GEOCHEMICAL EVALUATION OF THE DIENG MOUNTAINS

CENTRAL JAVA

FOR THE PRODUCTION OF GEOTHERMAL ENERGY

by

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CONTENTS

SUMMARY

Insofar as can be determined from a geochemical survey of hot springs, fumaroles, and rivers, the Dieng Mountains appear favorable for exploitation of geothermal resources. Exploratory drilling recommended by Muffler (1970) as step two should proceed.

Specific findings covered in this final geochemical report are:

1. The Dieng geothermal systems will probably produce a mixture of hot water and steam rather than steam alone.

2. Three or possibly four geothermal systems are found in the near-surface (<200 meters) in the Dieng. These may be connected at much greater depths. The largest of these is the Pagerkandang system which is at least 2.5 km^2 in area.

3. The top of the Pagerkandang reservoir is at about 1875 meters above sea level. Drilling between Siglagah and Pagerkandang should be at least 200 meters deep to intercept the reservoir.

4. The subsurface temperatures indicated by critical chemical constituents are 203°C (silica) and approximately 200°C (alkali ratios).

5. No problems are expected at Pagerkandang with corrosion from acidity of the geothermal fluid and few from H_2S attack of electrical equipment. The geothermal fluid has about 700 mg/l chloride if its reservoir temperature is 200°C. No pollution problems are anticipated from boron in the effluent.

6. The natural heat flow of the Dieng region is at least 5,000 Kcal/sec, as calculated from production of geothermal chloride. This estimate does not take into account the heat escaping as vapor, and may be low by perhaps 100%.

INTRODUCTION

Chronology

This report contains results of a 3-week geochemical study of the Dieng geothermal systems. This is part of a cooperative program of the Indonesian Ministry of Mining, the Indonesian Directorate General for Power and Electricity and the U.S. Geological Survey under the auspices of the Government of Indonesia and the Agency for International Development, U.S. Department of State. This is part of the first stage of investigation suggested by Muffler (1970) in his appraisal of the geothermal potential of the Dieng mountains.

The 3 weeks in Indonesia was spent in this way:

August 4-5 :	Djakarta. Conferences with USAID and USGS personnel. Formal meeting with representatives of the Indonesian Directorate General for Power and Electricity.
August 5-6 :	Bandung. Review of available reports. Conferences with personnel of the Geological Survey of Indonesia (G.S.I.).
August 6 :	Drive to Wonosobo, Central Java.
August 7-8 :	Reconnaissance and sampling of fumaroles and hot springs in the Dieng and Karangkobar areas with Dr. M. R. Klepper of the U.S.G.S. and personnel of the G.S.I.
August 9-17 :	Field sampling in the Dieng and of rivers draining the Dieng. Limited field analyses of samples.
August 18 :	Drive to Bandung.
August 19-21 :	Review of data. Preparation of preliminary report.
August 22 :	All day lecture and discussion session on geology and chemistry of geothermal systems with all interested parties.
August 23 :	Visit Kawah Kamodjang fumarole area.
August 24 :	Drive to Djakarta. Presentation of report to representatives of the Indonesian Directorate General for Power and Electricity. Leave Indonesia.
October :	At the writer's request, Soeharto Oemar and other scientists of the G.S.I. made further collections in the Dieng. The analyses of these samples are included in this final report.

During late 1970 and early 1971 several partial analyses of critical fluid samples were completed by U.S.G.S. chemistry laboratories in Menlo Park, California. These analyses are also included in this final report.

Acknowledgements

The support of the Geological Survey of Indonesia (G.S.I.) and the Directorate General for Power and Electricity (D.G.P.E.) has been superb. The work described in this report could not have been accomplished without an all-out effort from the personnel of these agencies and from the personnel of the USAID and the U.S.G.S. in Indonesia. Of his many new friends the writer particularly wants to thank Mr. Vincent Radja and Mr. Oemar Hasan Soewarho of the D.G.P.E. Mr. Muzil Alzwar of the Volcanology Division, G.S.I., and Mr. Soeharto Oemar and Mr. Wishnu Sudarsono Kartokusumo of the Chemistry Division, G.S.I. Enthusiastic support in the field was given by many others who will be well remembered. Discussions in the field and afterwards with Indonesian colleagues already mentioned and with Drs. J. R. Pritchard and J. J. Jacobson were very valuable. The presence in the background of Dr. A. Arismunandar and Mr. C. S. Hutasoit of the D.G.P.E., Dr. M. R. Klepper of the U.S.G.S. and Mr. Bruce E. Kent of the USAID contributed greatly to the success of the mission. Chemical analyses of critical fluid samples were done in Menlo Park, California by R. B. Barnes, Water Resources Division, U.S.G.S.

Objectives

Chemical studies of geothermal systems cannot be strictly separated from geologic observations. The location, intensity and character of thermal features as well as their chemistry must be considered to present as complete an analysis of the system as possible. In this investigation I have attempted to cover the following problems related to the Dieng geothermal systems:

- I Character of the geothermal systems - hot-water or vapor-dominated.
- II Areal extent of the systems.
- III Depth to the geothermal reservoirs.
- IV Subsurface temperature.
- V Chemical character of the geothermal fluid.
- VI Rate of natural energy production.

CHARACTER--HOT-WATER OR VAPOR-DOMINATED

Geothermal systems consist of a volume of porous rock containing heated water or steam and water in its central part, a source of heat at its base and cooler water at its margins which becomes heated and replenishes hot water and steam lost from the central part. Geothermal systems may produce either water and steam (a "hot-water" system) or steam alone (a "vapor-dominated" system), but recent work shows that in both cases liquid water predominates by weight in the reservoir. The important difference lies in the porosity of the reservoir rocks and the impedance of flow at the reservoir margins. Highly porous and permeable rocks do not usually contain vapor-dominated geothermal systems. Vapor-dominated systems are pressure-deficient relative to adjacent water saturated rocks, and with high permeability they can neither form nor be maintained. In addition, the drying of the fluid from mostly liquid water to entirely steam depends on transfer of heat from the rock due to a pressure and temperature drop during production. With highly permeable rock this pressure drop occurs in the well and no heat is transferred from the rock.

In evaluating which type of system is likely to be found at depth, the chloride content of surface springs is the most important single index. Chlorides with few exceptions are not appreciably soluble in steam below 300°C, and, since upward transfer of water and heat occurs by movement of liquid water in hot-water systems and by movement of steam in vapor-dominated systems, these may be differentiated by the chloride contents of the surface leakages. As a general rule of thumb if chloride contents of flowing springs exceed 50 mg/l a hot water system is indicated. There are a very few exceptions. The Beowawe, Nevada, USA hot water system has average chloride contents of 40 mg/l and the Carboli, Italy hot-water system has 43 mg/l.

The general principles are somewhat difficult to apply to volcanic areas where high permeability in the near-surface rocks may combine with copious flushing by ground water to prevent the formation of distinct hot-spring vents. High chloride water may be so diluted in the process that the chemical criterion discussed above for distinguishing between hot-water and vapor-dominated systems may not be applicable. The physical necessity for low porosity and permeability in vapor-dominated systems may, however, rule these out in volcanic reservoir rocks.

