significant oil and gas deposits are found in carbonate reservoirs in reefs and structural traps of the subsalt sequence. There are much fewer reserves in many suprasalt series fields. These suprasalt fields are mainly found in shallow Jurassic and Cretaceous clastic reservoirs in salt dome-related traps. The main stage of hydrocarbon creation occurred during the Late Permian and Triassic periods, when thick orogenic clastics were deposited.

CHAPTER 3: ANALYSIS OF THE PRODUCTION AND CONSUMPTION OF HYDROCARBONS (OIL AND GAS) MEDITERRANEAN AND CASPIAN AREA

3.1 Analysis of the production and consumption of hydrocarbons in the Mediterranean Area

Oil and gas exploration and production are not as widespread in the Mediterranean as they are in the Gulf of Mexico, the North Sea, and the Caspian Sea, but they have a long history dating back to Greece in the early twentieth century. In the mid-1970s, a small number of significant petroleum finds were made in the Aegean Sea in Prinos, with production continuing. Over 350 offshore production wells have been drilled in the waters off Italy, Egypt, Greece, Libya, Tunisia, and Spain, the majority of which are located along Italy's Northern and Central Adriatic shores [8]. Now we'll look at the production and consumption of hydrocarbons in Mediterranean countries with oil reserves separately.

ITALY

The geology of Italy is very complex, and as a result, the peninsula has a complicated sedimentary and structural order that is not very calm. This has not favoured the production of huge and extensive oil fields, but it has created local conditions that have favoured the formation of several oil provinces that are significant despite their small size.

The Northern Adriatic Sea, the Po Valley (gas and oil), the Pescara field (oil and gas), the Southern Apennines (oil), the Fossa Bradanica in Puglia (gas and oil), the Calabria region's off-shore platforms (gas), Central Sicily (gas), and the Pelagic fields (oil) are the most important hydrocarbon provinces in Italy. The largest substantial oil reserves are in Val d'Agri (Potenza) and Villafortuna-Trecate (Novara). The province of Val d'Agri holds Italy's largest oil reserves. The anticline folds of the Mesozoic calcareous portions of the Apulian Platform, covered by the Apennine slopes in the Campania and Basilicata provinces, contain hydrocarbons. In Tramutola, the presence of oil and gas was reported on the surface. These escaped from deeper traps as a result of tectonic deformations in the Apennine Mountain range.

In the Villafortuna-Trecate fields, which include one of the world's deepest liquid hydrocarbon reserves, hydrocarbons are found in Mesozoic carbonate rocks split by Alpine deformations buried beneath the Po Valley (6,200 m) [9]. The geological situation is reflected in the geographical distribution of Italy's major oil regions. Indeed, a comparison of a structural map of Italy with a map of the key fields reveals that about 40% of the reserves are in mountain range areas (such as the reserves of the Southern Apennines and Central Sicily), with the remaining 60% in fore-rifts and fore-country areas.

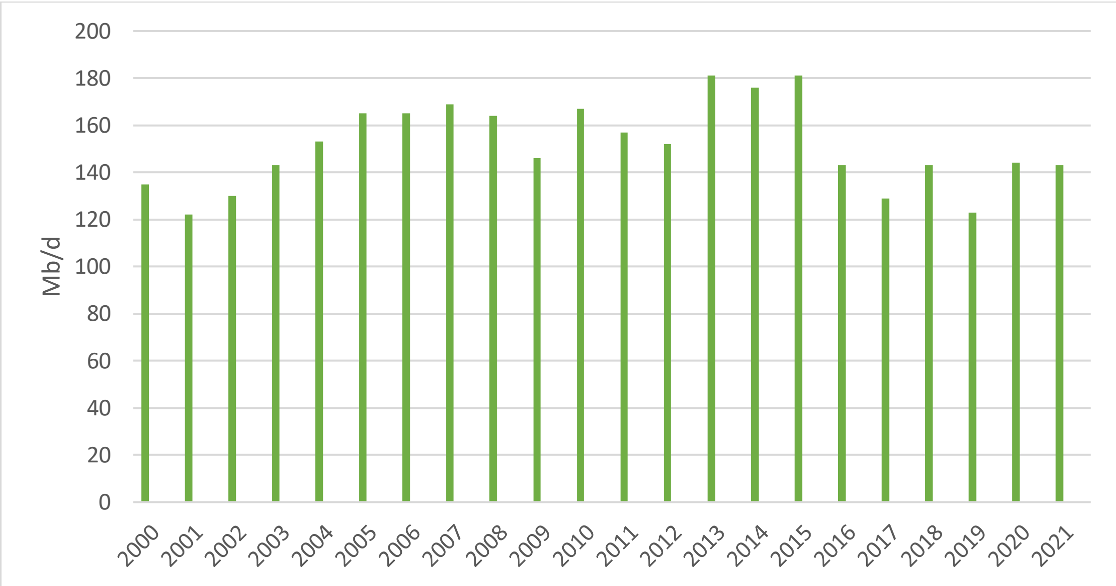

Figure 6: Annual oil production of Italy [10]

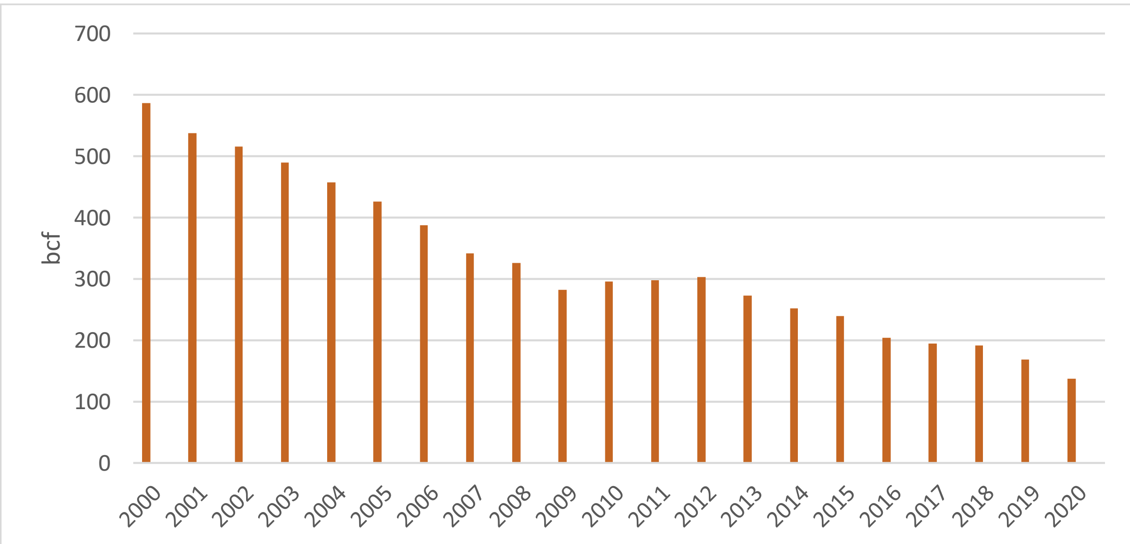

Figure 7: Annual natural gas production of Italy [10]

Italy is Europe's fourth-largest energy consumer, behind Germany, France, and the United Kingdom. Petroleum and other liquids, as well as natural gas, make for more than three-quarters of total primary energy consumption in Italy. Italy, as a net importer of crude oil and natural gas, relies largely on imports to cover roughly 93 percent of its oil and natural gas demands, as well as to maintain refined petroleum product exports. Net imports of oil and other liquids were slightly above 1.2 million barrels per day (b/d). With around 0.6 million barrels per day exported, Italy is a major oil refining centre in Europe and a large exporter of refined products. Italy is also a significant crude oil transit country. The Transalpine Pipeline begins in Trieste on Italy's north-eastern coast and can transport up to 900,000 b/d of crude oil to destinations in Germany, Austria, and the Czech Republic.

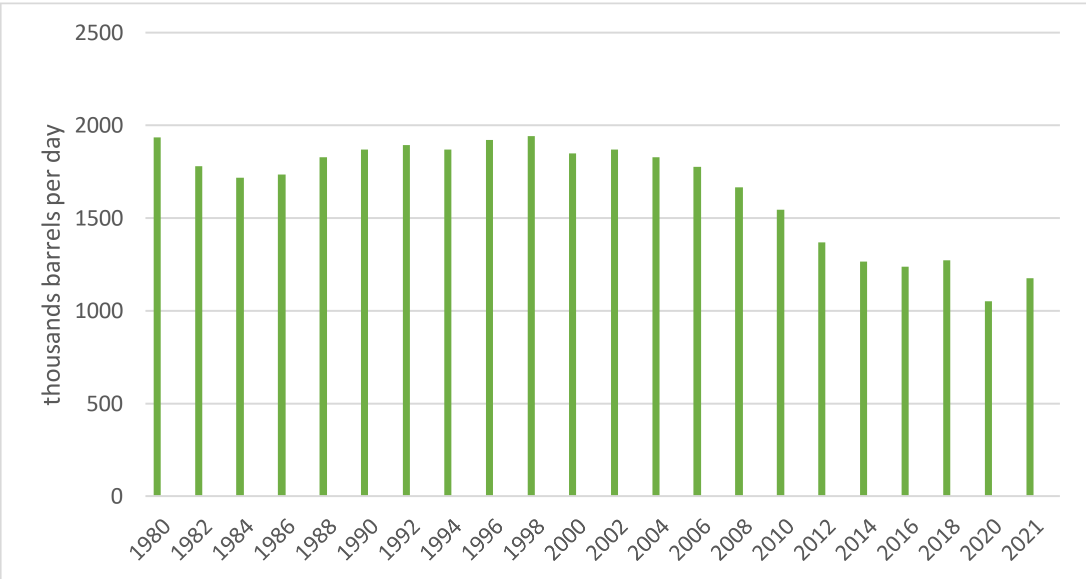

Figure 8: Annual oil consumption of Italy [10]

After Germany, Italy is Europe's second-largest natural gas importer and third-largest natural gas consumer, behind Germany and the United Kingdom. Natural gas imports totaled 2.3 trillion cubic feet (Tcf) in 2016, compared to 0.2 Tcf of dry natural gas output. The majority of Italy's natural gas comes from Russia via pipelines that pass via Ukraine and southern Europe. In 2016, pipeline natural gas from Russia accounted for around 44% of Italy's total natural gas imports.

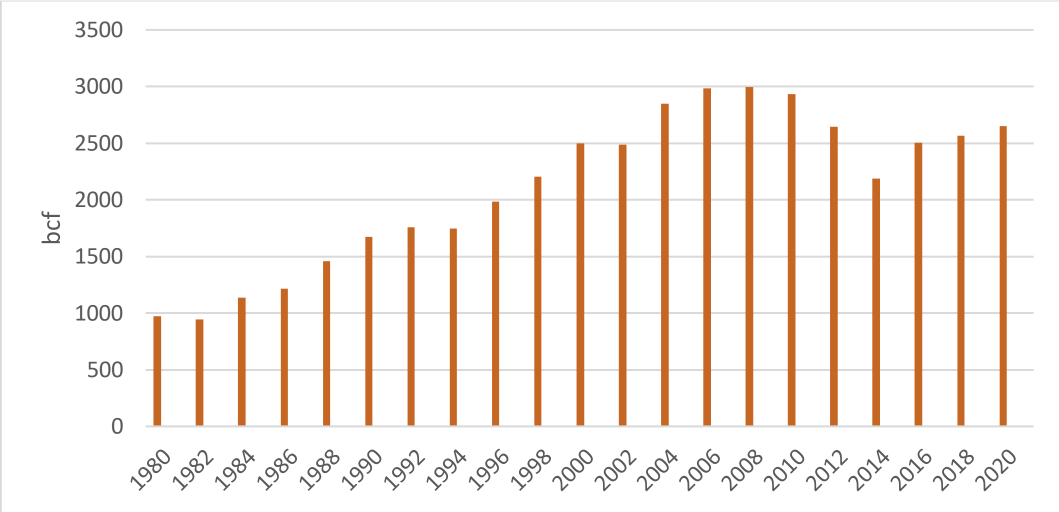

Figure 9: Annual natural gas consumption of Italy [10]

ALGERIA

Algeria has the world's tenth-largest proven natural gas reserves, is the sixth-largest gas exporter, and possesses the world's third-largest shale gas reserves, with a total landmass of 919,600 square miles. Africa and the Middle East. The country is rich in natural resources and belongs to OPEC. It is ranked seventeenth in terms of proven oil reserves. Algeria has a $75 billion foreign currency reserve cushion because to hydrocarbon profits, albeit the balance has decreased dramatically since 2014 due to decreasing oil and gas prices. Algeria is mainly undiscovered, and foreign businesses can form joint ventures to discover new reserves [11]. Sonatrach, Algeria's state-owned national oil company and Africa's largest, owns roughly 80% of total hydrocarbon production, with international oil companies (IOCs) accounting for the remaining 20%.

