SUBSURFACE GEOLOGY OF THE NASUJI-SOGONGON SECTOR, SO. NEGROS GEOTHERMAL FIELD, PHILIPPINES

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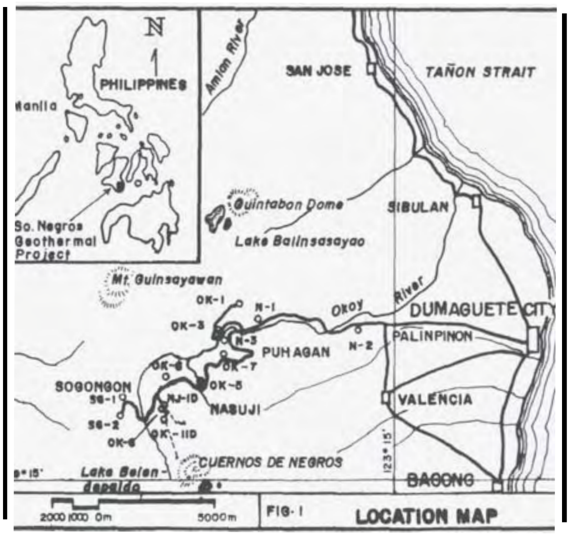
ABSTRACT

A geological assessment of the Nasuji-Sogongon sector in the Southern Negros Geothermal Field, including salient features of the subsurface stratigraphy, lithology, alteration mineralogy, temperature, permeability and structure acquired from wells completed in this area as of February 1982, is discussed.

Hydrothermal alteration zones are established based on the relative distribution and association of alteration minerals in cores and cuttings of the Nasuji-Sogongon wells. Fluid inclusion and alteration mineralogy temperatures compared with stable rock temperatures indicate that the present system has undergone considerable temperature decline but remains economically exploitable. Most of the production zones are confined within the plutonic body as recogniaed in SG-1, SG-2 and OK-6.



INTRODUCTION

The So. Negros Geothermal Field (fig. 1) encompassing the sectors of Puhagan, Nasuji and Sogongon is situated within the coalescing volcanic centers of Cuernos de Negros, Guinsayawan and Balinsasayao.

The Puhagan sector, where 6 wells viz: OK-7, OK-9D* OK-10D, PN-13D, PN-15D, and PN-17D have already been tested, accounts for a proven energy potential of 42 MWe. The first of the three 37.5 MWe steam turbines will be commissioned for the 112.5 MWe (Palinpinon I) power plant in this area by June 1983 (Harper and Arevalo, 1982).

A 110 MWe (Palinpinon 11) power plant will be committed for development in the Nasuji-Sogongon sector for 1983-86. A power potential of approx. 37 MWe has been proven in this area based on five wells drilled (OK-S, OK-6, OK-8, SG-1 and SG-2). However, OK-11D and NJ-1D are both relatively impermeable and OK-11D did not sustain discharge while NJ-1D is still undergoing further testing. These 7 wells drilled in the Nasuji-Sogongon sector (as of February 1982) have provided the basis of discussion in this paper.

SURFACE GEOLOGICAL BACKGROUND

Surface exposure within the So. Negros Geothermal Field (fig, 2) consists mostly of 3 lithological units of the Cuernos Volcanics (CV), viz: younger andesite (upper member), dacite (middle member) and older andesite (lower member). In the Nasuji-Sogongon sector, outcropping units of dacite and older andesite are usually encountered. Further, no distinct surface thermal manifestations exist like hot springs or fumaroles but extensive hydrothermally altered ground and few Kaipohans** have been observed. Petrographic and XRD analyses of the Nasuji-Sogongon surface samples (Zaide, 1982) indicate the occurrence of high temperature alteration minerals within the lower member of Cuernos Volcanics, namely: kaolinite, illite, illite-montmorillonite and pyrophyllite?, which suggest a former high temperature system that was reduced to a fossil hydrothermal zone.

*D - abbreviation for a direction well as opposed to a vertical well.

**Kaipohan is an area of low temperature acidic leaching devoid of vegetation which is mainly due to the passage of separated H_2S and CO_2 gases probably emanating from a deep high temperature reservoir.