In the Dieng the abundance of fumaroles and the scarcity of hot springs combined with the low chloride contents of most of them would suggest the presence of a vapor-dominated system, were it not for the high chloride water from Sileri (173 mg/l Cl), Pulosari (426 mg/l Cl) and the river Tulis (160 mg/l Cl). These high chloride discharges strongly suggest that the Dieng systems are the hot-water type. Although the extraction of stored energy from a hot-water system is not as efficient as from a vapor-dominated system, the application of geochemistry to indicate subsurface temperature is much better established and the prediction of subsurface temperature conditions is more reliable.

AREAL EXTENT

In highly permeable recent volcanic rocks the presence of boiling water at depth will be revealed by fumarolic or steam-heated hot-spring activity at the surface since little resistance to the passage of vapor can be offered by the near surface rocks. Thus high priority was given to locating, examining and sampling as many as possible of the thermal features of the Dieng and surrounding areas. The results of this survey are shown in figure 1 and table 1.

Table 1.--Fumaroles, hot springs, and other thermal features of the Dieng Mountains observed by the writer.

Map No.	Name	Type*	Temperature, °C	Flow liter/sec.	Elevation, meters above sea level	pH	Chloride, mg/liter	Notes
1.	Kawah Sikidang	f,mp	91,94	large	2035	6.0	6	1967 vent.
2.	Near Kawah Sikidang	s	94	very small	2035	2.0	15.0	evaporation and oxidation of H_2S
3.	Kawah ~~Si~~bendang	f	-	feeble	2125	-	-	not collected
4.	Kawah Sigadjah	f	-	none or feeble	2125	-	-	not collected
5.	Near Telaga Warna	gv,s	cold	not overflowing	2065	1.5	75.0	evaporation and H_2S oxidation
6.	Near Telaga Terus	gv,s	cold	seeping	2065	6.0	14.0	
7.	Kawah Sileri (outflow)	f,s	55	50	1875	6.5	173	outflow
8.	Kawah Sileri (vent)	f,s,	86	-	1875	7	77	hot gassy vent on S side
9.	NE of Kawah Sileri	s	56	8	1875	-	18	probably heated surface water
10.	Pagerkandang SE	f	91	large	2025	5.5	-	
11.	Pagerkandang NE	f	95	large	2035	6.0	6	superheated
12.	Pagerkandang NE	f	94.5	mod. large	2035	-	0	outside crater on NW slope
13.	Bitingan	s	82.79	35	1900	6.7	20	3 vents, heated surface water

Table 1.--Fumaroles, hot springs, and other thermal features of the Dieng Mountains observed by the writer (cont'd)

Map No.	Name	Type*	Temperature, °C	Flow liter/sec.	Elevation, meters above sea level	pH	Chloride, mg/liter	Notes
14.	Near Kawah Siglagah	s	56	20	1800	6.5	15	heated surface water
15.	Kawah Siglagah	f	96.5	very large	2000	6.0	0	
16	Kawah Tjandradimuka	f,mp	99	large	1900-1950	7.0	6	2(3)? vents. NH_3 smell
17.	Wanaprija	s,gv	cold	0 to 1/2	1950	4.5-5.5	10-24	4 springs probably H_2S into surface water
18	Pulosari	s	55	10	1700	6.5	426	
	Springs outside the Dieng (see figure 2)							
	Kalibening	s	43	10	1000	6.8	98	deposits travertine
	Kaliputih	s	43	15	1150	6.8	390	deposits travertine
	Tempuran	s	43	10-20	1115	6.8	640	
	Panaraban	s	33	30-40	1100	6.7	72	deposits iron oxides and travertine (?)
	Kalianget	s	40	20 ?	800	7	350	
	Plantungan	s	43	20 ?	650	6.8	1400-2000	oil seeps nearby

*Key: f, fumarole; s, spring; mp, mud pot; gv gas vent. pH of fumaroles refers to condensate

The largest concentration of fumaroles and springs is in the area of the Pagerkandang crater from Kawah Sileri on the west to Kawah Siglagah on the east and north to the Kampung Bitingan. The fumaroles of Sikidang to the southeast and Tjandradimuka to the west as well as the spring at Kampung Pulosari are relatively isolated features. In the Sikidang and Tjandradimuka areas cold gas vents and gassy springs also occur, but the significance of these in outlining areas of subsurface hot fluids is very doubtful.

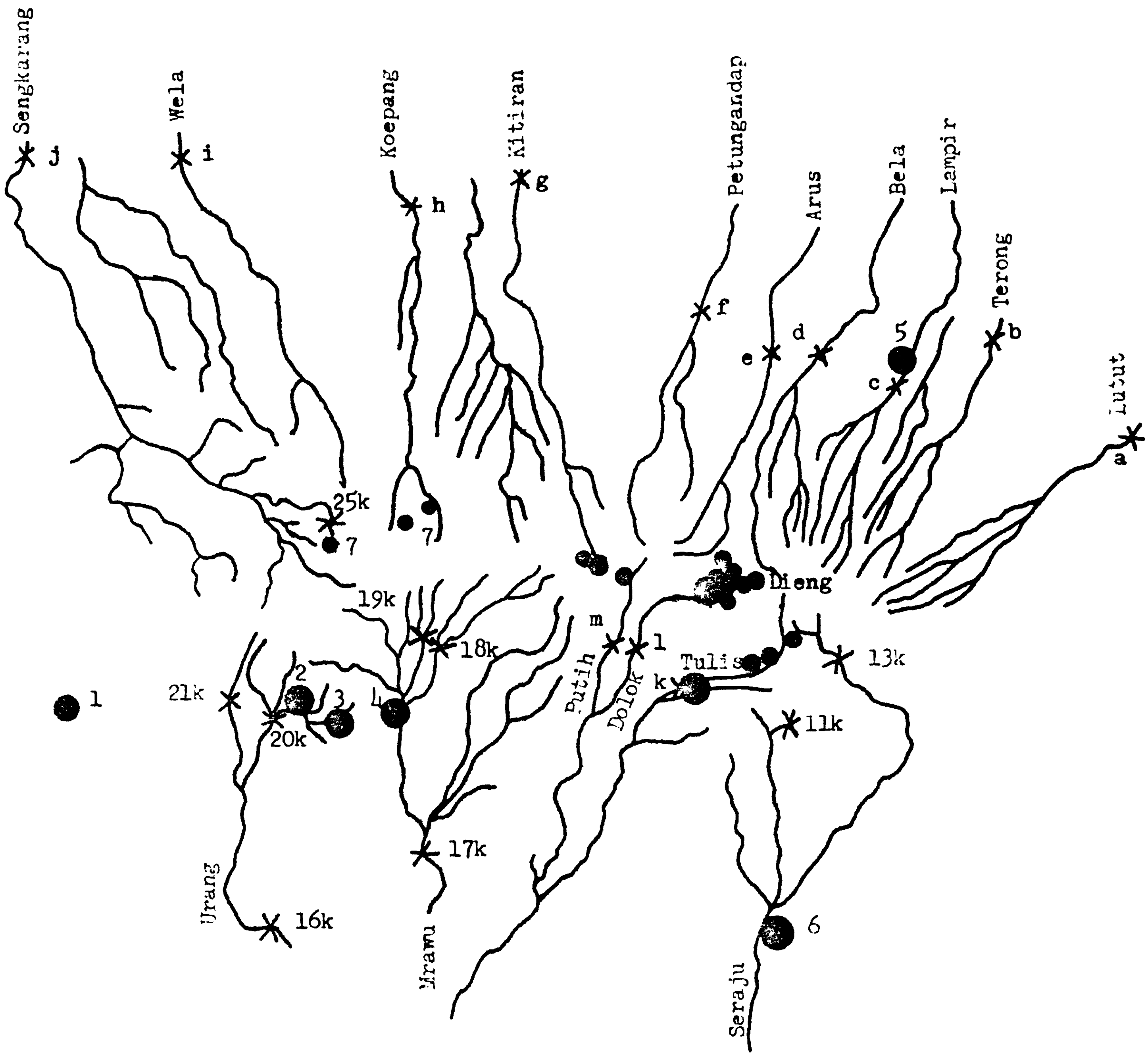
The Pagerkandang area (including features from Sileri to Siglagah and north to Bitingan under this name) extends 2.0 kilometers east to west and 1.25 kilometers north to south, thus covering an area of about 2.5 Km^2. The Sikidang and Tjandradimuka areas are considerably smaller. From Sikidang to the feeble or extinct fumaroles of Sibanteng and Sigadjeh is 1 Km; these features are aligned (fracture control?) and thus no area can be defined. A similar situation is found at Tjandradimuka where the two (three?) Tjandradimuka fumaroles are aligned (fracture control?) and about 1/4 Km apart.