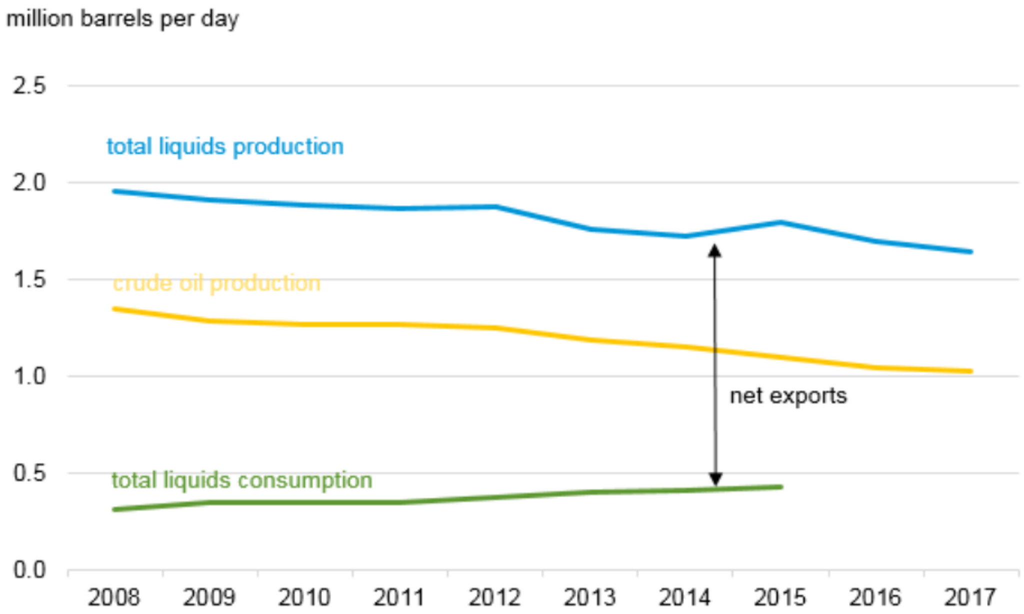

Figure 10: Oil and other liquids production and consumption of Algeria [11]

Algeria's oil consumption in 2016 was 429,000 barrels per day (B/d). Algeria consumes about 0.4 percent of the world's total oil consumption of 97,103,871 barrels per day, ranking it 35th in the world. Algeria uses 0.44 gallons of oil per person per day or 162 gallons per year.

As of 2017, Algeria consumes 1,457,626 million cubic feet (MMcf) of natural gas per year. Algeria is the world's 26th largest consumer of natural gas, accounting for about 1.1 percent of global consumption of 132,290,211 MMcf. Every year, Algeria consumes 35,218 cubic feet of natural gas per capita, or 96 cubic feet per day.

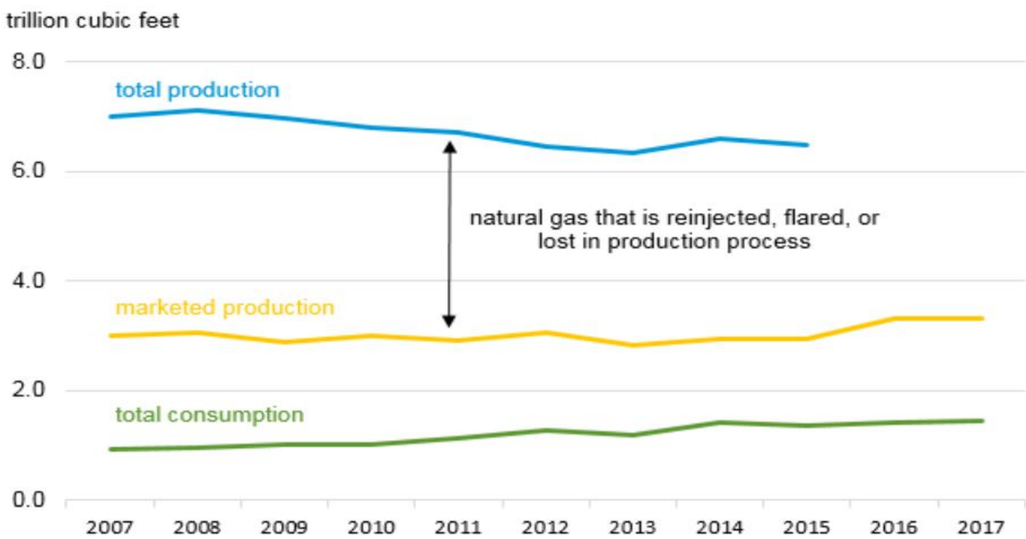

Figure 11: Natural gas production and consumption of Algeria [11]

EGYPT

Outside of OPEC, Egypt is Africa's largest oil exporter and the continent's third-largest natural gas exporter after Algeria and Nigeria. Egypt plays a crucial role in worldwide energy markets through operating the Suez Canal and the Suez-Mediterranean Pipeline [12]. The Suez Canal is used to transport oil and liquefied natural gas (LNG) northward from the Persian Gulf to Europe and North America, as well as southbound from North Africa and countries bordering the Mediterranean Sea to Asia.

Egypt's crude oil reserves are estimated differently by different sources. Egypt's known reserves have stayed stable at 4.4 billion barrels through 2011, according to the Oil & Gas Journal, up from 3.7 billion barrels in 2010. According to the Economist Intelligence Unit (EIU) and the 2017 BP Statistical Review of World Energy, Egypt's proved reserves have decreased from a peak of roughly 4.5 billion barrels in 2010 to around 3.5 billion barrels in 2016.

Egypt produced 666,000 barrels per day (b/d) of petroleum and other liquids on average in 2017. The Western Desert and Gulf of Suez produce the majority of Egypt's crude oil, with the rest coming from the Eastern Desert, Sinai, Mediterranean Sea, Nile Delta, and Upper Egypt. However, condensate and natural gas liquids production have increased over the past decade as a result of increasing natural gas production, partially offsetting declines in crude oil production.

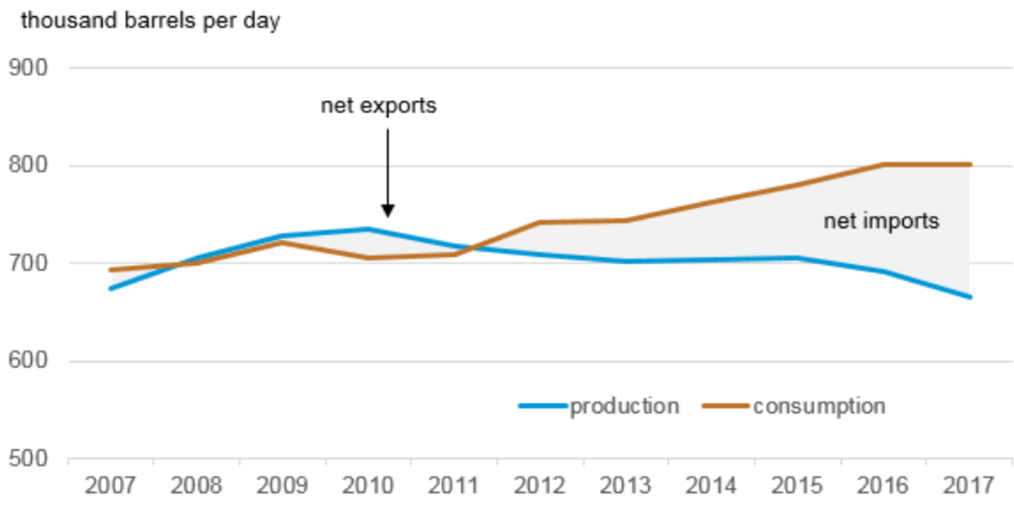

Figure 12: Oil and other liquids production and consumption of Egypt [12]

Natural gas reserves are calculated variably by different sources, just like crude oil reserves. Egypt's natural gas reserves have remained constant at 77.2 trillion cubic feet (Tcf) throughout 2011, according to OGJ, up from 58.5 Tcf in 2010. Egypt had roughly 65.2 trillion cubic feet (Tcf) of known natural gas reserves at the end of 2016, up from around 59 Tcf in 2010 and ranked fourth in Africa after Nigeria, Algeria, and Mozambique, according to the 2017 BP Statistical Review of World Energy. Total natural gas reserves are likely to grow dramatically in the next years as a result of recent natural gas discoveries. Despite new discoveries, Egypt's dry natural gas production fell by 31% between 2012 and 2016, leading to net imports since 2015. In 2016, Egypt produced 4.0 billion cubic feet per day of dry natural gas and imported 1.0 billion cubic feet per day. Natural gas production started in 2017 and is expected to reach 1 Bcf/d once the first phase of the project is completed in 2018; peak plateau production is expected to reach 2.7 Bcf/d by the end of 2019.

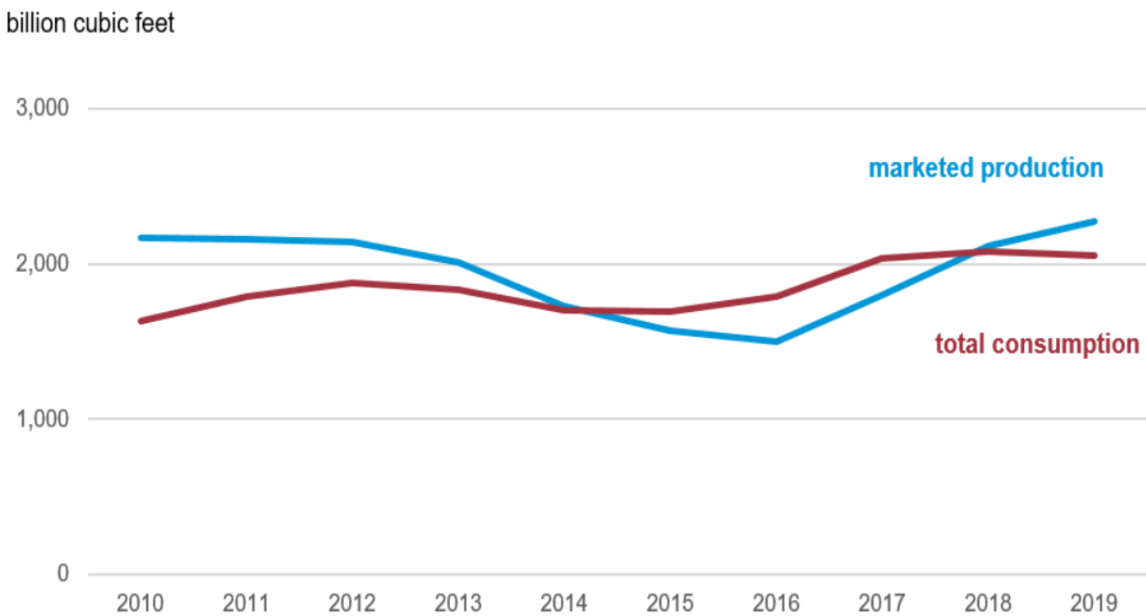

Figure 13: Natural gas production and consumption of Egypt [12]

3.2 Analysis of the production and consumption of hydrocarbons in the Caspian Area

AZERBAIJAN

Azerbaijan is a net energy exporter, with crude oil and natural gas production and exports contributing significantly to the economy and government revenue. Azerbaijan's entire domestic energy consumption is around two–thirds natural gas. Oil accounts for only around a third of global energy usage.

In 2017, Azerbaijan produced about 800,000 barrels of oil and other liquids per day (b/d) and consumed about 120,000 b/d [13]. Most of the oil is produced and sold to the West from offshore in the Caspian Sea. The production–sharing agreement (PSA) for Azerbaijan's key offshore Azeri–Chirag–Gunashli (ACG) fields was extended to 2049 in 2017, showing that Azerbaijan is likely to remain a strong oil producer with additional investment and improved recovery. Thanks to the new PSA, SOCAR's stake in the ACG complex has increased to 25%. In 2017, the ACG fields contributed about 70% of Azerbaijan's total oil output, or 588,000 barrels per day, down from 630,000 barrels per day in 2016.

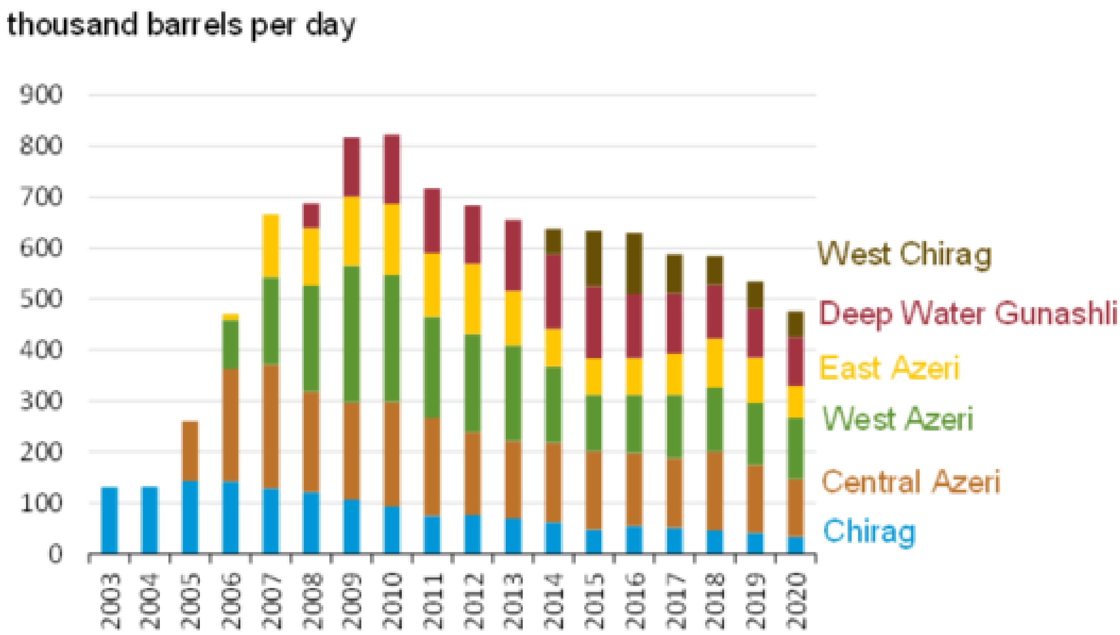

Figure 14: Azeri–Chirag–Gunashli production [13]

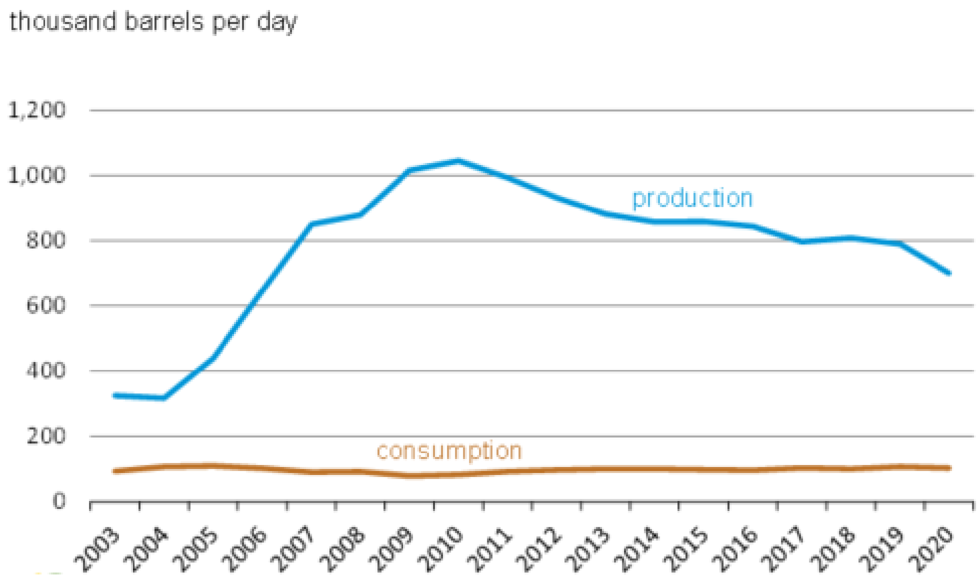

Figure 15: Oil and other liquids production and consumption of Azerbaijan [13]

In January 2018, Azerbaijan's proved natural gas reserves were projected to be over 35 trillion cubic feet (Tcf) in the Shah Deniz offshore natural gas and condensate field. Natural gas usage and output in the country declined by around 2.5 percent from 2015 to 2016, according to preliminary 2016 estimates. In 2017, the field produced 360 billion cubic feet (Bcf) of natural gas and 19 million barrels of condensate.

