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DETECTION OF A TWO-PHASE RESERVOIR BENEATH KUJU VOLCANO, JAPAN AND VOLCANO ENERGY UTILIZATION

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ABSTRACT

Kuju-iwoyama, which is the most active fumarolic area in central Kyushu, Japan is situated at an explosive crater of Kuju volcano. The natural heat discharge is estimated at about 100 MW aird most of it (more than 95 %) are from steaming grounds and fumaroles. Temperatures of fumaroles generally exceed 200℃ and the maximum temperature is 380°C.

Anomalously high microearthquake activities were detected just beneath the fumarolic area down to about 1 to 1.5 km depth from the surface. An extremely low resistivity zone lower than 5 ohm·m was detected just beneath the fumarolic area down Lo about, 1 to 2 km depth by ELF- and ULF-MT methods.

Thermal wodelling sliows that the above-mentioned seismic active and low resistive zone is in a state of two-phase. Numerical simulation of heat extraction from the reservoir shows that 10 MW power generation for more than 10 years is possible without having big effect on natural geothermal activities.

INTRODUCTION

One of the main goals of volcano energy utilization is extraction of heat from magma. But there are many problems Lo be solved in order Lo extract heat from magma, for example, location and delineation of magma, heat transfer mechanism in a magma, and safe and stable extraction of heat etc. Then an alternative strategy for volcano energy utilization is presented, based on our recent studies on Kuju volcano in central Kyusu, Japan.

Hecently, thermal, microseismic and magneto-telluric observations were made on Kuju volcano. Natural heat and mass discharges were estimated (Ehara et al., 1981). Microseismic and magnetotelluric observations clarified the undeground structure of Kuju volcaiio. Combining the thermal and structural data, a quantitative thermal wodel was presented by computer modelling. By using the model, extraction of heat was simulated. In this paper, we describe the thermal, seismic and magnetotelluric results first arid then discuss the thermal modelling.

KUJU VOLCANO AND ITS GEOTHERMAL ACTIVITY

Kuju volcano is to the northeast of Aso volcano, which *is* one of the most active volcanoes in Jpan. The distance between them is about 25 kn. The Kuju volcano group is composed of many lava domes. The oain rock type is hornblende andesite (VSJ arid IAVCEI,1971). The volcanic activity started about 0.3 Ma and the youngest K-Ar age of Kuju volcanic rocks is 0.05 Ma (Hayashi, 1988). Phreatic explosions occurred in historic ages. Kuju-iwoyama is an explosive crater of Mt. Hosshouyama of the group and show the most intense geothermal (mainly fumarolic) activity. The fumarolic area (c.a. 0.2 km^2) is at the northeastern flank of Mt.Hosshouyama.

The natural heat discharge is estimated at about 100 MW aiid most of it (more than 95%) are from fumaroles and steaming grounds (Ehara et al., 1981). The temperature of fumaroles generally exceed 200 ℃ and the observed maximum temperature of fumaroles is 480 ℃(Iwasaki et al.,1964). Volcanic gas emissions are estimated at 168 tons/day (CO_2), 53 tons/day (H_2S), 26 tons/day (SO_2), 3.1 tons/day (S), 3.1 tons/day (HCl) and 0.07 tons/day (HF) (Ehara et Al. ,1981).

SEISMIC OBSERVATION

A temporary seismic observation system was installed just around the fumarolic area (Fig.1, St.1 - 5), in order to investigate Ltie relation between seismic activity and thermal process beneath it. As a result., anomalously high microearthquake activities were detected just beneath the fumarolic area down to about 1.5 km below the surface (from May 27 to June 10 ,1986, Fig.2). Furthermore, the latest result (from July 27 to Dec. 8, 1988) shows that microearthquakes occur at relatively shallower depth (down to 1 km) of the fumarolic area. The daily numbers of observed microearthquakes are 10 to 20 on the average. However, the mode of occurrence is rather swarm type. For example, about 10 earthquakes occur very often in a few minutes. The b-values are about 0.9 Lo 1.2.

