



Geothermal Energy Worldwide and in Algeria: A Case Study of the Albian Geothermal Reservoir characterization

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Abstract

Geothermal energy is a clean, reliable, and versatile renewable energy resource derived from the Earth's internal heat. This heat results from the residual thermal energy of the Earth's interior and the radioactive decay of naturally occurring elements within the crust. It is transferred toward the surface through conduction, convection, and fluid circulation. In the continental crust, temperature generally increases with depth, with an average geothermal gradient of approximately 3°C per 100 m, although substantial regional variations occur. Geothermal resources can be used for electricity generation and a wide range of direct applications, including space heating, greenhouse heating, aquaculture, balneotherapy, and industrial processes. Despite their considerable potential, many geothermal resources remain underexploited worldwide. Algeria has significant geothermal resources, including more than 200 documented thermal springs in the northern part of the country and a major deep geothermal system in the northern Sahara, represented by the Albian aquifer (Continental Intercalaire). This paper reviews the main characteristics, exploration approaches, and applications of geothermal energy worldwide and in Algeria, with particular emphasis on the Albian geothermal reservoir in Southern Algeria. The study also highlights the contribution of geophysical methods, including well-log analysis and seismic interpretation, to the characterization and exploration of this important geothermal system.

Keywords: Geothermal energy; renewable energy; geothermal exploration; Albian aquifer; Continental Intercalaire; thermal springs; Southern Algeria; well logging; seismic interpretation; geophysics

1. Introduction

Algeria remains strongly dependent on fossil fuels for electricity generation and heating [1,2]. The diversification of the national energy mix therefore requires the development of renewable resources, including geothermal energy, for which Algeria possesses significant but still underexploited potential[3].

Geothermal energy concerns the study and utilization of the Earth's internal heat. The terrestrial heat transferred through the crust, commonly expressed as heat flow, is not uniformly distributed and therefore varies considerably from one region to another. Where heat flow is relatively high, groundwater can be heated at depth and may reach

the surface as thermal water through permeable formations, fractures, faults, or hydrothermal systems.

The geothermal resource is associated with heat stored in the subsurface and continuously supplied by natural geological processes. The main contributors include radiogenic heat production within the crust and heat transferred from deeper parts of the Earth. This study reviews geothermal energy worldwide and in Algeria, with particular emphasis on Algerian thermal springs and the Albian geothermal reservoir of Southern Algeria. It also examines the role of geophysics and Earth sciences in the exploration and characterization of geothermal resources.

2. Current status

2.1 Heat Flow and Geothermal Gradient

Terrestrial heat flow is spatially heterogeneous and reflects the thermal structure and geological evolution of the Earth's crust [4]. Heat flow represents the rate of heat transfer through a unit area of the Earth's surface. It results from both heat originating in the Earth's interior and radiogenic heat production within the crust. The relative contribution of these sources varies according to geological setting and crustal composition.

A large amount of thermal energy is stored within the Earth's mantle and core, but only part of this heat is transferred toward the surface. Within the continental crust, radioactive decay of naturally occurring elements such as uranium, thorium, and potassium constitutes an important source of heat. Additional contributions may arise from magmatic processes, chemical reactions, tectonic deformation, and the cooling and crystallization of molten rocks.

The geothermal gradient describes the rate at which temperature increases with depth. In continental areas, a commonly used average value is approximately 3°C per 100 m, although the actual gradient may vary substantially depending on lithology, tectonic setting, groundwater circulation, and regional heat flow. High geothermal gradients are associated with active or anomalously hot geological environments, whereas lower values occur in regions characterized by low heat flow or efficient groundwater circulation.

Figure 1. Schematic representation of the Earth's internal structure and geothermal gradient (adapted from [5]).