The spring at Pulosari has a high chloride discharge and probably represents hot water separated from steam under one of the fumarolic areas which has been diluted by cold water. It is at a considerable distance from the nearest fumarole and it is not certain in which area it originates.

Springs outside the Dieng Mountains

Warm springs (33-43°C) at Kalianget near Wonosobo (position shown in figure 2), Kalibening, Kaliputih, Tempuran and Panaraban in the Karangkobar area and Plantungan to the north were visited, but it is the opinion of the writer that these are not directly related to the Dieng geothermal systems, although they do indicate generally high heat flow over a broad area. The springs at Kaliputih and Kalibening are at present depositing travertine and similar springs at Tempuran and Panaraban may have done so in the recent past. Travertine deposition is significant because the solubility of $CaCO_3$ <u>decreases</u> with increasing temperature; accordingly water from a high temperature geothermal system that cools by boiling and dilution near the surface will not deposit travertine. A high volume warm spring that is depositing travertine most likely has the same temperature at depth as it does at the surface. These springs are at the edge of the central volcanic range (Van Bemmelen, 1937) and the source of calcite is probably the Tertiary sediments immediately underneath.

The spring at Plantungan (analysis in table 2) has the highest chloride content of any spring visited. Its position along the north flank of the volcanic belt and the presence in the immediate area of oil seeps suggests that the water is actually a connate brine whose path to the surface is the same as that of the oil.



● Thermal spring or fumarole

● High-chloride spring

River sample

Springs outside the Dieng:

1. Kalibening
2. Kaliputih
3. Tempuran
4. Panaraban
5. Plantungan
6. Kalianget
7. H_2S springs from Van Bemmelen (1937) not visited

Figure 2. Sketch map showing rivers and springs sampled in the region around the Dieng Mountains.

TABLE 2.--Analyses of spring waters of the Dieng area (in mg/l except as labelled)

Number	1	2	3	4	5	6	7	8	9	10
Location	Sikidang	Sikidang	Sileri (outflow?)	Tjandra-dimuka	Tjandra-dimuka	Kalianget	Tempuran	Sileri outflow	Sikidang	Siterus
Field No.	I	II	---	I	II	--	--	JT10	JT27	JT29
Lab. No.	566/69	567/69	568/69	569/69	570/69	571/69	572/69	1827/70	1828/70	1830/7
Collection Temperature	--	--	--	--	--	--	--	55°C	94°C	cold
pH F = field								6.5F	2.0F	6.0F
L = lab.	3.4L	2.2L	6.1L	6.6L	4.3L	6.1L	6.3L	7.5L	1.9L	3.1L
Na	na	na	na	848[a]	437[a]	273[a]	270[a]	236	14.7	na
K	na	na	na					39.0	11.9	na
Ca	42.8	52.8	68.5	48.6	9.1	52.1	127	106	36.3	39.4
Mg	102	103	40.8	17.8	15.3	126	181	37.6	55.0	20.2
Fe (total as Fe^{+3})	24.5	15.0	2.5	0.1	2.5	4.0	0.1	0.7	6.4	0.6
Mn	2.2	1.1	0.0	0.2	0.2	0.0	0.0	2.2	0.5	3.6
Cl	60.7	60.7	130	71.2	17.8	412	681	245	29.4	20.2
SO_4	1,841	1,662	508	1,774	977	262	0.0	588	1,284	217.6
HCO_3	0.0	0.0	27.8	111	--	827	837	— 80.9	0.0	90.7
SiO_2	390	350	168	116	200	136	122	160	88.0	76.0
Cations millieq./e	11.8	12.0	2.5	40.7[a]	20.8[a]	30.6[a]	32.9[a]	19.7	27.6[b]	1.9
Anion millieq./e	40.1	36.3	14.6	40.7	20.8	30.6	31.9	20.5	27.5	11.7

a. Na + K calculated by difference; given as Na
b. H^+ included; calculated from pH
c. pH too low for reported HCO_3 content
d. 472 ppm analysed in field
e. JT9 analysis in ppm. Also 16 ppm NH_4 , 0.06 ppm Li, 0.8 ppm Sr, and 7.7 ppm B.
f. JT10 analysis in ppm. Also 52 ppm NH_4, 0.3 ppm Li, 0.6 ppm Sr, and 17 ppm B.

