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COMBINATION OF GEOLOGICAL AND GEOPHYSICAL METHODS TO SURVEY AND ASSESS THE GEOTHERMAL POTENTIAL OF HOIVAN HOT WATER RESOURCE IN SOUTHERN VIETNAM.

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ABSTRACT

Research and evaluation on the geothermal potential of Vietnam has been systematically carried out since 1995. The Vietnamese government has paid a great deal of attention to this area and financed the Industry Ministry to conduct projects involved in the exploration and assessment of the geothermal potential in middle-southern Vietnam from 1994-1996 and in the middle-northern Vietnam from 1997-1998. The exploration and evaluation of geothermal potential for the rest of northern Vietnam will be implemented from 1999-2000.

In the preceding years, The Geological and Mineral Department of Vietnam has studied the geological structures of hot water resources which may be utilized for power generation in coming years.

Currently, the Vietnam government has agreed that the international geothermal company ORMAT from the USA and the Industry Ministry will complete procedures to carry out project surveys for the assessment and utilization of geothermal energy for power generation (approximately 50MW) of groups of hot water resources in the south of Vietnam.

The hot water resources at HoiVan, with a temperature of 83°C - at the surface will be produced for power generation in the this project., The Geological and Mineral Department of Vietnam has made a geological exploration and assessment of the geothermal potential at HoiVan using geological, hydrological, geochemical and especially geophysical methods. The most important and detailed of which are resistivity, magnetics, radio-active, gravity and temperature measurements at the 1.5-2m depth. The results of these surveys show that a deep fault system exists in this area and hot water concentrates in this system. Based upon the geophysical results, three holes (HV1, HV2 and HV3) were drilled. These discharge hot water at flow rates from 2.7 – 5 l/s. Chemical geothermometery(Na, K) showed that the temperature of the deeper water was around 140°C.

This paper presents the results of exploration methods involved in the assessment of the geothermal potential which would be utilized for power generation. The author expects that the presentation would provide readers who are interested in the geothermics in Vietnam with an interesting new source of information.

INTRODUCTION

Hoi Van area is located in Hoivan village, Phucat district, Binhdinh province. It is situated from $109^0 01^/$ to $109^0 03^/$ of ELO and $13^0 59^/$ to $14^0 02^/$ of NLA on the Phumy map sheet at a scale of 1/50,000 (e.g Fig.1) and about 40 km NW of Qui nhon City and 20 km from the coast at an elevation of less than 20m ASL. It can be reached by driving north from Qui nhon along the national highway and turning left down 2 km access road. In 1978, the balynological hospital opened on the site. The thermal activity is aligned along a shallow stream and consists of numerous seepages of hot water through the stream bed. The total flow of hot water into the stream bed could not be estimated. There are no steam emissions at Hoi van and no siliceous or calcareous scale is seen in outcrop. A small amount of gas can be seen in the stream bed springs.

Since 1983, experts from USA, New Zealand, Czech state, Italy have visited this site and Vietnamese geologists have acquired and interpreted exploration data to assess the geothermal potential of the Hoi van hot water springs. From these activities we conclude that geothermal energy could be used for electrical power in this area with the capacity of 15 MW.

2. STUDY AREA, METHODS OF RESEARCH, RESULTS AND CONCLUSIONS

2.1. Study area

The geological and hydrogeological surveys have been conducted over an area of 48km^2, and mapped at a scale of 1/25.000; geophysical surveys covered an area of 6km^2, at a map scale of 1/10.000 which determined where to put exploration wells., Three hot-water testing wells have been drilled in the area and the analysis of fluids from the springs and in the drill hole also have been carried out, in conjunction with sampling and petrological analysis (Fig. 1).

2.2. Geology

2.2.1. Structure

According to the results of geological and geophysical surveys in scales of 1/200,000 and 1/500,000, the Hoi Van area is located at the east boundary of the Kon Tum geomassif (Fig. 2), a deep fault system exists in the area trending north-south and 8is broken by young cross faults trending northeast-southwest and northwest-southeast. These fault systems could be easily intruded by the younger dyke phases. Quaternary sediments in the area, aged from Upper Holocene (Q_{IV}^3) to Lower Pleistocene (Q_I^3), are composed of of sand, silty sand, clay, and granules, with 5-40m thickness. Basaltic sediments (βN_2) exist in the western area, their composition is of tholeitic basalt and subalkaline olivine basalt, with 30-180m thickness.

Magmatic rock complex: Lower Magmatic Mesozoic-Cainozoic.

Deoca complex (γ_5^2 Kdc) (dc is the abbreviation of the location Deo Ca in Vietnam where the complex was first discovered): outcrops at the central area, including the following phases:

Dyke phase ($\gamma\rho$-$\gamma\,\pi$Kdc): aplite granite, porphyritic granite.