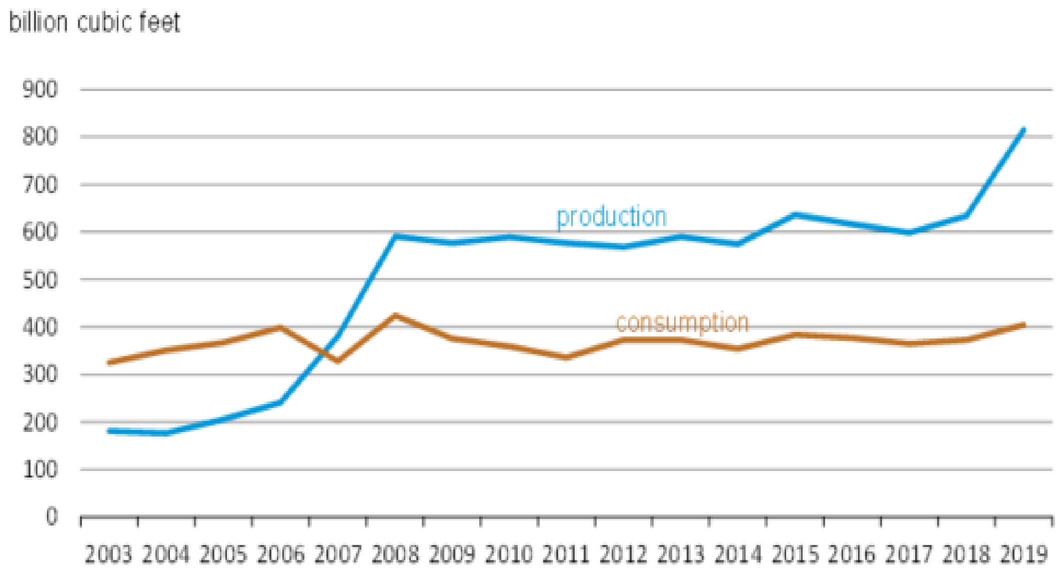

Figure 16: Natural gas production and consumption of Azerbaijan [13]

RUSSIA

Russia is a significant oil and natural gas producer and exporter. Because of its high oil and natural gas production, Russia's economy is driven by energy exports. Oil and natural gas revenues accounted for 36% of Russia's federal budget revenues in 2016.

Russia was the world's greatest producer of crude oil, including lease condensate, and the third-largest producer of petroleum and other liquids (after Saudi Arabia and the United States) in 2016, with average liquids production of 11.2 million barrels per day (b/d). With an estimated output of 21 trillion cubic feet in 2016 [14], Russia was the second-largest producer of dry natural gas (behind the United States) (Tcf).

Russia consumed 26.74 quadrillion British thermal units (Btu) of energy in 2016, according to the BP Statistical Review, the majority of which was natural gas (52 percent). Russia's consumption of petroleum and coal was 22% and 13%, respectively.

Russia's proven oil reserves were 80 billion barrels in January 2017, according to the Oil and Gas Journal. The Urals-Volga region, which reaches all the way to the Caspian Sea, has the majority of Russia's reserves, which are located between the Ural Mountains and the Central Siberian Plateau.

Russia produced an estimated 11.24 million barrels per day of petroleum and other liquids in 2016, with 10.55 million barrels per day of crude oil and lease condensate consumed (Figure 16). In 2016, Russia exported more than 7 million barrels per day, with about 5.3 million barrels per day of crude oil and the rest in products and other liquids.

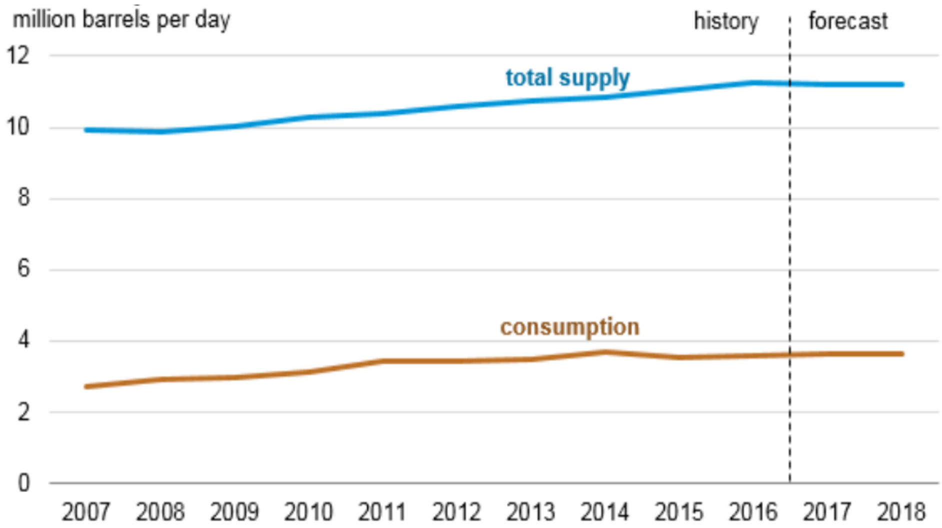

Figure 17: Oil and other liquids supply and consumption of Russia

Russia had the world's largest natural gas reserves as of January 1, 2017, according to Oil and Gas Journal, with 1,688 trillion cubic feet (Tcf) (Figure 17). [14]

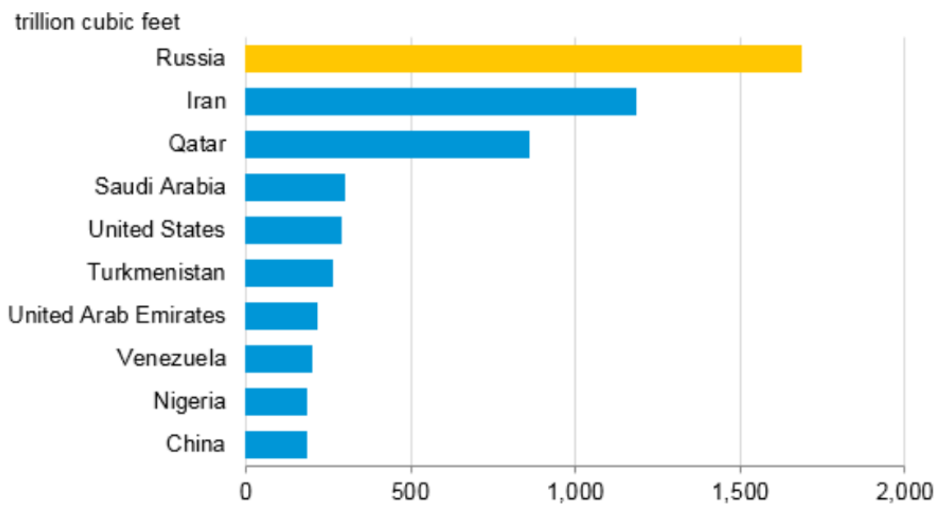

Figure 18: Estimated proved natural gas reserves of Russia, as of January 1, 2017 [14]

Russia's proven natural gas reserves account for almost a quarter of the global total. The vast majority of these deposits are contained in massive natural gas fields in West Siberia. Five of Gazprom's main operational fields (Yamburg, Urengoy, Medvezhye, Zapolyarnoye, and Bovanenkovo) account for nearly one-third of Russia's total natural gas reserves in the Yamal–Nenets region of West Siberia.

Only the United States (approximately 21 Tcf) surpassed Russia as the world's second-largest dry natural gas producer in 2016. (26.5 Tcf). The Yamal-Nenets region of West Siberia produces the majority of Russia's natural gas, according to Eastern Bloc Energy, which has slightly higher estimates for total natural gas production than the EIA.

Gazprom and other producers are rapidly investing in new regions to explore natural gas deposits, such as Eastern Siberia and Sakhalin Island. Gazprom is developing two huge natural gas projects in Eastern Siberia: the Chayadinskoye field in Yakutia and the Kovytka field in Irkutsk. The Power of Siberia natural gas pipeline will connect both resources, allowing them to meet demand in Eastern Russia and China. In addition, the Sakhalin 1 project partners, Rosneft and ExxonMobil, are looking for options to monetize their natural gas reserves, which might include building a new LNG export facility or selling the natural gas to Gazprom for export via the Sakhalin LNG terminal or planned future pipelines.

IRAN

Iran has some of the largest proven oil and natural gas reserves in the world. According to the Oil & Gas Journal, Iran had an estimated 157 billion barrels of proved crude oil reserves as of January 2018, accounting for nearly 10% of the world's crude oil reserves and roughly 13% of the Organization of Petroleum Exporting Countries' reserves (OPEC) [15].

Iran produced 4.7 million barrels per day of petroleum and other liquids in 2017, with crude oil accounting for 3.8 million barrels per day and condensate and hydrocarbon gas liquids accounting for the rest.

Since the United States announced in May 2018 that it would withdraw from the Joint Comprehensive Plan of Action (JCPOA) and reimpose sanctions on Iran, Iran's crude oil exports and production have decreased (Figure 18).

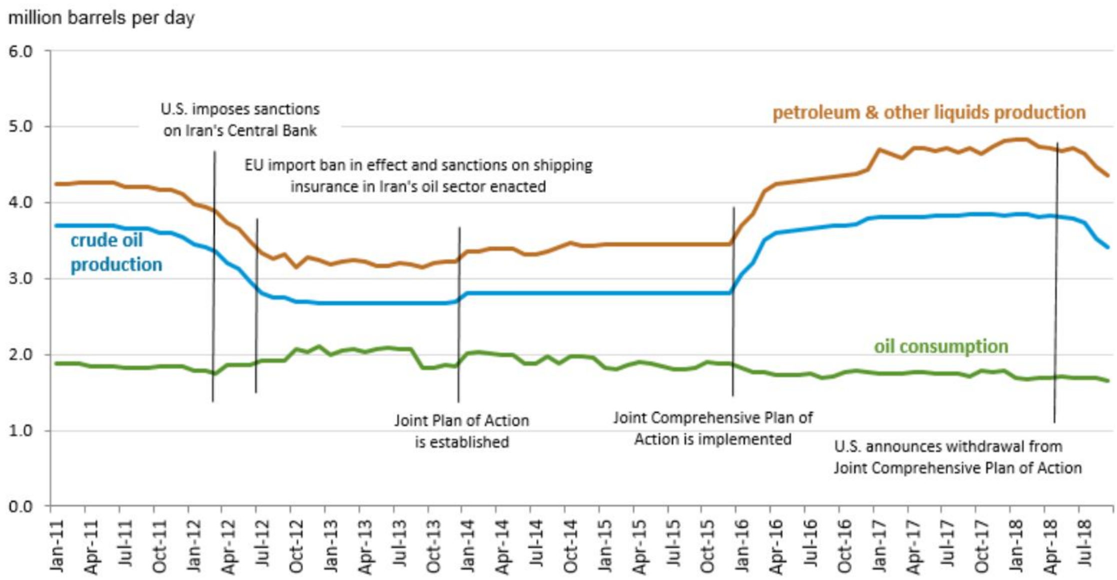

Figure 19: Oil and other liquids production and consumption of Iran [15]

After the United States and Russia, Iran is the world's third-largest producer of natural gas. Iran's estimated proved natural gas reserves were 1,191 trillion cubic feet (Tcf) in 2017 (Figure 19). According to Rystad Energy, Iran's total gross natural gas production in 2017 was nearly 9.5 Tcf, with 7.3 Tcf of dry natural gas, up nearly 9% from 2016. Iran consumes the majority of the natural gas it produces, with consumption averaging 6.9 Tcf in 2017.