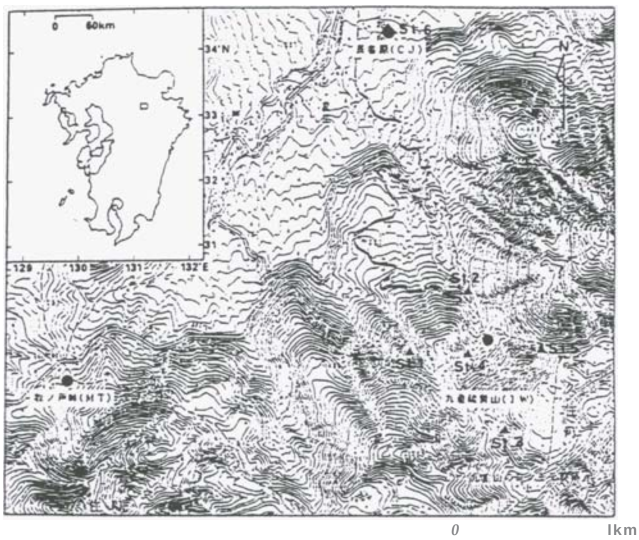


Fig. 1 Seismic stations on Kuju volcano. Solid triangle:Multipartite seismic stations(st.1-6). Solid circle : Seismic stations for monitoring.

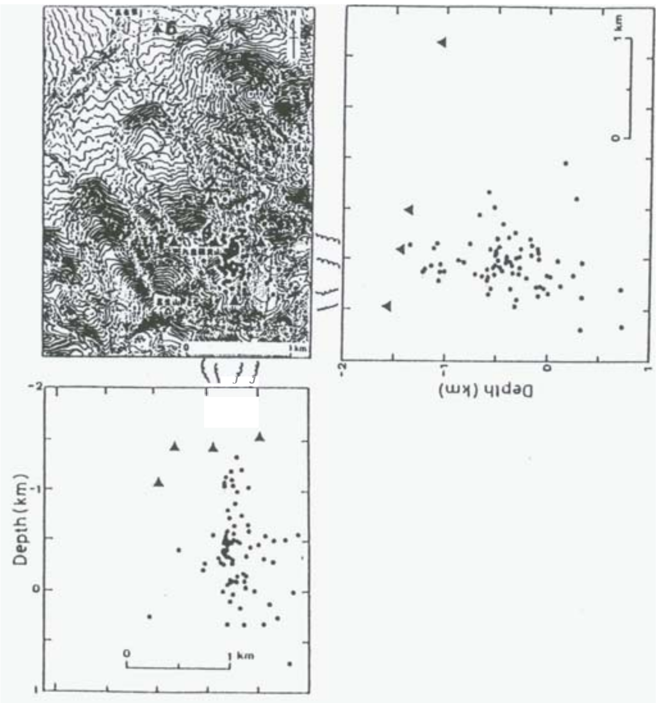


Fig. 2 Hypocenter distribution near the fumarolic area. Solid triangle: seismic stations. Solid circle: hypocenters.

Anomalously low velocity structure was detected just beneath the fumarolic area(Fig.3). The blocks with thick solid lines show lower P-wave velocities comparing with the initial velocity structure, which is used for hypocenter determination. The low velocity parts extend down to 2 km depth. Lower Poisson's ratio was also obtained just beneath the fumarolic area. Superimposed focal mechanisms do not show a unique solution.

The origin of such anomalous Microearthquake activities just beneath the fumarolic area is considered to be high pore fluid pressure in the two-phase reservoir beneath the area. The detailed discussion will be done later.

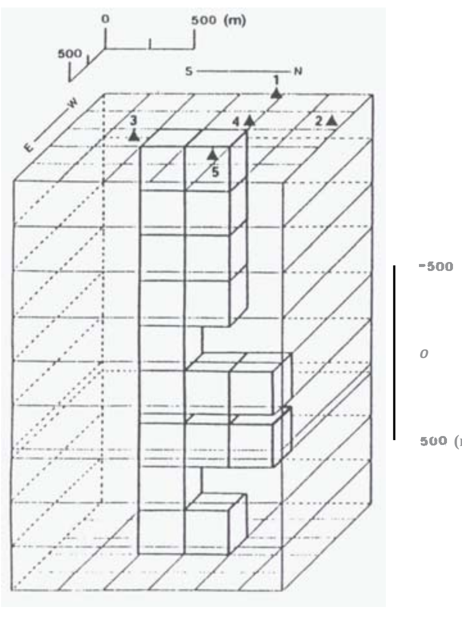


Fig. 3 Lower-velocity blocks (thick solid lines). Solid triangles show seismic stations.