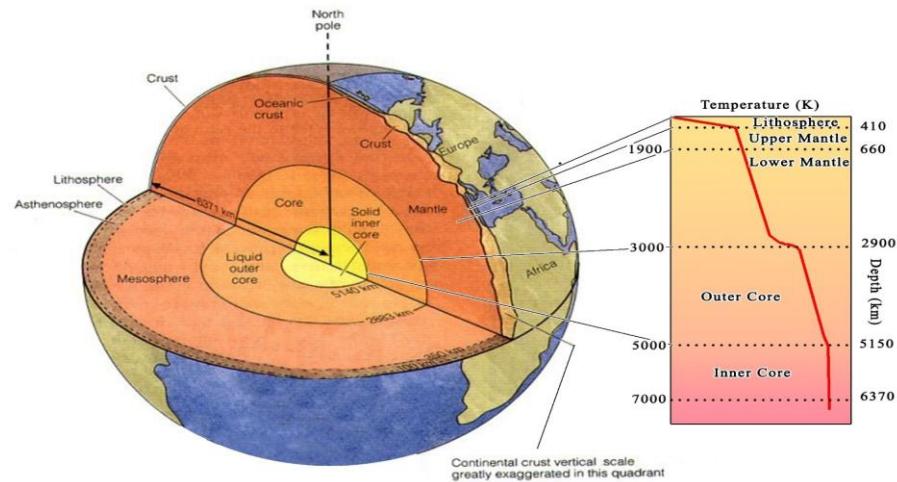


Figure 1: Earth's structure and geothermal gradient [5].

2.2 Geothermal Exploration Methods

Geothermal exploration commonly combines approaches developed in petroleum exploration, hydrogeology, geology, and geophysics [2]. An integrated exploration strategy is generally required to identify heat sources, permeable formations, fluid circulation pathways, and suitable reservoir conditions.

- Geological methods use field observations, geological maps, aerial photographs, and satellite imagery to identify lithological units, faults, fractures, volcanic structures, hydrothermal alteration, and other features that may control geothermal circulation.
- Geochemical methods involve the sampling and analysis of thermal waters, gases, and hydrothermal deposits. Measurements such as temperature, pH, electrical conductivity, and chemical composition provide information on fluid origin, water-rock interaction, mixing processes, and subsurface equilibrium temperatures. Geochemical surveys are often relatively inexpensive during the early stages of exploration.
- Geophysical methods include borehole temperature measurements, electrical and electromagnetic surveys, magnetic methods, gravity surveys, and seismic techniques. These methods help determine subsurface geometry, lithological contrasts, faults and fractures, reservoir boundaries, and thermal anomalies.

Additional techniques, including isotope studies, hydrochemical mixing models, magnetotelluric methods, and other potential-field or remote-sensing approaches, can complement conventional exploration methods and improve the conceptual model of a geothermal system.

2.3 Applications of Geothermal Energy

Lindal [6] summarized the main direct-use applications of geothermal resources according to temperature requirements.

Geothermal energy can be used for both direct thermal applications and electricity generation [5-7]. Depending on resource temperature and reservoir characteristics, applications include geothermal electricity generation, space and district heating, greenhouse heating, aquaculture, balneotherapy, industrial processes, agricultural drying, and heat-pump systems. Emerging applications also include the use of geothermal heat in integrated energy systems.

3. Geothermal energy worldwide

The Geothermal energy has developed considerably worldwide as exploration, drilling, reservoir engineering, and power-generation technologies have improved. Geothermal resources are now used in both electricity generation and direct thermal applications in many countries, particularly where favorable geological conditions provide accessible heat and permeable reservoirs.