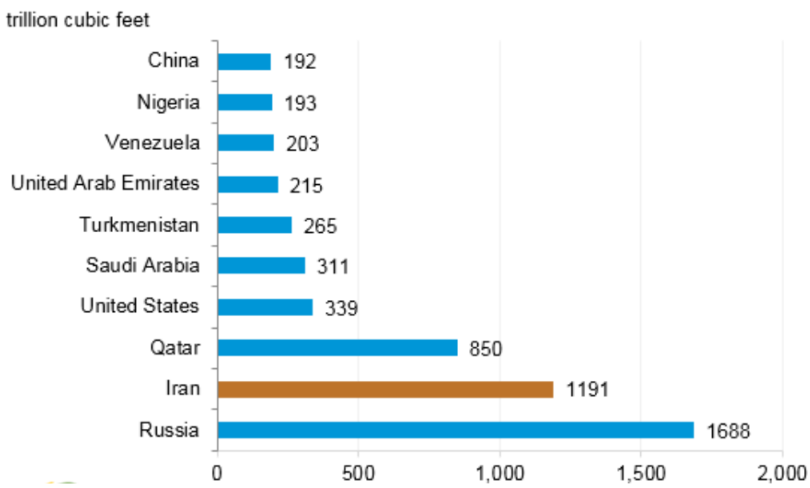

Figure 20: Largest proved reserve holders of natural gas, 2017 [15]

CHAPTER 4: Geothermal energy in sedimentary basins of Mediterranean and Caspian area

4.1 Geothermal energy in sedimentary basins of Mediterranean area

Geothermal resources are suitable for a wide range of applications, but they are commonly classified into two categories based on their enthalpy and energy content: high and low enthalpy. High enthalpy resources (>150 °C) are suitable for conventional cycle electrical generation, while low enthalpy resources (150 °C) are used for direct heat uses and binary fluids cycle electricity generation. The large geothermal potential available within a few kilometres of depth in several on land and marine areas of the Mediterranean Sea is encouraging investors and businesses to invest in geothermal exploration for power generation and combined heat and power cogeneration.

Geothermal energy is the earth's natural heat. The earth's core, mantle, and crust generate and store massive amounts of thermal energy. Conduction is the most common mode of heat transfer from the interior to the surface. This heat flow causes temperatures to rise with increasing depth in the crust by 25-30°C/km on average. An average thermal gradient of 30°C/km means that at a depth of 2 km the temperature in the rocks is around 70°C in areas where there is no volcanic activity and where ground water is not affecting the thermal gradient.

The exploitable geothermal resources in the Mediterranean are generally associated with convective rather than conductive systems. This means that heat is brought close to the surface by fluids (primarily waters) flowing vertically from depth to the surface, allowing a sufficiently high temperature to be reached by drilling at an economical depth. Geothermal resources are suitable for a wide range of applications and are commonly classified as high or low enthalpy based on their temperature. High enthalpy resources are suitable for conventional cycle electrical generation, while low enthalpy resources are used for direct uses.

- **High temperature resources** (temperatures above 150 °C) used for power generation are confined to geologically active areas, where movements of the earth's crust bring magma near the surface.

- **Low temperature resources,** which are primarily used for heat production (temperatures below 150°C), can, on the other hand, be found in the majority of countries. These are formed by the deep circulation of meteoric water along faults and fractures, as well as water residing at sufficient depths in high porosity rocks like sandstone and limestone to be heated by the Earth's geothermal gradient.

Geothermal resources are commonly confined where high heat flow (>70 mW/m^2) is recorded and extension controls tectonic evolution, determining diffuse fracturing in rocks, beneath an impervious cover. However, areas with low heat flow and located in foreland tectonic settings can also be affected by geothermal manifestations, although in spot areas and with low temperature (about 2528°C) geothermal fluids, as in the case of the Santa Cesare Terme zone, located in the Apulia carbonate platform, the foreland of the southern Apennines (Cretaceous Pleistocene). The platform is made up of a Jurassic Cretaceous succession that is more than 5 km thick in the study area and is thought to rest on top of a Late Triassic evaporite (Burano). Oligocene-Pleistocene calcareous and terrigenous sediments rest unconformably over the Platform. The area is deformed by trans tensional structures, thus determining extensional jogs and pull-apart structures where the permeability is enhanced. As a result, it is concluded that the up flow of deep fluids, heated by the thermal gradient typical of foreland areas, occurs along these almost vertical structural channels [1]

Outside of volcanic areas, carbonate aquifers are important thermal water resources, supplying spans or geothermal installations. The thermal springs serve as discharge points for deep groundwater flowing through these carbonate aquifers, whose hydraulic conductivity and geothermal fluid migration are tightly regulated by both the discontinuities network and karstification processes. An example of these springs occurs along the south-easternmost portion of the Apulia region (Southern Italy) where some sulphurous and warm waters (25-33°C) flow out in partially submerged caves located along the coast, supplying so the spas of Santa Cesarea Terme. These springs have been known since antiquity (Aristotele in the third century BC), and the physical and chemical characteristics of their thermal waters have been influenced in part by changes in sea level. Morocco has a number of geothermal anomalies and thermal clues, as well as a number of hot springs and significant deep aquifers, making it a true geothermal promising country.

Geothermal energy can be used directly in a variety of applications, including geothermal heat pumps. Heat production at temperatures of 50-100 °C, which are common in low-enthalpy geothermal areas, accounts for a significant portion of energy consumption in most industrialised countries. The majority of this energy comes from the high-temperature combustion of oil, coal, or gas. The scope for using geothermal water alone as well as in combination with other local sources of energy is therefore very large.

In comparison to other parts of the world, the direct use of geothermal energy in Europe is at a relatively advanced stage. Due to its versatility and demand for base-load heat demand, as well as the resource's availability, it serves a wide range of applications and uses. European countries were among the first to exploit geothermal resources. Other countries around the world have copied European experience and expertise in this field. However, European companies should be able to continue to play a leading role in the development and use of geothermal energy for both direct use and electricity generation.

4.2 Geothermal energy in sedimentary basins of Caspian area

The Caspian Sea and its surrounding areas form the vast oil and gas mega basin. Hundreds of deep boreholes and the Caspian Sea have been investigated for geothermal energy. But it is not popular in Caspian area, as Mediterranean. There is not geothermal investigations in the deep-water area of the South Caspian Depression until now [16].

There are a sparse heat flow data from the adjoining territory of Iran and only several local parts of the country were studied in heat flow. The heat flow determination for the Tehran well is available within this study area. Other estimates were published for the Persian Gulf. Heat flow values were reported from the country's north-western region, near the Sabalan Mountain, which is located in the Ardebil Province in Iran's north-western region. Heat flow data from a small area in Iran's southwestern oil-producing region are also available.

Positions of well with determined heat flow density, as well as marine heat flow stations within the studied Caspian region are shown in Figure 20. There is a very uneven position for boreholes or marine stations with studied heat flow within this area. There are very few heat flow data determinations in the land territory adjacent to the northern part of the Caspian Sea, as well as marine data due to the shallowness of the sea here. It was discovered experimentally that seasonal mixing of water during storms resulted in temperature perturbations reaching depths of up to 300 m on average, and sometimes even deeper.

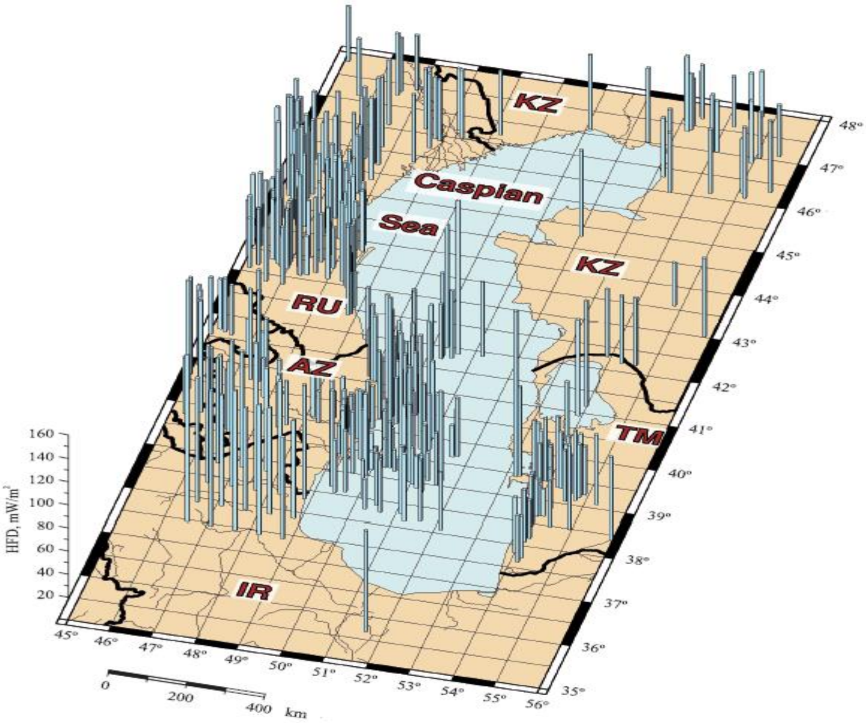

Figure 21: Available heat flow data and locations of studied wells and marine HFD stations. AZ – Azerbaijan, IR – Iran, KZ – Kazakhstan, RU – Russia, TM – Turkmenistan [16].

Until now, the Iranian portion of the sea had not been studied in terms of heat flow. Despite the fact that its sparse data are available in northern Iran, they are not available along the Turkmen border.

Territories of Azerbaijan, excluding the Greater Caucasus, are studied much better in geothermal terms in numerous wells drilled primarily for oil exploration. Many heat flow calculations were completed along the Azerbaijan and Dagestan coasts of the Caspian Sea (Russian Federation). A number of oil wells in the West Turkmenian Depression were also geothermally studied.

The heat flow histogram for the marine territory of the region is shown in Figure 21. It includes data from marine heat flow stations and shallow-drilling boreholes. The majority of individual heat flow data fall within the intervals of 9–34 and 34–59 mW/m², with only a few exceptions reaching high values (intervals 109–134; 134–159; and 184–209 mW/m²).

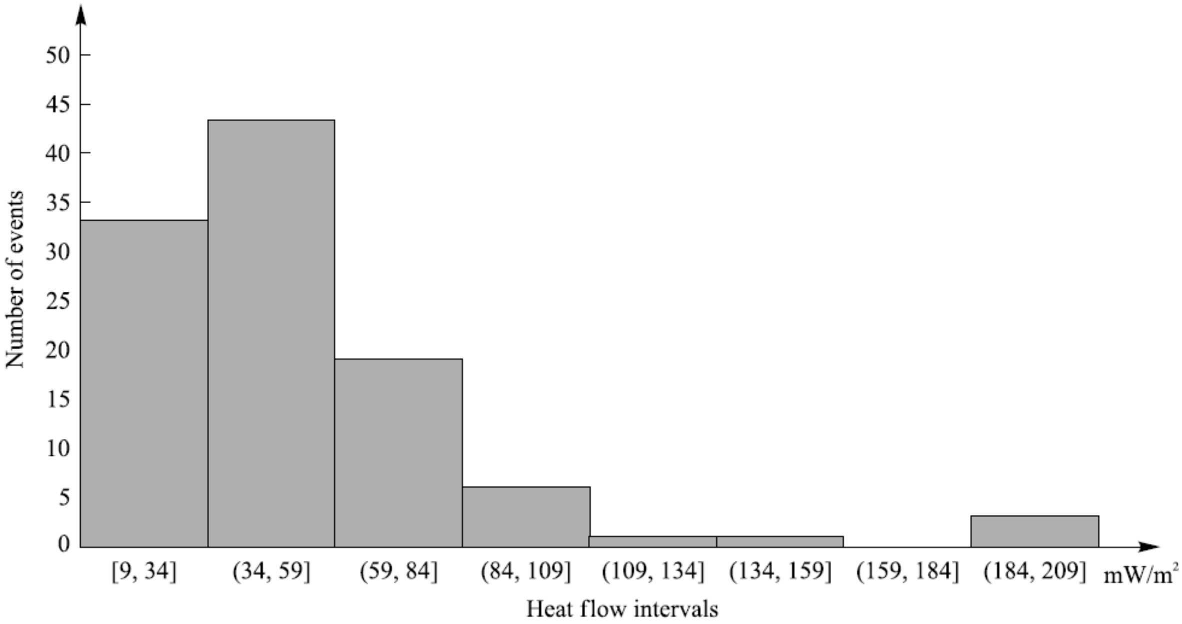

Figure 22: Heat flow density histogram for the Caspian Sea [16]

The heat flow interval 34–59 mW/m² is primarily found in the Caspian Sea's central and central-northern regions. Now, a number of marine boreholes have been drilled within the Caspian Sea's marine waters belonging to the Russian, Kazakhstan, Turkmenistan, and Iranian sectors, but their geothermal data of investigations are not yet accessible from drilling companies.

The histogram for land areas adjoining the Caspian Sea within territories of Azerbaijan, Iran, Turkmenistan, Kazakhstan and Russia is shown in Figure 22. Almost all heat flow calculations here were made using thermograms and thermal conductivities of rock samples collected from drill cores and measured in laboratories by a team of researchers from Azerbaijan, Russia, and Turkmenistan.