Phase 3 (γ K dc_3): fine-grained biotite granite.
Phase 2 ($\gamma\xi$ K dc_2): medium to coarse - grained granite, granosyenite.
Phase 1 (γ δK dc_1): biotite granodiorite.
Magmatic rock complexs: Lower magmatic Paleozoic - Upper Mesozoic:
Queson complex(δ_4^1-γ_4^1P qs) (qs is the abbreviation of the location Que Son where the complex was first discovered) :outcrops in the south and north-west of the area including:
Dyke phase (PZ_3qs): aplite granite, pegmatite, spessartite.
Phase 3 ($\gamma\xi PZ_{3qs\ 3}$): granite, granosyenite.
Phase 2 ($\gamma\delta PZ_3qs_2$): biotite hornblende granodiorite, tonalite.
Phase 1 ($\delta PZ_3qs_{\ 1}$): diorite, quartz diorite.
Vancanh complex (γ_4^2Tvc) (vc is the abbreviation of the location Van Canh where the complex was first discovered): outcrops in the south of the area, including the following phases:
Dyke phase ($\gamma\xi\pi T_2vc$): aplite granite, porphyritic granosyenite
Phase 3 (γ-$\gamma\xi T_2vc_3$): fine-grained granite, biotite granosyenite.
Phase 2 (γ-$\gamma\xi T_2vc_2$): medium to coarse-grained granite, granosyenite.
Phase1 ($\gamma\delta T_2vc_1$): medium - grained biotite granodiorite.
Magmatic rock Proterozoic:
Chulai complex (γ_2 PRcl) (cl is the abbreviation of the location Queson where the complex was first discovered): outcrops in the north and west of the area including granodiorite, granite, and granosyenite.
In the 6 km^2 area surrounding the hot water springs, on the scale of 1/10,000 map, a dyke phase of Queson complex is found (fig 1). Outcrops are in the north and northeast of the area. Another outcrop is along the Tien stream in the north-south and northeast-southwest directions. The nearest mapped intrusives are in the hills to the east and west about 5km distant from the Hoi Van hot water area. These mapped intrusives are thought to be acidic to intermediate in composition (KRTA). The nearest Neogene/Quaternary volcanics are more than 30km to the north-west.

2.2.2. Petrographical analysis

Petrographic analysis: Petrographic analysis of surface vein samples of the Que Son dyke phase (PZ_3qs), collected over an interval of approximately 150m within the surroundings of the thermal area, indicate the complete alteration of a dioritic host rock. The vein quartz and altered country rock clasts in all samples have jig-saw type brecciation fabrics and samples have a matrix comprising fine to medium- grained quartz and veinlets which contain milled clastic fragments and broken quartz crystals. These pattens indicate that shearing occurred prior to, and during, vein formation and that the clasts have not been disrupted since this initial brecciation event.

The alteration assemblage comprises quartz, illite, epidote, sphene, chlorite and carbonate. The presence of epidote in two of the samples implies fluid temperatures greater than 240^{O}C. Tourmaline was found in a sample obtained some 100m north of the thermal area. Its presence is indicative of low-pH fluid and boron or fluoride rich, high temperature fluids, possibly of magmatic or connate origin.

A single fluid inclusion was present in only one sample. The lack of fluid inclusions in the sample is generally attributed to post depositional recrystallization that is clearly evident in the clastic quartz. The absence of fluid inclusions in the quartz matrices and veinlets could also be due to recrystallisation and would not be unexpected considering the amount of shearing these rocks have undergone. A homogenisation temperature of 191^{O}C was obtained for the one fluid inclusion present. This is 30-70^{O}C below the temperatures indicated by illite alteration and is considered to reflect the temperature at which recrystallisation occurred.

The temperature implied by the alteration assemblage indicates that alteration took place at a depth of 560 m or greater (assuming a boiling point for depth curve based on pure water). This implies that a minimum of 560 m of material has been removed by erosion since the alteration event.

2.3. Hydrogeology and fluid chemistry.

The Hoi Van hot waters have a dilute Na-Cl-HCO_3 composition and total mineralisation of 570mg/kg. The waters have high fluoride concentrations. The Cl-HCO_3-SO_4 triangular plot shows the low SO_4 concentrations of between 30-35mg/kg. The chemistry of the discharge water (eg. Table. No.1) is almost the same as that of the surface water, indicating no mixing or chemical equilibration of the water down to a depth of 120m. (eg Tables 1and 2)

The measured silica concentrations indicate quartz and chalcedony saturation temperatures of about 140-110^{O}C respectively. The magnesium concentrations of the waters are low and increase little from 0.05mg/kg in the drill hole HV1 to 0.08mg/kg at the surface. The chemistry of bore water is relatively balanced in Na-K-Mg plot compared to other surveyed thermal areas in Vietnam. The temperature indicated by the K-Mg geothermometer is 120^{O}C; this lies between the Na-K temperatures of 109 and 142^{O}C. This might be a reasonable indication of deep source water conditions.

Analysis of a sample, collected from hot water ejecting point 2, detected no CO_2 or H_2S but a small amount of CH_4 was present. After reducing the air contamination (using O_2), the remaining gases are still large enough for deriving N_2 and A_r. Moreover, H_e component shows deep circulation.