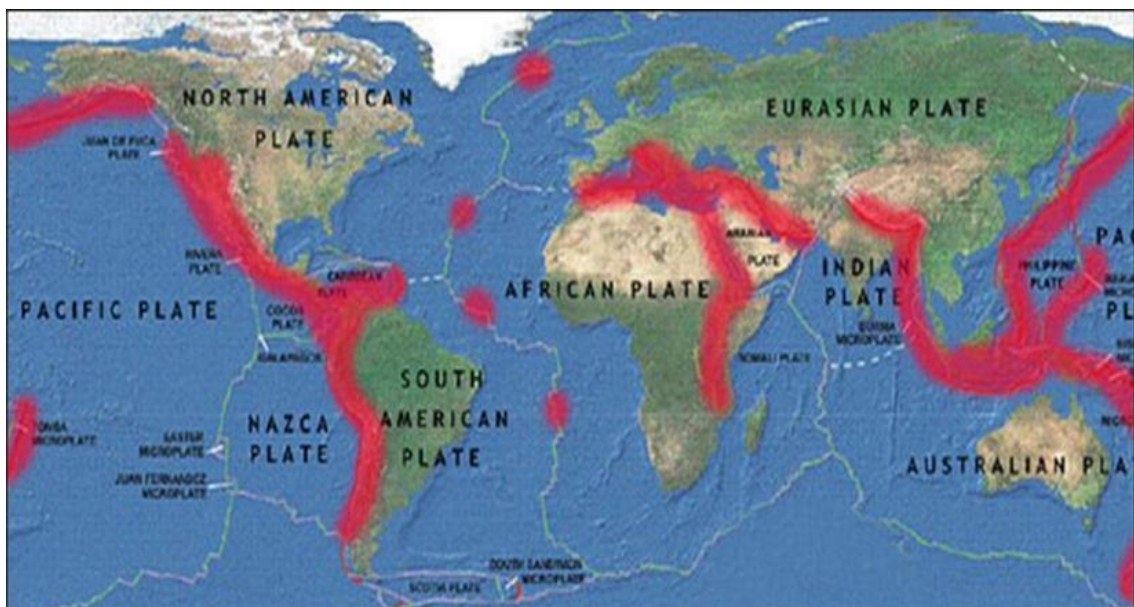


Figure 2: Distribution of major geothermal potential zones in relation to continental plate boundaries [8]

Deep geothermal reservoirs are exploited for both electricity and heat production in several countries, including Italy, Iceland, New Zealand, Japan, the United States, France, and Kenya [5,9]. The scale and type of development vary according to resource temperature, permeability, geological setting, economic conditions, and available technologies.

Mádlné [8]. presented a global overview of geothermal potential in relation to tectonic

and continental-plate settings. Northern Africa is characterized by significant geothermal resources, particularly associated with deep sedimentary aquifers and thermal springs, which has encouraged numerous geothermal investigations in the region.

Historical assessments demonstrate the long-standing importance of geothermal energy for both electricity production and direct use. However, global geothermal statistics have changed substantially since the estimates cited in earlier literature. For this reason, historical capacity and production values should be clearly identified by year and source when used for comparison. Direct applications remain particularly important because they can utilize moderate-temperature resources that are unsuitable for conventional electricity generation.

Geothermal electricity is generated in more than 20 countries, including the United States, Indonesia, the Philippines, Iceland, Turkey, New Zealand, Kenya, Italy, Mexico, and several countries in Central America and Asia. The leading producers have large high-temperature resources, but medium- and low-temperature geothermal systems are also increasingly exploited for direct use.

The Geysers geothermal field in California, USA, is one of the world's best-known high-temperature geothermal developments. Its long production history illustrates the importance of sustainable reservoir management, including production monitoring and fluid reinjection.

Iceland provides another major example of geothermal utilization, where geothermal resources contribute substantially to space heating and electricity generation. The Icelandic experience demonstrates the importance of integrating geothermal resources into national energy systems.

The East African Rift is also characterized by major geothermal potential. Kenya has developed several geothermal power plants, particularly in the Rift Valley, demonstrating the potential of high-temperature resources for electricity generation in Africa.