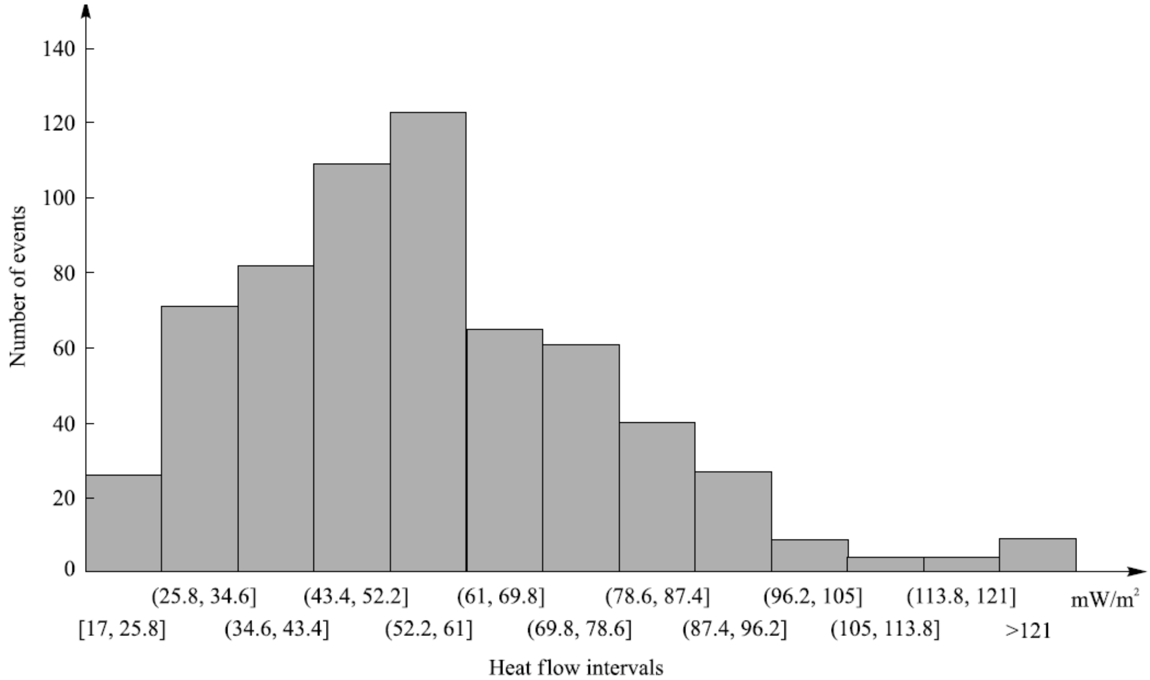

Figure 23: Histogram of heat flow density for land territories around the Caspian Sea [16]

The heat flow ranges from 17 to more than 120 mW/m², and the histogram is more symmetrical. The maximum number of heat flow data determinations falls between 43–52 and 52–61 mW/m², after which the number of observations gradually decreases to values between 96–105 mW/m² and then stops. A wide range of heat flow values reflects many factors, including borehole depths, local tectonic activation, ground water circulation, folding, proximity of deep faults to studied boreholes and their activity, and so on.

During a number of decades, geophysical investigations including geothermal observations were organized in relation to the growing attention to exploration for hydrocarbons within the Caspian Sea, as well as investigations of its internal structure. Previously, a number of researchers discussed heat flow in the Caspian Sea's water area. The region's geothermal data includes the results of measurements taken with marine heat flow probes. They were supplemented by the results of its determinations based on thermograms recorded in wells drilled in Azerbaijan's shelf zone.

Using the Generic Mapping Tools (GMT) package, a new heat flow density map (Figure 23) for the Caspian Sea region was recently compiled, taking into account available heat flow data and including Iranian territory within areas E 45–56° and N 35–48°.

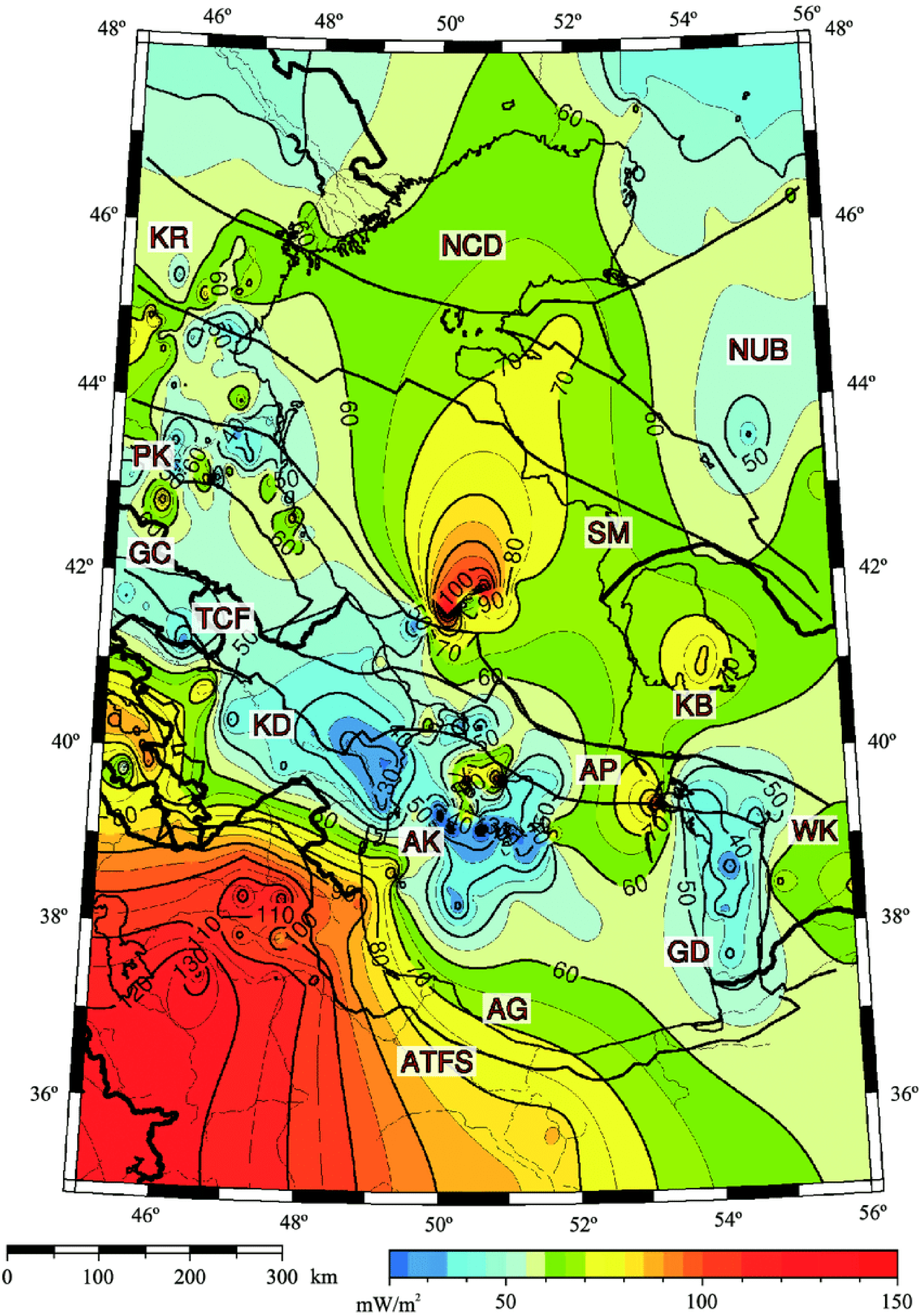

Figure 24: Heat flow density distribution within the Caspian Sea region

CHAPTER 5: GEOTHERMAL ENERGY EXTRACTION FROM A VERY DEEP OILFIELD

Abandoned oil well is deemed as a promising alternative to extract geothermal energy. Before moving on to the topic of converting an abandoned oil well into a geothermal well, it's important to go over the basics of geothermal energy extraction as well as oil well decommissioning and abandonment.

Technically, geothermal energy is available everywhere around the globe since the source of this energy is the hot core of the earth. This thermal energy dissipates from the earth core to the surface creating geothermal gradients, as shown in Figure 24. Depending on geological structure and conditions, geothermal energy received at the earth surface greatly varies from one place to another and form time to time. In some areas, the geothermal gradient can even reach as high as 150°C/km and in other areas the gradient can be as low as 20°C/km. Thus, its utilization has so far been limited to the areas near tectonic plate boundaries which has high geothermal gradients especially on the region near diverging plate boundaries. Example of this region is the area on the ring of fire which stretches around the Pacific Ocean. This area can generally be identified with the presence of volcanoes, geysers, fumaroles, hot springs, and steaming grounds. In some other places, however, these features may not be present.

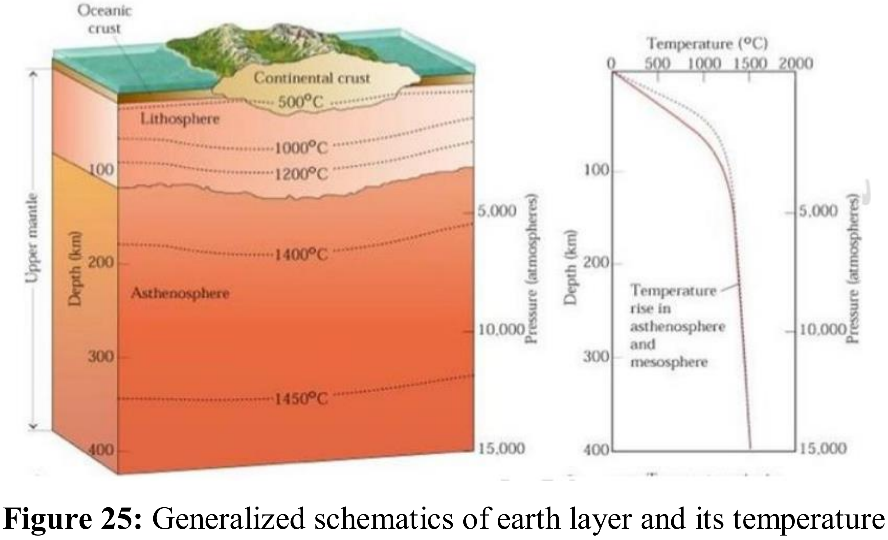

Figure 25: Generalized schematics of earth layer and its temperature [17]

Depending on the well's outlet temperature, the extracted thermal energy can be used for a various purpose. Dry steam or flash steam power plants will only be able to generate energy at temperatures above 150°C. Lower than that, the only way to generate electricity is to use a binary power plant.

The ultimate stage of the oil well life cycle, which includes exploration, drilling, production, and finally abandonment, is decommissioning and abandonment. The primary objective of well abandonment is to permanently seal off all strata rock formation penetrated by the well. The abandonment should, in theory, prevent reservoir fluid and other liquids from leaking out of the stratum rock and moving to adjacent formations. Due to the fact that many oil wells were drilled many centuries ago, they have reached or are approaching the end of their productive and economic eras. Thousands of onshore and offshore wells must be safely plugged and abandoned around the world. With the current pandemic, more wells are likely to be abandoned because of low oil and gas demand. Decommissioning and abandoning oil wells is a difficult task. Often, this process is more challenging than the initial exploration and installation. A decommissioning strategy should be submitted to the appropriate authority far in advance of any decommissioning work. In some countries, it may be as early as 5 years and at least 2 years prior to the decommissioning. This plan should include details of the facility design, fabrication, installation, and commissioning, as well as any risks and hazards associated with facility removal, intended procedure, analysis, and operation during decommissioning, waste control, and possible monitoring systems. In short, a detailed and thorough preparation is the determining factor in successful execution of well decommissioning and abandonment. Improper abandonment will not only be very difficult to be remedied but also very costly and bring bad reputation to the oil and gas industry.

Retrofitting abandoned oil and gas wells into geothermal well can be a promising alternative to extend the economical lifetime of oil and gas wells and eliminating problems related to decommissioning of the wells. . Its relatively well-recorded data log during active operation of oil and gas wells will ease the conversion process. Nevertheless, it should be noted that most of these wells are not located in the area that have big potential of geothermal energy. Hence, these wells usually have low-to-medium downhole temperature. Moreover, most of these wells do not have natural underground reservoir resources, triggering the need for artificial working fluid injection into the wells.

5.1 Geothermal energy extraction methods

There are two main system to extract geothermal energy. These are open loop system and closed loop system.

Open-Loop System

The heat exchange fluid in this system is well or surface body water, which circulates directly through the GHP system. Once it has circulated through the system, the water returns to the ground through the well, a recharge well, or surface discharge. This technique is obviously viable only if there is a sufficient supply of relatively pure water and all local groundwater discharge laws and requirements are followed.

Open-loop systems are often preferred to closed-loop systems due to higher inlet temperatures and higher efficiency. A powerful heat source can be harnessed at a low cost using open systems. Drilling expenses are lower than borehole heat exchangers, especially when using a shallow aquifer. Groundwater can be used for direct cooling without a heat pump ("free cooling") as well. Free cooling has a high efficiency and is therefore of great importance.

Closed-Loop System

Closed-loop geothermal (CLG) is an alternative technique that overcomes permeability difficulties by running a working fluid through a sealed downhole heat exchanger to absorb and transport heat. CLG is a versatile technology that may be used to optimize site-specific costs and performance in a number of well pipe layouts utilizing a variety of working fluids (such as water and supercritical CO2 (sCO2)). CLG significantly increases the potential for geothermal energy generation and use in four ways: First, closed-loop systems may operate in a far wider range of temperatures and rock compositions than typical hydrothermal projects, ranging from relatively low temperature sedimentary zones to hot, dry rock formations. This breadth of viable CLG operating parameters not only increases the number of viable geothermal projects, but also allows the use of high-temperature resources (300°C and above) that dramatically increase power output. Second, closed-loop systems can produce power from previously unproductive geothermal wells and from played out oil and gas wells in hot strata. Third, CLG's baseload and flexible power generating capabilities can assist stabilize the grid by providing consistent, reliable, and sustainable energy, capacity, and ancillary services. Finally, closed-loop geothermal systems can enhance industrial applications, including high-value lithium extraction and hydrogen production, while lowering GHG emissions.