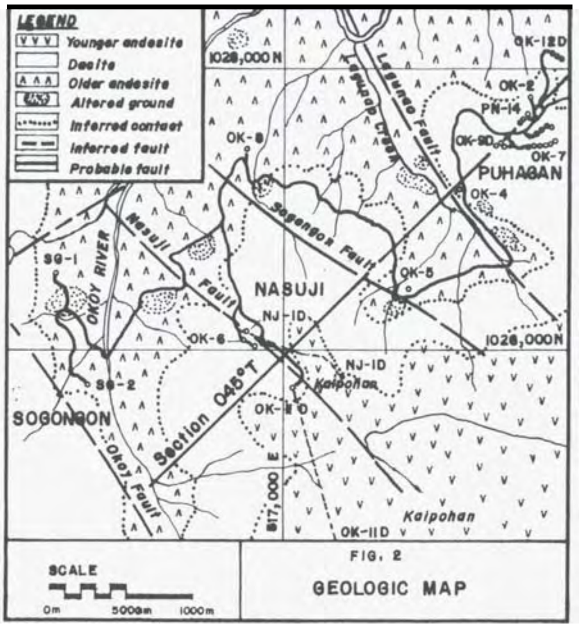


FIG. 2

GEOLOGIC MAP

The northwest-southeast trending faults (fig. 2) are identified as the major structures that transect the Cuernos Volcanics and control the drainage pattern in the area. Altered ground and Kaipohans occur along these recognized structures.

SUBSURFACE STRATIGRAPHY AND LITHOLOGY

The Cuernos Volcanics (table 1), characterized by weak hydrothermal alteration and porphyritic texture, is encountered by all the Nasuji-Sogongon wells (fig. 3-5). Although a black paleosol layer is found in the surface near Palinpinon (fig. 1) as the contact between the Cuernos Volcanics and So. Negros Formation, its occurrence in most of the wells drilled in the So. Negros Geothermal Field has not been clearly recognized. However, a convention that the first occurrence of breccia often succeeding a highly ferruginous layer which probably indicates the appearance of So. Negros Formation, is arbitrarily applied in this report. Typically, the So. Negros Formation includes lithological units of homogeneously andesitic composition.

Only the wells drilled on the east of the NW-SE trending Sogongon fault (fig. 2-5) viz: OK-5 and OK-8 penetrated the rock units of the Okoy Sedimentary Formation. The relative disappearance of the Okoy Sedimentary Formation from the west of Sogongon fault may be due to its relative southwest thinning from the Puhagan area to the Nasuji-Sogongon sector.

A significant thickness of homogeneous volcanics have been observed below the sedimentary members of the Okoy Sedimentary Formation in OK-8 (fig. 3-5). This has also been recognized in the Puhagan sector but was defined as the Puhagan Volcanic unit within the Okoy Sedimentary Formation. However, the Puhagan Volcanics should be considered as a separate formation instead of a unit status since it involves a different deposition mechanism.

TABLE-1

GENERALIZED SUBSURFACE STRATIGRAPHY OF THE NASUJI-SOGONGON SECTOR

FORMATION	LITHOLOGY	AGE	MAXIMUM THICKNESS PENETRATED
[illegible] (CV)	HB. ANDESITE / DACITE, TUFF	PLIOCENE QUATERNARY	150 m IN OK-7
SOUTHERN NEGROS FORMATION (SNF)	INTERCALATING UNITS OF VARIABLY SILICIFIED AND CHLORITIZED ANDESITE BRECCIA, ANDESITE LAVA, PROPYLITIC ANDESITE. TUFF AND TUFF BRECCIA.	LATE MIOCENE TO PLIOCENE	1680m IN OK-11D
OKOY SEDIMENTARY FORMATION (OSF)	SILTSTONE, VOLCANICLASTIC SEDIMENTS OFTEN INTERCALATED W/ PROPYLITIC ANDESITE.	LATE MIOCENE	475m IN OK-5
PUHAGAN VOLCANICS (PV)	SEQUENCE OF ANDESITE LAVA & VOLCANIC BRECCIA.	POST PLIOCENE TO LATE MIOCENE	783 m IN OK-8
CONTANT METAMORPHIC ZONE	HORNFELS	POST PLIOCENE	505 m IN OK-11 D
NASUJI PLUTON (NP)	QUARTZ MONZODIORITE.	POST PLIOCENE	1410m IN SG-1

The Contact Metamorphic zone consists of a light to dark greyish hornfels usually exhibiting a granoblastic texture. This zone is relatively thin in SG-1 where the main rock is cut by numerous veins of quartz + adularia + anhydrite + illite (Reyes, 1981).

