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How to Generate Electricity in the Republic of Djibouti?

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ABSTRACT

There are abundant geothermal resources in Djibouti, about 910 MWe. Geologically, the most active area in Djibouti is the Asal area, about 100 Km away from Djibouti city. Six wells have been drilled in the Asal area, with varying depths ranging from 1100 to 2100 m. The temperature of the wells ranges from 260 to 360°C. Wells Asal 1, 3 and 6 have produced extremely saline fluids from 1000-1300 m depth where the aquifer temperature is about 260°C. Wells Asal 3 and Asal 6 produce highly saline (about 120 g/l) reservoir fluid and the scaling of galena at high pressure reduces the discharge rate. The precipitation of galene in the pipeline produces a decline of the amount of output fluid. How to solve this problem? How to add inhibitor to prevent scaling?. Extensive exploration and field tests need to be performed to accurately estimate the actual size and capacity of the Asal reservoir. Sinopec Star will do the follow-up work, firstly prospecting the geothermal resources and secondly drilling new wells for the generation of electricity.

1 SURVEY

1.1 Geographic location

Djibouti is located in Northeast Africa, on the west coast of the Gulf of Aden, chokes the Red Sea into Indian Ocean at Mandeb Strait, south-east border with Somalia, north with Eritrea, West adjacent to Ethiopia. The area of the Republic of Djibouti is 23,200 Km^2, the total length of the coastline is 372 km. Asal block is located in the central section of the Republic of Djibouti, where the work area is located near the Asal Lake, west of the capital city of Djibouti, the total area is about 54 Km^2. As shown in Figure 1. Asal Lake, west of Djibouti City, is about 100 km away, there are asphalt roads leading directly to the lake. The work area from the nearest city, Arta, is about 82 km.

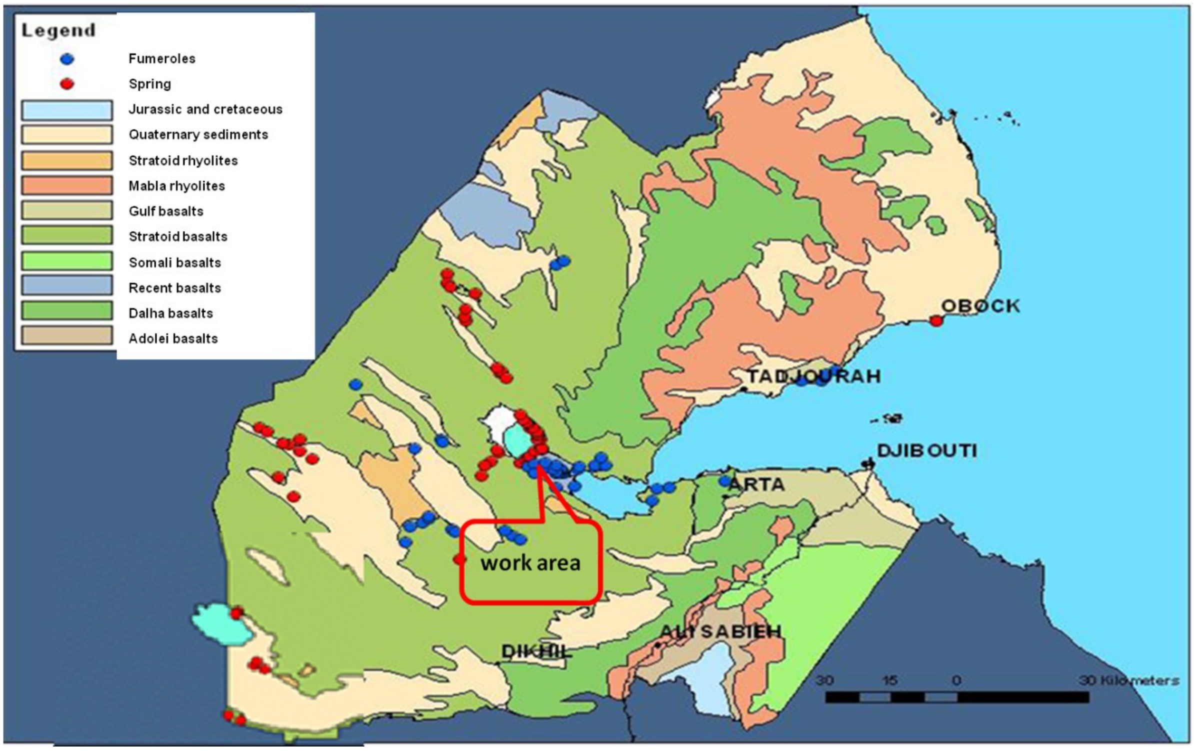

Fig. 1 Map with the location of the work area.

