UNALASKA GEOTHERMAL DEVELOPMENT

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ABSTRACT

There are 88 active volcanoes in the Aleutian Chain which contain an extensive geothermal resource. Geothermal resource investigations have been conducted for the past two years on Unalaska Island. The focus of these investigations have been Maskushin Volcano and Summer Bay, 12 km and 3 km respectively from the town of Unalaska.

Shallow drilling operations have discovered a small low temperature resource at Summer Bay. Eight fumarole fields have been located on Makushin Volcano.

Further work is now planned with the commitment by the State of Alaska to a multimillion dollar resource confirmation program for the Makushin geothermal anomaly. Projected increases of electrical consumption of 40 MW by the year 2000, and the location of $100,000,000 ftsheries industry will continue to be driving forces to develop this resource.

This paper presents the geological, geophysical and logistical studies for the development of a geothermal power plant on Unalaska Island of the Aleutian chain.

INTRODUCTION

Unalaska Island (Figure 1), in the Aleutian Chain, is rapidly becoming the "fish capital" of the United States. Approximately 200 million pounds of crab and fish are processed on the island. Growth in the permanent population, as well as the transient population employed by the processing industry, has been rapid. Demands in housing, services and utilities have escalated accordingly. Present peak electric utility demand is 15 MW, divided among the publicly owned diesel generators and those operated by the private fish processors.

Projections for future demand are risky. While a sizeable portion of the island population appears to be "pro-development" there are prominent forces that are apprehensive. The anticipated sea petroleum exploration activity in the Bering may tax the island's resources significantly. Hence, peak demand by the year 2000 could fluctuate between 30 and 60 MW.

THE UNALASKA GEOLOGY AND THE FUMAROLE FIELDS

The rocks of Unalaska Island consist of an older group of altered sedimentary and volcanic rocks designated the Unalaska Formation by Drewes et al.[1], a group of plutonic rocks intermediate in age, and a younger group of unaltered volcanic rocks. Such rock groups can be correlated with rock groups found throughout the eastern and central Aleutian Islands; i.e., an "early series" consisting mainly of a marine volcanic and sedimentary sequence that has been metamorphosed to a greenschist-grade, a "middle series" consisting mainly of plutonic rocks, and a "late series" consisting of an unaltered sequence of late Tertiary subaerial volcanic and sedimentary rocks.[2] The region to the southeast of Makushin Volcano consists mainly of rock exposures belonging to the Unalaska Formation, whereas unaltered volcanics make up the Makushin Volcano and most of the rock exposures to the northwest.

Several impressive fumarole fields were examined in the region during the summers of 1980 and 1981. They have been arbitrarily numbered for identification purposes in a clockwise direction.[3] Figure 2 illustrates the North portion of Unalaska and the position of the discovered fumarole fields.

Initial water analyses of some of these hot and/or warm springs indicate near neutral sodium/bicarbonate/sulphate waters similar to hydrothermal waters fournd in greater than 150 ^{o}C maximum temperature hydrothermal systems associated with volcanic arcs elsewhere.[4]

These fumarole and hot spring fields vary somewhat in character and dimension. More specifically, Fumarole field no. 1 consists of vapor-dominated fumarolic activity (i.e., at boiling point), a mudpot, and highly hydrothermally altered ground, covering approximately a 400' by 200' region. About 1000 feet upstream from the west edge of this region and at a slightly lower elevation, warm springs and small seeps occur having a maximum recorded temperature of 65 ^{o}C. These springs drain into a fairly large pond having a temperature of about 20 ^{o}C. Fumarole field no. 2 consists of vapor-dominated hydrothermal activity covering a region about 3000 feet long and up to 1300 feet wide. On the southeast side of this fumarole field near a stream channel, several hot springs occur having a maximum recorded temperature of 87°C. Fumarole field no. 3 consists of vapor-dominated hydrothermal activity covering a region about 1600 feet long and about 500 feet wide. The main fumarole activty is actually concentrated in a region 800 feet long and about 300 feet wide. About 1300 feet downslope to the south of this field exists several hot springs having a maximum recorded temperature of 94°C. Several more hot springs occur about 1000 feet further south along a creek having a maximum recorded temperature of 77°C. Fumarole field no. 4 consists of vapor-dominated hydrothermal activity covering a narrow region only about 200 feet long, positioned along a stream and lateral moraine. Fumarole field no. 5 consists of vapor-dominated hydrothermal activity covering an area having a diameter of about 300 feet. A warm spring exists about 600 feet downslope in the southwest direction. The impressive and noisy field on the top of Makushin Volcano occupies a 300 feet diameter region. This field occupies an ice covered region showing signs of subsurface thawing covering a region 3000 feet long and 1500 feet wide. A narrow region about 1400 feet long contains sulphur deposits. Field no. 7 and 8 both occupy very small areas.