To sum up, the chemistry of bore and spring water, and the absence of steam or acid-gas related signals, show deep temperatures of between 120-140^{O}C and deep non-magmatic fluid.

2.4. Geophysics.

An objective of geophysics is to determine the locations of fractures zones and faults that contain hot water and thus suggest drilling targets. This geophysical survey had been implemented with 13 east-west lines. The survey utilized grids of 200x10m for the vertical magnetic method (2,880 stations), and 200x50 for total radioactivity (1,124 stations), electrical profiling (750 stations), temperature measuring at 1.5-2m depth (750 stations), and 400x50m for resistivity soundings (40 stations). Aeromagnetic surveys (scale of 1/200,000) and gravity (scale of 1/500,000) are regarded as regional reference data.

An analysis of the data (e.g. fig 3,4,5,6) indicates that a system of fracture zones and deep tectonic faults in the area consists of a north-south dominant fault (F1) and northeast-southwest additional faults (F2,3) and another fault trending northwest-southeast (F7). The depth of the basement rocks from the surface ranges from 5 to 35m. The thermal prospects are distributed at the intersections of fault systems.(e.g.fig.7)

2.5. Drilling

Based on results of geophysical work, three wells have been drilled in Hoi Van. The two wells, HV1 and HV3, were sited at the intersections of a north-south trending fault (F1), an additional northwest-southeast fault (F2) and a northeast-southwest fault (F3). The first well, HV1, drilled to 126m, reached 83^{O}C water and had a flow rate of 5.5 l/s. Hot water from fracture zones, at depths of between 30.5-43m and 120m, was mainly supplied to the balneological hospital. Well HV2 was drilled to 253m and sited far from the north-south fault; its flow rate was low and its temperature cooler (71^{O}C). HV3, drilled to 200m, detected 78^{O}C water with a flow rate of 2.7l/s. All these three wells encountered Mesozoic granite. The HoiVan hot spring belongs to the group of geothermal systems which have equilibrium temperatures of 140-180^{O}C at 500m depth. The geothermal gradient reached 28-47^{O}/km and the gross power is estimated at around 15 MW.

3. DISCUSSION ON ORIGIN AND POTENTIAL OF THE HOI VAN HOT SPRINGS.

According to results derived from studies of earthquake epicenters in Vietnam, there exists a volcanic zone and one with a distinctive seashore geomorphology (Fig.8); these two zones are located in the southwest and east (109^{o} of ELO) of the study area. There were times of volcanic activity occurring around the Kontum geomassive in upland area in the Neogene. The latest volcanic activity happened in 1923 and generated an ash island near the Vietnam seashore. This ash island was destroyed by waves in two months. At present, many earthquakes have epicenters at these two volcanic zones.

According to the results of gravity survey along a line crossing the Kontum geomassive from west to east, the negative gravity anomaly of the field can be explained by a welling out of the asthenosphere, and ascent of material from the middle mantle. These resulted from activity of a subduction zone that descended near the seashore (near 110^{O} ELO). The existence of hot water springs in the mid-southern Vietnam might be an outcome of this. This point of view should be clarified in the future.

Until now, young active or on-shore volcanism has not been discovered. This, together with the appearance of the individual hot water discharge of a type similar to the Hoi Van hot springs, indicates that they are likely to medium temperature systems. There is no hot water at the surface at boiling point and no significant flow of gas that characterises high temperature systems having magmatic type heat sources. Together with their low chloride contents and the absence of significant CO_2 and H_2S, or associated acid-SO_4 waters, this data suggest the thermal water does not derive from a magmatic fluid. A relatively high He content in a small sample of collected gas proves that the origin of the hot springs is related to a deep tectonic process. Hot water that moves in fracture zones caused by faulting in the basement rocks. Meteoric water deeply penetrates into the ground and is warmed in an anomalous thermal gradient; it is transferred to the surface by convection. The systems of meteoric hot water that have been discovered are all artesian indicating that they are recharged by ground water from adjacent high areas.

Comparison of geothermal areas in southern Vietnam in general, and Hoi Van in particular, with geothermal resources in Pumpernickel Valley- Nevada, USA, show that they are relatively similar.

Component	Vietnam	Nevada
Heat Source	Tectonic	Tectonic
Fluids	Meteoric	Meteoric
Fractures	Fault zones	Fault zones
Geothermometers	> 160^{0} c	>180^{0}c
pH	7.0 - 8.0	7.2 – 7.9
Thermal surface features	Hot spring	Hot spring, sinter
Thermal gradient	28 - 47^{0} C/km ( )	35^{0} C/km
Reservoir model	Deep circulation	Deep circulation
TDS	500 – 5000	2000 - 3000

An assessment of the geothermal potential of the Hoi Van hot springs is regarded as a scientific experiment. Geology and geophysics interpretations support the existence of electrical power producing resources with minimum temperatures of between 120-140^{O}C. These temperatures can be utilized for building a small-scale thermo-electricity plant in the area. This will be a power-generating resource for development by ORMAT.