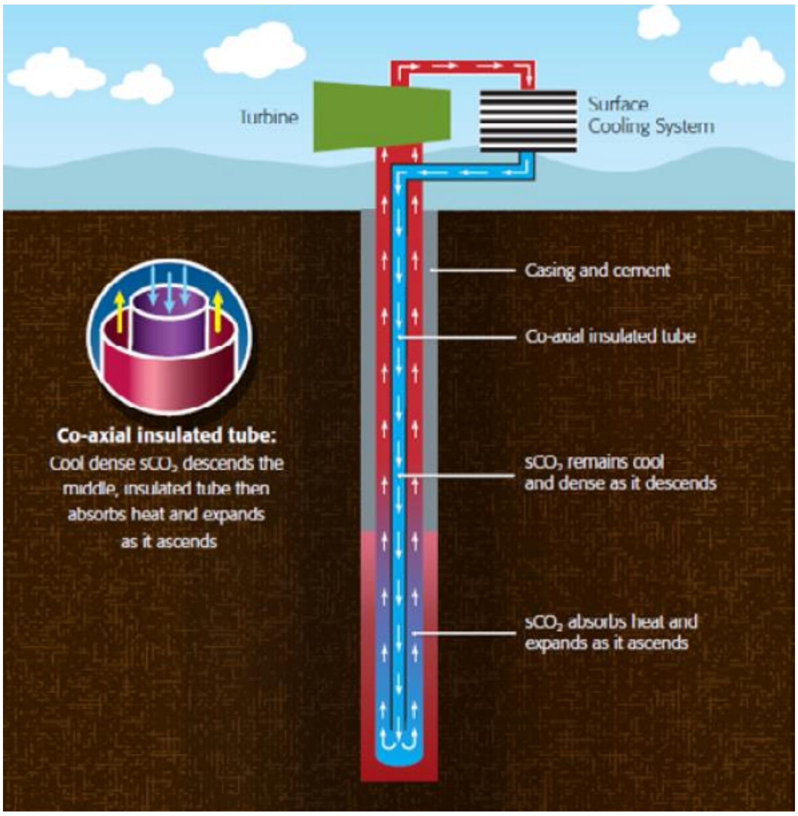

Figure 26: Well with a Concentric Tube Configuration [21]

Closed systems are installed in mainly two ways: U-TUBE heat exchanger model and COAXIAL DOUBLE-PIPE heat exchanger model.

U-tubes: This BHE configuration consists of one (or more) inner pipe, which is inserted in the borehole from its middle to forma U-shape. Two main configurations are in use: single U-tube BHE and double U-tube BHE. Figure 30 shows a sketch of these two types of BHEs. The working fluid enters through the pipe-in; the working fluid exits through the pipe-out; and the working fluid contacts the surrounding soil mass through the grout. The double U-tube consists of two pipes-in, two pipes-out and grout.

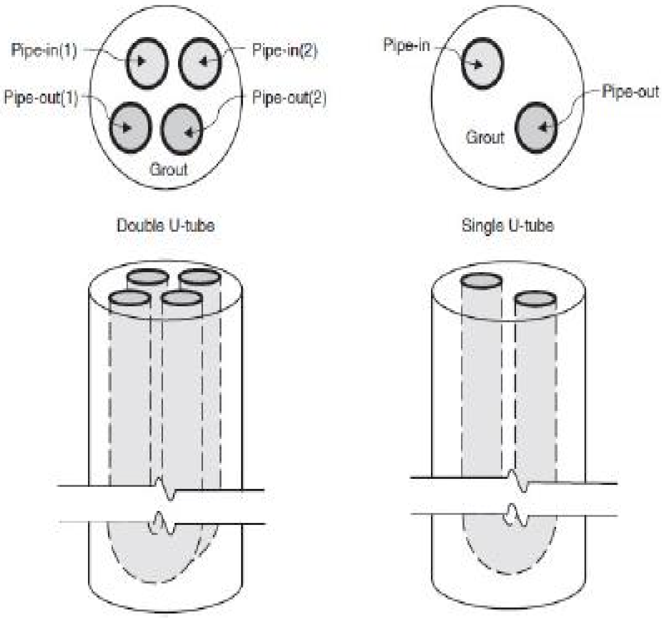

Figure 27: U-tube shallow geothermal system [21]

Coaxial: This BHE configuration consists of concentric pipes. In practice, there are mainly two coaxial configurations: annular (CXA) and centred (CXC), Figure 31. Pipe-out is positioned inside pipe-in in CXA, resulting in an annular inlet and a centred outlet. Heat exchange of the inner pipes with the grout occurs along the surface area of pipe-in. In CXC, pipe-in is configured inside pipe-out, forming a centred inlet and an annular outlet. Here, heat exchange with the grout occurs via pipe-out.

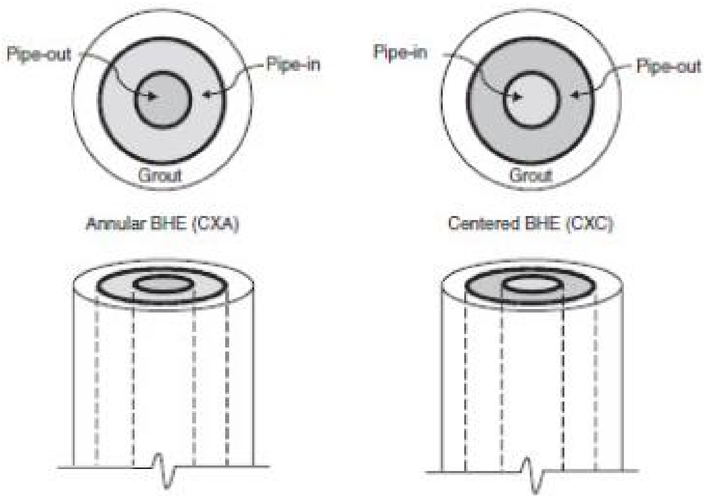

Figure 28: Coaxial shallow geothermal system [21]

The coaxial WBHX model is based on the following assumptions: heat is transferred to the reservoir rock by conduction, and heat is transferred to the fluid moving through the tubes via conduction and convection. The WBHX heat transfer model was established based on the differences in behaviour between the downward and upward pipes.

5.1.1 Heat transfer in the pipe system

The fluid in the downward pipe comes into direct touch with the borehole wall on the outside. This is made of steel casing cemented to the rock wall. A finishing fluid or cement is used to fill the annular area between each pair of casings.

As a result, it is thought that heat is transferred via conduction from the reservoir rock to the borehole wall, and by convection between the wall and the fluid. Convection inside the reservoir rock is not considered.

The fluid is in contact with the internal tube on the downward pipe's interior side. Conduction through the pipe and convection between the wall and the fluid are the primary modes of heat transmission between the two pipes.

In the WBHX, the heat flux from the rock to the fluid is given as:

$$Q_{down} = 2\pi r_w k_t (T_w(z) - T_{f,down}) \Delta z$$

5.1.2 Heat exchange coefficient in terms of thermal resistance

The sum of heat transfer components gives the total heat exchange coefficient k_t. In terms of heat resistance, it's possible to write:

$$R_t = R_a + R_c + R_s$$

Because the conductive term dominates in the calculation of total thermal resistance, the thermal exchange is proportional to the convective transfer coefficient. The following is how conductive thermal resistance (Rs) is expressed:

$$R_s = \frac{1}{2\lambda_s} ln \frac{\sqrt[2]{a_s(t')}}{r_w}$$

The convective thermal resistance Ra is calculated using the following formula:

$$R_a = \frac{1}{2r_c h}$$

The Nusselt number, Nu, is used to calculate the convective heat transfer coefficient:

$$h = \frac{Nu \times \lambda_f}{2r_c}$$

having assumed turbulent flow inside tubes, and by a variant of the Dittuse Boelter equation

$$Nu = 0{,}023 \times Re^{0{,}8} \times Pr^{0{,}4}$$

The thermal resistance to heat conduction through the well completion casings is calculated as follows:

$$R_c = \sum\nolimits_{i=1}^{n} R_{\lambda_i} = \frac{1}{2} \sum\nolimits_{i=1}^{n} \frac{1}{\lambda_i} \ln \frac{r_{c,i} + 1}{r_{c,1}}$$

As a result, the heat exchange coefficient kw may be calculated appropriately:

$$\frac{1}{k_t} = \frac{D_c}{2 \times \lambda_s} \times \ln \frac{\sqrt[4]{a_s t}}{D_w} + \frac{1}{h}$$

A conductive component through the composite pipe and two convective components, one on the internal wall and one on the external wall of the WBHX, combine to generate the overall heat flow. The total heat exchange coefficient k_o is defined as:

$$\frac{1}{k_0} = \frac{r_0}{r_0 + t} \times \frac{1}{h_i} + r_0 \sum_{i=1}^{n} \ln \frac{(r_i + 1)}{r_i} \times \frac{1}{\lambda_i} + \frac{1}{h_0}$$

5.2 Hydrocarbon wells for a geothermal energy extraction in Mediterranean Area

The aim of this chapter is analyse of abandoned deep-hydrocarbon reservoirs and dry wells in the Mediterranean area as a geothermal energy source. Many oil and gas wells are reaching the end of their production phase and many are already abandoned. The coaxial heat exchanger principle, which is commonly employed in shallow geothermal energy extraction, could be investigated for geothermal energy generation in these wells. We will analyse 2 deep oilwells as a case study in Mediterranean area. First one is deep well Pcelic located in the Drava subbasin in Croatia, second is well located the Villafortuna Trecate oilfield in Italy.

Pcelic (Croatia)

Croatia has a lengthy history of oil production that dates back to the late 1800s. In the 1950s, modern exploration and production began. Since then, approximately 4500 of exploration, production and development wells have been drilled in Pannonian Basin, with a total depth of about seven million meters [18]. Nowadays, due to production decline, high water-cut, and reservoir depletion, most of these wells are abandoned or reassigned to be injection or monitoring wells. Converting deep abandoned and negative dry wells to exploit geothermal energy has gained popularity in recent years. Extracted energy might subsequently be used to generate electricity in suitable Organic Rankine Cycle (ORC) power plants, or immediately by creating hot fluids or utilizing heat through closed-loop circulation. Currently, there are few projects underway to produce electricity from such wells via ORC system, where

Velika Ciglena with 5 MW_e in the initial design phase and Draškovec with 7 MW_e being the most perspective ones.

Aside from potential geopressured brine reserves, there is open investor interest in exploiting deep dry wells that were abandoned during the Pannonian structural geology exploration phase. In such an energy system, extraction of heat is conducted by a closed-loop heat exchanger, similar to the already-developed low-enthalpy technology using ground source heat pumps. Because there is a constant recirculation of subcooled fluid inside the wellbore, heat transfer is generated due to the temperature gradient between the wellbore wall and an infinite radial heat source. Heat extraction rates must be quantified using a variety of technical factors, including fluid flow rate and variable or constant heat loads, depending on the users' heat demands. Extracted energy from Pcelic retrofitted well generally could be used in broad industrial, commercial, and agricultural sectors, especially if a well is located near the habited areas. By retrofitting already existing well near the potential consumers, initial investment costs would exclude expensive drilling and partially cost of well completion.

Even though in the continental part of Croatia natural springs were used for centuries, its true geothermal potential was first noticed during extensive oil and gas exploration. Numerous collected data allowed precise determination of the thermogeological properties of the Pannonian Basin. Analysis of collected data showed the geothermal gradient (0.05°C⁄m–0.07°C⁄m; Figure 25) and heat flow (60–80 mW⁄m^2) being higher than the European average [18]. The proximity of the Mohorovicic discontinuity, which is only 28 kilometers below the surface, could explain such numbers. In addition, local thermal anomalies attributed to deep faults are frequent, which allows for greater convective heat flow to surface.

For each method of measurement, correlations for the geothermal gradient, thermal conductivity, and heat flux were derived from data collected for the Sava and Drava subbasins. Because there are no available data for micro location of wellbore Pcelic , the thermogeological properties used in the calculations are derived from the Jelic correlations for the Drava subbasin with the following values: maximal mean density 2.63 × 106 g⁄m^3; mean heat flow 0.082 W⁄m^2; and thermal conductivity 2.26 W⁄m°C, with the mean surface temperature estimated at 11.6°C.

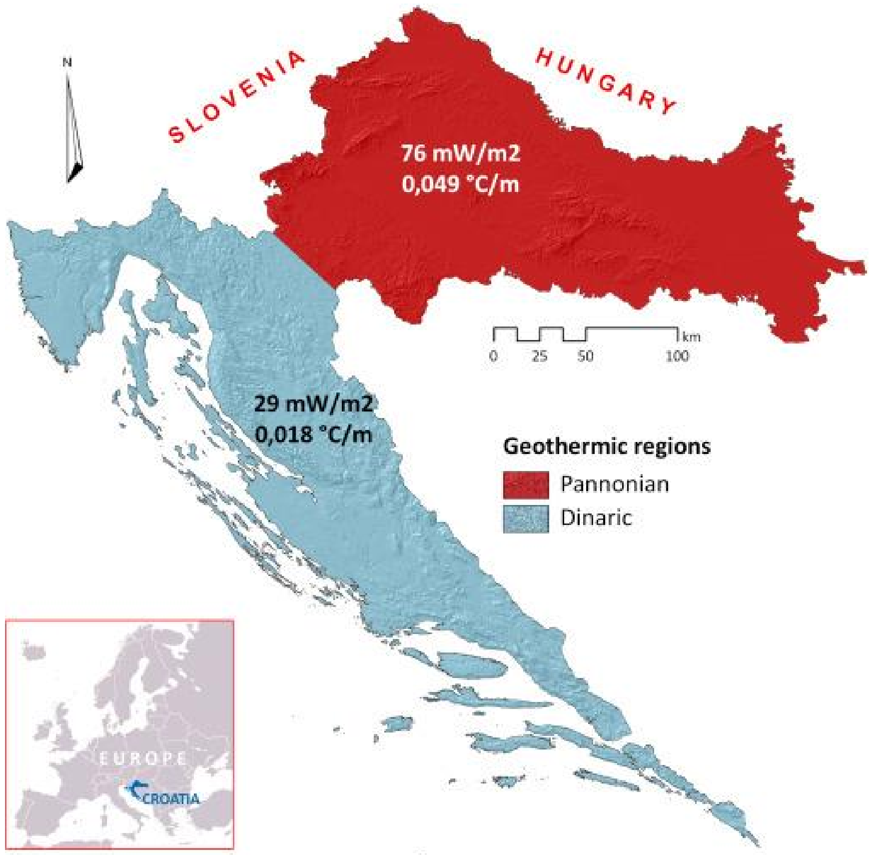

Figure 29: Geothermal gradient in Croatia (°C⁄m) [18]

Wellbore Pcelic-1 was completed in 1989, with a depth of 4915m. Parameter properties of the well ground is shown below Table 1:

Ground properties	Symbol	Value	Unit
Temperature at the bottom hole at 4772 m	T_g	206.2	°C
Surface mean temperature	T_s	11.6	°C
Mean temperature along the wellbore section	T_w	97.5	°C
Mean ground thermal conductivity	λ_g	2.26	W/m°C
Ground volumetric heat capacity	ρc_p	2445.9	kJ/°C m^3
Geothermal gradient	Γ	0.041	°C/m

Table 1: Parameter properties of the well ground [18]

Villafortuna Trecate oilfield (Italy)

The oil field of Villafortuna is located in Trecate, Piedmont. Eni found it in 1984 and developed it. It began production in 1984 and produces oil. The total proven reserves of the Villafortuna oil field are around 300 million barrels, and production is centered on 60,000 barrels per day (9,500 m^3/d).