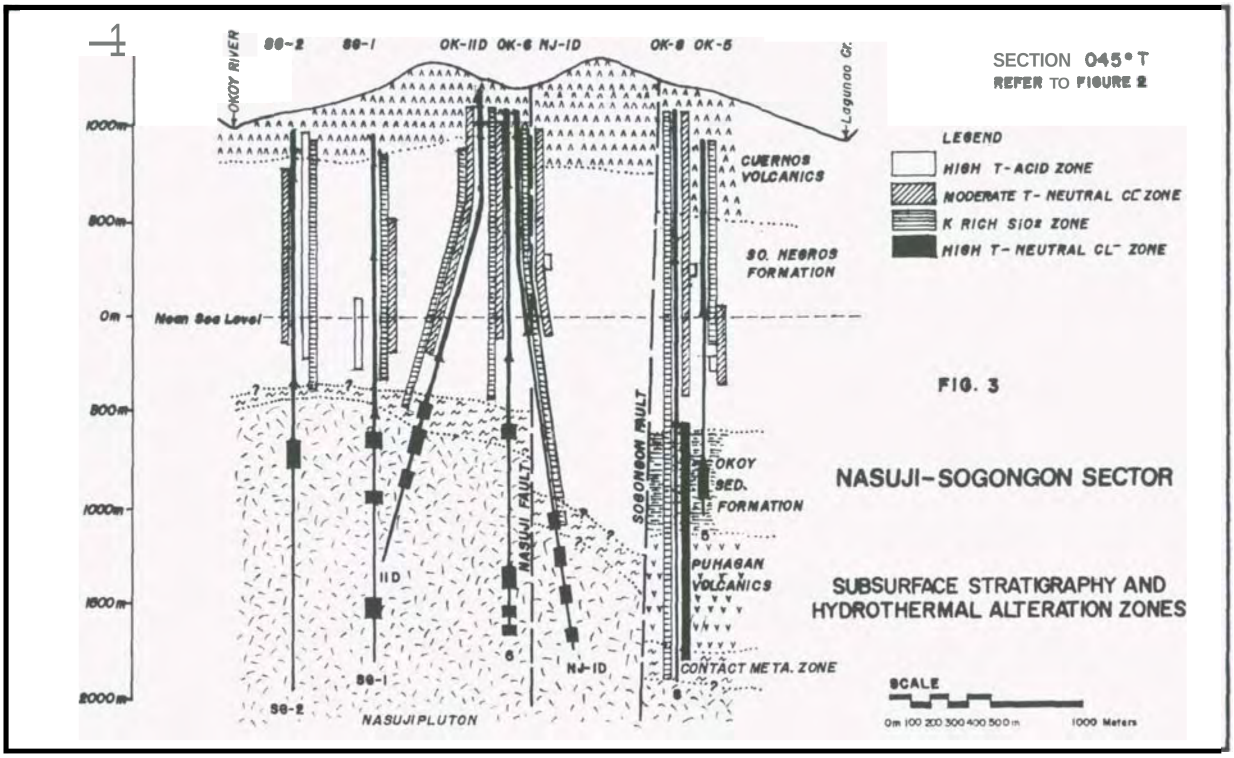
The Nasuji Pluton is generally light grey, massive monzodiorite with green hornblende as the main ferromagnesian mineral. However, as the alkali feldspar and quartz content of the rock increases, it grades into granodiorite (e.g. SG-1). In OK-11D and SG-1, the periphery of the intrusive is characterized by the presence of cataclasites. This indicates a continuous intrusive movement after the pluton had become partially or wholly solidified where grains and grain boundaries may be fractured and mafic minerals aligned (Huang, 1962). In addition, chilled dacite occasionally forms the margin of the pluton as observed in SG-1 and OK-6.