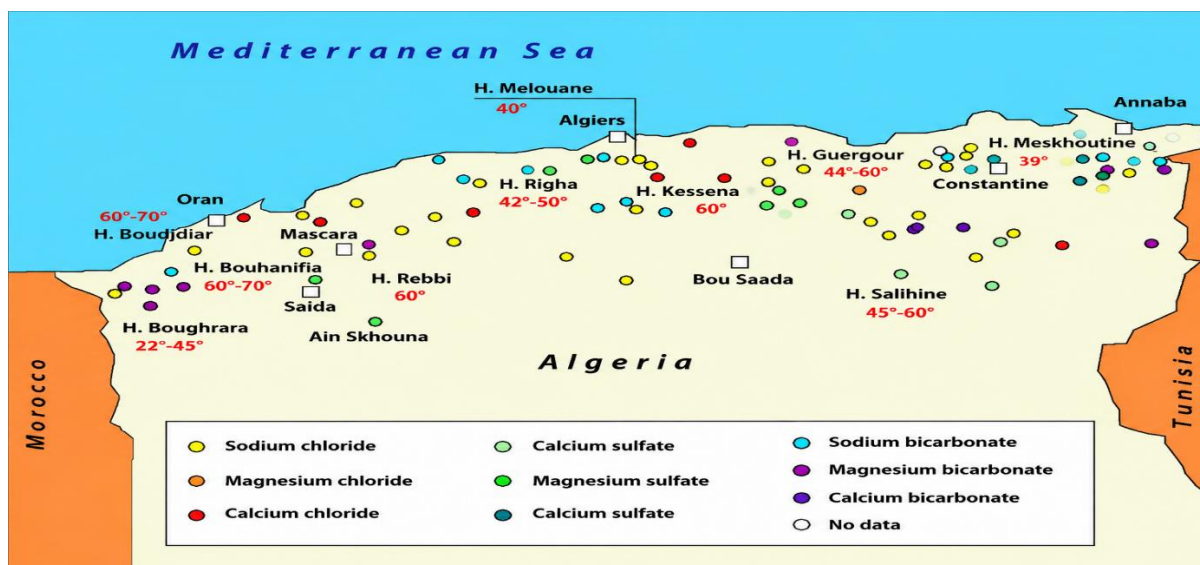
Germany has developed deep geothermal projects for combined heat and power generation, particularly in southern Germany. Such projects illustrate the potential of medium-temperature resources when suitable deep aquifers and heat-demand centers are available.

Tunisia provides a particularly relevant regional example because it exploits the same transboundary Sahara groundwater system as Algeria. Geothermal water has been used for greenhouse heating, demonstrating the potential of moderate-temperature groundwater for agricultural applications [10].

4. Geothermal exploration and energy in algeria

In Algeria, geothermal research has involved universities, industrial companies, research centers, and national institutions, including Sonatrach, CRAAG, and CDER [2,10,11,12]. These studies have combined geological, hydrogeological, geochemical, and geophysical information to identify and characterize geothermal resources.

Approximately one-third of the inventoried springs have temperatures above 45°C, and temperatures as high as about 118°C have been reported for some thermal springs in the Biskra region.



The main uses of geothermal water in Algeria include balneotherapy and the heating of buildings and greenhouses. Other applications, including aquaculture and agricultural projects, have also been developed or investigated.

northwestern Algeria, for heating and cooling. The system used thermal water at approximately 46°C with a flow rate of 25 m³/h. Similar projects have been considered in other regions, together with the development of binary-cycle geothermal power-generation concepts.

Tilapia aquaculture projects have also been developed in southern Algeria, particularly in the Ghardaïa and Ouargla regions. These projects can take advantage of the relatively warm water available from the Albian aquifer.

The regions of Ouargla and Touggourt, in the northeastern Algerian Sahara, have been investigated for geothermal greenhouse heating. These systems are particularly relevant because the Sahara experiences substantial temperature variations, and nighttime winter temperatures can become very low despite the generally hot climate.

Experimental greenhouse systems in the Touggourt and Ouargla regions have used Albian geothermal water at approximately 57°C. An installation comprising 18 greenhouses and covering a total area of about 7,200 m² was reported to use geothermal water to maintain suitable indoor temperatures for crop production.