TABLE 2.--Analyses of spring waters of the Dieng area (in mg/l except as labelled) (Continued)

Number	11	12	13	14	15	16	17	18	19	20[e]
Location	Wanaprij'i	Pulosari	Sileri outflow	Kalianget	Kali Balun seepage	Plantungen oil seep	Plantungen hot water	Bitingan I	Bitingan II	Sileri vent
Field No.	JT23?	JT31	7K	14K	20bK	23aK	23bK	KK3	KK4	JT9
Lab. No.	1831/70	1832/70	1872/70	1874/70	1875/70	1876/70	1877/70	1900/70	1901/70	2165
Collection temperature	cold	55°C	--	40°C	--	--	--	--	--	86°C
pH F = field	4.5F	6.5F		7.0F						7.0F
L = lab.	1.0L°	8.1L	7.1L	7.7L	8.0L	7.1L	6.7L	7.1L	7.7L	7.9L
Na	na	147	232	149	203	731	1066	50.8	8.4	180
K	na	64.3	56.6	45.0	17.7	16.1	48.2	16.1	1.9	42
Ca	30.3	133	121	57.8	15.1	215	218	33.3	6.1	108
Mg	4.6	57.3	55.0	154	82.4	3.7	3.7	9.2	1.8	20
Fe(total as Fe^{+3})	17.2	0.7	10.4	0.2	0.2	0.2	2.1	0.4	0.2	0.5
Mn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	na
Cl	18.4	414[d]	57.0	392	234	1058	1242	20.2	11.0	77
SO_4	1367	196	837	201	0.0	89.3	67.0	156.2	33.5	206
HCO_3	2041	193	149	572	572	764	1456	128	25.6	476
SiO_2	70.0	132	40.0	92.0	132	24	84	74	22	152
Cations millieq./l	2.9	19.6	22.6	23.2	16.8	39.7	57.8	5.0	0.63	16.8
Anion millieq./e	62.5	18.9	21.5	24.6	16.0	44.1	60.4	5.9	1.4	14.3

g. JT31 analysis in ppm. Also 1.4 ppm NH_4, 0.05 ppm Li, 0.5 ppm Sr, and 4.1 ppm B.
h. Plantungan also 3.3 mg/l NH_4 and 1.7 mg/l NO_3.
Nos. 1-19 analysed at the laboratories of the Geological Survey of Indonesia, Bandung, Indonesia.
Nos. 20-22 analysed by R. Barnes at the U.S. Geological Survey, Menlo Park, California, USA
No. 23 quoted from Purbo-Hadiwidjojo (1968), Table II, Analysis 3.

TABLE 2.--Analyses of spring waters of the Dieng area (in mg/l except as labelled) (Continued)

Number	21[f]	22[g]	23[h]
Location	Sileri outflow	Pulosari	Plantungen
Field No.	JT10	JT31	--
Lab. No.	2166	2167	--
Collection temperature	55°C	55°C	46°C
pH F = field L = lab.	6.5F 7.8L	6.5F 7.6L	 7.5L
Na	157	116	944
K	36	56	792
Ca	109	142	176
Mg	28	46	120
Fe(total as Fe^{+3})	0.7	0.1	1.1
Mn	na	na	0.2
Cl	173	426	2006
SO_4	592	169	140
HCO_3	61	131	1244
SiO_2	95	177	62
Cations millieq./l	18.7	17.4	80.0
Anion millieq./e	18.21	17.7	79.8

Chloride water discharges from the Dieng hot water systems occur right in the Dieng (Pulosari, Sileri and those indicated by the river survey), and it is unnecessary to assume long distance under surface transport.

Chloride inventory of rivers

In the Dieng mountains only two springs, Sileri and Pulosari, have chloride contents greater than 20 mg/liter. Fumaroles, however, are relatively abundant. This suggests that if a hot-water system exists, the liquid water discharge from the system is diluted by abundant ground water and finds its way directly into streams and rivers. In order to test this inference and to search for possible springs in the heavily wooded and sparsely inhabited northern slopes of the Dieng, the rivers draining the Dieng were sampled and analysed for chloride and their flow estimated. The inventory was incomplete due to the limited time available and difficult access to parts of the area. The rivers draining the Dieng are shown in figure 2 and sampling points are indicated by "X". Analyses for chloride were made in the field by titration with $AgNO_3$ by Mr. W. S. Kartokusumo and his associates of the chemistry section of GSI.

In October a second collection of river samples was made by Mr. Soeharto Oemar and other scientists of the GSI. These were analysed in the GSI chemical laboratories.

Steam flows were approximated, probably with a range of $\pm$ 50%, from visual estimates of the width, depth and velocity of each river. The results are shown in table 5. The chloride content of samples from rivers Petungangap and Putih as well as the low-chloride cold and warm springs in the Dieng (see spring data, table 2) indicate that for the August collections the chloride background of the Dieng area is about 20 mg/liter, certainly no higher than 25 mg/liter.

The October collections were made at higher elevations and from the headwaters of the rivers, principally on the south side of the drainage divide. These show a lower background near 9-11 mg/l Cl (see fig. 3). This Cl content has been adopted for the background of rivers sampled at high elevations in the Dieng in both collections. The higher background has been retained for rivers sampled nearer the coast (where a greater contribution of sea salt may be expected) and on their lower reaches (where evaporation may have occurred during irrigation). The use of two background figures is considered quite unsatisfactory, but necessary.

Although both the August and October chloride contents are considerably higher than the 2 mg/l found at Yellowstone Park, USA, in a similar study, they are reasonable considering the relative closeness of the Dieng to the ocean.