The Unalaska Formation in the region of fields no. 1, no. 2 and no. 3 has been extensively intruded by plutonic bodies of gabbro and/or intermediate plutonic rocks. These intrusive bodies and the surrounding Unalaska Formation are severely fractured especially along contact boundaries. For example, a small plutonic body occupies the region between fields no. 2 and no. 3 and extends for several kilometers in a NE direction. The hydrothermal surface manifestations of fields no. 2 and no. 3 are oriented in general in a NE direction along the contact of this plutonic body and the Unalaska Formation. There is evidence of a forceful instrusion of this plutonic body and extensive fracturing along this contact is expected. Unaltered "andesitic and basaltic" volcanic rocks and volcanoclastics lie unconformably over the Unalaska Formation in the vicinity of fields no. 1, no. 2 and no. 3. In all three cases, these unaltered rocks are located just upslope of the fields in a direction toward Makushin Volcano. All of the other fields occur in regions consisting of unaltered volcanic rocks where fields no. 4 and no. 7 are covered with glacial tills. The Unalaska Formation and plutonic bodies in this area are suspected to immediately underlie all of these other fields except for fields no. 6 and no. 8. In the case of field no. 8, a small body of hot magma is suspected at a very shallow depth, but the Unalaska Formation and/or plutonic rocks probably occur at this site at least at depths greater than 1000 feet below the ground suface.

Just north of the field no. 2 and in the vicinity of field no. 1 is a sequence of pyroclastic flow deposits positioned on top of glacial tills. Although the thickness of this sequence of recent phyroclasitc deposits varies throughout the valley, its surface is fairly smooth, sloping away from Makushin Volcano. In the vicinity of field no. 1, the base of the sequence consists of a welded breccia flow about 4 to 8 feet thick containing chunks of black "dacitic" glass as large as 20 cm in diameter, dark "andesitic" scoria and pumice. The unit above consists of pumice and scoria chunks as large as 15 cm in diamter in a matrix of lithic fragments and ash, and contains a few blocks as large as 10 feet in diameter. This unit has some crude layering, believed to be flow structures, and is about 300 feet in thickness.

Other thick phyroclastic units were observed to the north and northeast of Makushin Volcano. A similar but much thinner sequence of pyroclasitc deposits was found between fields no. 2 and 3 on the south side of Makushin Volcano.

At present, these phyroclastic deposits are suspected to be related to a caldera forming event that occurred since the last glacial maximum which ended about 11,000 y.b.p.[5], and which may be related to the formation of the existing 1.5 mile diameter Makushin summit caldera. Makushin Volcano has erupted 14 times since 1760[6]. The last eruption occurred in 1938.

Several faults striking between N 40°W to N 70°W were found near the vicinity of the fumarole figlds. Two of these faults which strike about N 60°W extend nearly the entire length of the northern part of Unalaska Island, a distance of over 36 KM, and are considered to be presently active since they disrupt soil horizons. These two faults bound the largest fumarole field in the region.

Due to the underthrusting of one plate under another, such as is presently occurring at the Aleutian trench, compressional stresses in the direction of plate convergence rill exist in the arc region of the upper plate. Since fractures and dikes tend to propagate in a direction normal to the minimum principal stress, their general orientation should reflect the direction of maximum horizontal compression. Nakamura et al.[8] determined the direction of the prinicpal tectonic stress based on the orientation of flank eruptions on volcanoes for the Aleutian volcanic arc. Their findings roughly correlate with the relative motion between the Pacific and North American Plates. For Makushin Volcano, Nakamura et al.[8] determined a maximum stress orientation of N 60°W where the expected asimuth was about N 45°W. If the expected N 45°W asimuth is the actual correct one, then the recognized normal faults striking in a more N 60°W direction should also contain a strike-slip component.

The hydrothermal systems are expected to extend throughout a much larger area than actually indicated by the observed active hydrothermal manifestations. For example, the hillsides throughout the region southeast of Makushin Volcano contain numerous areas of highly altered country rock, which is relic of past hydrothermal activity. In addition, some hydrothermal systems may be capped by less permeable unaltered volcanics, and thus may not be represented by active surface hydrothermal manifestations. On the other extreme, not all and possibly none of the fields observed in 1980 and 1981 are necessarily connected at depth. Instead, several hydrothermal systems are expected, being driven by individual magma bodies oriented in an expected N 60°W direction.

