

Concentrations of H₂S in air around the Olkaria geothermal field, Kenya

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ABSTRACT

Changes in concentrations of H₂S with distance away from the Olkaria geothermal power station, and at one discharging well were continuously monitored over periods of up to 11 days. The changes in H₂S were correlated with changes in weather parameters.

Results show that within the power station, concentrations of H₂S can be expected to exceed 7.5 ppm over half hour periods at least once over a two week period. The levels of H₂S decay with distance away from the power plant to levels below 0.3 ppm within about 0.5 km from the power station. Concentrations of H₂S capable of causing plant injury are therefore expected to be present within 0.5 km of the power station, and over distances of several hundred meters away from a discharging well.

The highest concentrations of H₂S were obtained when winds were calm, humidity high, and atmospheric temperatures low. In the Olkaria area, these weather conditions exist between 2000Hrs and 0300 Hrs local time. The study suggests that if these weather conditions persist for prolonged periods of time, H₂S concentrations around the power station may rise to unsafe levels with regard to human health. There is therefore need for an H₂S monitoring

program, and installation of an early warning system, particularly when weather conditions point towards the build up of H₂S.

Measurement of the acidity of rain water showed no evidence that the high H₂S concentrations are contributing to acid rain formation in the immediate vicinity of the power station.

1. INTRODUCTION

The Olkaria geothermal power station is located 36 km south west of Naivasha town in Kenya (Figure 1). It currently generates 45 MW of electricity, and there are plans to increase the total power production to 109 Mwe. When first commissioned in 1981, the power station was in an area of low population density. With improvements in provision of social amenities, such as a good road network, human settlements have sprung up in the vicinity of the power station. In 1984, the Hell's Gate National Park was created to completely

enclose the geothermal field. Flower growing firms have also expanded their operations to within 1 – 2 km of the steam wells, with schools and employee houses close to the geothermal steam wells. This has raised the potential for conflicts between Kenya's national need for geothermal electricity, and environmental concerns for the health of humans, animals and plants in the area of exploitation of geothermal energy (Virikir/Mertz McLellan, 1977; Tole, 1990; Sinclair Knight and Partners, 1994; Simiyu, 1995; Marani, 1996; Tole, 1996; Tole, 1997). The liquid wastes and gaseous effluents are potential pollutants of the environment, in addition to other environmental hazards from physical, biological, and socio – economic impacts (Tole, 1990; Sinclair Knight and Partners, 1994; Tole, 1996). Whereas liquid effluents can be readily be contained in fenced off areas, and later reinjected back into the ground, thereby minimising contact with plants, animals, and humans, gaseous effluents are more difficult (and expensive) to deal with. They get dispersed over a wide area, depending on prevailing weather conditions. It is therefore important to evaluate the potential impacts of various gaseous constituents for each geothermal power station, in relation to weather conditions at the site. In the Olkaria area, CO₂, H₂S and radon have been identified as important gaseous emissions (Sinclair Knight and Partners, 1994), although work by Simiyu (1995) suggests that air borne trace metals particularly mercury and boron may also be important.

This study was conducted in order to measure the space – time characteristics of concentrations of H₂S in the Olkaria area, arising from the operation of the current 45 Mwe power station, and the impact of atmospheric parameters of wind speed and direction, humidity, and temperature on the H₂S concentrations. The extent to which H₂S contributes to the formation of acid rain in the Olkaria area (through oxidation to SO_x) was also investigated. Such studies are important to guide policy formulation on land use in the vicinity of geothermal power stations, in view of their possible future importance in meeting national electrical energy requirements in Kenya.

As more power stations are constructed, more H₂S will be released in the area. Physiological impacts of H₂S to humans range from odour nuisance at low concentrations (0.06 ppm), to death within 1 hour at very high concentrations (> 600 ppm). In plants, low levels of H₂S are beneficial to growth in the concentration range 0.03 to 0.1 ppm (WHO, 1981). Concentrations in the range 0.3 to 3 ppm cause injury to most plants, and higher concentrations cause leaf

lesions, defoliation, and reduced or stunted growth, with young plants being most affected. Once in the atmosphere, H₂S is oxidised to oxides of sulphur (SO_x) and water, eventually falling to the ground as wet or dry deposition. It is therefore important to monitor the acidity of rain downwind of geothermal power stations, and the sulphate content of precipitation.