Reported results included earlier harvesting and increased production compared with unheated greenhouses. Previous assessments also indicated that the geothermal resource in these regions could support a much larger number of heated greenhouses, subject to sustainable production rates, reinjection requirements, and appropriate reservoir management.

Algeria has adopted national programs and legislation aimed at increasing the contribution of renewable energy and improving energy efficiency. Because energy-policy targets evolve over time, the specific national target and its implementation status should be verified against the most recent official legislation and policy documents before publication.

5. The albian geothermal reservoir

In Algeria, the Albian aquifer occupies a vast area of the Northern Sahara (Figure 4). It is bounded approximately to the north by the Biskra–Béchar line, corresponding to the South Atlas flexure; to the west by the Béchar–Adrar line; to the south by the Adrar–In Amenas line; and to the east by the Algerian–Tunisian border. In Southern Algeria, the Albian aquifer is generally considered a deep and largely fossil groundwater system.

The Albian reservoir is predominantly composed of sandstone and has an average thickness of approximately 700 m. Its depth generally increases from southwest to northeast. The greatest depths occur along its northeastern margin, particularly in the Biskra, El Oued, and Touggourt regions, where the aquifer may reach depths exceeding 2,000 m. Toward the southwest, the aquifer becomes shallower and approaches or

reaches the surface in areas including Adrar, In Salah, and In Amenas (Figure 4).

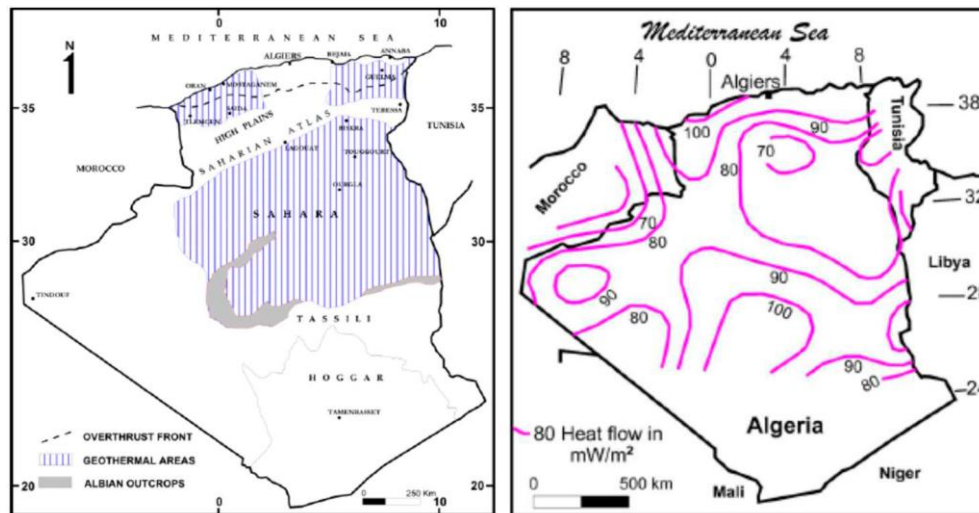


Figure 4: Main geothermal areas of Algeria and regional heat-flow distribution [17,20].

The principal geothermal reservoir rocks differ between northern and southern Algeria. In the north, thermal resources are commonly associated with Jurassic carbonate formations, whereas in the south the major deep geothermal resource is associated with the sandstone-dominated Albian Continental Intercalaire.