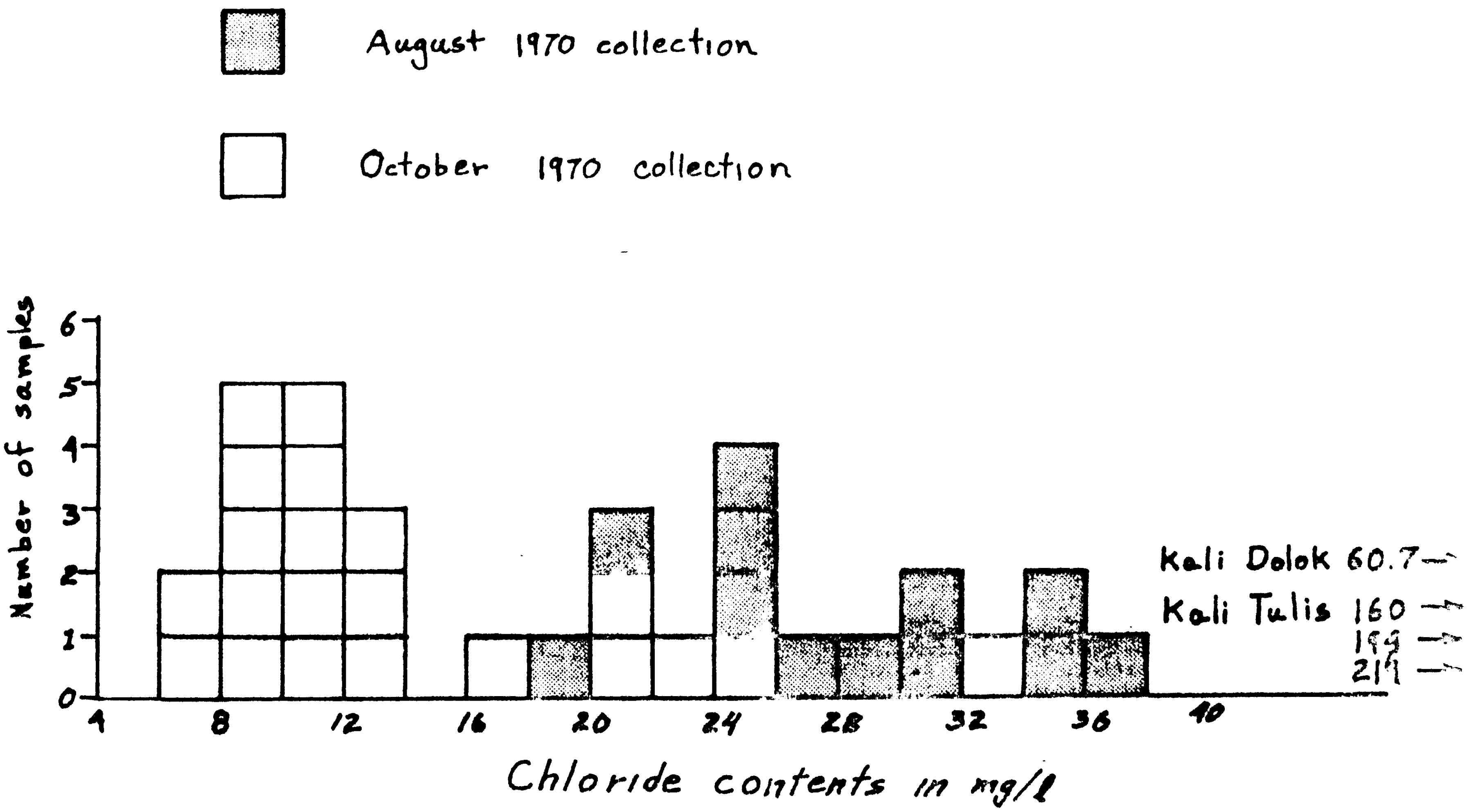


Figure 3. Chloride distribution of river samples.

Table 5.-- Chloride inventory of rivers draining the Dieng Mountains.

I. Collections of August, 1970

River	Sample location (fig. 1 and 2)	Chloride content mg/l	Flow l/sec	Excess chloride from geothermal flui[d] mg/sec *
Lutit	a	27	150	1050
Terong	b	29.5	120	1680
Lampir	c	35	300	4500
Bela	d	25	400	2000
Arus	e	35	450	6750
Petungangap	f	20.5	600	0
Kitiran	g	35	600	9000
Koepang	h	30	600	6000
Wela	i	31.5	800	9200
Singkarang	j	36.0	700	11200
Tulis	k	160	100	15000
Dolok	l	25	40	600
Putih	m	18	25	200

Table 5.-- Chloride inventory of rivers draining the Dieng Mountains (cont'd).

II. Collections of October, 1970.

River	Sample location (fig. 1 and 2)	Chloride content mg/l	Silica content mg/l	Flow l/sec	Excess Chloride from geothermal fluid mg/sec *
Dolok	9k	11.0	50	60	0
Dolok	6k	11.0	30	300	0
Dolok	5k	60.7	42	300**	15000
Tulis	4k	9.2	22	1	0
Tulis	8bk	175	128	--	--
Tulis	8ak	219	48	100**	20000
Tulis	12k	11.0	22	75	0
Putih	1k	12.9	38	7.5	15
Putih	2k	7.4	20	30	0
Seraju	3k	7.4	28	1	0
Kongkong	10k	11.0	76	15	0
Seraju	13k	16.6	60	290	1750
Merawu	15k	20.2	18	14000	0
Urang	16k	25.8	24	4000	24000
Panaraban	17k	12.9	20	8000	16000
Sibanger	18k	21.9	16	700	7000
Gembrosan	19k	9.2	12	250	0
Balun	20ak	33.1	28	3200	70000
Urangatas	21k	9.2	16	280	0
Arus	22k	22.1	54	400	4400
Larangan	24k	9.2	10	50	0
Sinkarang	25k	9.2	20	420	0

Table 5.-- Chloride inventory of rivers draining the Dieng Mountains (cont'd)

* Chloride contributed from hot or cold mineral springs and by seepages. Chloride background of rivers at high altitudes in the Dieng is assumed to be 9-11 mg/l. Lower elevation river samples are assumed to have a chloride background of 20 mg/l. See text.

** See text.

There seems to be a discrepancy in the flow estimates of Kali Tulis near Pulosari, which was estimated in August to be 100 l/sec and in October to be 1 l/sec (even though it was estimated in October to be 75 l/sec upstream). The original figure of 100 l/sec has been adopted. The flow of Kali Dolok (600 l/sec) seems high; 300 l/sec has been adopted.

Using these background chloride values, the contribution from mineral spring inflow is calculated in the last column of table 5. The excess chloride is considered significant for the rivers Lampir, Arus, Kitiran, Koepang, Wela, Singkarang, Dolok, Urang, Panaraban, Sibanger, Balun, and Tulis. The presence of excess chloride in these rivers indicates that in addition to known chloride springs in their drainages, a considerable amount of chloride enters the rivers with ground water. Mineral springs have not been reported in the drainage areas of the Lampir and Wela rivers, but should be looked for.

The springs in the drainages of the Koepang and Singkarang rivers were not visited by the writer; they may be similar to the high chloride springs north and west of Karangkobar or may be a western extension of the Dieng activity. In either case, they should be sampled and their volume of flow determined. The high chloride in K. Sibanger suggests that the activity does extend in this direction.

The August collection of K. Dolok south of Pekasiran showed lower chloride contents and flow than would be expected. In the later collection this discrepancy does not appear and it may have been due to a mistaken location.

Chloride content of river samples, together with the high chloride outflow of Pulosari and Sileri, indicates that the Dieng geothermal systems are almost certainly of the hot water variety. This is to be expected because of the probable high permeability of the andesitic volcanic reservoir rocks.

DEPTH TO THE GEOTHERMAL RESERVOIR

The thermal activity of the Pagerkandang area, the Tjandradimuka area and to a lesser extent the Sikidang area is at high elevations relative to nearby areas and it is predominately fumarolic. These facts suggest that the top of the geothermal reservoir is below the ground surface over much of the area. This contrasts with the geyser basins of Yellowstone Park where hot springs predominate and the geothermal reservoir extends to the surface. The depth to the reservoir is obviously important in planning the depth of exploratory drilling.

The high chloride springs at Sileri, Pulosari and the chloride seepage into the river Tulis are outflows of the reservoir fluid. In highly, permeable rock without an impermeable or self-sealed cap (which would result in artesian pressures) the elevations of these springs give an estimate of the elevation of the top of the reservoir. Sileri is at 1875 meters and Pulosari and the river Tulis at the point sampled are close to 1700 meters. The distance of these last two chloride outflows from either the Sikidang or Pagerkandang fumarolic area is about 3.5 Km, and if the elevation of Sileri (1875 m) is assumed to be the elevation of the top of the Pagerkandang reservoir, the gradient of hot-water flow from Pagerkandang to Pulosari is about 4%. A similar gradient assumed towards Sikidang results in an estimated elevation of about 1850 meters for the top of that reservoir.

Based on these estimates, drill holes 200 m deep in the Pagerkandang area would intercept the reservoir. More information will be gained from holes deeper than 250 meters that penetrate well into the reservoir. The Sikidang reservoir may be nearer the surface. No estimates can be made for the Tjandradimuka reservoir because the elevation of its chloride outflow, which is probably to the north into the Kitiran river, (see river survey), is unknown.