ALTERATION MINERALOGY

Alteration in the Nasuji-Sogongon area of the So. Negros Geothermal Field is usually of the contact metamorphic or hydrothermal type.

The intrusion of the pluton resulted in the contact metamorphism of the *So.* Negros Formation and Puhagan Volcanics. There is no distinct evidence yet of the contact metamorphism of Okoy Sedimentary Formation. In well-defined hornfelsic texture (e.g. OK-6 and OK-11D), a contact metamorphic assemblage of secondary intermediate plagioclase + biotite + actinolite + magnetite + epidote + albite is encountered (Reyes, 1981). This assemblage appears equivocal when obliterated by intense hydrothermal alteration. Alteration within the contact metamorphic zone is conaidered hydrothermal only when it is found in veins associated with other hydrothermal minerals.

Hydrothermal alteration exists in all the formation encountered in the sector, i.e., from the lower



member of Cuernos Volcanics to the Nasuji Pluton (fig. 3). Since blind drilling* is usually encountered in the Nasuji Pluton except in OK-11D, hydrothermal alteration distribution within the plutonic body was based on cores (fig. 4). Commonly, four distinct types of hydrothermal alteration (fig. 3) often superposing each other, have been recognized as enumerated and discussed below:

1. High Temperature Acid Alteration Zone

This zone consists of pyrophyllite + diaspore assemblage resulting from intense leaching under acidic conditions. Since an assemblage of pyrophyllite + diaspore usually forms at a minimum temperature of 280°C (Hemley et al, 1980), the acid leached zone is believed to be relict when compared to the present stable rock temperature of generally less than 230°C (fig. 3 and 5).

However, aside from pyrophyllite + diaspore assemblage, a lower temperature acid assemblage of kaolinite + alunite has been found locally occurring in So-2 (Bogie, 1982). A temperature of -260°C is inferred for this zone since:

a. Kaolinite is stable only up to 260°C (Hemley et al, 1980).

b. Alunite has been identified at depth in the Matsukawa field in Japan at temperature of 250-280°C with a pH of 3-4 but it is also stable up to a temperature of around 380°C at 1 kb at an extremely acid condition (Hemley. et al, 1969).

The kaolinite + alunite assemblage in SG-2 is considered relict if compared to the stable rock temperature of -235°C.

2. Moderate Temp. Neutral Chloride Alteration Zone

The moderate temperature neutral chloride zone is characterized by an assemblage of chlorite + calcite + anhydrite + epidote. Based on the presence of epidote, a temperature of 240-260°C (Browne, 1978) is estimated for this assemblage. However, if compared with the stable rock temperature of less than 240°C, this zone is also considered relict.

3. K rich Si02 Alteration Zone

The K rich Si02 alteration zone as adapted from Reyes (1981), consists of abundant quartz + adularia + anhydrite + illite. The estimated temperature of formation for this assemblasge based on the presence of illite is set at less than 220°C (Browne, 1978). This has been classified as relict but the corresponding stable rock temperature reaches 280°C which is greater than the -220°C inferred for this zone. It is believed that the stable rock temperatures pertaining to a current phase of hydrothermal activity postdates the K rich Si02 alteration episode.

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*Blind drilling is a term applied when wells are drilled without fluid returns.

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4. High Temperature Neutral Chloride Alteration Zone

This zone is an assemblage of anhydrite + chlorite + epidote + biotite + actinclite ± garnet. Since the Nasuji Pluton has been altered hydrothermally i.e. by high temp. neutral chloride waters (fig. 3), it suggests a recent phase of hydrothermal activity. Hence, the present stable rock temperatures probably represent the high temp. neutral chloride alteration stage. A temp. of formation greater than 320°C is estimated for this assemblage based on the following.

a. Biotite is found occurring at temperature of +325°C in the Cerro Prieto Geothermal Field. (Wood, 1980).

b. Hydrothermal garnet is usually found at temperature above 320°C (Browne, 1978).

If compared with the stable rock temperature of 220-290°C within this zone, the high temperature neutral chloride alteration is relict.