1.2 Natural Geography

The Republic of Djibouti is in the sub-tropical, arid and semi-arid climate region. The climate is mainly influenced by the inter-tropical convergence zone. At the same time, local and regional landscapes also have a great influence on the climate in different regions of Djibouti.

The annual average temperature is high (25-35 ℃), every year 60-80 days the temperature is over 40 ℃, from May to September, for the hot season, the average temperature is 35 ℃, the highest temperatures are up to 46 ℃. As a whole in the Republic of

Djibouti precipitation is scarce, the annual total precipitation is less than 150 mm, but the evaporation rate is strong. But, in the Gardy region, the average annual rainfall is 300-350 mm.

As Djibouti's domestic uneven spatial and temporal distribution of rainfall, is generally short showers, less rainfall and strong evaporation, evaporation of water accounted for about 83% of total rainfall. The surface runoff is about 6% of annual rainfall, but most of the water formed in the mountains torrents into the sea or into depressions forming temporary lakes, lasting for several days until, eventually they evaporate. Therefore, the country's fresh water resources are very scarce. During geological exploration, it is hard to see flowing rivers and streams.

The work area is characterized by high temperatures, strong sunlight, with a sweltering heat and strong winds.

1.3 Social economic status

The Republic of Djibouti has a population of about 906,000, mainly for the Issa family and the Afar. Residents mainly believe in Islam, of which about 50% of the population is below the poverty line. Above about 65% of the nation's population is concentrated in the city of Djibouti. The population that is scattered around the country lives by the nomadic way (sheep). The Djibouti Republic has poor foundation conditions, and the industrial, agricultural production is backward, almost a blank, about 95% of materials depends on imports.

Djibouti depends heavily on imported energy, about 85% of the energy consumption is from imports of petroleum products, the rest is from wood and charcoal, these two materials are also very shortage. At present, the government has made the security of energy, water and food as a primary problem for the next 5 years in its government development plan. So, it is urgent and necessary to find new and local clean energy sources. It aims to reduce dependence on imported energy, reduce oil imports and to meet its own energy needs, and ultimately, achieve the country's energy independence. Among them, the development of geothermal energy has been identified as the priority among priorities.

2 GEOTHERMAL GEOLOGICAL CONDITIONS

2.1 Topography

Controlled by the regional geological structure, on the whole, Asal area is surrounded to the East, West, South and North by high and middle low lands (Asal Lake). The North-East up and the Gaody distribution of mountain, the highest peak 1799 meters above sea level, is the Djibouti best growth area for the few vegetation. The lowest point is the Asal Lake with an elevation of -157 meters.

The Asal Lake area terrain is mainly plain, with banded mountains forming a graben structure (basin). The trend and main tectonic lineament is in the West-Southeast direction, plain lying flat open, and a stepped topography in the mountains. Asal Lake Rift shows a Northwest-east trending, which separates Tarzhula Bay from the Asal Lake.

2.2 Lithology

The Republic of Djibouti has frequent earthquakes and a strong magmatic activity. The land area is composed of more than 90% of magmatic rocks and a loose accumulation layer covering.

Layered basalt is the main rock found in the Republic of Djibouti, universally outcropping, forming the inland block body. The rock is mainly grey, black, columnar joints are visible in rock outcrops, in general looks fragmented with an intense weathering.

The Somali Basalts are exposed in the Asal rift, in the Day north mountain. Gulf basalt is located in the Tarzhula Gulf. Acid rhyolites are found in between the Dahal basalt. The lava flow distribution in the modern Asal rift is mainly along the NW-SE distributed cracks outflow.

The Quaternary strata are mainly lacustrine sediments, diluvium and residual, colluvial deposit composition. There is a small amount of aeolian sandy soil.

The lacustrine strata lithology is mainly composed of silty soils, mainly located in the plain.

Diluvium deposits are formed mainly during the rainy season runoff floods. These deposits are mainly composed of sand and gravel (crushed stone), usually located in the gully and plain river alluvial fans, etc. Sand and gravel (crushed stone) have a miscellaneous grain size distribution, mainly composed of sand, silt and clay filling.