2. AREA OF STUDY

The Olkaria geothermal power station is located approximately 5 km south of the southern shores of Lake Naivasha. It is related to the Olkaria volcanic complex, which last erupted 180 50 years ago to give rise to the Ololbotut lava flow (Clarke *ET al.*, 1990). The area of the geothermal field is at least 50 km², although only 2 km² are currently utilised in the generation of the 45 Mwe from the 34 wells drilled, of which only 25 are on line to the power station. A further 27 production wells have been tested for the proposed 64 MWe Olkaria northeast power station (Sinclair Knight and Partners, 1994). Producing wells have individual power potentials of between 1.5 and 8.5 Mwe, and release between 3 tonnes/hour and 85 tonnes/hour of water, and up to 77 tonnes/hour of steam, containing 2 ppm and 200 ppm of H₂S in waters and steam respectively. It has been estimated that 890 tonnes of H₂S are released annually from the operation of the current 45 MWe power plant at Olkaria (Tole, 1990).

The topography at Olkaria is rugged, with altitude ranging from about 1880 m above sea level at Lake Naivasha, to more than 2400 m a.s.l. at the top of the Olkaria hill. Around the power station, elevation varies from 1800 m a.s.l. in the Njorowa gorge, to about 2300 m a.s.l. There is therefore the danger of H₂S accumulating in valleys and depressions in the area, since it is denser than air.

Mean maximum temperatures range from 29 °C in February and March, to 21 °C in June through August (Sinclair Knight and Partners, 1994). Mean monthly temperatures range from 15 °C in April, to 11 °C in June through September. Mean monthly relative humidity ranges from 92% to 30%. Annual average rainfall is around 670 mm, compared to annual average potential evaporation of 1760 mm (Sinclair Knight and Partners, 1994). Winds tend to be predominantly southeasterly, with wind speeds commonly below 7.5 m/s.

2. FIELD AND LABORATORY METHODS

2.1 Field Methods

Six sampling stations, each in an open area free from obstruction to the natural air flow, and free from extreme terrain effects, were selected for H₂S sampling (figure 2). At eight locations, rain water was

collected for determination of pH and sulphate concentrations.

H₂S was collected in an evacuated 500 ml flask, containing 50 ml of 25% NaOH. In the field at the sampling site, air was slowly allowed into the flask by releasing the vacuum. As soon as the vacuum was exhausted (hissing sound ceased), the flask was closed off from air contact, and preserved for later analysis of the H₂S absorbed into the NaOH. This simple method is based on the assumption that the volume of air sampled is equal to the volume of the flask under vacuum. No correction for absorption of CO₂ into NaOH, or variations in atmospheric pressure was made. Such corrections would not significantly alter the conclusions of this study.

At distances greater than approximately 5 km from the geothermal power station, the above methods gave "zero" readings. To enhance H₂S detection, therefore, a known volume of air was pumped through a flask containing 50 ml of 25% NaOH. Typically, 225 liters of air were bubbled through the NaOH using a pump of predetermined flow rate for a measured period of time. A Neotex portable hydrogen sulphide analyser was used to compare some of the values measured using the chemical methods with those given by the instrument, when H₂S values were greater than 0.1 ppm. The two methods gave results which were within 10% of each other.

Wind direction and speed, humidity, and ambient air temperatures were recorded using a meteorological data logger at the Olkaria meteorological station, which continuously records the above parameters at 10 minute intervals. The data logger records were periodically assessed for accuracy by comparing with hand held electronic wind speed recorder, and an MR 58 Assman psychrometer.

Rain water was collected in pre-cleaned plastic containers placed inside the rain gauges. pH and SO₄ concentrations of rain waters were measured within 24 hours of collection of the rain water samples.

3.2 Laboratory Methods

The concentration of H₂S was measured at the geochemistry laboratory of the Olkaria geothermal station. 2 ml of the NaOH solution containing the dissolved H₂S was placed in a 250 ml conical flask, to which 5 ml of acetone and 10 ml of 25% NaOH were added. The resulting mixture was titrated with 0.001 M mercuric acetate, using dithizone as indicator. pH was measured with a pH meter, while SO₄ was determined spectrophotometrically on precipitation with BaCl₂.

3. RESULTS

3.1 Variations of H₂S Concentrations with time at one site

Table 1 gives the measured half – hourly concentrations of H₂S over eleven 24 hour cycles at site B. Over the 11 day period, H₂S concentrations varied from a low of 0.13 ppm at 2300 Hrs on 10/11/93 (and also 0.14 ppm at 1100 Hrs on 22/11/93), to a high of 5.04 ppm at 0300 Hrs on 22/11/93. Figure 3 which summarises the means of the eleven 24 hour cycles, shows that the diurnal variations of H₂S at Olkaria have minimum concentrations generally occurring at around 1600 Hrs, and again at 0500 Hrs, while maximum concentrations occur at around 0100 Hrs, and again at around 1200 Hrs (that is, two maxima and 2 minima per day), although there are exceptions to this generalisation, as can be seen from table 2(b) for data taken over a 24 hour period in September, 1993. The time of the worst H₂S pollution at Olkaria is the time period between 2000 Hrs and 0300 Hrs local time.