SUBSURFACE TEMPERATURE

The use of chemical analyses of surface springs to estimate subsurface temperatures has recently been reviewed by White (1970). The most useful geothermometers are the silica content (which has been shown for hot springs and geothermal wells to be related to saturation with quartz in the geothermal reservoir; Fournier and Rowe, 1966) and alkali (and alkali earth) ratios (which reflect equilibrium with various minerals in the reservoir).

The geothermal fluids that could be sampled at the surface in the Dieng Mountains probably have been greatly diluted by meteoric water, and accordingly the chemical indices of subsurface temperature are of uncertain, but probably low, reliability. Nevertheless, temperatures at depth in excess of 200°C are suggested.

In using the silica geothermometer on the Dieng hot-spring waters, the dilution with cooler low-silica surface waters must be corrected for. The Pulosari spring (analysis 22, table 2) is the highest in chloride and is considered to be the best available sample of the deep water. Its temperature of 55°C indicates that it has undergone a considerable dilution with near-surface water, assumed to be at 20°C and to contain about 15 ppm SiO_2 (the calculation is not materially changed by assuming twice this). If the deep water cooled to boiling (93°C at this elevation) by steam separation, we can calculate for the fraction, x, of hot water:

$$93\,x + 20(1-x) = 55$$

$$x = 0.48$$

For the silica content (177 ppm in the mixture),

$$0.48y + 0.52(15) = 177$$

$$y = 352 \text{ mg/l } SiO_2$$

This gives an indicated temperature (fig. 4) of 203°C (Fournier and Rowe, 1966). Other samples of the deep fluid (e.g., Sileri) have undergone an unpredictable amount of evaporation and possibly have precipitated some silica near the surface. The silica content of Sileri dropped between the sampled vent (analysis 20, table 2) and the outflow (analysis 21, table 2), even though the chloride content increased.

The use of alkali ratios to estimate the underground temperature of the Dieng geothermal system is even less satisfactory. Comparison of Na/K ratios of Dieng waters with published curves (e.g., White, 1970, fig. 3) gives temperatures that are unrealistically and unreasonably high (>450°C). The failure of this index is due to the presence of abundant Ca in the waters (and presumably in the minerals of the reservoir rocks). Curves that relate various functions of Ca, Na, and K to temperature are currently being developed by R. O. Fournier and the writer. Comparison of the Dieng data with these preliminary curves suggests that underground temperatures are in the vicinity of 200°C.

Both silica and alkali temperatures represent the temperature at a depth at which the geothermal fluid last had a residence time sufficiently long for the rocks and water to react thoroughly. Therefore, any deeper (and possibly hotter) reservoir may well not be detectable by chemical indices.

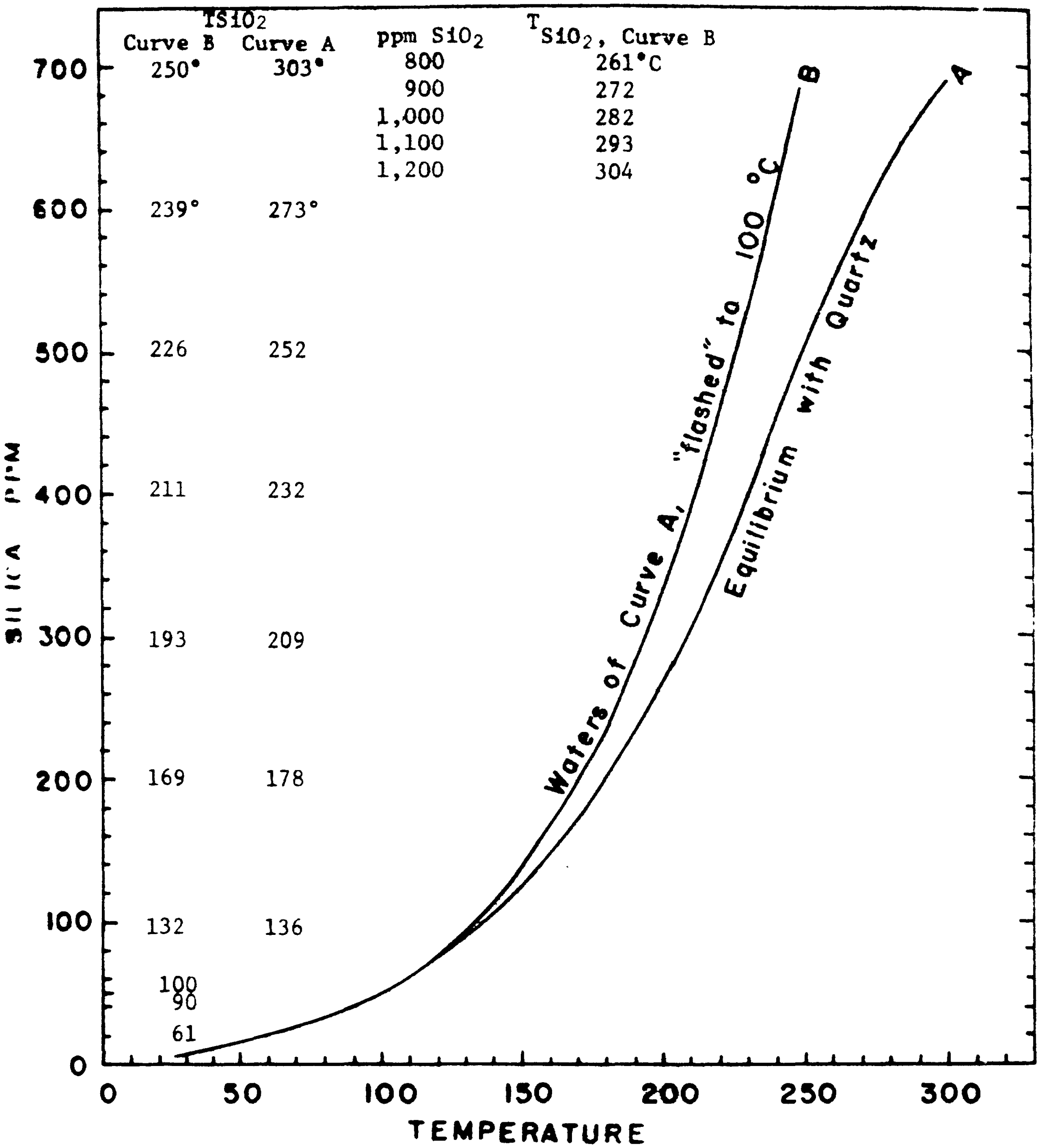


Figure 4. SiO_2 concentrations in thermal waters versus temperature

CHEMICAL CHARACTER OF THE GEOTHERMAL FLUID

Production problems that may result from the chemistry of the geothermal fluid include corrosion of the well-liner and turbine by fluids of high acidity, deposition of silica or calcite in the well and attack of electrical equipment by sulfur gases. Without direct samples of the reservoir fluid it is not possible to know whether mineral deposition will become a problem. It is, however, possible to make some preliminary remarks on acidic corrosion and attack by gases.