Eluvial-colluvial deposits are mainly composed of grey and black crushed stones derived from the basalt weathering accumulation. The former is mainly distributed in the mountain slopes and slope surfaces, the latter is distributed in the mountains or steep slopes. Almost no fine-grained material is filling the space between stone fragments. The thickness of these deposits is less than 1 meter.

2.3 Geological Structure

The Djibouti Republic is a terrain with a frequent magmatic activity and earthquakes. The geological structure is complex.

The region of Djibouti is in the center of the Afar Depression, as the extension of the Arabia plate and the separation of Africa produced by the extensional regime of the crust. The Red ocean ridge to the north of Djibouti is the inland rift valley of lateral development to the east of the Gulf of Aden ridge with two axes nearly orthogonal to the Afar Depression and the rift valley of Southern Cross, which is formed for three lithospheric plates (Arabia plate, the Nubian plate and the Somali plate), the triangle intersection.

The Afar Depression is the origin of many different geological structures within the territory of the Republic of Djibouti. The main tectonic lineaments (faults, cracks) are NW-SE oriented with secondary tectonic lineaments in the NE-SW direction, intersecting the main structures. It is this graben, horst structure, formed a plain strip mountain area of many parallel and fault-controlled depressions (basin) and terrains.

The Asal–Gebit rift is the youngest part of the Gulf of Aden ridge, the western section, but also a part of the Gulf of Aden ridge extending to inland. NE vertical faults in the Aden ridge cut the Asal–Gebit rift, making the lake Asal into a closed depression lowland (Figure 2).

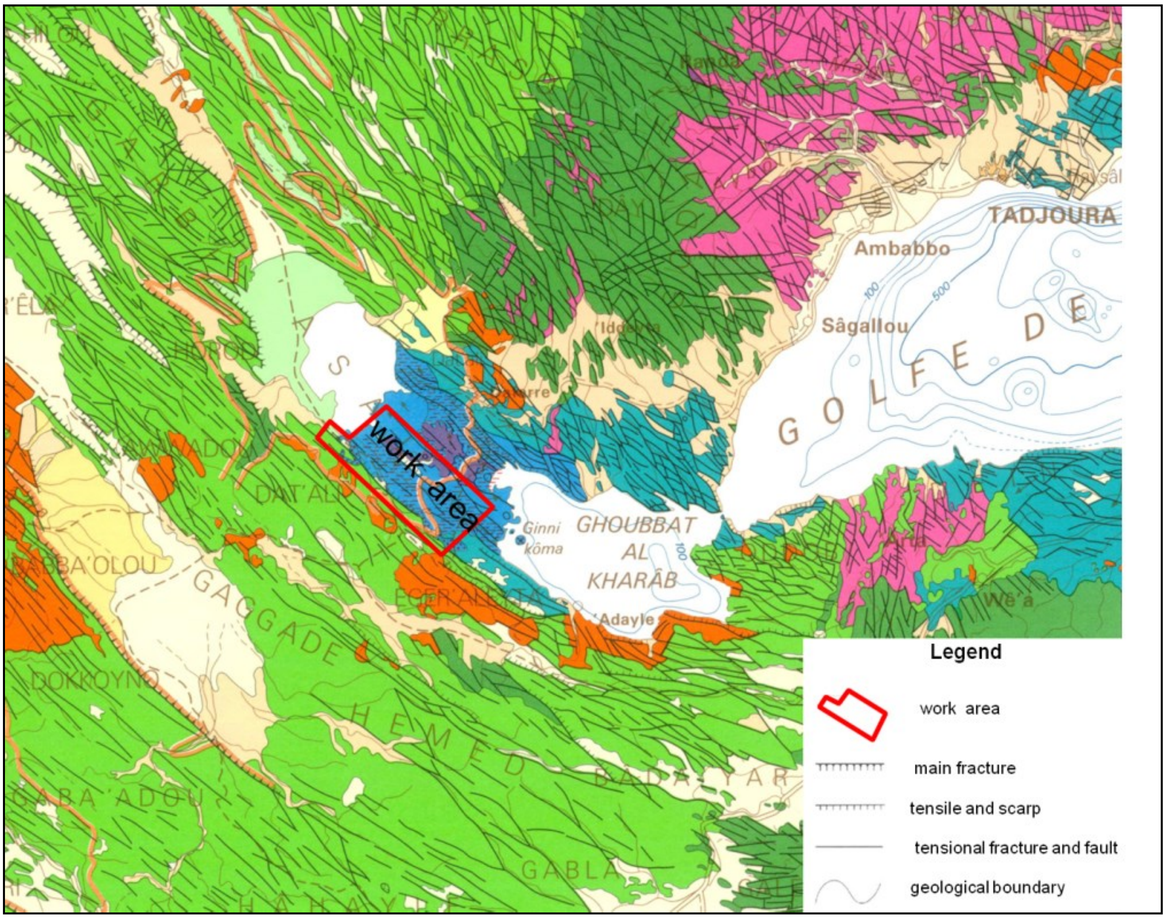

Fig. 2 regional tectonic map

2.4 Hydrogeological conditions

According to a survey made in the area for studying formation water properties and the spatial distribution of groundwater resources, the work of groundwater are mainly of Quaternary pore water and bedrock fissure water.