SUBSURFACE TEMPERATURES AND INTERPRETATION

1. Stable Rock Temperature Trend

Downhole temperature data obtained during heat-up, medium term discharge test, post medium term test and shut-in conditions after discharge were evaluated to determine the stable rock temperature profile of each well (Amistoso, 1982). The stable rock temperatures are based on the following:

a. stable inflow temperature with the well shut or on bleed.

b. stable bottomhole temperature under no flow or on discharging conditions.

c. stable well temperature under no flow condition.

d. stable inflow temperature under discharging conditions.

A generalized cross section showing the estimated stable rock temperature trend at 045°T (fig. 5) indicates a decreasing temperature trend towards the southwest from OK-5 to SG-1. This suggests that, generally, the Nasuji-Sogongon sector lies in a cooler region. However, the temperature data obtained from SG-2 appears anomalous since it exhibits an abnormally high temperature of 280°C near the casing shoe (fig. 5). This anomaly may be due to the presence of the Okoy fault through which a near vertical flow of hot fluids may arise.

2. Fluid Inclusion, Alteration Mineralogy and Stable Rock Temperatures

A comparison of the stable rock temperatures with fluid inclusion temperatures (table 2) shows that the hydrothermal system has cooled down. However, in core 3 of OK-8 (table 2), the fluid inclusion temperature of 245-250°C is in close agreement with stable rock temperature of 252°C indicating fhe most recent fluid incursion at this depth. The abundance of epidote in this core suggests a much higher temperature of alteration mineralogy at 280-300°C (Leach, 1981). It seems, therefore, that this level has significantly cooled down since the episode of hydrothermal alteration that formed abundant epidote and chlorite.

TABLE - 2
SUBSURFACE TEMPERATURE CORRELATION

WELL NAME	CORE NO.	VERTICAL DEPTH m CHF	FLUID INCLUSION TEMP. (°C)*	ALTERATION MINERALOLOGY TEMPERATURE (°C)	STABLE ROCK TEMP(°C)
OK-8	2	748	245-250	230-250-* (I+I-M+Wel)	79
	3	1688	245-250	280-300* (Abundant Ept+Ch)	252
OK-11D	1	1800	238-262	240-260** (Ep+Ch)	231
SG-1	1	1501	248-268	240-260** (Ep+Ch)	235
	4	2493	268-290	280-300* (Abund.Ep+Ch)	246
SG-2	1	1393	304-306	240-260** (Ep+Ch)	278
NJ-1D	2	1710	260	+320** (Bio)	914
	4	2029	285	+320** (Act.	901

* Leach (1981-82)
** REFER TO SECTION ON ALTERATION MINERALOGY.

The stable rock temperatures are comparatively lower than the alteration mineralogy temperatures (table 2) suggesting that cooling has occurred since the formation of the hydrothermal minerals.