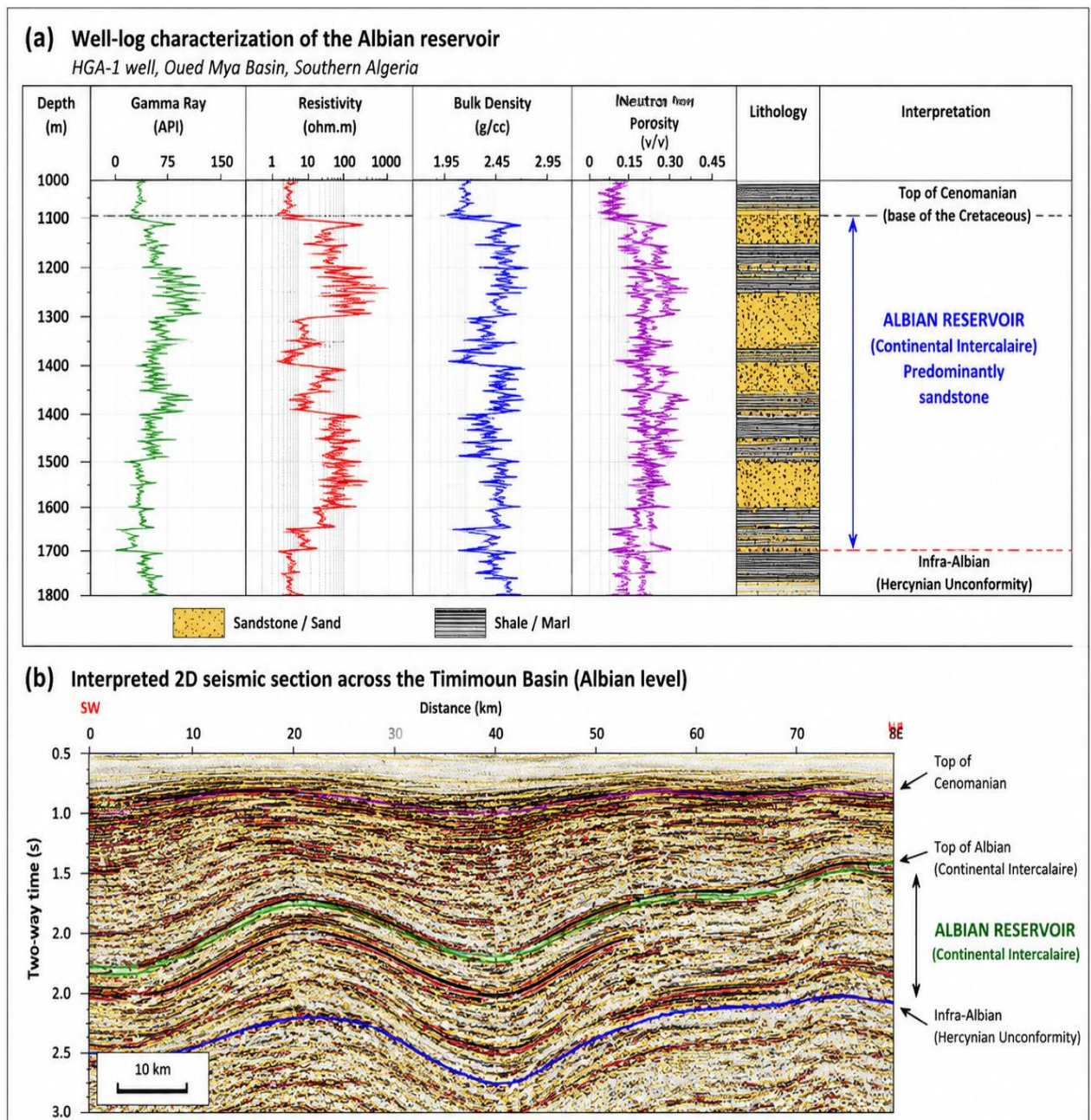
Geothermal-water temperature generally increases with depth according to the local geothermal gradient. A commonly adopted continental average is approximately 3°C per 100 m, although local gradients may range from about 1°C per 100 m to 10°C per 100 m or more depending on geological and hydrogeological conditions. In the Algerian Sahara, temperature distribution is therefore controlled by both depth and regional thermal regime.