MAGNETOTELLURIC OBSERVATION

ELF (8 to 40 Hz)- AND ULF (0.0026 to 0.05 Hz) - magnetotelluric soundings were made at 147 and 7 points on Kuju volcano, respectively. The artificial electromagnetic wave from a military VLF transmitter station at 17.4 kHz was also observed in order to detect the shallow structure. Apparent resislivity distribution(7.8 Hz) is shown in Fig.4. The apparent resistivity values in Fig.4 are invariant resistivity ones (Berdictievsky et al.,1980) at 7.8 Hz. Fig. 4 shows that an extremely low resistivity zone, less than 10 ohm-m , exists at the Kuju-iwoyama area (around KI in Fig.4). The two-dimensional inversion was done by the finite element modelling Cor the profile A-A' in Fig.4. The subsurface structure was assumed to be simple two or three layer-structure in this study. Fig.5 shows a result of the two-dimensional inversion. Extremely low resistivity value was detected beneath the Kuju-iwoyama area. Generally, the first layers show 50 to 300 ohm-m and their thicknesses are 30 to 200 m. The second layers show different values at different sites. The third layers show about. 300 ohm-m, except the Kuju-iwoyama area, where the resistivity is about 1 ohm-m. The depth of the low resistivity zone (about 1 km) beneath the Kuju-iwoyama area was determined by using ULF MT data. The three-dimensional analysis was also done by the finite element modelling for the region around Kuju-iwoyama (broken rectangle in Fig. 4). The low resistivity zone lower than 5 ohm-m cas detected just beneath the fumarolic area (Fig.6). The lor. resistivity zone was limited to 900 m in the E-W direction arid 500 m in the N-S direction.

The above-mentioned low resistivity zone just beneath the fumarolic area is considered to originate io the hot geothermal fluid.

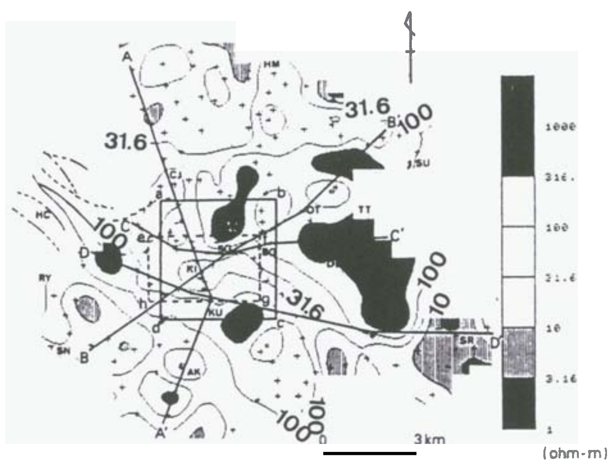
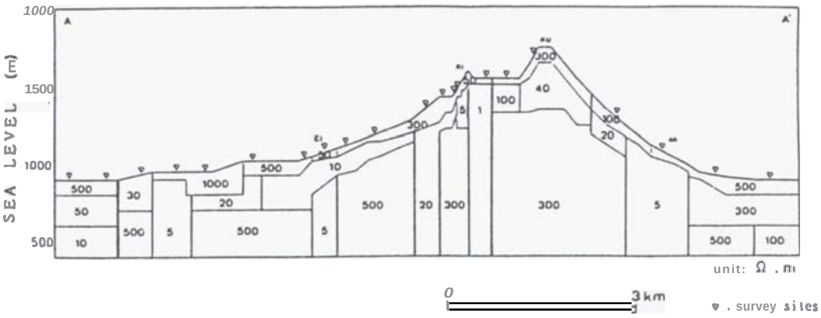


Fig. 4 MT survey sites and apparcnl resistivity distribution(7.8 Hz). + :ELF-MT method, O ULF-MT method. KI : Kuju-iwoyama. HC : Hatchoubaru geothermal power station, A-A', B-B', C-C' and D-D': profile for two-dimentional analysis. Broken rectangle : area for three-dimensional analysis. Solid line : faults. Broken line : assumed faults.



Pig. 5 Two-dimensional resistivity model for the profile A-A'.