STRUCTURES AND PERMEABILITY

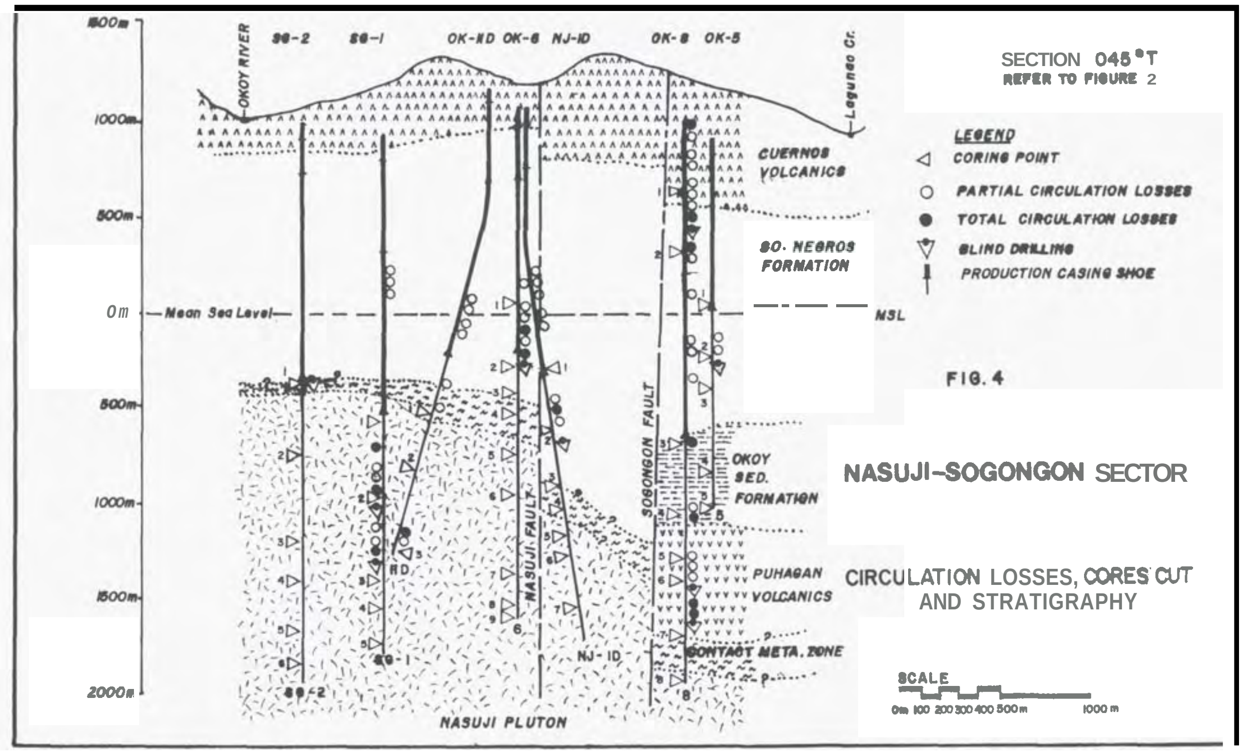
1. Circulation Losses:

Massive circulation losses encountered during drilling in the Nasuji-Sogongon wells are concentrated mostly within the So. Negros Formation except in SG-1 where they are confined in the plutonic body (fig. 4). However, majority of the extensive losses in the So. Negros Formation have already been cased-off.

It is also evident that circulation losses at the periphery of the Nasuji Pluton are relatively scarce. Most wells are drilled blind in the pluton except from OK-11D where full circulation was maintained until the bottom.

2. Production/Permeable Zones:

Completion testing, heat-up and flowing surveys delineated various production/permeable zones in the Nasuji-Sogongon sector. In consonance with circulation losses, the production/permeable zones are relatively scarce at the margin of the Nasuji Pluton but are generally confined within



the plutonic body as recognized in OK-6, SG-1 and SG-2 (fig. 5). It is only in SG-2 where production at the periphery of the Nasuji Pluton was defined.

3. Mechanics of Plutonic Emplacement and Fracturing

Based on the cores and cuttings analyzed from wells drilled in this area, it seems that the plutonic body was forcefully injected as suggested by the following.

a. The presence of distinct linear flow structures, suggesting the parallel arrangement of the long axes of prismatic minerals viz: feldspar and hornblende, indicate parallelism to the direction of magmatic flow. This suggests forceful injection through an active upward rise of an intrusive magma (Badgley, 1965).

b. The presence of cataclasites at the immediate periphery of Nasuji Pluton indicate a continuous movement by forceful injection of the central portion of the pluton after it partially or wholly solidified.

In a forcefully injected pluton, fractures develop at its outer shell after this portion has completely solidified while the interior is still mobile (Badgley, 1965). However, in the Nasuji-Sogongon sector, these fractures may have been sealed by the advent of SiO_2 rich geothermal fluids which account for the relative scarcity of production/permeable zones and circulation losses within the periphery of the Nasuji Pluton.

It has been observed in the Nasuji-Sogongon wells that permeability within the plutonic body is generally unpredictable. Whatever permeability there is in the Nasuji Pluton may be due to a pervasive fracture system.

Although there are indications of permeability within the pluton, plutonic bodies are inherently less permeable than the volcanics (Alcaraz, 1982). However, wells OK-6, SG-1 and SG-2 which obtained the bulk of their production within the pluton account for approx. 26 MWe of the total 37 MWe that have already been proven.