The petroleum system is entirely formed inside a Triassic depositional sequence, consisting of two reservoirs made up of dolomitized carbonate platforms rocks and source rock deposited in anoxic intra-platform basins (Figure 26).

The Anisian Monte San Giorgio Dolomite represents the lower reservoir. The porous system is represented by a few minor vugs, molds, and intracrystalline porosity on rare occasions; porosity and permeability values are generally modest, and the reservoir is formed by a fracture network that offers permeability and improved porosity.

Dolomia Principale, Campo dei Fiori Limestone and Conchodon Dolomite are there carbonate platforms units of the upper reservoir. Due to low values of porosity and permeability Dolomia Principale and Campo dei Fiori Limestone formations have similar petrophysical properties [19].

The hydrocarbons were created inside the Villafortuna-Trecate structure, from Middle Triassic source rock formations (Besano Shales and Meride Limestone).

The reservoir has been identified between 5800 and 6100 m depth with a temperature of about 160-170 °C, so the asset can be classified as a medium enthalpy geothermal resource. Although the Villafortuna-Trecate field continues to produce, it is significantly depleted. Only 8 wells have been drilled and are now producing.

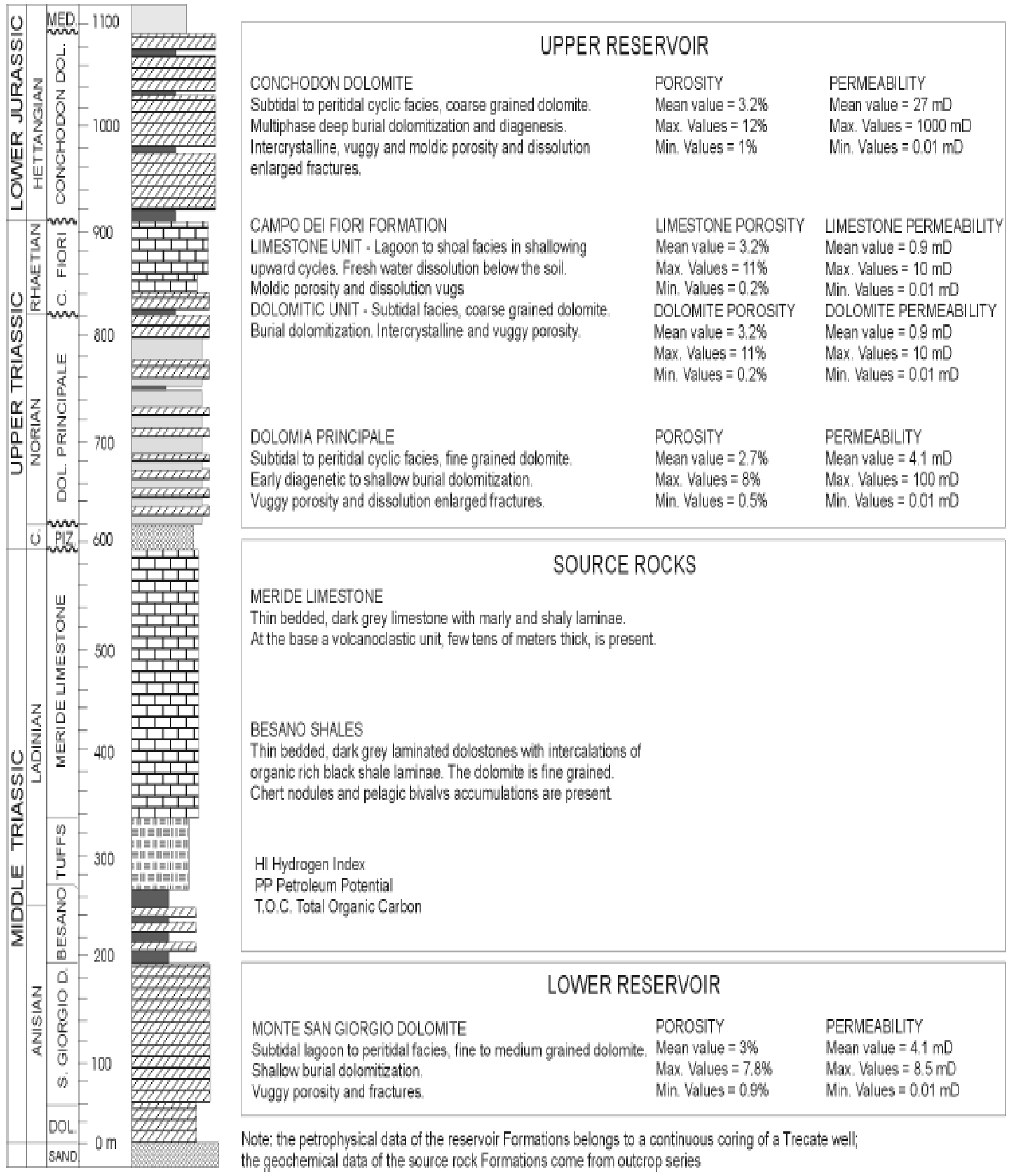

Figure 30: Villafortuna-Trecate petroleum system [19]

The Villafortuna-Trecate field is still producing but it is strongly depleted. About 50 wells have been drilled and only 8 are in production.

Depth (m)	Name of Rock Formation	Type of Rock Formation
0-609	Quaternary	Sedimentary
609-1258	Sand	Sedimentary
1258-1405	Clay	Sedimentary
1405-1660	Gonfolite	Sedimentary
1660-2611	Formazione Gallare	Sedimentary
2611-4457	Gonfolite	Sedimentary
4457-4460	Formazione Gallare	Sedimentary
4460-5430	Scale	Sedimentary
5430-5493	Marl	Sedimentary
5493-5568	Majolica	Carbonate
5568-5573	Silificated rock+ Red ammonite	Carbonate
5573-5586	Medolo	Carbonate
5586-6132	Limestone	Carbonate
6132 6202	Dolomite	Carbonate

Table 2: Type of rock formation in the Villafortuna-Trecate oilfield

Materials	Porosity(fraction)	Thermal conductivity (J/m/s/K)	Specific Heat (MJ/kgK)
Sedimentary Rock - Sandstone	0.4	2.47	0.9
Carbonate Rock – Limestone	0.12	2.29	1

Table 3: Parameter properties of the well ground

5.3 Hydrocarbon wells for a geothermal energy extraction in Caspian Area

Ahwaz oilfield (Iran)

The Ahwaz oil field is located at the southwest of Dezful Embayment in 48º 30' northern latitude and 30º 30' eastern longitude. Ahwaz oil field (Figure 27), one of the most important Iranian super Giant oil fields, was discovered in 1956 and now has more than 450 producing wells. This oil field has an anticline structure 72 km long and 6 km wide with NW-SE trending symmetrical anticlinal, located in the southwest of Iran and central part of north Dezful region. The Asmari Formation and Bangestan Group are its primary reservoirs, with a daily production rate of 1000,000 barrels [20]. The recoverable hydrocarbon reserves are expected to be 10 billion barrels of oil and 13 trillion cubic feet of gas.

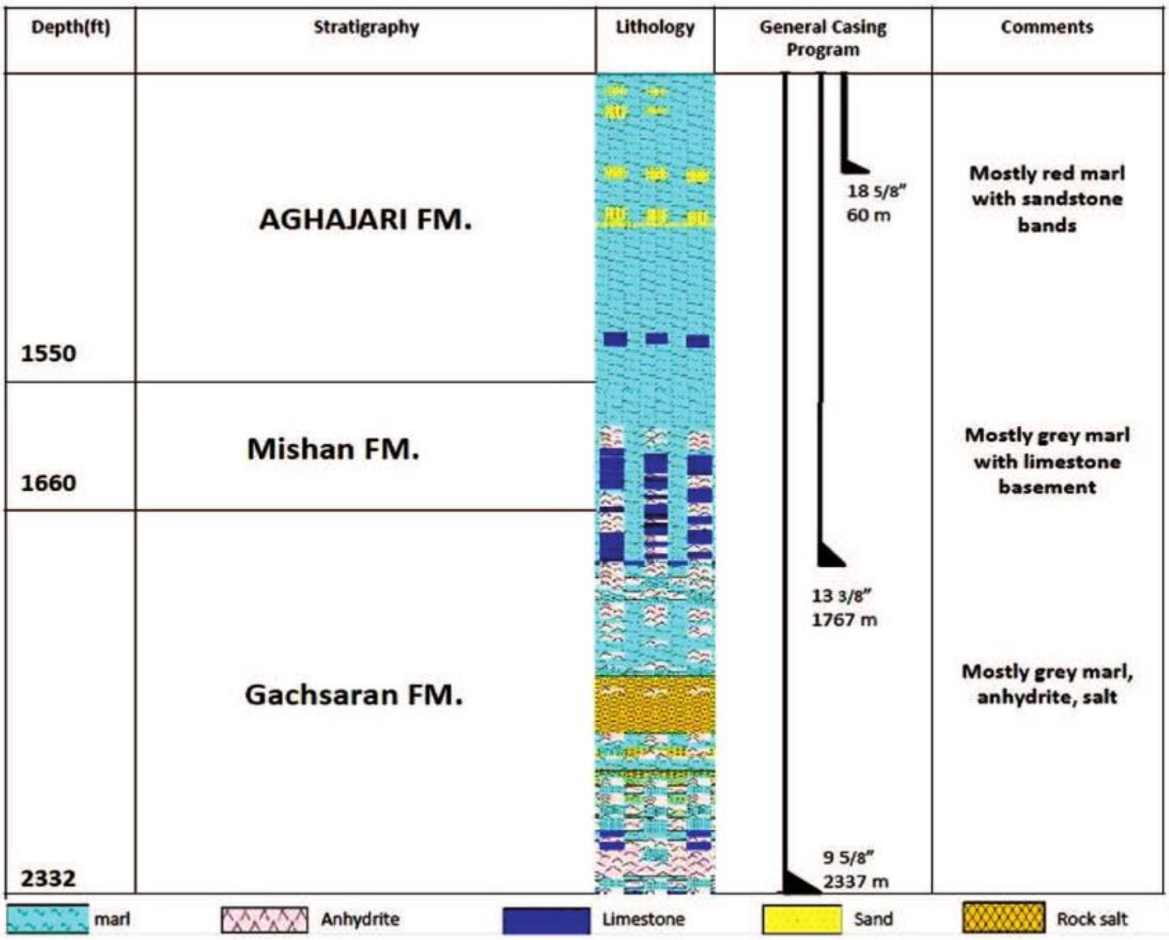

Figure 31: Generalized geological section of Ahwaz oilfield [20]

Most of the source rocks in the south of Iran were deposited in tropical or equatorial dominating calcareous environments. The Mesozoic and Cenozoic source rocks were deposited in intracratonic depression at the time when anoxic conditions prevailed as a result of water-column stratification, during high stand. These source rocks contain at least 70% carbonate and are best referred to as argillaceous limestone or as marls. They have excellent source characteristics with TOC values up to 8% and hydrogen Indexes to 550 g HC/kg TOC.