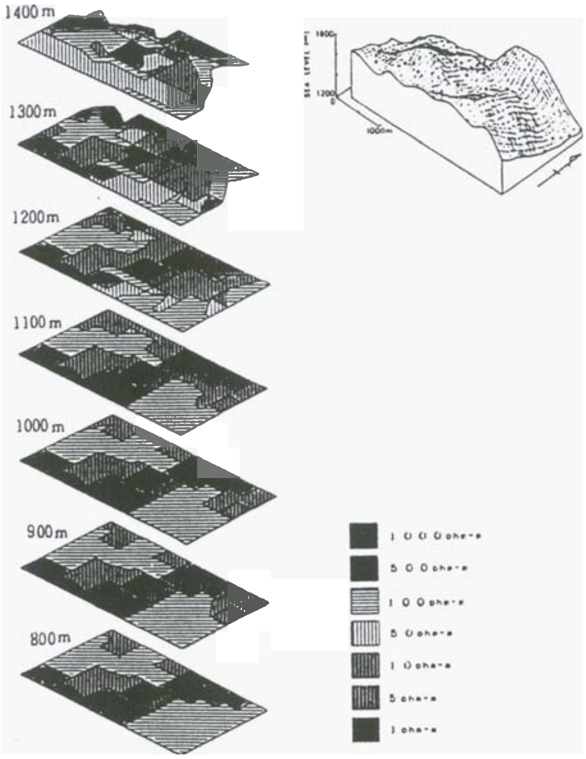


Fig. 6 Three-dimensional resistivity model for the broken rectangle in Fig. 4.

THERMAL MODELLING

A conceptual thermal model 'cas presented based on the thermal(Ehara et al.,1981),isotopical(Matsubaya et al.,1975) and structural (this study) data as shown in Fig.7. The drilling(NEDO,1988) and gravity (Komazawa and Kamata, 1985) data show the depth of basement is 1.5 to 2 km in this area. The isotopic study of fumaroles, hot springs, arid groundwater shows mixing meteoric water with magmatic water. The lor resistivity zone will extend to the depth of the basement. Microearthquakes occur at a shallower depth than that of basement.

Based on Ltie above-mentioned conceputual model, thermal process beneath the active fumarolic area was simulated by computer modelling(Pruess and Schroeder, 1980, O'Sullivan, 1985), assuming a cylindrical symmetric body. The high permeable zone extends from the surface Lo 2 km depth. The diameter of the area concerned is 5 km, considering the recharge area (Kawamura,1984) as shown in Fig.8. Magmatic steam is supplied from the bottom surface of the central part but the boundary conditions at the side are adiabatic and impermeable. A good fit model is shown in Fig.9. In the model, the magmatic steam of 30 kg/s (enthalpy = 3500 kJ/kg) is supplied from below, mixes wilh the ueteoric water of' about 10 kg/s and finally the steam (35.8 kg/s) and the hot water(4.3 kg/s) are discharged at the surface. The calculated heat discharge is 104.4 MW. The temperature, pressure and vapor saturation are shown in Fig. 10. Tlie temperature of the first layer (0-250 m depth) at the central part is about 210℃, which agrees well with the observed fumarolic temperatures. The temperature in the bottom layer. (1750-2000 m) exceeds 340°C. The central high permeable zone is in a state of tho-phase at any depth. The tewpcratures outside the central part are nearly linear with depth, which means that the heat transfer is mainly by conduction. The pressure distribution outside the central part, is near hydrostatic. However, in the central part, the pressure is a little (to 1 MPa) higher than the hydrostatic one. I'he high pressure in the high permeable zone may become an origin of tlie high seismic activity in this part, since the high pore pressure lowers the strength of the rock. This means that microearthquake activities are limited to shallower part of the reservoir. On the other hand, the low resistivity zone extends to the whole reservoir.

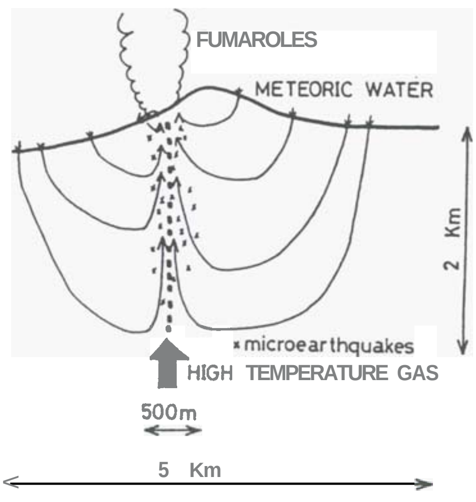


Fig. 7 Conceptual thermal model beneath the Kuju-iwoyama region.