In high temperature gases from active volcanoes halogen acids and oxides of sulfur are present, often in considerable abundance. Some quantity of these same gases presumably enters the base of geothermal systems along with heat and is dissolved in the geothermal fluid. If the acids produced are not neutralized, they can corrode and shorten the working life for the well casing and possibly the steam separators and turbines and thus constitute an almost insuperable problem in the development of the system. In an area in Taiwan known to the writer, these acid conditions probably occur at depth. The reservoir is a clean quartz sandstone without the capacity to neutralize acid. HCl occurs in springs and along with SO_2 as a component of fumarole gases. Springs of large discharge have pH values below 2 and fumarole condensates have pH values near 1 and contain up to 400 mg/l chloride.

Possible acidity of the Dieng geothermal fluid

With this background considerable attention was paid in the preliminary geochemical survey of the Dieng to look for evidence of deep acidity. The Tertiary sediments exposed in nearby areas and assumed to underlie the Dieng volcanics at unknown depth consist of tuffaceous sandstones with plentiful feldspar, volcanic breccias and minor marl and clay (Keith Ketner, personal communication). The volcanic pile itself consists largely of andesite pyroclastics and tuffs (Van Bemmelen, 1937). These rocks are considered to have ample neutralizing capacity. Fumarole condensates were analyzed for pH and chloride with the results shown in table 4. All fumarole condensates except one contained less than 6 mg/l chloride and all had a pH above 5.5. The 20 mg/l Cl measured at Tjandradimuka is probably high due to interference by ammonia. The flowing springs also show near neutral pH and only a few where oxidation of H_2S to sulfuric acid has probably occurred show lower pH values. There is evidently no problem with deep acidity in the Dieng.

Attack of equipment by hydrogen sulfide

In the Sikidang and Tjandradimuka systems H_2S is relatively abundant and copper switches would show attack. In the Pagerkandang system, however, H_2S is noticeable only to a minor degree near Sileri and not

Table 4.-- Analyses of fumarole condensates (ppm).

Field No.	JT 13	JT 19	JT 22
Location	Pagerkandang north fumarole	Siglagah fumarole	Tjandradimuka fumarole
NH_4	15	0.7	256
B	0.01	$<$0.01	0.25
Cl	0.7	0.6	6.2

at all elsewhere. The abundant iron oxide deposited by cold springs and abundant pyrite in the altered and disturbed rock in the Sileri area indicate that sulfur is being removed by reaction with iron. This process will probably continue during exploitation. Thus, attack by H_2S of electrical contacts during the exploitation of the Pagerkandang should be minimal.

Salinity of geothermal fluid

The salinity of the deep fluid may be approximated from the temperature and chloride content of the Pulosari spring. This may allow an estimate of the underground temperature to be made from conductivity measurements by the geophysical team, Drs. Pritchard and Jacobson. It was calculated earlier that Pulosari spring contains 0.48 fraction of deep geothermal fluid.

Now considering the chloride,

$$0.48x + 0.52(20) = 472$$
$$x = 960 \text{ mg/l Cl}$$

Steam separation during the adiabatic cooling from about 200°C to 93°C will have concentrated the chloride in the water by about 1.25 times so the geothermal fluid at depth would have contained 700 mg/l chloride.

Possible pollution by geothermal effluent

The possible effect on the growing of tobacco and rice by irrigation with diluted geothermal effluent has been briefly considered. The deep geothermal fluid may have 4 to 17 mg/l Boron (see analyses 20-22, table 2). It has been found that rice needed at least 0.4 mg/l B and that concentrations of more than 20 mg/l were toxic (Tokuoka and Morooka, 1936a and b). Tobacco shows Boron deficiency below 3 mg/l and toxicity is developed with more than 6 mg/l (Kuijper, 1930; Meurs, 1932). Symptoms of boron poisoning become noticeable when public water supplies exceed 30 ppm.

It is considered on the basis of these studies that few problems will occur from the Boron content of these waters in an area of as high rainfall as the Dieng because considerable dilution by rainwater will occur. When samples of deep water are available analyses for components such as arsenic (requiring large samples) may be made and their possible effects considered.

RATE OF NATURAL ENERGY PRODUCTION

The rate of natural energy production is of some importance in predicting the maximum rate of sustained production of a geothermal field. Most geothermal systems that have been thoroughly studied (Wairakei, New Zealand; Steamboat Springs, Nevada; Yellowstone Park) have maintained some rate of thermal activity over a span of tens to hundreds of thousands of years. The rate of natural energy outflow in these systems is thus approximately equal to the rate of the replenishment of the reservoir with heat and water. Withdrawal during production usually exceeds the rate of natural outflow by several times (e.g., 5 times at Wairakei, New Zealand); this of course leads to declining pressures and a finite production life.

The estimation of natural heat flow in the Dieng is complicated by the predominately fumarolic character of the activity. Measurements of fumarole flow have been made in New Zealand with specialized equipment, but visual estimation is essentially impossible. The estimation of flow of hot water is relatively easy and an attempt will be made to estimate the ratio of heat content to chloride content in the geothermal fluid as soon as exploratory drilling yields temperatures and samples of the fluid. Temperatures, volume of discharge, and heat flows of all the observed hot springs of the Dieng are shown in table 6, and estimates of the amount of heat escaping into rivers are given in table 7. These crude estimates do not contain the heat escaping as vapor and may be low by perhaps 100%.

COMPARISON OF USGS AND GSI CHEMICAL ANALYSES

When this project was begun I was not aware of the analytical chemistry facilities of the GSI, and arranged that an indefinite number of analyses be done in the laboratories of the U.S. Geological Survey at Menlo Park by our best analyst, Mrs. Roberta Barnes. Because of other demands on her time, I reduced these to a bare minimum of four complete and three partial analyses and was delighted to have other analyses, particularly those of river waters, done in the GSI laboratories in Bandung. Considering the handicaps suffered by these laboratories, especially the lack of modern instruments, their results have been quite creditable. Comparisons of the two sets of analyses may serve to indicate which GSI procedures could be improved, possibly by the purchase of more modern equipment.

These comparisons are based on samples of Pulosari spring (analyses 12 and 22, table 2), Sileri outflow (analyses 8 and 21, table 2; analysis 13 is of a sample collected later), and Kali Tulis (analyses 4 and 8, table 3; analyses 2 and 7 are from different locations on the river). The two Pulosari analyses are almost identical in Cl and within about 10%-15% in K, Ca, Mg and SO_4. The results for Na, HCO_3, and SiO_2, however, differ by 30%. The Sileri outflow analyses are almost identical in K, Ca, SO_4, and Fe, but Cl, SiO_2, Mg, Na, and HCO_3 differ by more than 30%. The analyses of Kali Tulis are similar in Cl and K, but differ significantly in Na and SiO_2.