2.4.1 Quaternary Pore Water

The work area is located in the SW and SE side of the Asal rift. The Asal Lake soil is mainly composed of lacustrine or diluvia silt, with a sandy soil composition, soil with certain pore, Containing Quaternary loose pore water.

The work area of mountain surface is mainly of Quaternary eluvial, colluvial slope crushed stone soil, which is of a loose structure, with large pore spaces and with a big water storage space. But the thickness of the soil is generally less than 1 meter. Due to the atmospheric evaporation depth within the scope of influence, therefore, the layer is a permeable layer without water.

In the valley, piedmont alluvial fan, and plain (basin), because the wide distribution area of the soil, large thickness, the catchment conditions are relatively good the groundwater recharge obtained is correspondingly larger, rich water is relatively good, as the main burial area of pore phreatic.

The groundwater is mainly phreatic water with a groundwater level dynamic changing considerably.

2.4.2 Bedrock Fissure Water

In some areas of exposed bedrocks the rock is a hard rock (basalt) with development of porosity and vertical fractures, mostly open without filling minerals. These pores and fractures provided a good space for groundwater flow and storage and hence constitute the bedrock aquifer, containing bedrock fissure water.

The Asal rift surface is made of the newly lava flow deposits, performance of fracture development, which is favorable to the infiltration of precipitation, but due to less rainfall, therefore, groundwater recharge capacity to accept less.

The top of the hill and their slope are the main recharge areas of groundwater. Groundwater generally follows the terrain from high to low elevations when at the foot of the mountain is the place by cutting is a spring excretion.

Valley, plain (basin) as the main burial groundwater, according to statistics the water quality is fresh water, which has dispersed water supply significance, but the groundwater level depth is relatively large.

3 THE PREVIOUS ACHIEVEMENTS

3.1 Research for Analysis of Trace Element in the Working Area and its Surrounding Areas

Based on the trace element distribution in this region, elements such as lithium, strontium, bromine and boron studies, showed that: strontium isotope in the spring component is composed of seawater with basalt interaction and evaporation, Bromine chlorine ratio without any exception, that decomposition does not affect the spring elements; Bromine chlorine low ratios can confirm that evaporation is one of the controlling factors of reservoir fluid.

3.2 With The Geophysical Survey Work on Asal Fault Zone

In the previous study, many geophysical survey methods were used, such as earth magnetism, gravity model method, MELOS method, matrix method and seismic methods. According to the gravity anomalies and resistivity changes recorded, they were used to explored the formation of this area, and thus determine the wells location.

3.3 The Deep Well Drilling Work on the Asal Block

In the previous geothermal exploration work, in the Asal fault zone, 6 deep wells were drilled (Table 1). The reached depth is between 1,137 to 2,105 m, the water temperature fluctuates between 233 to 359 ℃. Among them, Asal 1, 3 and 6 wells are located in the same area, near the mouth of the volcano; Asal 4 and 5 wells are located in the fault zone.

No	Drilled wells	Beginning of drilling	End of drilling	Final depth (m)	Temperature at bottom (°C)	Total mass flow (t/h)	Salinity (g/l)	Drilling duration (day)
1	Asal 1	8-03-75	12-06-75	1146	260	135	120	97
2	Asal 2	1-07-75	10-09-75	1554	233 (926m)	-	-	72
3	Asal 3	11-06-87	11-09-87	1316	264	350 (WHP = 12,5Bars)	130	93
4	Asal 4	15-09-87	21-12-87	2013	359	-	180	97
5	Asal 5	7-01-88	7-03-88	2105	359	-	-	61
6	Asal 6	8-04-88	10-07-88	1761	265	150	130	94
Total								524

Table 1: Characteristics of Asal wells

3.4 A Preliminary Geothermal Resource Evaluation on the Asal Block

Asal consists of three blocks of Gale Le Goma, Fiale and South of Asal Lake. Their surface area is 20, 12, 9km^2, respectively. Parameters used in the evaluation are shown in Table 2, the application of Monte Carlo simulation calculation results are shown in Table 3. Reservoir in the Asal area is about 41km^2, with a thickness of about 2000 m. The estimated potential power is 352MWe.