4. CONCLUSIONS.

1. The thermal water can be considered tectonic in origin, having formed through circulation to considerable depth along discrete zones of tectonic fracturing. Circulation of water can be considered, i.e. there is no input of deep connate or magmatic derived water.
2. The Hoi Van thermal water source was derived from tectonic process and moved in channels created by faulting.
3. The survey revealed that the water equilibrated at temperatures of between 120-140^{O}C.
4. Further deep drilling and physical-chemical analysis are necessary to confirm the relatively accurate results that have been already obtained in the area.
5. More detailed exploration in the area and surroundings ought to be conducted in order to get more information about the geological structures.
6. Building a geothermal plant in Hoi Van, which is one of the favoured locations, between ORMAT and Vietnam is possibly feasible.

5. ACKNOWLEDGEMENTS.

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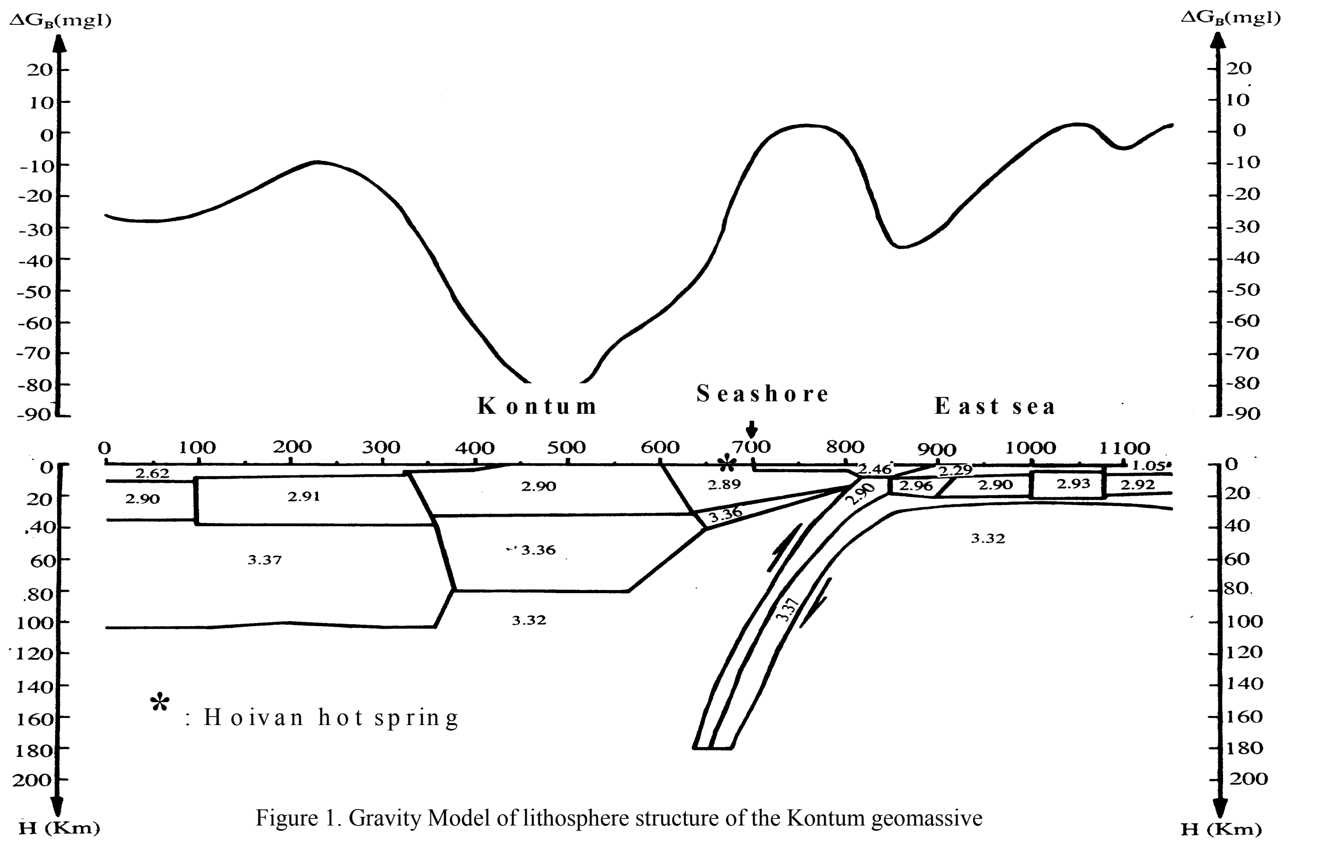