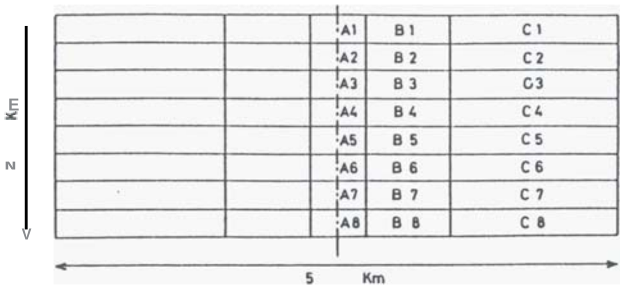


Fig. 8 Block layout for the radially symmetric model (vertical cross section).

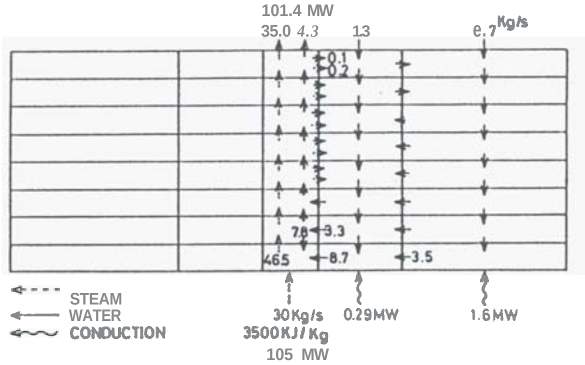


Fig. 9 Quantitative thermal model beneath the Kuju-iwoyama region.

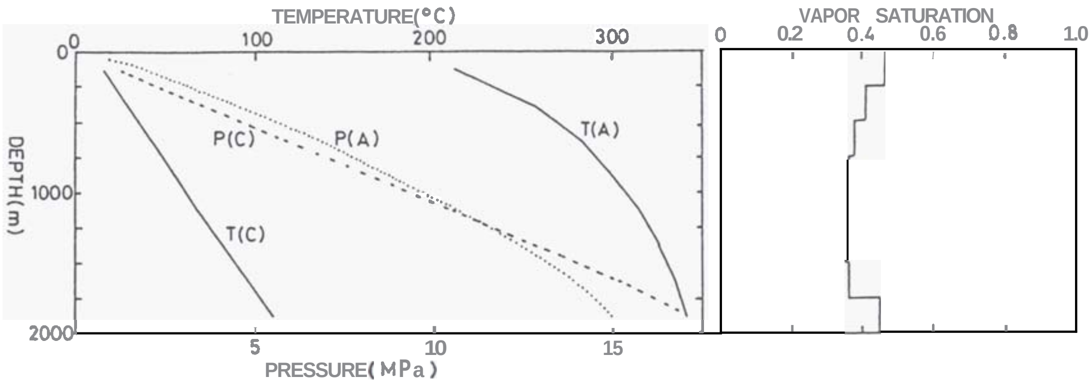


Fig.10 Temperature(T), Pressure(P) and vapor saturation profiles of Zone A (discharge area) and Zone C(recharge area).Refer to Fig. 8 for Zones A and C.

EXTRACTION OF HEAT

A production process was simulated by extracting the fluid from the shallow part (250-500 m), by using the above-mentioned good fit model. The production rate is 30 kg/s, which is coaparable to 10 MW power generation. The temporal variation of several physical properties during exploitation are shown in Fig.11. As a result, it is concluded that heat extraction for more than 10 years is possible without having big effect on natural geothermal activities.

CONCLUSION

A seismic active arid low resistivity zone was detected just beneath an active fumarolic area of Kuju volcano in central Kyushu, Japan. Combining the structural and thermal data, a numerical thermal model was presented by computer modelling. The model shows the existence of two-phase geothermal reservoir just beneath the fumarolic area. l'he origin of anomalous microearthquake activity just beneath the fumarolic area is considerd to be high pore fluid pressure in the two-phase reservoir. Microearthquakes occur only in Lhc shallower part (1 Lo 1.5 km depth) of the reservoir. On the other hand, the low resistivity zone, which originate in the hot geothermal fluid extends to the whole reservoir.