CONCLUSIONS

Four types of hydrothermal alteration have been identified in the Nasuji-Sogongon sector, namely: the high temperature acid alteration, moderate temperature neutral chloride alteration, K rich SiO_2 alteration and high temperature neutral chloride alteration.

A comparison of stable rock temperatures with fluid inclusion and alteration mineralogy temperatures, generally, indicates that the present hydrothermal system has significantly cooled down but still commercially exploitable.

K rich SiO_2 hydrothermal waters have probably sealed the fractures formed at the margin of the Nasuji Pluton which account for the relative scarcity of circulation losses and permeable/production zones at this mentioned margin.

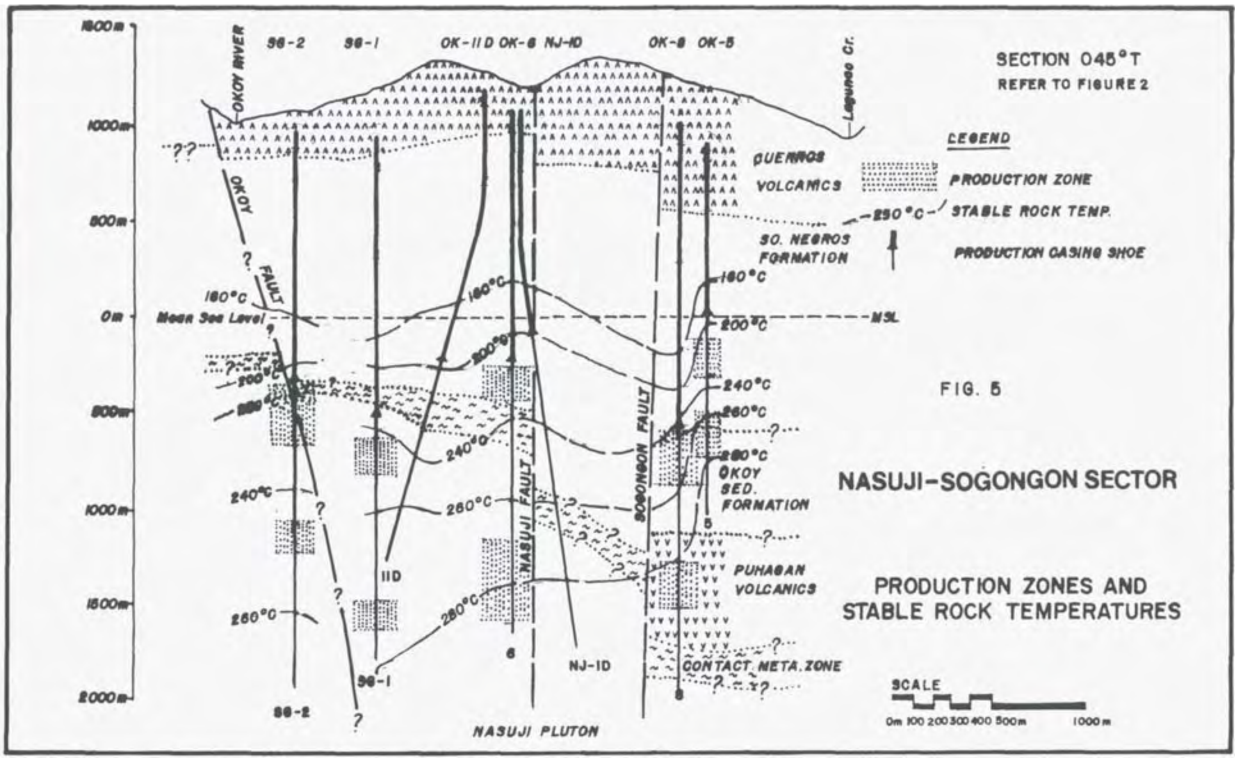


FIG. 5

NASUJI-SOGONGON SECTOR

PRODUCTION ZONES AND STABLE ROCK TEMPERATURES

Permeable/production zones within the plutonic body have been recognized in the Nasuji-Sogongon sector but its mechanism remains equivocal.

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