ISLAND LOGISTICS AND GEOTHERMAL POWER PLANT ECONOMICS

.The approaches to the fumarole fields and hence to the potential power plant site are cumbersome. An abandoned military airstrip, 3500 feet by 100 feet, is located at Driftwood Bay.

It is 'expected that this airfield will serve as logistical base for the planned drilling program. The surface of the airstrip is currently in fair condition but it can be upgraded in a short period of time to receive incoming traffic.

Approximately 6 'miles from the end of the runway is Sugar Loaf. An existing road connects the two; however, the road is washed out at various places and considerable repairs are necessary.

Barge transport is possible. Special landing craft should be utilized if Driftwood Bay is to be the landing site. Rocky shores and high surf may hinder the landing operations.

Transmission lines to Unalaska/Dutch Harbor following the construction of the power plant must be helicopter installed. Underwater cable is expected for the final portion of the lines.

Construction costs on Unalaska are significantly higher than elsewhere in the United States. Drilling costs, because of the cumbersome logistics, are expected to be twice the level of established sites such as in the Greysers or in the Imperial Valley. Table 1 presents a best estimate scenario for a 30 MW geothermal power plant on Unalaska Island. A conservative estimate of 50% dry holes is assumed.

A Transmission line, 16 miles long, and a connecting 16 mile gravel road are assessed to the cost of a power plant.

An average geothermal well, producing 200,000 lb/hr of steam (either superheated or separated) can support a 10 MW maximum capacity power plant. Hence, considering the high costs to access the formation, estimates for various sizes of power plants (over 10 MW) are presented on Table 2. All power plant cost estimates include a 55 MW standard generator, a transformer station to handle 55 MW , and 16 miles of transmission line and access road.

The rationale behind the assessment is the anticipated electric utility demand for the Island over the next three decades. Installation of the higher capacity hardware will necessitate only infield drilling to boost sagging well output or increase capacity as the demand escalates.

As expected, the installed cost per MW declines dramatically at higher power plant capacity since the initial construction and access costs are distributed more evenly.

Annual operating costs for a geothermal power plant are showing a much smoother trend. Table 3 presents the estimated annual costs (in 1981 dollars) for various sizes of geothermal power plants.

In the case of an Unalaska geothermal, power plant, with all the prohibitive construction, drilling and transmission costs, a close comparison between this and other alternatives is necessary. Presently, the electric power generation derives almost exclusively from diesel units. While a variety of power plants exists (all commercial processors own private units) an economic incentive may indicate consolidation. Larger units cost proportionally less than several smaller units.

Table 4 presents the capital and operating costs for various sizes of diesel power plants (in 1981 dollars) for Unalaska Island. The fuel cost is set at $1.40/gallon. While all other costs are expected to follow the general inflationary trends, both the supply and price of diesel are unpredictable. A U.S. Bureau of Mines report[9], published in 1975 compared a 2 MW geothermal power plant with a 2 MW diesel unit for Unalaska Island. In addition to the obvious fallacies (an 8000 ft well, and 16 miles of transmission lines and road were assessed against a 2 MW geothermal plant), the cost of fuel was given as 41¢ per gallon. While all other costs escalated by the normal rate of inflation, fuel has increased by a rate several times larger. Hence, the operating costs as shown in Table 4 may be highly underestimated when projected into the future.

Finally, a comparison between geothermal and diesel power plants can be made only in terms of same, maximum output sizes. It is obvious that at small sizes, diesel power plants--the high cost of fuel notwithstanding--will be more attractive. Hence, the search is for that capacity (if any) where the high initial logistical costs of geothermal power generation are balanced by the high operating costs of diesel generation.

Table 5 presents such comparison. The rates of return listed include only costs at the gate of the power plant. They do not'include household system maintenance, in-town transmission and installation and office and support staff. Hence, they are higher than expected but are offerred here far comparison purposes only. Revenues are for sales of 75% of maximum capacity at 15¢/KWh.

Depreciation is for a 30 year life while the tax rate is 50%.

Figure 3 depicts the "joint" where a geothermal power plant appears more attractive than diesel generation.

CONCLUSIONS

Geothermal development on Unalaska Island appears attractive if the electric utility needs of the island exceed 30 MW. The terrain and the location of the potential geothermal resource will pose significant logistical problems; hence, the design of a large output power plant must follow the resource evaluation and the projection of future needs. The latter point touches on significant social and economic considerations that need to be addressed by the local and state governments.