[illegible] 3.-- Analyses of river waters in the vicinity [illegible] (in mg/l except as indicated)

Number	1	2	3	4	5	6	7	8*
Location	K. Dolok	K. Tulis	K. Dolok	K. Tulis	K. Arus	K. Lampir	K. Tulis	K. Tulis
Field No.	9k	4	5	8k	22k	kk1	kk2	JT36
Lab. No.	1873/70	1878/70	1879/70	1880/70	1881/70	1898/70	1899/70	2168
Collection temperature	--	--	--	--	--	--	--	26°C
pH F=field L=lab	8.1 L	na	na	na	na	8.1 L	7.3 L	6.0 F 7.9 L
Na	4.5	5.1	11.7	57.5	10.8	4.1	32.0	32
K	0.8	1.4	8.2	18.7	4.3	5.5	9.8	16
Ca	6.1	na	na	na	na	6.1	30.3	66
Mg	9.2	na	na	na	na	1.8	7.3	22
Fe total as Fe^{+3}	0.0	na	na	na	na	0.3	0.8	1.4
Mn	0.0	na	na	na	na	0.0	0.2	na
Cl	11.0	9.2	60.7	175	22.1	11.0	25.8	160
SO_4	0.0	na	na	na	na	33.5	167	56
HCO_3	74.6	na	na	na	na	51.1	141	71
SiO_2	50.0	22.5	42	128	54	26	66	79
Cation millieq./l	1.3	--	--	--	--	0.74	3.2	6.9
Anion millieq./l	1.8	--	--	--	--	1.8	6.5	6.8

*JT36 analysis in ppm. Also 0.26 ppm NH_4, 0.01 ppm Li, 0.2 ppm Sr, and 2.3 ppm B. Analysis (No. 8) by R. Barnes, USGS. Other analyses (1-7) by GSI.

Table 6.-- Minimum heat flow estimates (relative to 20°C) of liquid water.

Spring	Chloride mg/l	Flow l/sec	Temperature °C	Heat/chloride Kcal/mg Cl	Hea[illegible] Kcal/[illegible]
Sileri	173	50	55	0.20*	175[illegible]
Bitingan	20	35	79,82	-- *	21[illegible]
near Siglagah	20	20	56	-- *	[illegible]
Pulosari	426	10	55	0.084	3[illegible]
					4[illegible]

* Large fumarolic contribution

Table 7.-- Minimum heat flow estimates from chloride production

(minimum because much chloride production undoubtedly not measured)

River or spring	Geothermal chloride* mg/sec	Heat flow at 0.084 Kcal/mg Kcal/sec
Seraju	1750*	147
Lampir	4500*	378
Arus	6750*	567
Kitiran	9000*	756
Tulis	17500*	1470
Dolok	15000*	1260
Pulosari	4260**	357
Bitingan	700**	59
near Siglagah	400**	34
TOTAL	59860	5028

* From Table 5

** From Table 6

In general the analyses for Na and SiO_2 are consistently diffferent and Mg, HCO_3 and Cl sometimes give trouble. Analyses for K, Ca, Fe, and SO_4 seem quite reasonable.

Silica analyses may be improved by dilution in the field and use of the molybdate blue method with a colorimeter. New equipment, possibly a flame photometer, also may be necessary for consistent Na and Mg analyses, but better technique should solve the problems with Cl and HCO_3.

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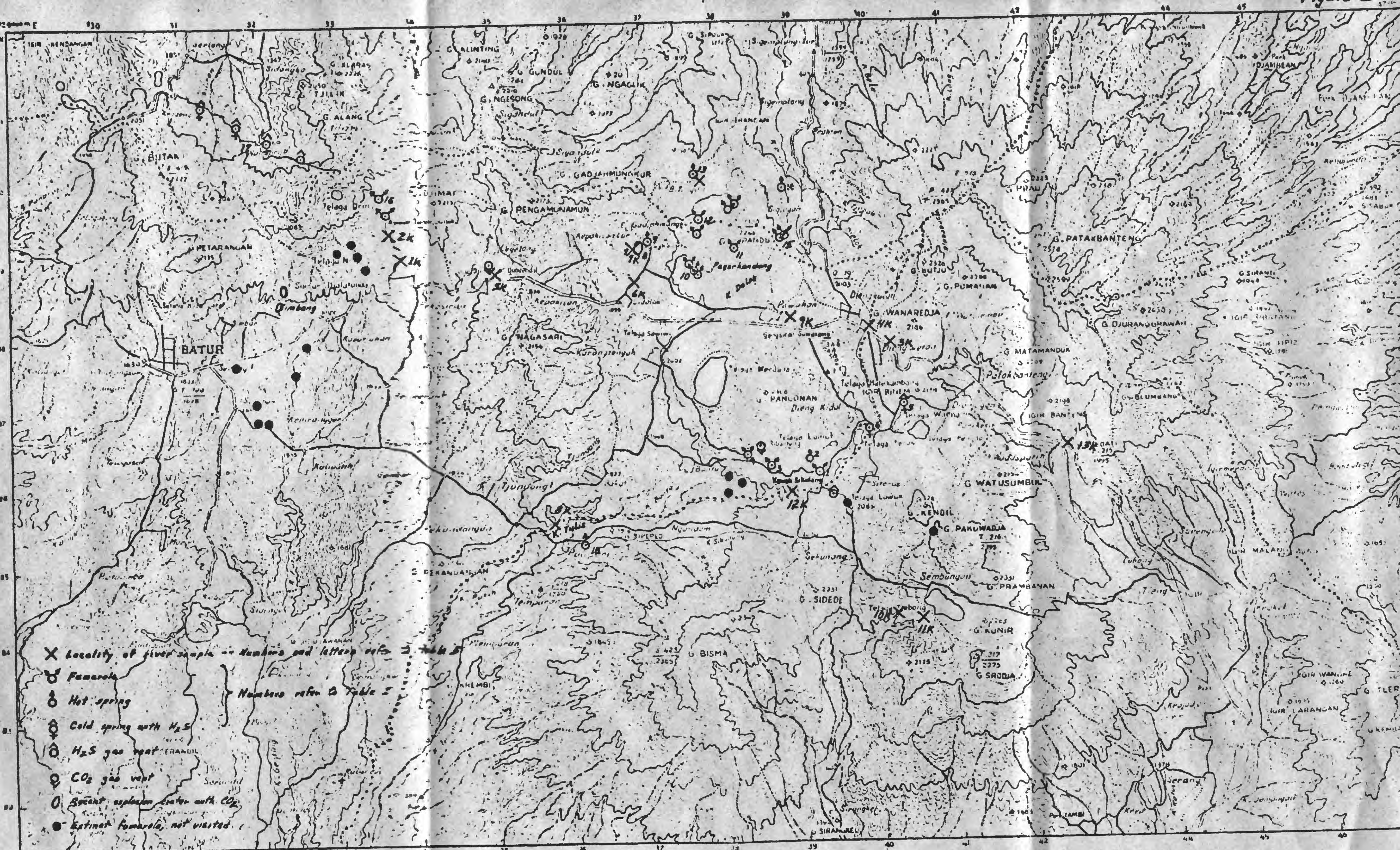
Figure 1



TOPOGRAPHIC MAP OF DIENG AREA, INDONESIA, SHOWING HOT SPRINGS AND FUMAROLES

U.S. Geological Survey
OPEN FILE MAP
This map is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature.