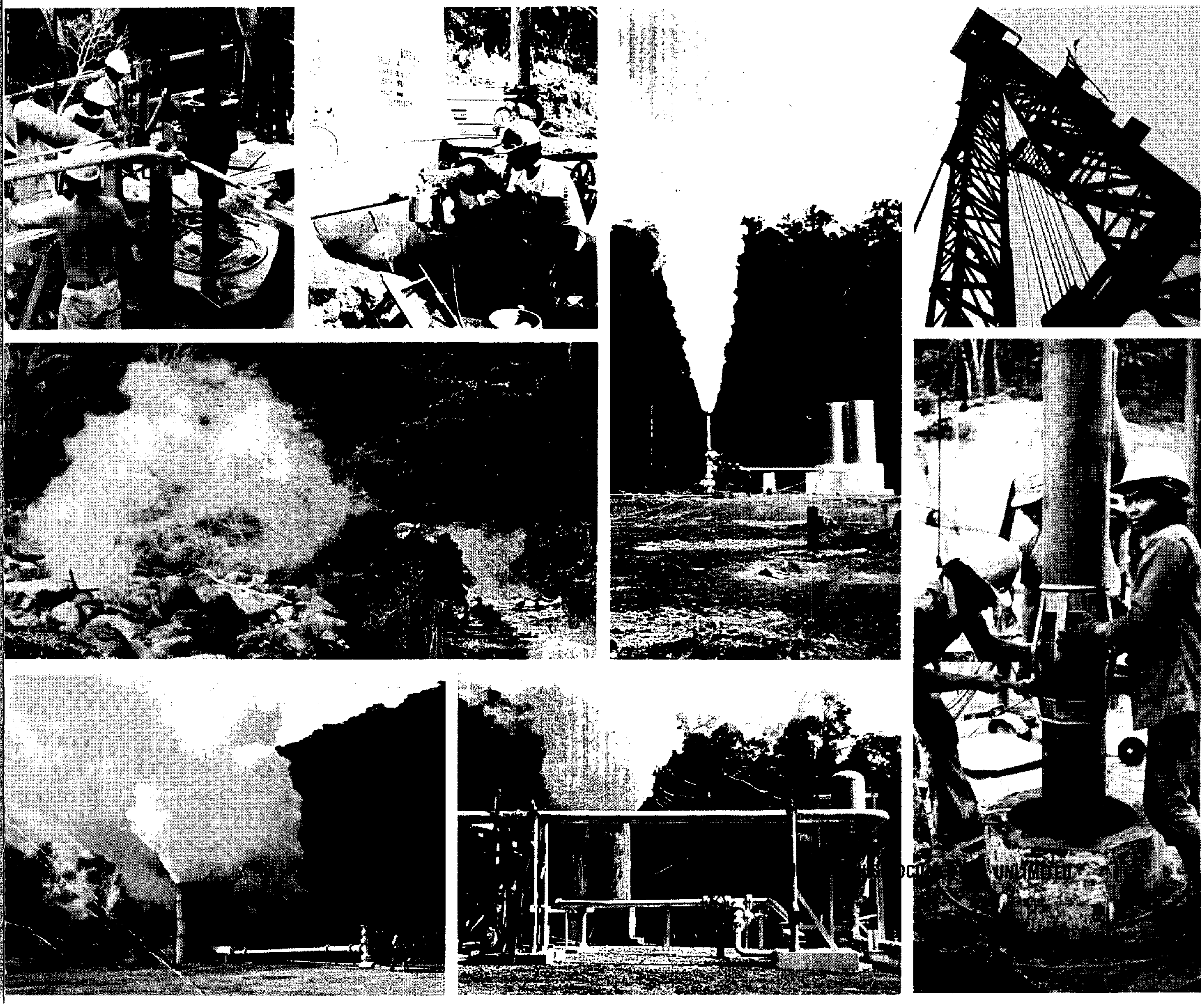
THE TONGONAN GEOTHERMAL FIELD
LEYTE PHILIPPINES

Report on Exploration and Development

Kingston Reynolds Thom and Allardice Ltd



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Kingston Reynolds Thom and Allardice Ltd
geothermal power consultants

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September 1979

FOREWORD

In the early 1970's the Philippines Commission on Volcanology made a preliminary survey of surface geothermal phenomena in the Philippine Islands, and in December 1971 the New Zealand Government was invited to provide an assessment of the geothermal power potential of the Island of Leyte, as a Colombo Plan project. Kingston Reynolds Thom & Allardice Ltd (KRTA) was asked to make a reconnaissance, following which the Tongonan Valley was chosen for more detailed study.

In 1973 KRTA set out a proposal for the exploration and development of geothermal power in Leyte. This proposal was submitted in association with the New Zealand Ministry of Works & Development (MWD) and Department of Scientific & Industrial Research (DSIR), and was accepted by the New Zealand and Philippines Governments as a technical co-operation project.

Work began in December 1973, with a MWD Failing 1500 rig, on a series of shallow temperature gradient wells, accompanied by wide-ranging scientific surveys. By July 1976 twelve wells had been completed, and two extensive hot zones had been indicated, with temperatures up to 254°C measured in one of them.

Following a review of progress the two Governments agreed to co-operate on a programme of deeper drilling. KRTA was appointed executing agent for the New Zealand Government, an Ideco H525 rig was purchased and shipped to Leyte, and deep drilling began in October 1976.

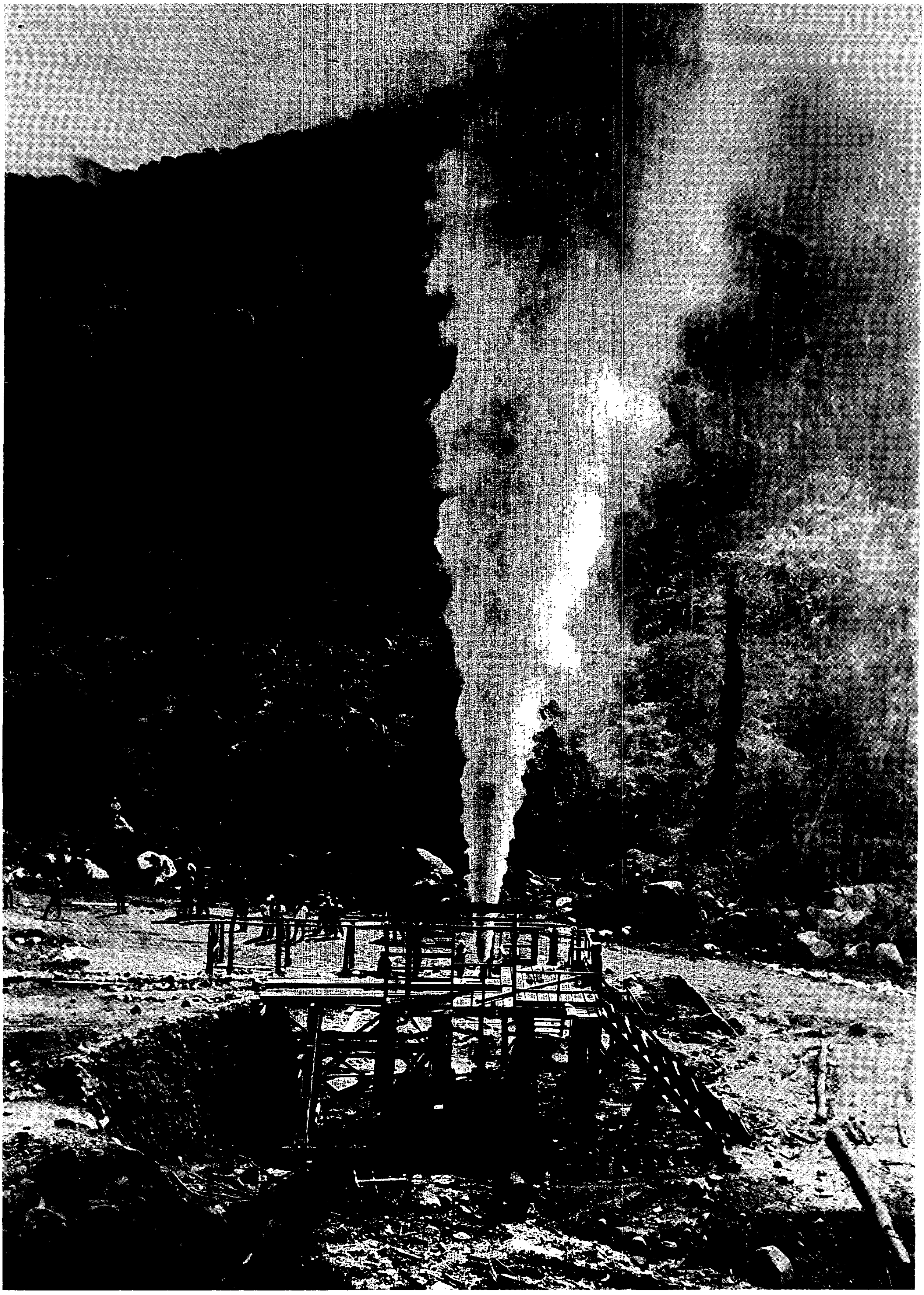
Only nine months later a 3 MW turbo-alternator, powered by steam from the first deep well, had been commissioned and was supplying electricity to the nearby city of Ormoc. In addition a 112 MW development was planned on the strength of a 3000 MW-year estimate of the potential output from the Mahiao sector of the Tongonan field.

At the time of writing, twelve production wells with outputs averaging more than 10 MWe per well, and three injection wells for waste water disposal, are available for the 112 MW project. Design work is well advanced and construction will shortly be under way.

Exploration is continuing. Six deep exploration wells so far completed indicate that the ultimate potential of Tongonan is likely to be several times larger than the 112 MW Stage 1 project. Every deep well drilled to date has been a good producer, with the exception of one located beyond the field margin specifically for injection purposes. Scientific work in two other Leyte fields has begun. The geothermal resources of the island appear big enough to encourage either large scale industrial development on Leyte itself, or the transmission of large blocks of power across the sea to other parts of the Republic.

KRTA is proud to have taken a leading part in this work and to acknowledge the close collaboration and support of the Filipino counterparts, the Energy Development Corporation and National Power Corporation, together with the New Zealand Ministry of Foreign Affairs, Ministry of Works & Development and the Department of Scientific & Industrial Research.

R. Kingston
September 1979



Shallow well TGE-10 discharging.

TONGONAN GEOTHERMAL FIELD

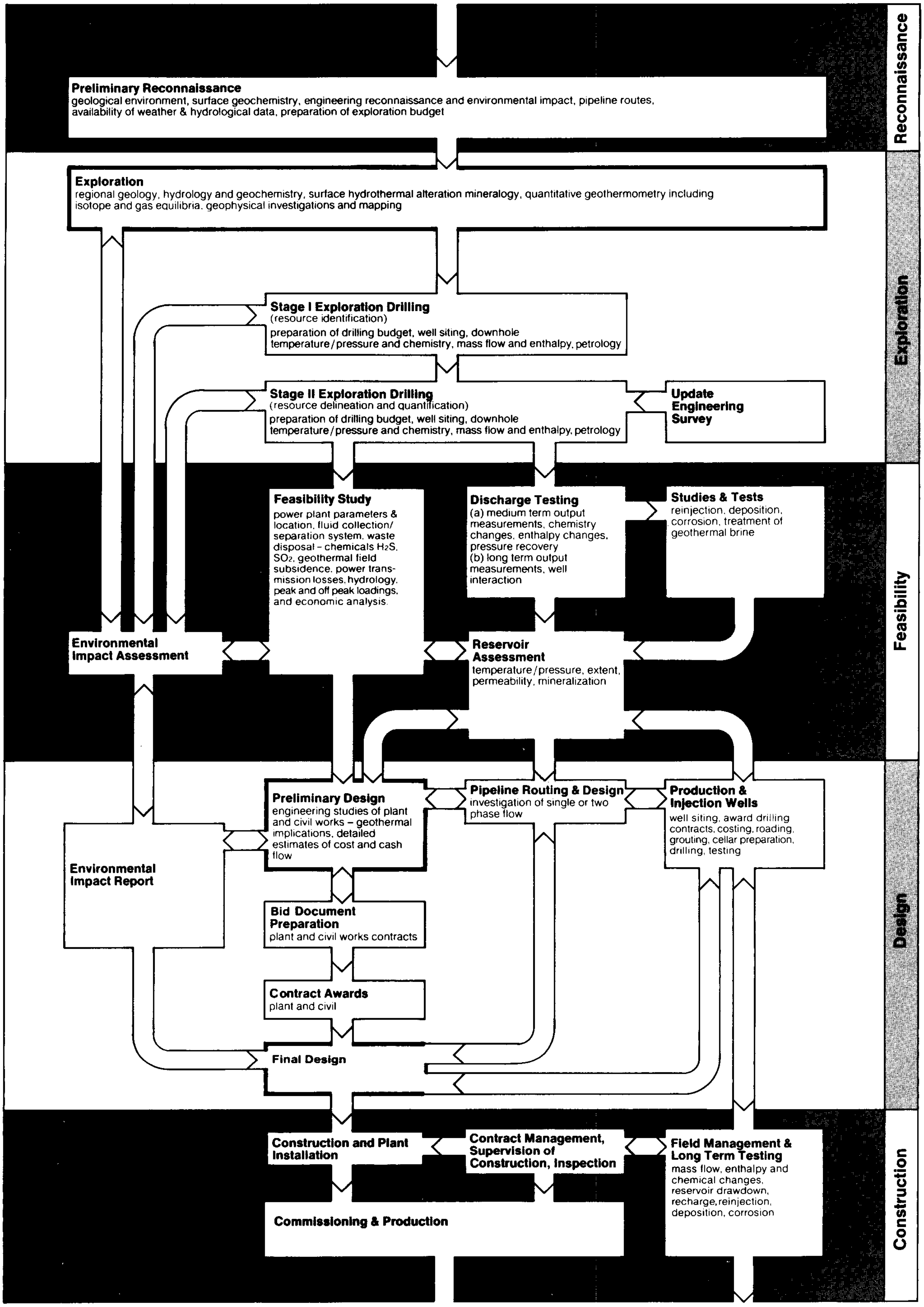
LEYTE, PHILIPPINES

EXPLORATION AND DEVELOPMENT

Introduction

A geothermal resource is essentially a subsurface reservoir of usable heat. If this heat is to be used for generating electricity by conventional steam-fed turbo-alternators, the reservoir should also contain hot water or steam. In addition the reservoir should be permeable enough for this fluid to be extracted and recharged. Finally, the temperature should be at least 180°C and preferably well above 200°C. It follows that the two main targets of geothermal exploration are high temperature and good permeability. Various methods have been designed to exploit resources that do not satisfy these criteria, but they are not widely used at present and not required at Tongonan. It is common to classify geothermal reservoirs as either liquid-dominated or steam-dominated, but it is more helpful to look upon Tongonan as a boiling water field. In some areas it contains only hot water, but in others both steam and water are present, and there are some wells that discharge practically dry steam.

A geothermal development project, such as that at Tongonan, is a multi-discipline exercise that requires a high degree of co-ordination for satisfactory progress. Moreover the subsequent management of the field in production and the evaluation of additional potential for later stage development depend very much on the adequacy of information assembled in the early investigation stages. The steps involved are illustrated in Figure 1; at Tongonan KRTA has been engaged in all phases of this work. The whole sequence of operations would in future be planned for completion within six years in the Philippines, providing the resource could be exploited by conventional methods. Elsewhere, delays inherent in obtaining official approvals and environmental clearances might bring slower progress.



Geothermal Exploration and Development — Flow Chart

Fig 1

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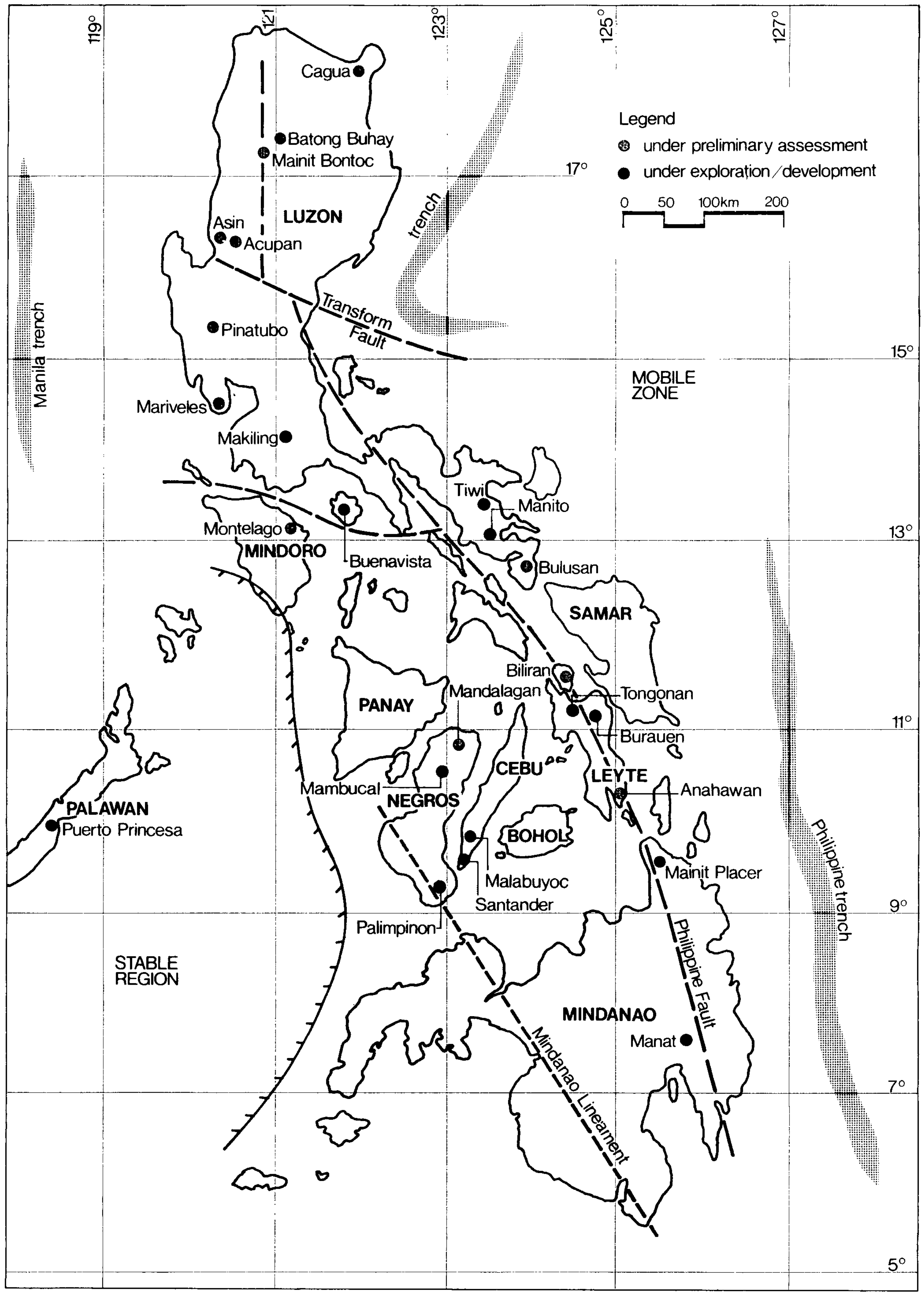

Major Tectonic Features & Geothermal Operations of the Philippines

Fig 2

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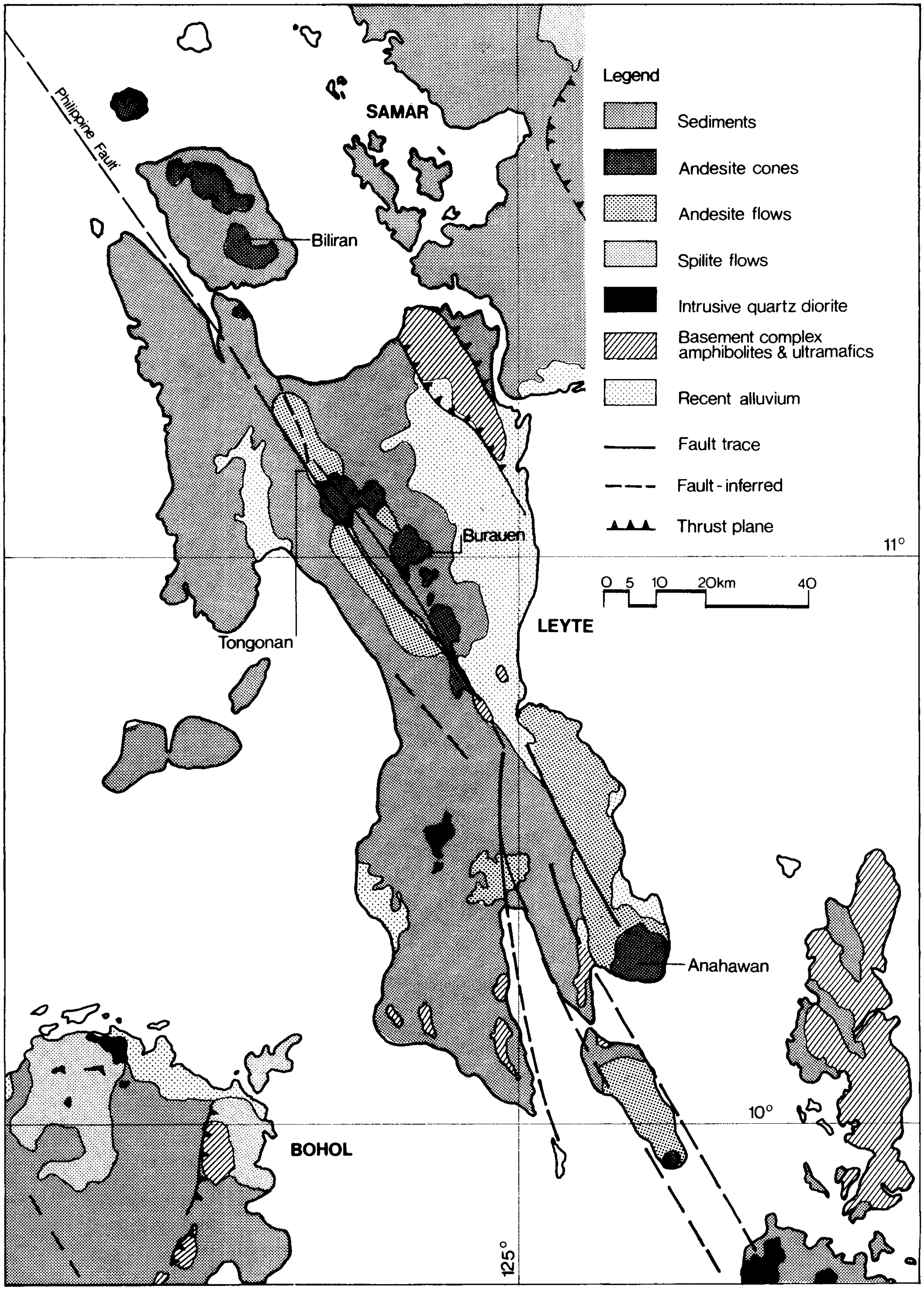

General Geology of Leyte with Major Thermal Areas Indicated

Fig 3

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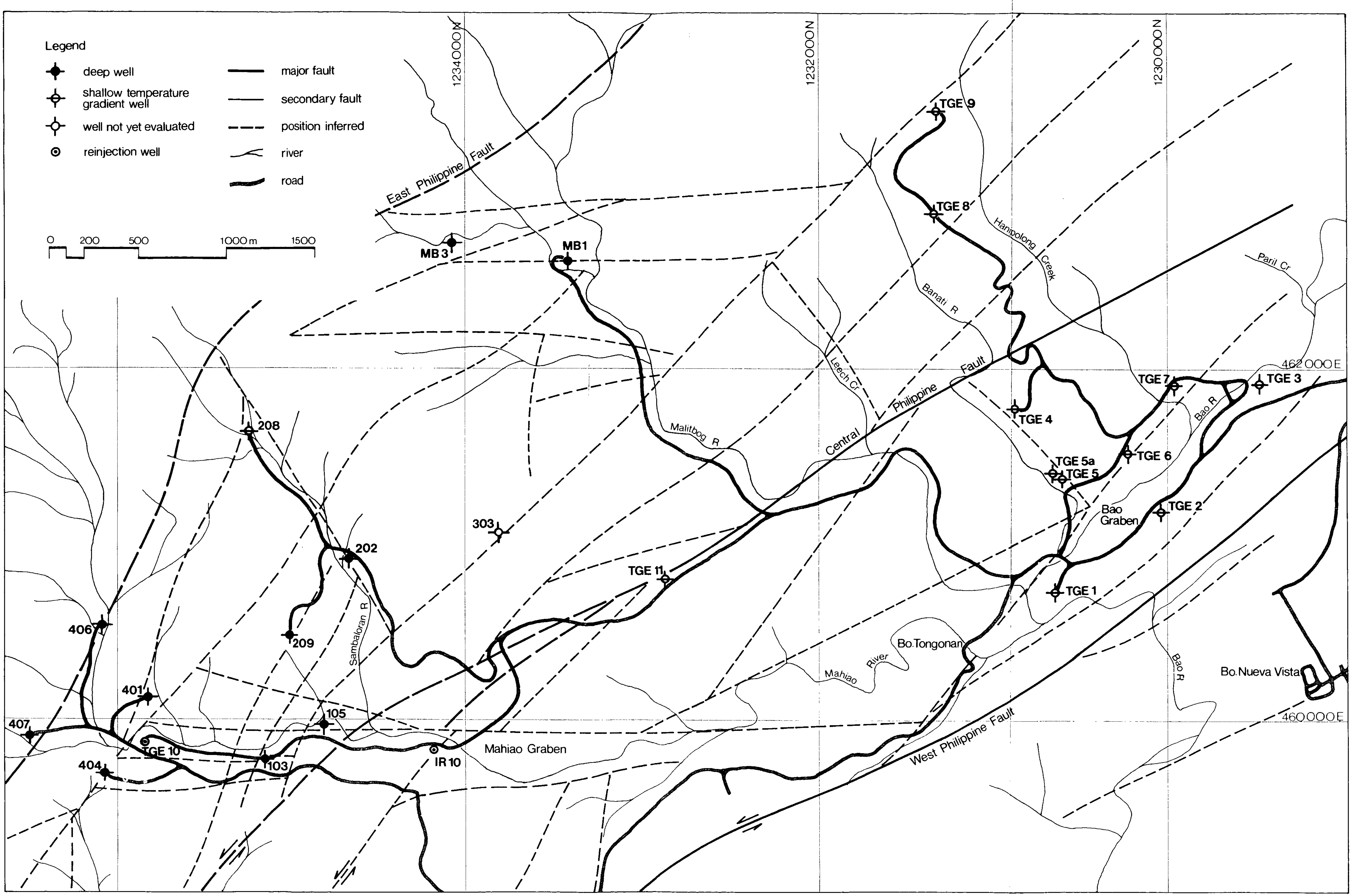

Tongonan Geothermal Area - Structural Geology
(Based on air photo interpretation by G.W.Grindley N.Z.G.S.)

Fig 4

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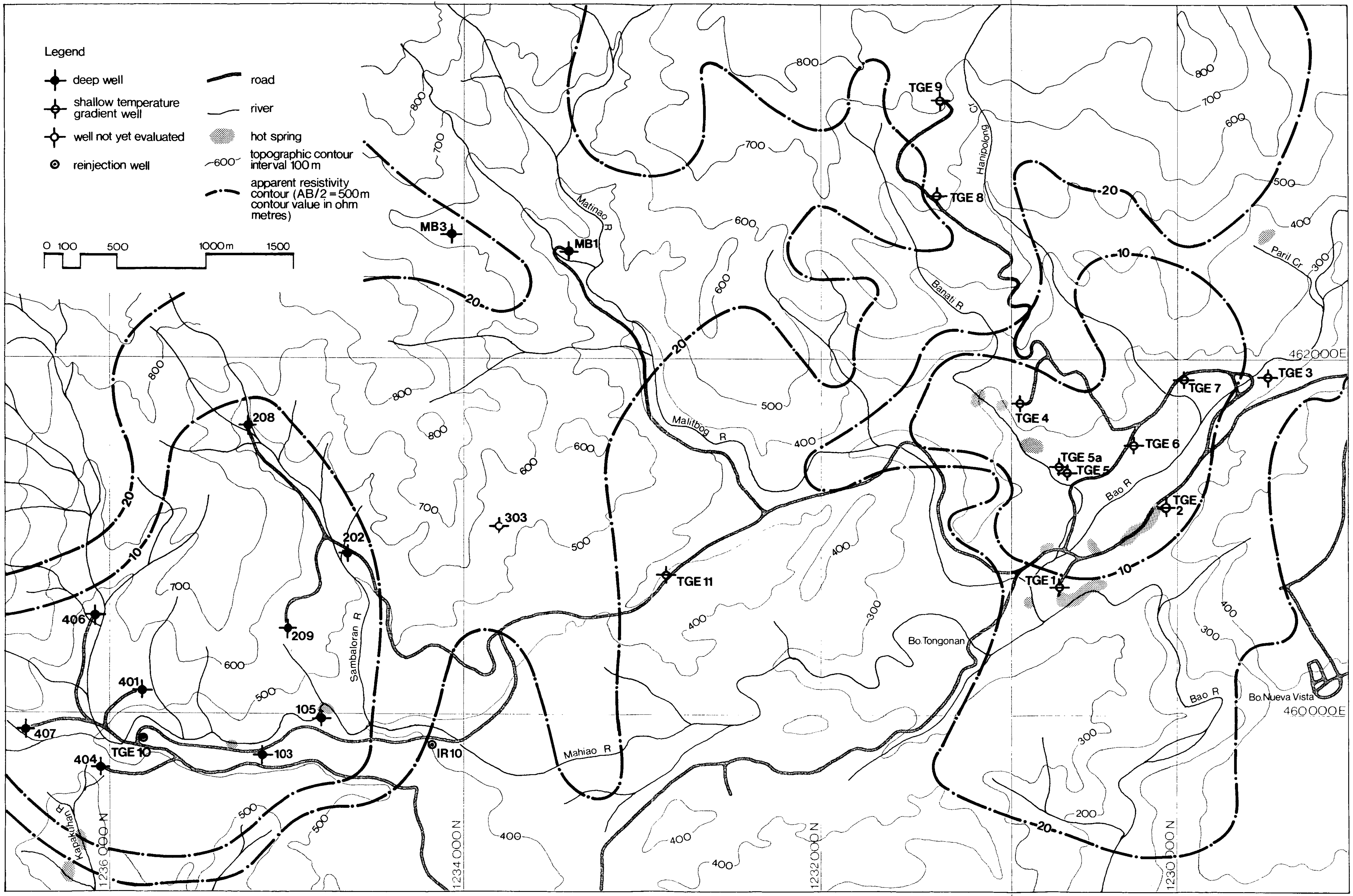

Tongonan Geothermal Area Well Location & Apparent Resistivity

Fig 5

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Tectonism and geothermal fields of the Philippines

Apart from the island of Palawan and the western edge of Mindoro, the Philippines comprises a typical island arc with an active subduction zone off the eastern coast. Figure 2 illustrates the general tectonic setting. A major transcurrent fault system, the Philippine Fault, strikes north to north-westward through the islands, and it appears that some of the major geothermal areas are associated with this feature. Similarly, the Mindanao Lineament is of importance in western Mindanao and southern Negros.

A tentative history for the mobile zone has been outlined by Wolfe in 1973 and summarised by Pelton and Smith in 1974. It is suggested that active subduction took place along the Philippine Trench approximately 60 million years ago, resulting in the emplacement of the oldest known, intermediate, intrusives. There was then a period of relative quiescence until the late Miocene, when subduction again became active, accounting for many of the intrusives, dated 15 million years to the present, associated with the Philippine Fault. It is to this later activity that the Tongonan geothermal system appears related.

Geology

The structure of the island of Leyte is dominated by the Philippine Fault (Figure 3). Approximately along the strike of this fault, extrusions of andesitic material have developed flows and cones that form the central mountain spine of the island. Hot springs and fumarolic activity are frequently associated with these andesitic centres, e.g. at Burauen, Anahawan, Biliran and Alto Peak.

The Tongonan geothermal area lies in one such andesitic region within a bifurcation of the Philippine Fault. The Tongonan area is, therefore, structurally complex and intensely faulted. Figure 4, based on air photo interpretations by G.W. Grindley (NZGS), illustrates this.

Three major faults with approximately northwest-southeast strike dominate the area. These have been designated the Western Philippine Fault to the west of the Bao Valley, the Central Philippine Fault cutting the west flank of the ranges east of the Bao River, and the rather vaguely defined East Philippine Fault along the crest of the central ranges. Small grabens (Grindley, 1973) have been formed in the Mahiao and Bao valleys.

The numerous minor cross-faults that accommodate the compressive and extensional forces between the major faults are believed to play an important role in creating adequate fracture permeability for the extraction of geothermal fluids.

KRTA well correlations, together with earlier mapping by Vasquez and Tolentino (1973), Grindley (1973), Wood (1976), have established the stratigraphy shown in Table 1.

Table 1: Generalised stratigraphy of Tongonan

<table>
<tr><th>Unit and Description</th><th>Thickness</th><th>Age</th></tr>
<tr><td>JANAGDAN ANDESITE

Volcanics and flows comprising a 2-pyroxene andesite. Does not extend into area drilled.</td><td>Unknown</td><td>Quaternary</td></tr>
<tr><td>NORTH CENTRAL LEYTE FORMATION

Andesitic conglomerates and laharic breccias encountered in several Bao Valley wells.</td><td>580 m in TGE-3</td><td rowspan="2">Upper Miocene to Mid Pleistocene</td></tr>
<tr><td>BAO VOLCANICS

Crystal rich, hornblende andesite lavas and associated breccias and tuffs, encountered in all wells to date.

Clay zone: extensive clay development sometimes accompanied by calcarenites and conglomerates.

Black shale: thin, fine grained, black rock with minor organic content.</td><td>1860 m max. logged</td></tr>
<tr><td>MAHIAO PLUTONIC COMPLEX

Medium to fine grained, massive rock of diorite to quartz diorite composition. Granites have been identified in two holes. Weakly fractured and propylitic.</td><td>Unknown</td><td>Not certain but believed younger than Bao Volcanics</td></tr>
</table>

Hornblende dacite: medium grained, pale coloured rock with fresh hornblende occurring in numerous short intervals. Intrudes both the Mahiao Plutonic Complex and Bao Volcanics.	Inter-mittent max. 2m	Unknown

The eruption of the Bao Volcanic complex began in late Miocene, probably as island arc volcanoes overlying continental rocks in a peripheral marine environment, but not directly onto oceanic crust. Lavas of entirely hornblende andesite composition are not recognised to be erupted in oceanic crustal areas.

The calcareous conglomerates and calcarenites probably represent the marginal marine facies of subaerial Bao Volcanics. An apron of volcaniclastic sediments would have accumulated on the flanks of the active volcanoes. Such deposits may underlie the North Central Leyte Formation (NCLF) and be indistinguishable from it. It is suggested that most of the NCLF deposition post-dates the Bao Volcanics and belongs to a period of intense uplift and erosion of Pleistocene age.

The age of the plutonic complex encountered in many of the deep Mahiao wells is uncertain. Occasional short sections of dioritic material are encountered within Bao Volcanics in some holes. It would therefore seem likely that the diorite pluton has intruded the Bao Volcanics, but the diorite itself is also intersected by small hornblende dacite intrusions.

Geophysics

In order to discover the extent of the postulated geothermal field, a systematic programme of D.C. resistivity traversing was proposed by W.J.P. Macdonald (DSIR Geophysics Division). This programme was adopted by KRTA in November 1974 and continued until November 1976. More than 600 stations were occupied, covering an area in excess of 300 km^2. Considering the rugged terrain and very high rainfall, this represents a notable achievement by New Zealand and Filipino field staff.

A Schlumberger configuration was adopted, with current electrode spacings (AB/2) of 250 m and 500 m and potential electrode spacing of 25 m. To date the 500 m results have proved most useful and a small part of the survey is shown in Figure 5. For clarity, only 10 and 20 ohm-metre iso-resistivity lines are shown in Figure 5; it should be understood that the apparent resistivity values increase markedly in most areas beyond these lines. As a crude initial interpretation it is often assumed that the 10 ohm-metre contour outlines the near-surface (within 500 m) distribution of hot water. Although useful, this interpretation involves implicit assumptions that are not always valid; it can therefore be misleading in some circumstances. This is dealt with in a later section on further exploration.

There are two prominent areas of low apparent resistivity, one closely following the Bao Valley and its eastern tributaries, and the second containing sections of the Mahiao, Sambaloran, and upper Malitbog river valleys, together with the rugged terrain in between. Both anomalies contain current thermal activity and extensive areas of hydrothermally altered rocks.

Geochemistry

Early work (Abiog, 1969; Farjardo and Tansinsin, 1973; Glover, 1974), showed the hot springs discharging at low elevation (200 to 260 m) in the Tongonan area of the Bao Valley to be high chloride, low bicarbonate, near neutral waters. By comparison the waters from springs at high elevation (260 to 560 m) in the Hanipolong, Paril and Mahanagdong Valleys were found to be of low chloride, acid-sulphate composition. (Refer Table 2.)

Homogeneous Cl/B ratios of 28.9 to 30.4 and Cl/As ratios of 2377 to 2527 suggest the Bao Valley springs to be derived from the same source of hot water. Oxygen-deuterium analyses of hot springs showed this parent water to have an oxygen shift of +3‰ relative to meteoric water, indicating a long residence underground and equilibrium with country rocks.

Progressive changes in the elemental ratios of solution chemical geothermometers particularly Na/K and Na/K/Ca indicate that springs to the west draw progressively cooler chloride water. On this basis the concept of an aquifer underlying the Banati thermal area and flowing west to the Bao River springs was postulated.

Springs in the Mahiao Valley and Kapakuhan headwaters, 6 km to the northwest of the Bao Springs, were later analysed and found to be acid, low chloride, sulphate rich waters indicative of steam upflow. Water/gas equilibrium data suggested that this steam separated from a deep body of water at a temperature of 330-340°C.

Table 2: Comparative chemistries of Tongonan hot springs

Area	pH	Cl mg/l	SO_4 mg/l
Bao River and Banati	7.67 to 8.25	3163 to 3606	74 to 84
Paril	5.0	5	700
Hanipolong	4.0	1	350
Kapakuhan A	2.25	2.0	1990
Mahiao A	3.1	2.7	330

Drilling

Four phases of drilling have been undertaken at Tongonan. The first two, exploratory, phases comprised 12 shallow temperature gradient wells (228 to 617 m deep) drilled with a Failing 1500 rig. Although drilled for temperature gradient information, these wells provided a great deal of other data. Cores, taken at approximately 130 m intervals, and cuttings gave a picture of the stratigraphy and hydrothermal alteration sequence. The wells were drilled with blowout preventers and equipped for downhole sampling. Several were discharged to provide more chemical data, formation characteristics, and scaling tendencies.

The third phase comprised deep (1121 to 1992 m) delineation, production and reinjection wells for a 3 MW demonstration plant and 112 MW power station. Phase IV began further deep exploration. Deep wells were drilled with two Ideco rigs (H525 and H725). Locations of the shallow TGE wells (Tongonan geothermal exploration) and the deep wells are shown in Figures 4 and 5. The numbering system for deep wells is based on planned pipeline collection zones.

Shallow Temperature Gradient Wells

In the first phase of drilling, wells TGE-1 to 7 were sited on the basis of geology and surface geochemistry, without the benefit of geophysics, because resistivity survey results were not available at the time. TGE-1, 2, 3, 6 and 7 were drilled in the Bao Valley, but despite the proximity of hot springs with high chloride content, these wells encountered only hot water with little or no chloride. The degree of mineralisation and oxygen isotope data in bottom samples from TGE-3 indicated that the chloride water supplying the hot springs comprised no more than 5% of the well water. Estimates for TGE-7 were similar. The maximum temperature recorded was 180°C in TGE-1 at 100 m depth, but the bottom temperature was less than 100°C.

Wells TGE-4, 5, and 5A, drilled in the Banati Valley, successfully located chloride-bearing water similar to that in the Bao Valley springs. The highest temperature was 197°C at a depth of 214 m in TGE-4, but all three wells showed temperature inversions, suggesting that they may have intersected an outflow tongue of hot water. Both TGE-4 and 5A produced low enthalpy discharges, but both became blocked with calcite/aragonite within a few days of opening, except when back-pressured by orifice plates to retain carbon dioxide in solution.

The results of this programme suggested that the source of the chloride-bearing water might be beneath the headwaters of the Malitbog, Banati, and Hanipolong streams to the northeast. By this time also, there was known to be an extensive resistivity anomaly to the northeast, and a decrease in apparent resistivity with increase of electrode separation suggested that temperatures might rise with depth. Finally, the silica content of the water discharged from TGE-4 indicated a source temperature above 210°C.

Phase II drilling therefore began with TGE-8 and 9 to test these indications. Although conductive gradients averaging 9°C/100 m were recorded, geothermal activity was found to be extinct, at least within the depths drilled. With respect to sea level, these two wells are among the shallowest drilled, however, and the area is to be tested by deep exploration wells. TGE-11 was sited to test the Central Philippine Fault as a possible conduit for geothermal fluids but failed to intersect significant permeability. It had a recorded temperature gradient of 18°C/100 m over the last 150 m, but core analysis revealed that the degree of hydrothermal alteration was low.

During the progress of electrical surveying, the presence of the Mahiao and Kapakuhan hot springs was noted in what the geologists believed to be a fault-controlled section of the Mahiao Valley. Geochemical indications of a high-temperature steam feed below these springs, and the large extent of the Mahiao resistivity anomaly, together with the limited success of shallow wells in the Bao-Banati area, soon combined to divert attention to the Mahiao Valley.

TGE-10, drilled to test this area, encountered temperatures closely parallelling the curve relating boiling point with depth, the bottom temperature being 254°C. Epidote, an alteration mineral whose formation requires temperatures above 250°C, was seen for the first time, and anhydrite, previously recorded only in TGE-9, was identified in veins. The well fluids were similar in composition to the nearby spring waters, but neutral or slightly alkaline, instead of acid. The mild degree of sodium enrichment again indicated that the heat was brought by steam rising from below.

Unfortunately, the permeability was not sufficient for TGE-10 to sustain a substantial long-term discharge. Despite this, data from this well were thought to warrant a deeper test, and Phase III drilling therefore began. Since early 1978 TGE-10 has been used as an injection well, taking the waste fluids from the 3 MW demonstration plant nearby.

Deep Wells

The first Phase III well, 401, was drilled 250 m from TGE-10 to a depth of 1942 m. Its maximum temperature was 324°C and it produces a total mass output, at a pressure of 0.7 MPa, of 27 kg/s with an enthalpy of 2230 J/g. After 24 months cumulative discharge the potential of 401 is estimated to be 9.9 MWe. Since July 1977, this well or the nearby 404, has supplied steam to a 3 MW demonstration unit distributing electricity to the city of Ormoc and neighbourhood.

Of 12 deep wells in the Mahiao and Sambaloran Valleys currently available for inclusion in the 112 MW development, six have been given 90 day tests. The aggregate mass output of these six wells at 0.7 MPa was 343 kg/s with an enthalpy of 1547 J/g, and the mean power potential was assessed at more than 11 MWe per well. Individual enthalpies ranged from 1380 to 2675 J/g. Production comes mainly from a zone of varying width close to the contact of andesitic lavas and tuffs, belonging to the Bao Volcanics, with the underlying Mahiao Plutonics, in which most of the wells terminate. Subsidiary production may also come from beneath silicified, clay, or black shale layers, interbedded with the volcanics. Selected data relating to the deep wells appear in Table 3.

Table 3: Characteristics of some deep wells

	103	105	202	208	209	212	401	404	406	407	MB1
1) Elevation (CHF) in m msl	432.73	409.60	510.00	592.28	535.22	519.50	523.16	519.35	570.52	537.78	476.30
2) Completion data m (CHF)											
Total depth	1402.0	1796.0	1896.9	1997.6	1121.3	1519.9	1942.1	1668.2	1794.5	1605.4	1665.1
Shoe of 9-5/8 casing	580.9	613.2	682.3	676.7	671.7	647.6	475.4	673.8	676.4	662.7	670.4
3) Permeability											
Injectivity index (1/s MPa)											
a) initial	28	42	60	16	18	51	14	25	23	65	196
b) retest	58	63	-	-	-	-	-	-	-	-	-
Transmissivity (darcy metres)	-	10	-	-	2	2	-	5	4	8	50
Pressure drawdown during discharge, % at -762 m msl	<18	16	16	-	63	-	<45	60	-	54	-
4) Discharge data (at 0.7 MPa)											
Mass flow rate (kg/s)	48	66	69	-	24	-	27	20	34	35	118
Enthalpy (J/g)	1600	1380	1450	-	2460	-	2230	2100	1850	1770	1250
Main production zone (m)	1200/ 1300	1700/ 1740	1250/ 1470	-	1100/ 1121	1450/ 1500	1450/ 1800	1500/ 1600	1600/ 1700	1325/ 1405	1410/ 1661
Temperature at main production zone before discharge (°C)	280	313	312	-	280	-	322	302	310	302	280
5) Power potential (MWe)											
Vertical clearing discharge	9	6	8	10	7	11	6	-	4	5	13
Medium term tests at 0.7 MPa	10.2	10.5	12.1	-	10.1	-	9.9	6.5	9.3	8.9	15.1
6) Temperature											
Maximum (°C)	312	317	317	317+	286	311	324	313	323	315	284

All of these wells produce a two-phase mixture of high-chloride brine and steam which is chemically dissimilar to the Bao fluids. Inspection of cuttings, together with detailed petrological examination of cores from stage III drilling, have provided further petrological information, which is summarised in Table 4.

Table 4: Generalised lithology and alteration assemblages encountered in Mahiao wells

Depth	Lithology	Alteration assemblage	Vein minerals
0	Weathered andesite rubble	Limonite and hematite	Usually nil
50 m	Andesite porphyry	Illite-montmorillonite clays replacing feldspar and matrix. Disintegration of hornblende, partial replacement by magnetite.	Calcite
350 m	Sedimentary unit not always present. May be a pebble horizon, limestone, or fossiliferous volcaniclastic. Depth variable.	Hematite, often but not always intense. Clay developments often strong.	Calcite abundant
400 m	Andesitic tuffs and porphyries. Sometimes major fracture (eg 401, 403, 407)	Increasing magnetite and sulphide. Silification of matrix (development of cap?). Calcite replacing feldspar. Rare epidote.	Calcite, quartz, wairakite, adularia, occasional ankerite or dolomite.
1000 m	Pyritic, feldspathic tuffs with some intercalations of andesitic lava or porphyry.	Magnetite decreased to rare but pyrite up to 30%. Feldspars indistinct. In lavas and porphyries epidote is common replacing feldspar and as vein mineral (propylite). Rare garnet MB1 & 209.	Epidote, quartz, anhydrite, adularia.
1350 m	Propylitic lavas and porphyries, with minor tuffs. Some sections dioritic intrusive.	Epidote abundant in veins and replacing feldspar. Magnetite pseudomorphing hornblende. Sulphide reduced, rare chalcopyrite, pyrrhotite. Increasing silica. Minor leucoxene.	Epidote, quartz, anhydrite.
1500 m	Diorite, quartz-diorite intrusive.	Propylitic, epidote in veins and replacing feldspars.	

NB The above lithologies are not intended to be correlated with those shown in Table 1.

Permeability is derived from fracture zones and indicated in cuttings by growth of drusy vein minerals, particularly quartz, adularia, wairakite and anhydrite, and during drilling by fluid losses. That self-sealing is in progress is witnessed by silicification, and in some instances the sealing of fractures by anhydrite. Mineral assemblages, summarised in Table 4, record a steady increase in the degree of hydrothermal alteration grading into a propylitic horizon at depth.

Two wells, located outside the 10 ohm-metre contour of apparent resistivity are of interest. One, 1R10, was drilled as a reinjection well on the strike of the Central Philippine Fault and encountered considerable pugs. It is hot and has been discharged in an attempt to improve the permeability, but with little success. It does however accept water and is still under test for reinjection.

The second, Malitbog 1, was drilled in an area devoid of hot springs but with extensive hydrothermal alteration. The well passed through propylitic rocks which record previous hydrothermal activity, but fractures are sealed and a dense silica cap has developed. At a depth of 1542 m massive permeability was encountered and the well was completed to 1665 m without fluid return. The well is a little cooler than some of the Mahiao wells at corresponding depths and the temperature gradient in the upper levels is conductive, rather than convective as in Mahiao wells. Nevertheless, medium-term tests indicate a power potential of 15 MWe and significantly enhance the overall indicated power potential of the field.

The Reservoir

A comprehensive picture of the Mahiao reservoir is still being built up, but some aspects can now be described. The main production zone is the neighbourhood of the contact between the diorite and the overlying volcanics. It is uncertain whether the diorite is an old basement, or a young intrusive that might also be a heat source. The intensity of hydrothermal alteration at its surface makes this difficult to determine, but this altered zone is certainly a permeable reservoir of high temperature fluids. The overlying tuffs and breccias are no doubt porous except where sealed with calcite or silica, but they are not, in general, very permeable. The geological background thus appears somewhat similar to New Zealand's Wairakei, where porous but rather impermeable pumice breccias overlie the main production zone close to the top of a massive ignimbrite formation.

Hydrologically the two fields differ greatly, however, in that parts of the Mahiao reservoir contain two-phase conditions extending below the deepest wells, whereas there was little free steam initially at Wairakei. On the other hand, a few Mahiao wells do appear to tap only hot water. The two-phase condition is more akin to New Zealand's Broadlands, and, like Broadlands, the Mahiao is rather a gassy reservoir. The wells at present discharge an average of 1-2 percent by weight of gas in the steam, of which about 95 percent is CO_2, 4 percent H_2S, plus methane and hydrogen.

These reservoir characteristics suggest that substantial changes may accompany sustained production. Any general drawdown is likely to produce a transient rise in enthalpy and gas content of some well discharges as the pressure drop propagates through the two-phase region. Steam and gas may in time displace some of the water from the Bao volcanics, creating high enthalpy pockets beneath shale or silica caps. It is possible also that some of this steam will reach the surface to cause an increase in intensity of the Mahiao and Kapakuhan hot spring activity. The production wells are undergoing comprehensive transient, interference, and drawdown tests, in order that the operating characteristics of the field can be predicted as far as possible in advance of full scale production.

The chemistry of the deep well fluids is shown in Table 5. Although the rocks are heavily veined with calcite at higher levels, this mineral is rare at the main production zone. The rapid calcite deposition in the shallow wells TGE-4 and 5A is not matched in the deep wells. Nor, in spite of high silica content, has silica deposition been significant, except where separated water has been exposed to the atmosphere. The only significant silica deposition occurred when intermittent operation has permitted access of air, or when a faulty wellhead separator has caused water to be carried over into steam lines.

The high arsenic and boron content of the well water presents a substantial environmental hazard. Restrictions have therefore been placed on vertical discharge to the atmosphere and waste water discharge to streams and rivers. Chemical dosing in holding ponds has been used for short periods, but reinjection is the only satisfactory method of waste water disposal. For testing purposes injection may be into a nearby production well, but for long-term production dedicated injection wells are being provided. Chemical and radioactive tracer tests will be made to establish the extent and effects of any recycling of the reinjected water that may occur in production conditions. Tests will also be made to determine the lowest pressures at which steam separation can be effected without causing silica deposition from the supersaturated waste water in the absence of oxygen.

Table 5: Well characteristics and water phase stable chemistry (mg/kg)

	401	202	103	404	407	209	Mean of Mahiao wells	MB1
Depth (m CHF)	1942	1897	1400	1669	1605	1122		1665
Main production zone (m)	1450 to 1800	1250 to 1470	1200 to 1300	1500 to 1600	1325 to 1405	1100 to 1121		1410 to 1661
Max. T^o	324	317	305	305	311	280	307	268
Fluid flow* (kg/s)	8.2	44.4	27.4	6.5	17.1	4	17.9	85.8
Steam flow* (kg/s)	16.8	24.6	20.6	13.5	17.9	21	19.1	32.2
Enthalpy* (kJ/kg)	2100	1450	1600	2100	1770	2440	1910	1280
pH	6.7	7.1	6.9	7.1	6.6	6.4	6.8	7.4
As	28	20	23	26	34	33	27	14.1
B	320	235	260	354	390	-	312	160
Ca	220	216	253	210	276	-	235	170
Cl^-**	8965	7705	8509	8014	9910	9650	8792	5386
Cl^-	15000	12390	13480	13805	16514	24250	15907	8966
CO_2	28	67	23	43	42	80	47	23
Cs	3.5	3.4	4.4	3.0	5.7	8.0	4.7	3.09
H_2S	12	10	11	15	11	16	13	3.9
K	2110	1710	2000	2025	2433	4130	2401	1250
Li	39.8	33.5	34.1	37.8	41.6	51.3	39.7	21.1
Mg	0.30	0.10	0.70	0.24	0.36	2.16	0.64	0.21
Na	7800	6750	6734	7688	8230	12913	8353	4444
NH_3	6.4	4.8	-	9.6	10.1	-	7.7	-
Rb	12.5	10.8	9.9	11.5	12.0	17.6	12.4	7.64
SiO_2	995	1034	947	1010	1071	947	1001	890
SO_4	32	19	32	100	72	-	51	21

Notes: * At 0.7 MPa wellhead pressure ** Deep fluid chloride concentration
Data are those available at March 1979
Fluids separated at atmospheric pressure and about 98^o.

Drilling Costs

Direct drilling costs of a typical Tongonan well, as they vary with depth, are shown in Figure 6. For an average depth of 1600 m, the total cost would be US$600,000 to 700,000, of which fixed costs (access, site, wellhead) would account for about 10%. Assuming a standard steam rate of 2.02 kg/s per MWe, as used in New Zealand geothermal work, the average direct cost at the wellhead would be about US$55,000 to 65,000 per MWe at a wellhead pressure of 0.7 MPag.

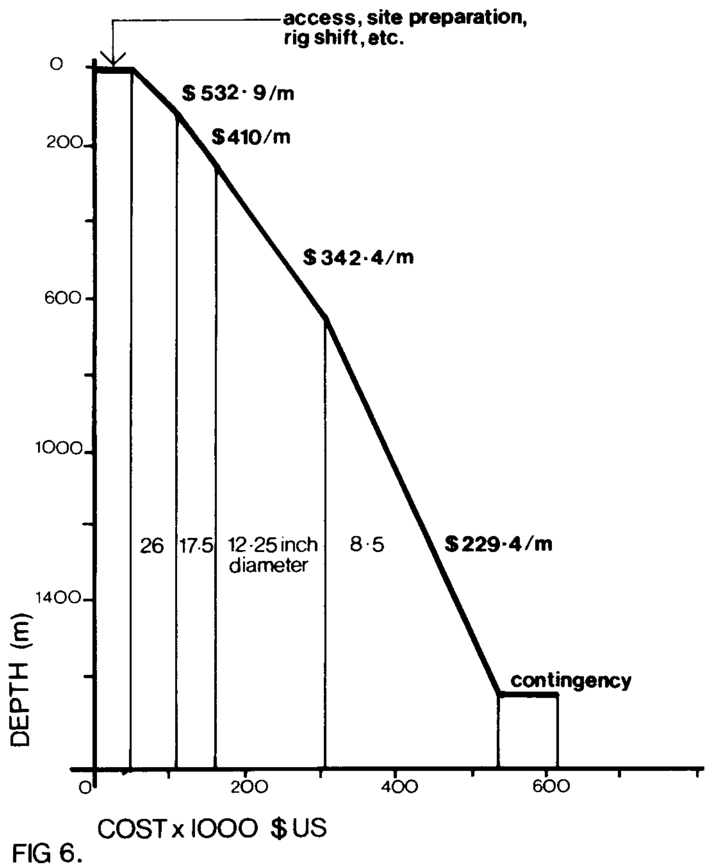
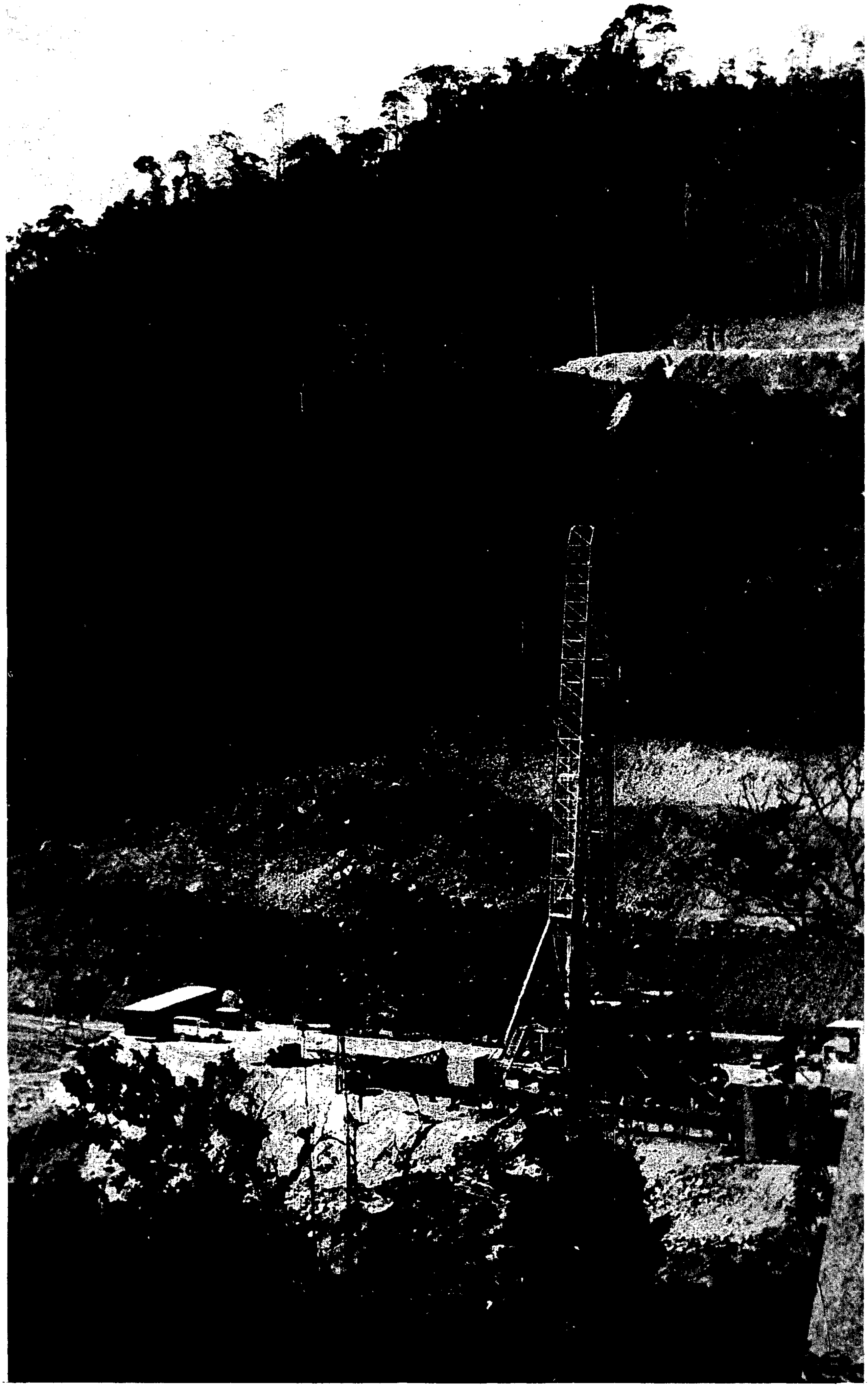


FIG 6.
DIRECT COST OF TYPICAL TONGONAN WELL VERSUS DEPTH



Ideco rig H725 at injection well site 2R2.
Production well 209 above.

Power Development

The initial approach to geothermal development at Tongonan was relatively modest, but as the demand for energy in the Philippines continued to grow and the cost of oil climbed rapidly, expectations from geothermal resources expanded also. A 100 MW Tongonan development project was tentatively scheduled as soon as the assessed potential of the field reached 3000 MWe-years. As a demonstration of geothermal capability, a 3 MW non-condensing unit was installed to make use of steam from the first deep well in the Mahiao area, waste water being reinjected into the only shallow well drilled in the vicinity. This demonstration unit has provided worthwhile experience of sustained well production, steam separation, station operation, and reinjection, while also supplying electricity to the city and neighbourhood of Ormoc.

There are however difficulties inherent in larger scale development at Tongonan. There is, for instance, very limited generating capacity in Leyte and no extensive reticulation of electricity. The Tongonan development cannot therefore conform very closely to the common concept of geothermal as a base-load energy source. Moreover, this situation would be aggravated by the proposal to establish a metallurgical smelter nearby, because the load characteristics would be dominated by the demands of this single consumer. For this reason it has been necessary to incorporate into the 112 MW development a higher degree of flexibility and more complex control systems than would otherwise be required.

A three unit station is planned (3 x 37.5 MW), but one machine will initially, in effect, provide reserve capacity. By the time this machine becomes fully loaded, it is expected that interconnection with other generating capacity will provide an adequate reserve.

Additional difficulties are presented by the rugged terrain of the Tongonan field, seismicity and general soil instability, and the liability to erratic and severe flooding and erosion in typhoon conditions. For this reason further development in Tongonan is expected to follow a modular concept, with a number of stations of similar size located to suit steam collection from topographically distinct sectors of the field.

Micro-seismic activity is being monitored; this will serve to indicate whether there is any tendency for increased seismicity to accompany large scale waste water injection. A levelling network has been established to study possible earth movements and gravity observations at a number of benchmarks will provide data on the water balance in the reservoir when production gets under way.

The chosen powerhouse site is above the confluence of the Sambaloran and Mahiao valleys. The steam collection system extends up both valleys, and further safeguards are provided by pipeline duplication in each area. A two-phase transmission system is planned between the wellheads and two central steam separator stations. Waste water injection wells are mainly located close to the margin of the field and are drilled to circulation loss zones in similar manner to the production wells.

Dual pressure turbines are specified, but it is probable that the use of low pressure steam will be treated as an option for future review. Many considerations are involved in this decision, in addition to the cost of the low pressure facilities and the extra energy involved. For example, some of the lost energy is regained in the higher temperature of the reinjected water. The higher temperature also reduces the danger of silica deposits in plant, pipes and injection wells. There are also problems of balancing high pressure and low pressure steam under fluctuating load conditions. In view of the high enthalpy available, the turbine manufacturers have guaranteed the full rated output with single inlet pressure.

Further Exploration

At an early stage in the deep drilling programme it became apparent that the total potential of the Tongonan field would be considerably higher than the initial 112 MW development. Even before the success of Malitbog 1, there were several lines of evidence to support this.

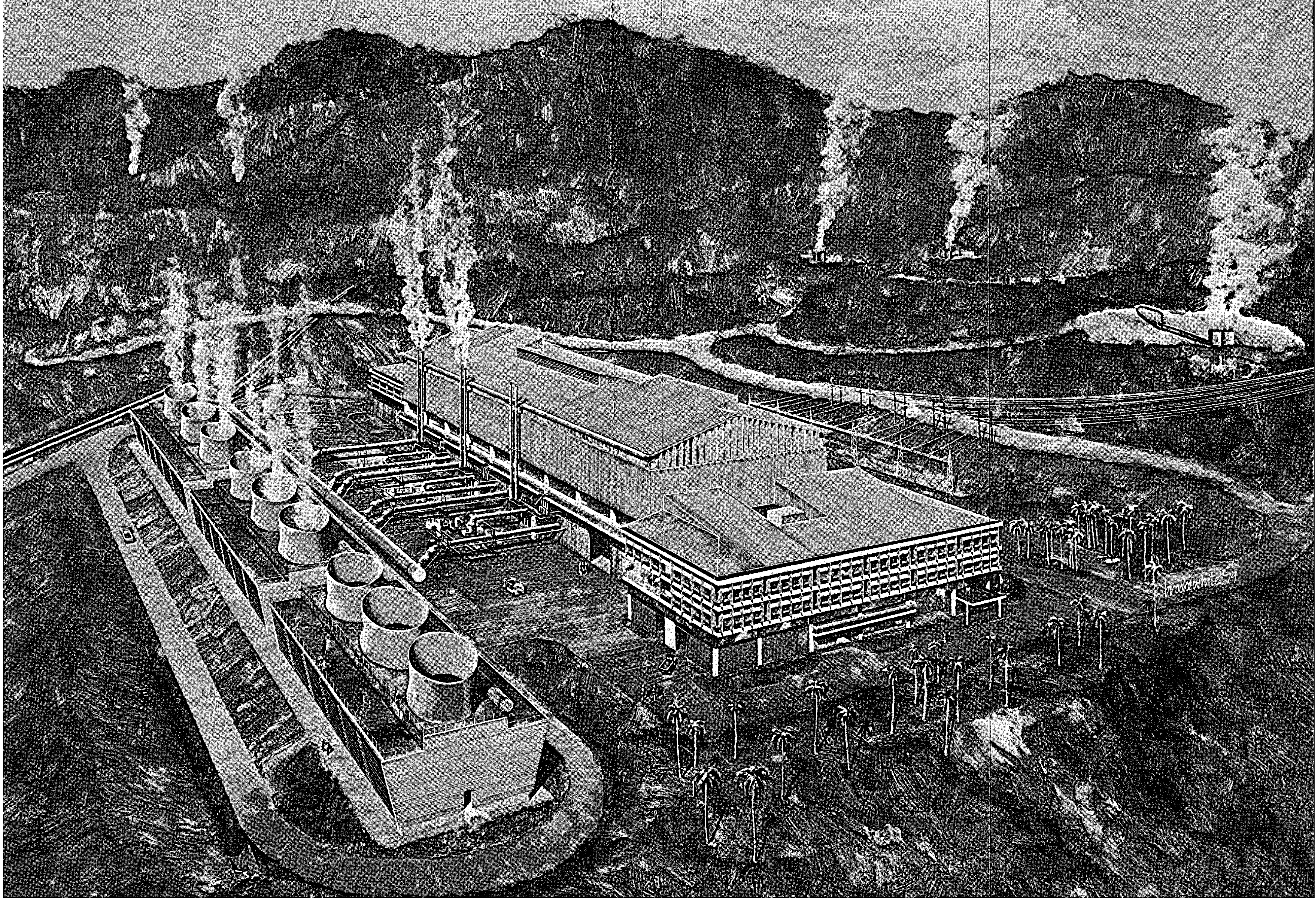
The first concerns the source of the Bao Valley hot springs, which has yet to be located. Marked chemical differences show that the Mahiao and Malitbog well fluids have a different source from that supplying the Bao Valley wells and springs. It has also been deduced from the presence of sulphate minerals in TGE-8 and 9 that the hydrothermal alteration in this area is more akin to that in the Mahiao than in the Bao Valley. It follows that, unless the Bao Valley hot water comes directly upward, which is not likely in view of temperature inversions in TGE-1, 4, 5, and 5A, the most probable source area is in the southeast.

This hypothesis presents Tongonan as a combination of two fields, disposed on echelon, of which only one has been explored to date. It also accounts for small thermal areas in the Paril Creek and upper Bao Valleys, which are difficult to explain otherwise. Analysis of gases in the Paril fumarole indicates a minimum source temperature of 216°C. It has also been pointed out that the much higher chloride/boron ratio in the Bao waters is more suggestive of dacitic or granitic host rocks than the diorite and andesite in the Mahiao area.

An additional consideration concerns the resistivity map. Initially it may be useful to postulate that areas with apparent resistivity of 10 ohm-metres or less represent the near-surface distribution of hot mineralised water. Clearly however, in outflow areas the hot water may overlie colder temperatures and be of little practical value. Conversely, an exploitable hot water reservoir may itself be covered by relatively cold temperatures, so that its influence on the measured resistivity is reduced. Apparent resistivities above 10 ohm-metres may then be recorded within the field boundary. It is known that the Tongonan field extends beyond the 20 ohm-metre contour in the steep, high terrain of the upper Malitbog, and the full extent of the field has yet to be discovered in the whole of the north, east, and south perimeter. If a 50 ohm-metre margin is adopted in the high country, the area of the field may be more than 30 km^2.

The total potential of the Tongonan field might thus be four or five times the 3000 MW-years originally estimated for its Mahiao sector. Final constraints on development may, however, be the engineering difficulties imposed by the rugged and unstable terrain rather than geothermal conditions. For this reason engineering studies are being undertaken before commitment is made to drilling programmes in difficult areas.

Finally, the geothermal resources of Leyte are not confined to Tongonan. Scientific surveys are under way in neighbouring fields with a view to assessing the overall geothermal potential of the island and considering the way in which it can best be used. KRTA has also undertaken scientific work on another valuable geothermal resource in the Okoy Valley of Southern Negros, and drilling is in progress to assess its size.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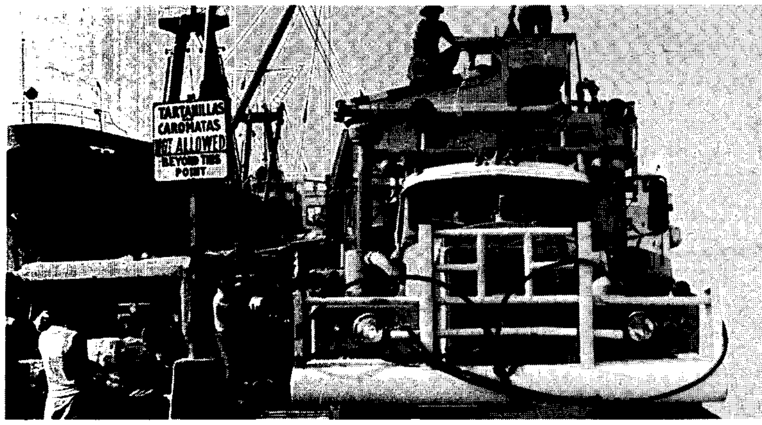

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POINT