5.1 Well-Log Characterization

Well-log characterization of the Albian reservoir (Continental Intercalaire) in the HGA-1 well, Oued Mya Basin, Southern Algeria, combines lithological information with Gamma Ray (GR), resistivity, bulk-density, and neutron-porosity responses. The log responses indicate a predominantly sandy reservoir with interbedded argillaceous intervals (Figure 5a). Such well-log data are valuable for identifying reservoir intervals and assessing lithological and petrophysical variability.

2. 2D Seismic Interpretation

The interpreted 2D seismic section across the Timimoun Basin, Southern Algeria, illustrates the geometry and continuity of the Albian interval. The main interpreted stratigraphic horizons include the top of the Cenomanian, the top of the Albian (Continental Intercalaire), and the Infra-Albian boundary. The seismic interpretation provides information on the structural configuration and lateral continuity of the Albian sandstone reservoir (Figure 5b).



These figures illustrate the integration of well-log and seismic data for the identification and characterization of the Albian (Continental Intercalaire) geothermal reservoir in Southern Algeria.

Figure 5: Integrated characterization of the Albian reservoir: (a) well-log data showing lithology, Gamma Ray, resistivity, bulk density, and neutron porosity; and (b) interpreted 2D seismic section illustrating the geometry and continuity of the Albian interval.

6. Results Analysis

The integrated interpretation of well logs and seismic data provides complementary information on the Albian reservoir. The well logs help identify lithological changes and distinguish the predominantly sandstone reservoir from argillaceous interbeds, whereas the seismic section provides a broader view of reservoir geometry, continuity, and structural configuration. Together, these datasets demonstrate the value of integrating petroleum-style geophysical data with geothermal studies to improve the delineation and characterization of the Albian geothermal reservoir.

7. Conclusions and recommendations

Northern Algeria is characterized by active tectonic processes related to the interaction of the African and Eurasian plates. This tectonic setting contributes to the occurrence of numerous thermal manifestations. More than 200 thermal springs have been documented in northern Algeria, with concentrations in the western, central, and eastern regions.

In addition to the numerous thermal springs of northern Algeria, the southern part of the country contains a major deep geothermal resource associated with the Albian aquifer. The Algerian portion of the Albian aquifer extends over approximately 650,000 km² and forms one of the largest fossil groundwater systems in North Africa.

The increasing demand for low-carbon energy and the need to diversify Algeria's energy mix strengthen the case for developing geothermal resources, particularly for direct uses that can exploit moderate-temperature water.

Since the early 1990s, geothermal applications have been developed in the Algerian Sahara, including greenhouse heating in the Touggourt region. These projects demonstrate the technical feasibility of using Albian geothermal water for agricultural applications.

The development of geothermal energy in Southern Algeria could be facilitated by the extensive subsurface information already available from petroleum exploration and production. However, the reuse of petroleum data for geothermal purposes requires careful assessment of temperature data, reservoir pressure, water chemistry, permeability, well integrity, and sustainable production conditions.

a. Existing subsurface information from the hydrocarbon sector should be systematically evaluated for geothermal purposes. High-resolution 2D and 3D seismic data, well logs, temperature measurements, pressure data, and petrophysical information can significantly improve geothermal reservoir characterization. Geothermal exploration can therefore benefit from the multidisciplinary expertise developed within the petroleum sector.

b. Geothermal development strategies should be adapted to the specific geological, hydrogeological, climatic, and economic conditions of Algeria. Direct-use applications are particularly promising for moderate-temperature resources, while electricity

generation should be considered where reservoir temperature, flow rate, permeability, and economic conditions are favorable.

c. The development of geothermal systems should include sustainable reservoir management, monitoring of pressure and temperature, assessment of induced seismicity where relevant, and appropriate reinjection strategies. Techniques developed in the oil and gas industry may contribute to reservoir stimulation and monitoring, but their application to geothermal systems must be evaluated on a site-specific basis.

d. Geothermal technologies can also contribute to building heating and cooling. Ground-source heat pumps and other geothermal heat-exchange systems may provide efficient solutions for reducing conventional energy consumption, particularly when properly adapted to local geological and climatic conditions.

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