Figure 1. Gravity Model of lithosphere structure of the Kontum geomassive

Table 1. Hoivan Thermal Waters: from KRTA, 1993 Analytical Data

No	Date	Type	Flow L/s	Temp ^{O}C	pH	Li	Na	K	Rb	Ca	Fe	Mg	Cl mg/kg	F	Br	SO_4	HCO_3 (total)	B	SiO_2	NH_3	ION Bal	CATS	ANS	TDS
1	02/25/93	bore	5.5	83	8.55	0.22	157	5.6	0.22	4.4	0.05	0.05	128	14		34	129	0.08	92	0.021	0.3	7.2	7.2	560
2		spring	-	77	8.41	0.21	157	5.5	0.22	4.6	0.06	0.06	126	14		37	131	0.09	100	0.011	0.6	7.2	7.3	580
3		bore	2-3	80	8.51	0.19	138	4.8	0.21	3.8	0.04	0.07	85	17		30	141	0.07	97	0.02	1	6.4	6.3	520
4		spring	0.1-0.2	71	8.55	0.2	150	5.2	0.22	4.3	0.03	0.08	121	15		32	132	0.06	106	0.054	2.7	6.9	7.1	570

Table 2. Hoivan Thermal Waters: KRTA 1993 Caculated Data

No	Date	Type	Flow L/s	Temp ^{O}C	Cl/Li	Cl/Rb	Cl/Ca	Cl/B	Cl/SO_4	Na/K	Na/Ca	QTZ ^{O}C	CHAL ^{O}C	T;Na-K (A83) ^{O}C	T;Na-K (F79) ^{O}C	T;K-Mg ^{O}C	T;Na-K-Ca beta
1	02/25/93	bore	5.5	83	114	1403	32.9	488	10.2	48	62	133	105	109	142	121	0.33
2		spring	-	77	117	1381	31	427	9.2	49	60	137	110	108	141	113	0.33
3		bore	2-3	80	88	976	25.3	370	7.7	49	63	135	109	107	141	111	0.33
4		spring	0.1-0.2	71	118	1326	31.8	461	10.2	49	61	141	114	107	140	111	0.33

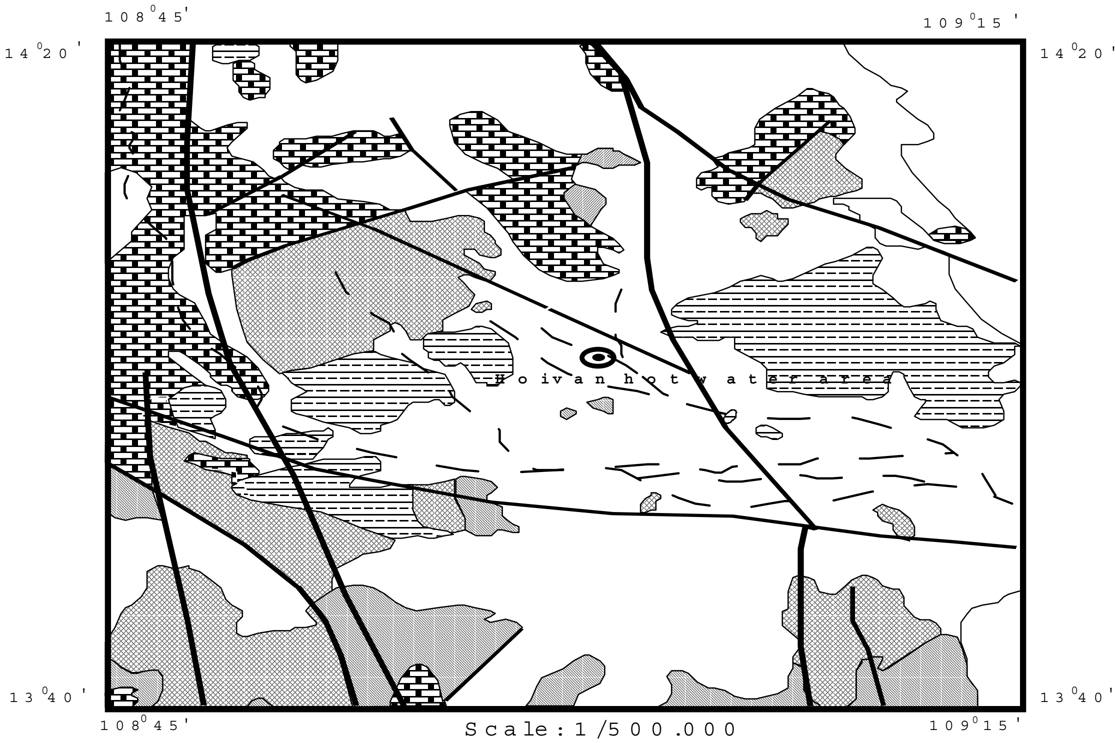

Figure 2. Structure and tectonic scheme of Hoivan area

Stream

Faults

Magmatic bodies of Chulai complex
Gabro diorit, granit,

Magmatic bodies of Queson complex
Gabro diorit, grano

Magmatic bodies of Vancanh complex
Granit,

Magmatic bodies of Deoca complex
Gabro diorit, granit,

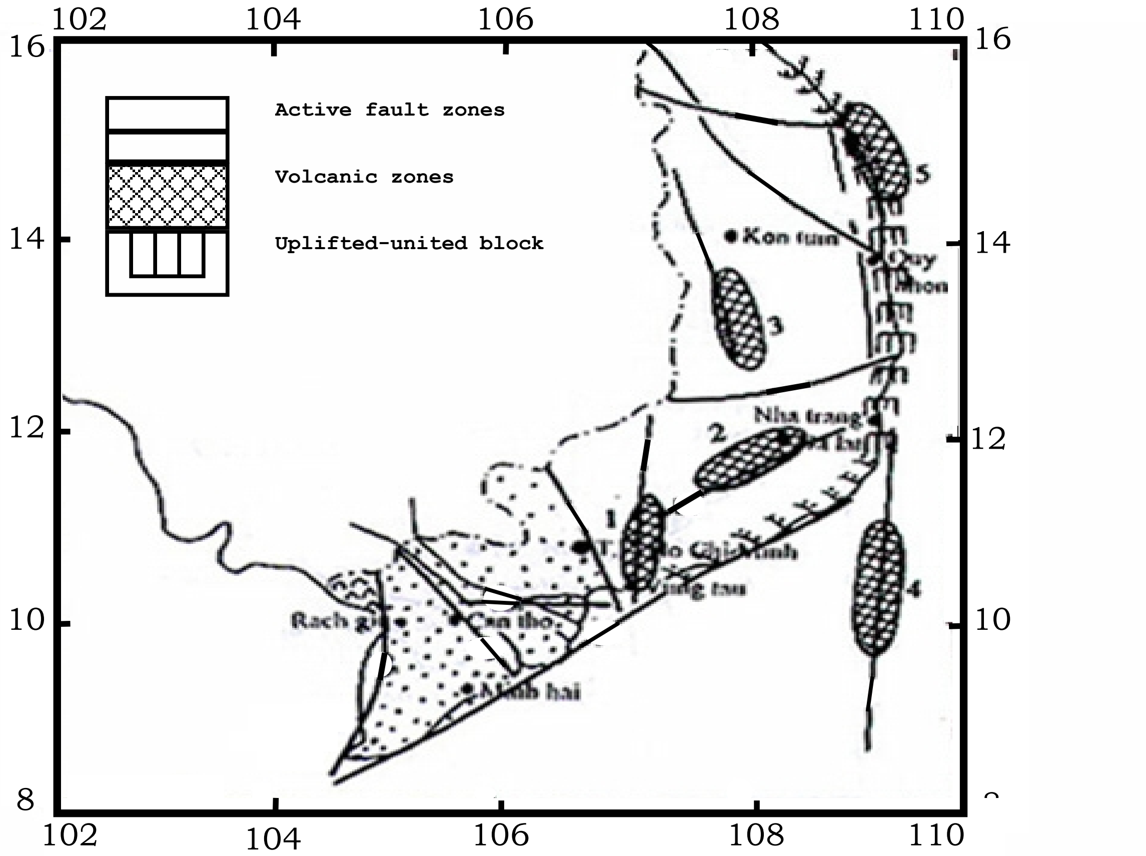

Fig 3. Volcanic and active fault zones in South of Vietnam

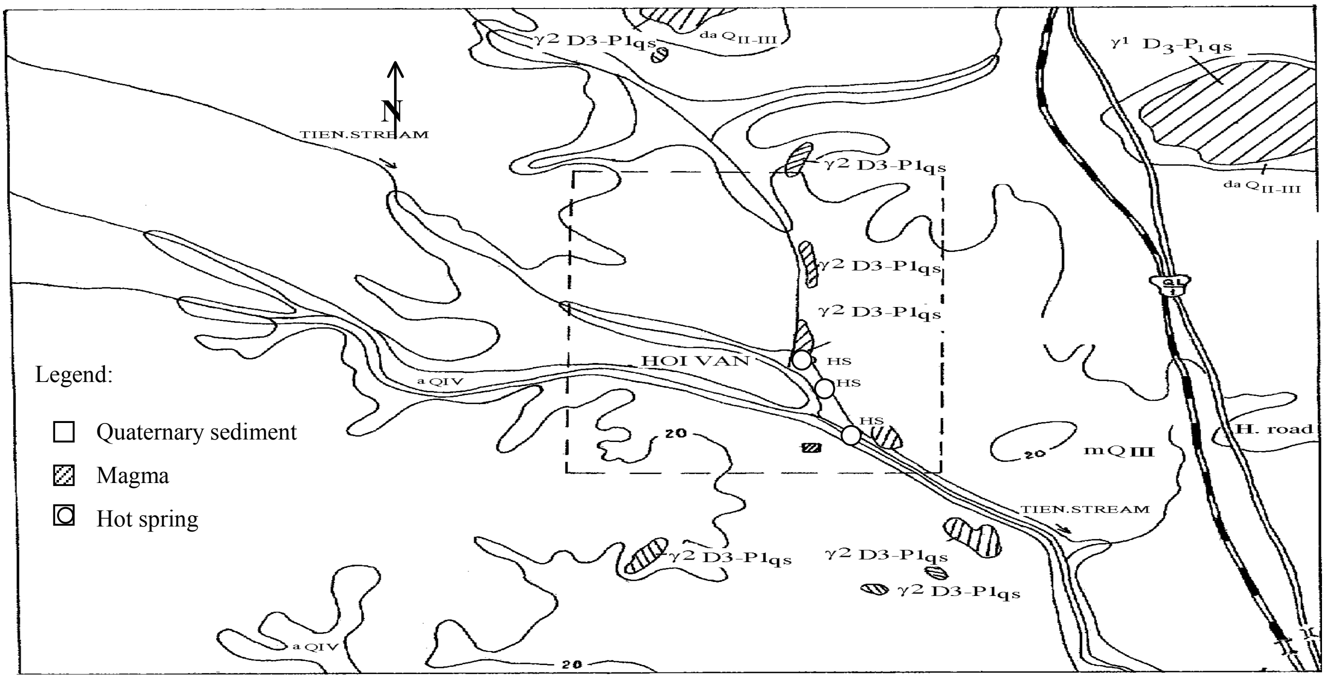

Figure 4. Geological scheme of Hoi Van area
1/10.000

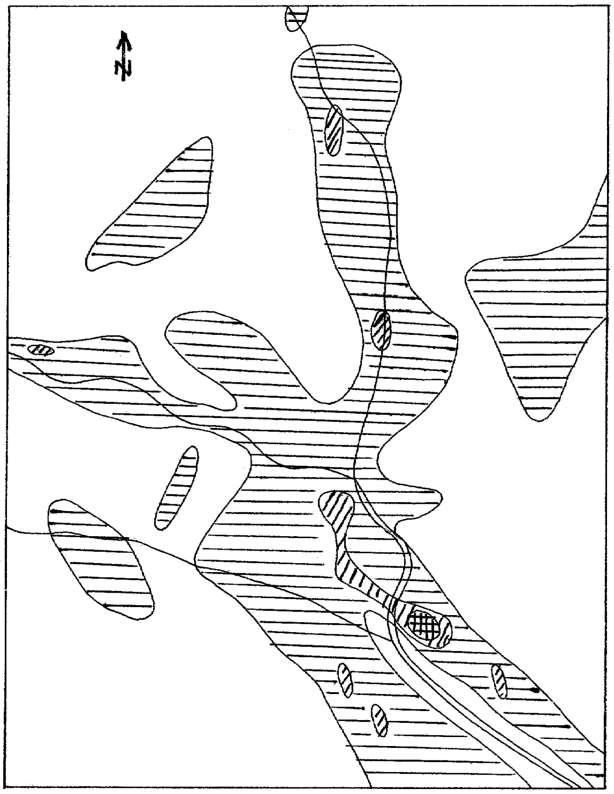

Figure 5. Isolines for total natural radioactivity (μcr/h)

- J<10 μcr/h
- J=10-15 μcr/h
- J=15-20 μcr/h
- J>20 μcr/h

Figure 6. Isolines for temperature at 2m deep (real temperature plus 33^{O}C)

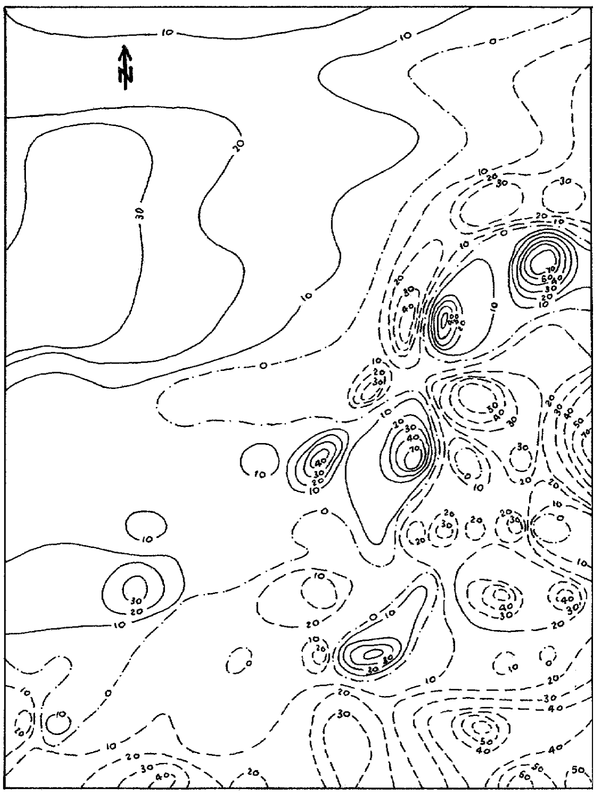

Figure 7. Isolines for vertical component (ΔM_V) of magnetic field (nT)

30 $\Delta M_V>0$ ---- 0---- $\Delta M_V=0$

30 $\Delta M_V<0$

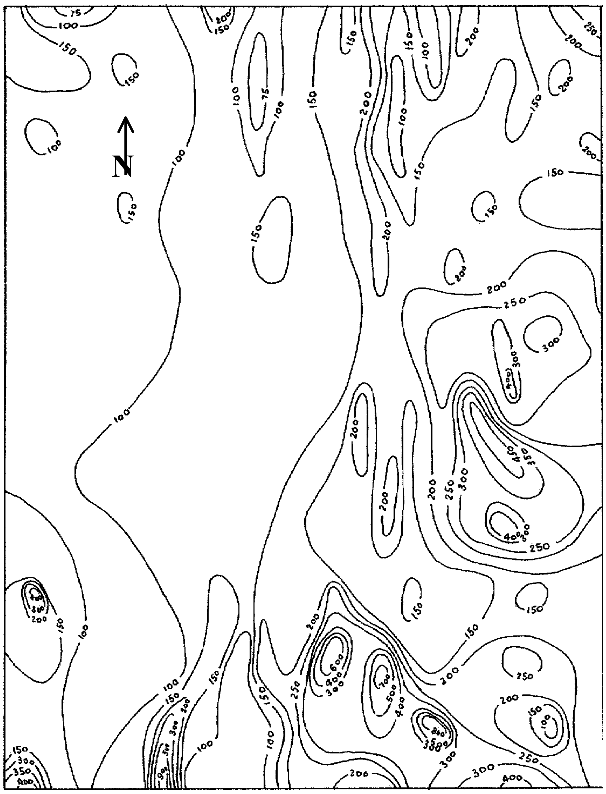

Figure 8. Isolines for apparent resistivity Ωm (AB=250m, MN=50m)

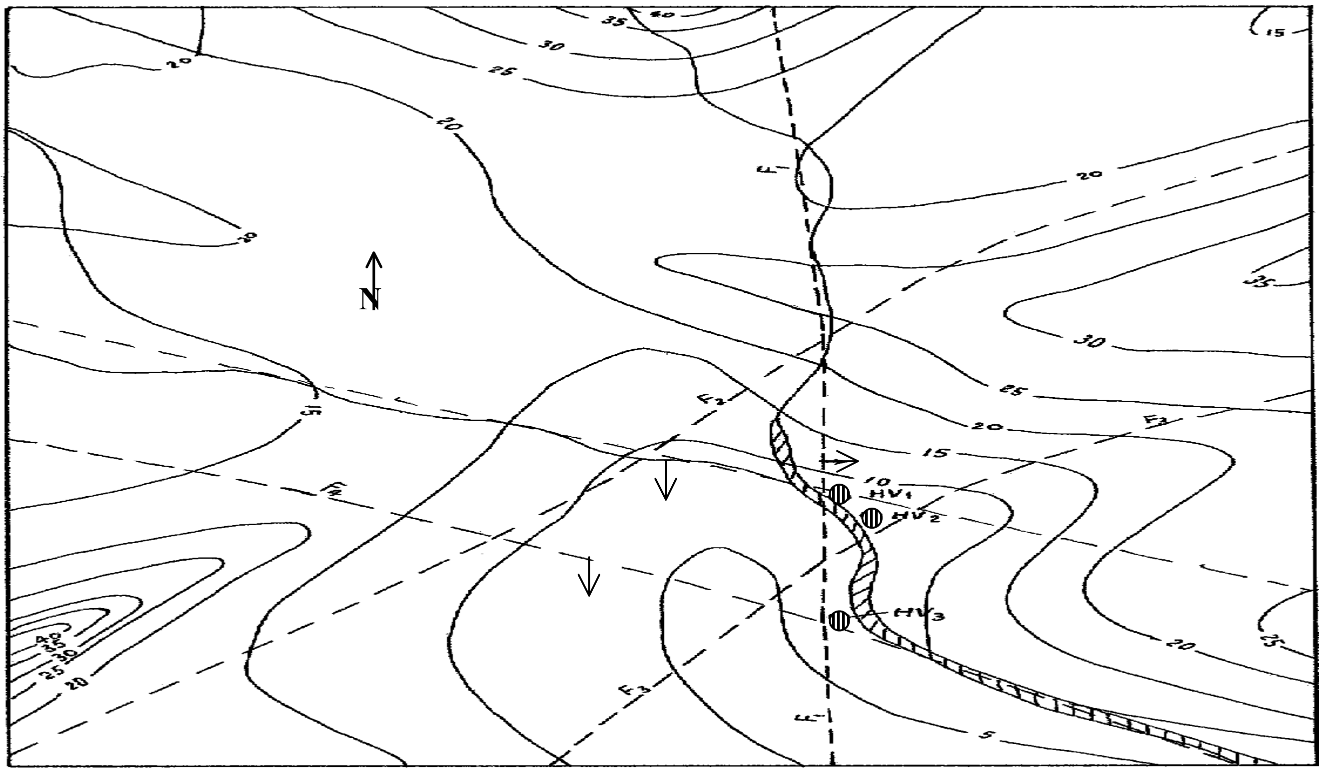

Figure 9. Scheme of geophysical results

— 20 — Isolines of basement rock face

HV1 Drill & No.

Fault & direction

Tien Stream