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Table 1. Capital Investment for a 30 MW Geothermal Power Plant, Unalaska Island

ITEM	NUMBER	DESCRIPTION	COST
Well	6	8,000 ft., 7 3/4" diameter (assumed 50% dry wells)	$12,000,000
Piping		3,000 ft., 8" diameter pipe, installed	250,000
Road		3000 ft. of service road, 18-ft-wide gravel, at $200,000/mile	115,000
Generator		55 MW maximum capacity generator, installed	20,000,000
Transformer Station		55 MW at $30/kW, installed	1,375,000
Transmission Line	1	11 miles of transmission line overland (helicopter installed), 5 miles underwater, $100,000/mile	1,600,000
Road		16 miles of 18-ft gravel road at $200,000/mile	3,200,000
		Subtotal	$38,500,000
Contingency		10% of capital	3.850.000
Total to be depreciated			$42,350,000

Table 2. Capital Expenditures for Various Sizes of Geothermal Steam Power Plants

SIZE (MW)	TOTAL EXPENDITURE ($)	$/MW
10	33,300,000	3,330,000
20	40,000,000	2,000,000
30	42,350,000	1,410,000
40	46,920,000	1,170,000
55	56,000,000	1,000,000

Table 3. Esimated Annual Operating Costs for a Geothermal Power Plant on Unalaska Island

PLANT SIZE	$1000/YEAR
10 MW	4,502
20 MW	4,971
30 MW	5,136
40 MW	5,455
55 MW	6,091

30 MW CASE

ITEM	DESCRIPTION	COST ($1000)
Employee Compensation	3 Professionals x $50,000, 25 Hourly x $40,000 Plus 50% Benefits	1,725
Wells	Maintenance	100
Plant Facilities	.1% Generator Cost	200
Piping	20% of Pipe Cost	50
Transmission Line	2% of cost	32
Road	2% of cost	64
Fixed Costs	7% of Investment	2,965
	TOTAL ANNUAL COSTS	5,136

Table 4. Capital and Operating Costs ($1000) for Diesel Power Plants on Unalaska Island (including generators, transformers, fuel tanks and 10% contingency)

SIZE	CAPITAL COST	WAGES ($40/kW)	FIXED COSTS (7%)	FUEL COST (1.40/gal)*	TOTAL OPERATING COSTS
10 MW	8,600	400	602	5,082	6,084
20 MW	15,400	800	1,078	10,164	12,042
30 MW	20,600	1,200	1,442	15,246	17,888
40 MW	24,100	1,600	1,687	20,328	23,615
55 MW	33,000	2,200	2,310	27,951	32,461

* 363,000 gallons/MW/year.

Table 5. Comparative Economics of Geothermal and Diesel Power Plants

SIZE	GEOTHERMAL (ROR)	DIESEL (ROR)
10 MW	9%	24%
20 MW	20%	27%
30 MW	31%	31%
40 MW	38%	35%
55 MW	45%	36%

30 MW CASE ($1000)

	GEOTHERMAL	DIESEL
Revenues	29565	29565
Operating Costs	5136	17888
Depreciation	1412	667
Cash Flow Before Taxes	23017	11010
Minus 50% Taxes	11509	5505
Cash Flow after Taxes (+Depreciation)	12921	6172
Rate of Return	31%	31%

Figure 1: Some of the Aleutian islands and the Alaska Peninsula

Figure 2: Northern Unalaska Island, Showing the Position of the Fumarole Fields

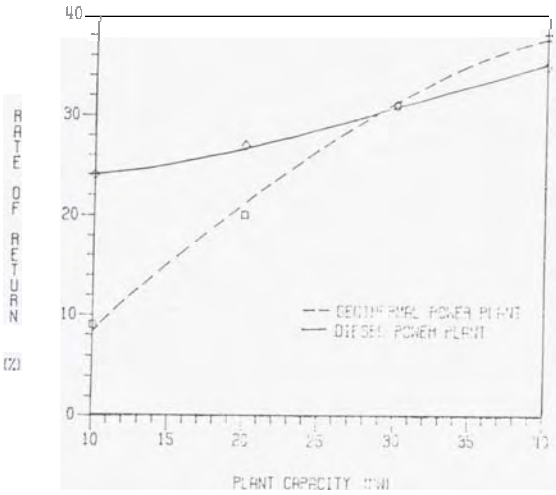

Figure 3: Comparative Economics for Geothermal and Diesel Power Plants on Unalaska Island