3.5 A Single Discharge Well Test

(1) In the Asal3 well, a single discharge test was done, the velocity is reduced by 25-28%. From the pressure of 19 bar to 15 bar, the mass flow is changed from 48-36kg/s to 38-29kg/s. The heat content is maintained at 1070 kJ/kg, the production of steam drainage rate is 29kg/s while well head pressure is 19 bar, the yield is 2.5kg/s; while the well head pressure is 15 bar, drainage rate is 48kg/s, the yield is 5.2kg/s.

(2) The discharged fluid is a sodium-chloride solution, with a general pH value of 4-5. Salinity is 12%, containing feldspar, clay minerals, carbonate, silicon iron and other iron sulfide, the solution is saturated. The silica concentration is the same as the reservoir temperature is 260^{o}C, then cooling and the formation of various deposition products.

(3) While Asal 3 well blowout test, pipeline present some scaling. Well head pressure goes down to 16 bar and the scaling rate increased 6 times. The scale velocity is 1-2 um / h at 18-20 bar. High pressure scaling is the PbS, low pressure (12-16 bar) scaling is iron silicate, and even lower pressures is amorphous silica. Because the pipe scaling, after 6 months of production makes the effective cross section reduced to 24%.

For pipeline scaling, keeping the pressure in mining, adding inhibitors and other measures can be used to reduce the adverse effects of scaling on the production, and the ground can adopt a screw expansion power generator.

Input	Unit	Optimal value	Type	Min	Max
Area	Km^2	The three block area were: 12,20 and 9			
Thickness	m	1500	Trigonometric function	1000	2000
Rock density	Kg/m^3	2670	Constant		
Specific heat of rock	J/Kg°C	800	Trigonometric function	900	1000
Porosity	%	10	Constant		
Comparison of temperature	°C	180	Constant		
Heat reservoir temperature	°C	Heat reservoir temperature corresponding to the three blocks were: 350,280 and 280			
Fluid density	Kg/m^3	890	Constant		
Fluid specific heat	J/Kg°C	4800	Constant		
Recovery	%	0.05	Trigonometric function	0.1	0.2
Efficiency	%	95	Constant		
Conversion factor	%	11	Constant		
Service life	Year	25	Constant		

Table 2: Relevant parameters

Geothermal field	Generating capacity		
	Min	Mean	Max
Gale le Goma	83	156	258
South of Asal Lake	34	59	93
Fiale	77	137	206
Total Asal area	194	352	557

Table 3: 90% confidence interval for the power estimation of generation potential by volumetric method.

4. THE MAIN CONTENTS FOR THE NEXT STEP WORK

4.1 Work Objective

Identify the geothermal geological background, fence geothermal display distribution area, estimated geothermal reserves and exploitation of geothermal fluid, evaluated the geothermal power generation potential, provide basis for further exploration well deployment.

Based on regional geological, hydrogeological and other basic data, through various investigations, find out the deep faults that control the heat reservoir, on this basis, to provide geothermal well location and depth, predict production and temperature of hot water, and then provide the basis for further developing the geothermal exploration.

4.2 Job Content

Generate a comprehensive analysis and utilization of data for research in the Asal block and its neighboring areas. To develop investigation of geothermal resources in the Djibouti Asal block, by focusing on the use of geological and hydrogeological investigations. Use geophysical and geochemical methods; make comments on the prospect of development and utilization of geothermal resources in the Asal block. Write investigation reports of geothermal resources.

The specific task:

(1) A full collection survey of data from geology, hydrogeology and other aspects of the work area, with an analysis and research on geological and hydrogeological conditions.

(2) Determine the topography, lithology and tectonic conditions of the work area; deployment and measurement of geology, hydrogeology and geophysical test profile.

(3) to investigate the temperature, thermal spring dew point, including landform, geological structure, stratum lithology parts, parts of structural fissure, production, output, dynamic change of environment, development and utilization conditions, development and utilization status, and determination for water temperature, temperature and flow.

(4) Using field surveys and geophysical testing means, comprehensive analysis of the field investigation and testing data; determine the thermal storage layer, for further exploration to determine the exploration well; write investigation and evaluation project report.

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