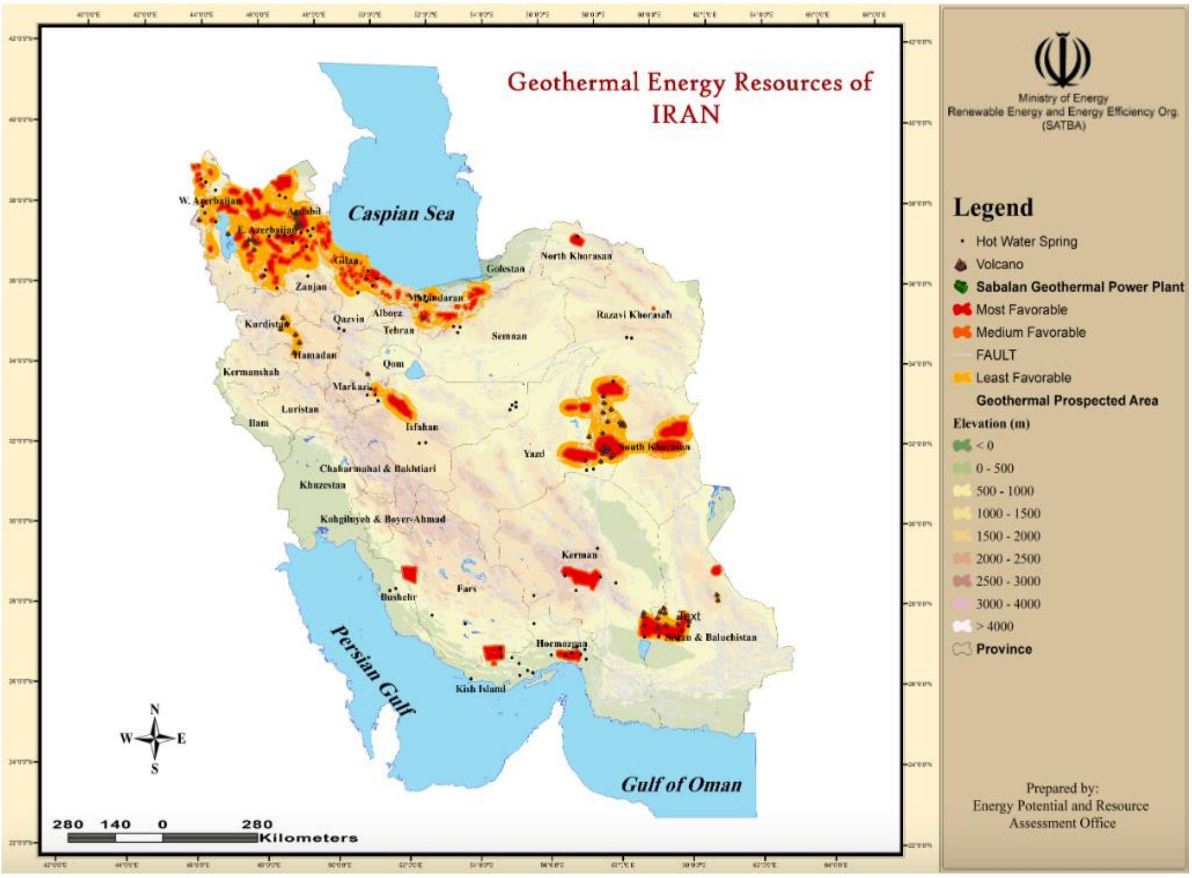

Figure 32: Geothermal Atlas of Iran [20]

Some researchers simulated a geothermal system that extracted geothermal energy by using two abandoned oil wells in Ahwaz oil field in Southern Iran.

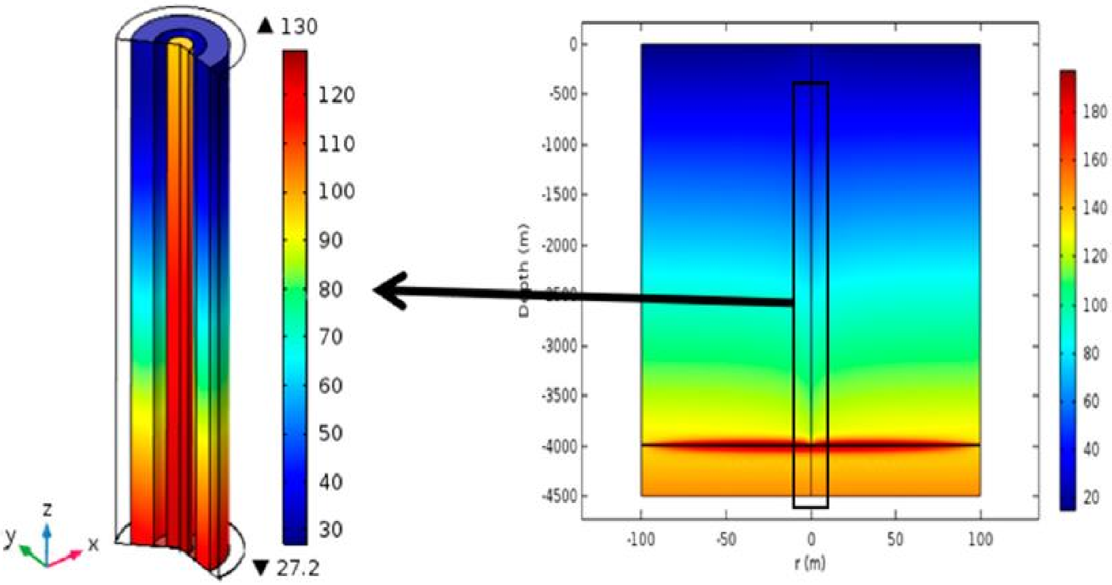

Figure 33: Temperature profile of well in Ahwaz oilfield (°C/100 m) [20]

CHAPTER 6: RESULTS AND CONCLUSION

6.1 Results

After researching a total of three case studies, one in the Mediterranean Area and two in the Caspian area, we saw their geothermal potentials. Each of them has different parameters in relation to their location. There are different methods for extracting the geothermal energy from the oilfields here, but this thesis is more focused on one. This method is the Coaxial Double-Pipe heat exchanger model. By applying this method to three case studies, it is aimed to extract the geothermal energy. All these case studies are discussed separately below.

As a case study for Italy, Villafortuna Oilfield was investigated which is located in Trecate and it has geothermal potential. After extensive research, it is seen that the temperature in the oil wells located here, which has reached the end of its production life, reaches up to 150 °C at some points. Thermal conductivity for the carbonate type of rock formations is 2.29 (J/m/s/K) and for the sedimentary type of rock formation is 2.47 (J/m/s/K). All this information make them suitable for geothermal energy extraction.

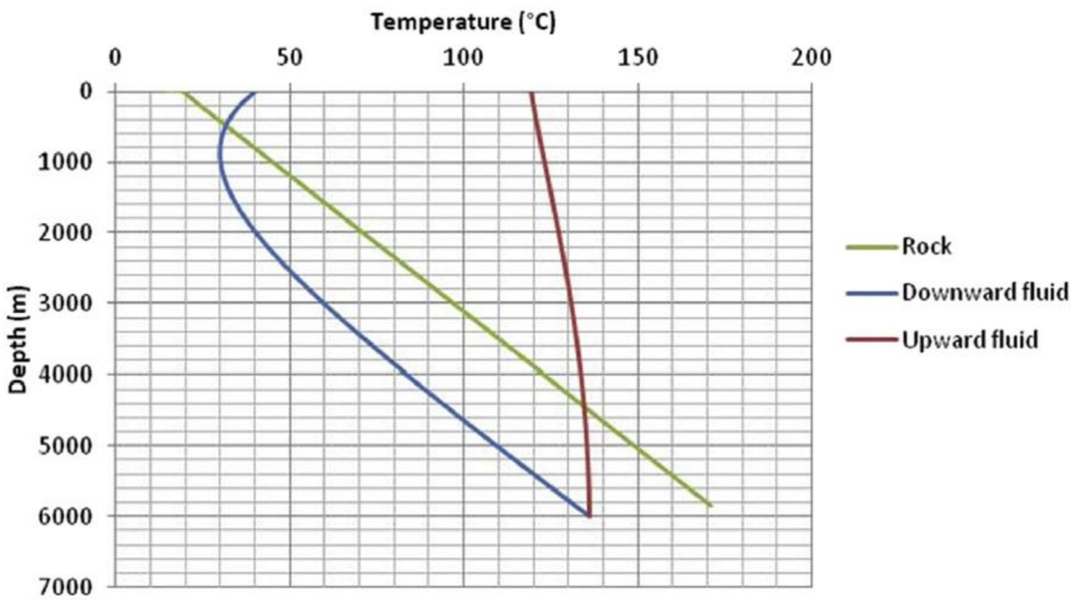

Figure 34: Fluid and rock temperature versus depth (flowrate 10 m3/h)

Also, when we investigate the Pcelic oilfield which is another oilfield located in the Mediterranean area, we see that there is an important potential for geothermal energy here. The fact that the temperature here is even higher than the case study we discussed in Italy at some depths, it makes this place very important for geothermal energy extraction. Because at some points of this oilfield, the temperature can go up to 206 °C. The geothermal gradient (0.05°C-0.07°C and heat flow (60-80 mW/m2) were found to be higher than the average for Europe based on data analysis [18]. These statistics could be explained by the Mohorovicic discontinuity, which is nearby and only 28 kilometres below the surface. Additionally, deep faults are frequently associated with local thermal anomalies, which promotes increased convective heat transfer to the surface.

Ahvaz oilfield, which is located in the Caspian Zone and belongs to Iran, is the only oilfield in this geography where studies are carried out on the extraction of geothermal energy. When we look at it here, the temperature changes between 130-180°C. At this level, it makes this place one of the important places for the extraction of geothermal energy in Caspian Area.

Figure 35 shows the evolution of the outlet temperature and the actual acquired power generated by the heat exchange system over the course of 30 years with in situ combustion as functions of thermal conductivity of the insulation, intake temperature, and injection water velocity.

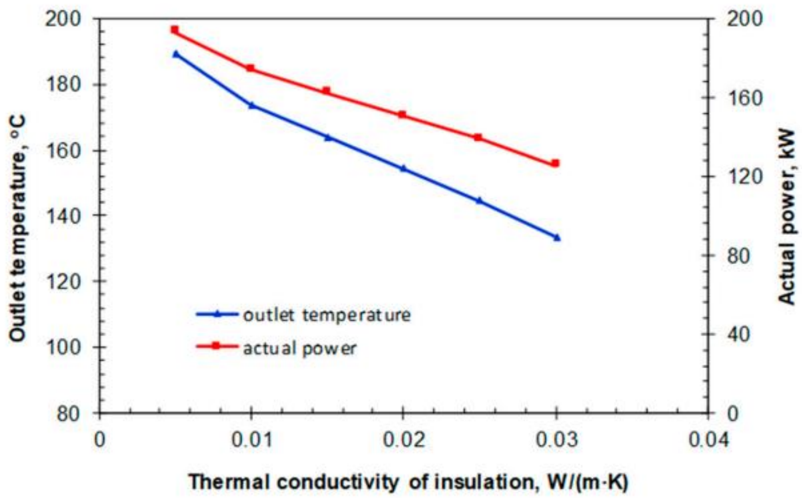

Figure 35: a) Thermal conductivity of the insulation

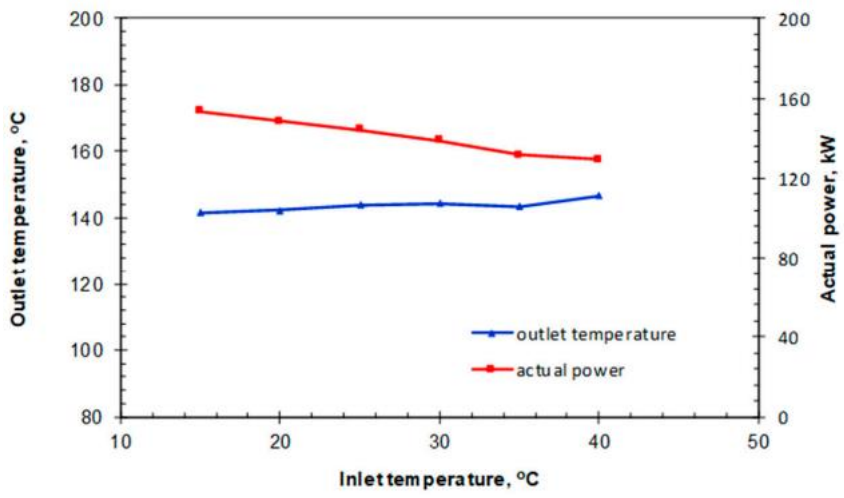

Figure 35: b) Inlet temperature

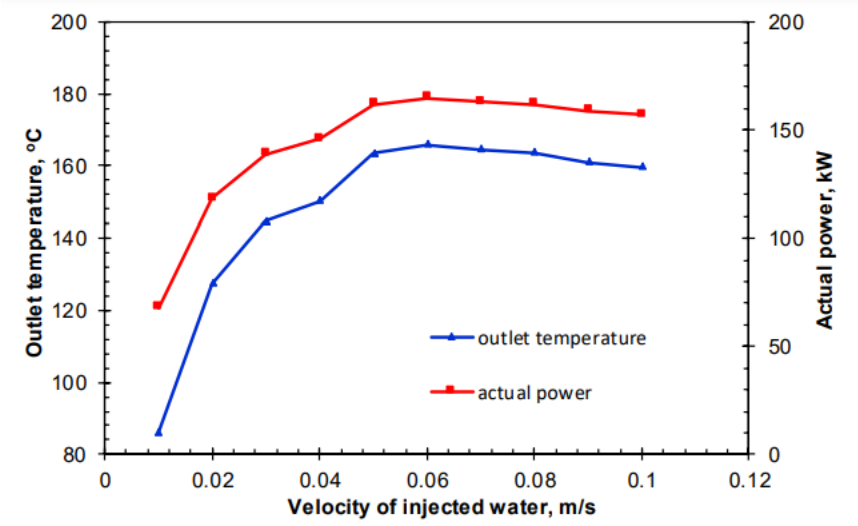

Figure 35: c) Velocity of injected water

6.2 Concluison

This work presents information about Geothermal energy extraction from sedimentary basins in Mediterranean and Caspian areas.

In the first chapter, what geothermal energy means, its place in the world, its usage and advantages are emphasized. As can be seen, geothermal energy has a great importance in the future energy use planning of our world.

The main purpose of the work is to obtain geothermal energy from oil wells which production life has expired in the Caspian and Mediterranean zone. Therefore, in the second chapter, information about the sedimentary basin in these zones that hosted hydrocarbon was included and focused.

In the third chapter, the oil and natural gas production and consumption of the countries belonging to the Caspian and Mediterranean zones, their energy reserves are shown in detail by means of figures and charts.

Based on three selected case studies, the extraction methods of geothermal energy from oil wells that have exhausted their production life are included in chapters 4 and 5. The data that makes these wells important for the extraction of geothermal energy are processed in this chapter.

When we look from a broad perspective, we see that Mediterranean Zone and Caspian zone countries are a little behind in comparison with other countries, in the extraction of geothermal energy from oil wells that have ended production life . For the country in the Mediterranean Zone, perhaps the main reason is that they do not have many oil reserves. However, for the Caspian Region countries we cannot say this. Because the most important part of the economy of these countries is oil production. However, unfortunately, they were not very insistent on extraction of geothermal energy from oil wells that have ended their production life. However, countries that have this potential for a new and clean world need to conduct serious research on this issue.

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