A production process was simulated by extracting fluid from the shallow part(250-500 m). As a result,it is concluded that the heat extraction which is comparable to 10 MW power generation for more than 10 years is possible without having big effect on natural geothermal activities. The development of the two-phase reservoir just beneath the active fumarolic area of a volcano is a possible method to utilize volcaiio energy in the near future.

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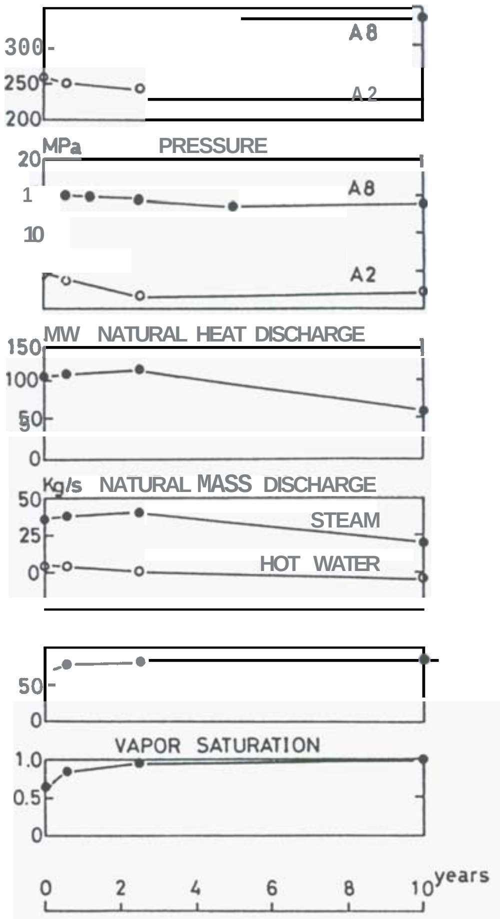

Fig. 11 Temporal variations of several physical properties during the short term exploitation of' the shallow reservoir(250 m-500 m depth).

REFERENCES

Herdichevsky, M. N. et al. 1980: Geoelectrical model of the Bikal region, Phys. Earth Planet. Inter., 22, 1-11.

Ehara, et al. 1981: Hydrothermal system and the origin of the volcanic gas of Kuju-iwoyama volcano, Japan, deduced from heat discharge, water discharge and volcanic gas emission data. Bull. Volcanol. Soc. Japan, 26; 35-56(in Japanese with English abstract).

Hayashi, M. 1988: Quaternary volcanisa as the heat source for some geothermal fields in Kyushu, Japan. Proceedings of the international Symposium on Geothermal Energy, 1988, Kumamoto and Beppu, Japan; 446.

Iwasaki, et al. 1964: Volcanic gases in Japan. Bull. Tokyo Inst. Tech., 47; 1-52.

Kawarura, M. 1984 : Thermal condition of the geothermal field around Mt. Waita in central Kyushu, Japan, (1) Distributions of' subsurface temperature arid heat discharge, Jour. Geotherm. Res. Soci. Japan, 6 ; 217-241(in Japanese with English abstract).

Komazawa, M. aiid Kamata, H. 1985 : The basement structure of the Hohi geothermal area obtained by gravinetric analysis in central-north Kyushu, Japan, Rep. Geol. Surv. Japan, 264; 303-333 (in Japanese with English abstract)

New Energy Development Organization, 1988 : An interim report, Kuju area, 65-120(in Japanese).

Matsubaya, et, al. 1975 : Isotopic study of hot springs and volcanic gases in Satsuma-iwojima and other volcanoes in Kyusu, Japan, Bull. Geol. Sur. of Japan, 26: 375-392(in Japanese with English abstract).

O'Sullivan, M. J. 1985 : Geothermal reservoir simulation, Energy research, 9 : 319-332.

Pruess, K. and Schroeder, R. C. 1980 : SHAFT79, USER'S MANUAL, LBL-10861; 1-47.

Volcanolgical Society. of Japan and IAVCEI, 1972 : List of the world active volcanoes, 1-160.