3.2 Variation of H₂S concentrations with distance from the source

Figures 4 and 5 show that H₂S concentrations decrease away from the source of emission, as would be expected (The increase after 100 m is due to the influence of the next adjacent well). In the case of H₂S from a well, concentrations decrease from 0.43 ppm, 5 meters away from the well, to 0.18 ppm, 100 m away from the well. The effect of H₂S from the power station is, however, much greater, with concentrations decreasing from 2.9 ppm at the power station, to values near zero, 4 km away from the power station. At the Oserian field station, H₂S concentrations are 0.011 ppm (0.017 mg/m³ of air), while at the lakeside Kenya Power Company housing, H₂S concentrations are 0.0036 ppm (0.0054 mg/m³ of air).

3.3 Variations of H₂S with weather parameters

Figure 6 shows variations of H₂S with the weather parameters of wind speed, humidity and temperature at site B. In general, the higher the wind speed, (period between 1200 Hrs and about 1800 Hrs), the lower the ambient H₂S concentrations, as would be expected from the enhanced rapid dispersion of H₂S by the wind. The higher the humidity (between 2000 Hrs and 0900 Hrs), the higher the ambient H₂S concentration. Also, the lower the temperature (between 1800 Hrs and 0700 Hrs), the higher the H₂S concentration in the immediate vicinity of the power station. These results can be used to set up a weather dependent early H₂S warning system for workers in and around the power station.

3.4 Rain acidity and SO₄ concentrations

Table 2 gives the measured pH values and SO₄ concentrations of rainwater collected after rainstorms at several sites in the Olkaria area. pH values range from 5.1 to 7.5, while sulphate concentrations range from 1 ppm to 45 ppm. There is no obvious

relationship between the pH of the rain water and its sulphate concentration, as would be expected if rain water acidity was being generated by the oxidation of geothermal derived H₂S. This applies whether the data are examined for each locality, or on a rainfall event basis (that is all the rain falling at about the same time). There is also no relationship between acidity of the rain and distance from the power station. These results taken together point to lack of contribution to acid rain by geothermally derived H₂S, at least within the area of study.

4. DISCUSSION

H₂S concentrations in the Olkaria area vary widely. Within one site, H₂S concentrations can vary with time by almost two orders of magnitude. Assuming that the gross output of H₂S from the geothermal power station is constant with time, the concentrations of H₂S at a given locality would be expected to depend on the prevailing weather characteristics, particularly the wind speed and direction. This is confirmed by the results obtained in this study. It is not obvious why the H₂S concentrations should increase with increase in humidity, or with decrease in atmospheric temperature. Further analysis of the data is called for to isolate these factors, and check that the observed relationships are not fortuitous.

The results suggest that an “H₂S alert” should be declared around the power station when the winds remain calm for extended periods of time, and particularly when this happens when temperatures are low, and humidity is high.

Such a system would involve installation of visual warning system (flashing red lights) and an audio warning system (siren) in the vicinity of the power station where high levels of H₂S are likely to be recorded. At times of the “H₂S alert”, personnel would be deployed to continuously record H₂S concentrations at strategic locations around the power station, especially the low lying zones that are down wind from the station. If levels of H₂S remain above predetermined critical levels for specified periods of time, monitoring personnel should be empowered to issue an evacuation order for people in the danger zone.

Figure 5 indicates that site A can have 1.5 times more H₂S than site B. This implies that the highest values of H₂S at site A can be as much as 7.5 ppm over half hour periods within a 2 week period. Site B was out in the open near the cooling towers, while site A is more sheltered from the effects of direct wind dispersion.

The H₂S concentrations around the cooling towers also frequently exceed values that are beneficial to plants (0.1 ppm). This is also the case at site C, 0.4 km away from the power station, and within 50 meters of a discharging well.

5. CONCLUSIONS

This study has shown that ambient H₂S concentrations are high between the time period 2000 Hrs and 0300 Hrs local time, when the wind speeds are lowest. There is a clear relationship between wind speed and H₂S concentrations around the power station. When conditions of low winds, high humidity, and low temperatures persist, there should be an "H₂S alert" issued to warn people in the power station.

H₂S values in the Olkaria area can be expected to reach values of 7.5 ppm over half an hour in a 2-week period within the power station area.

Away from the power station, the H₂S concentrations decay to levels below those which would harm human, animal, or plant life, so that locations 0.5 km away from the power station are relatively safe.

Discharging wells can emit H₂S amounts that are harmful to plants within about 50 m of the wells.

More work needs to be done to derive empirical relations between H₂S concentrations and weather parameters, in order to aid with prediction of hazardous conditions with respect to high H₂S levels.

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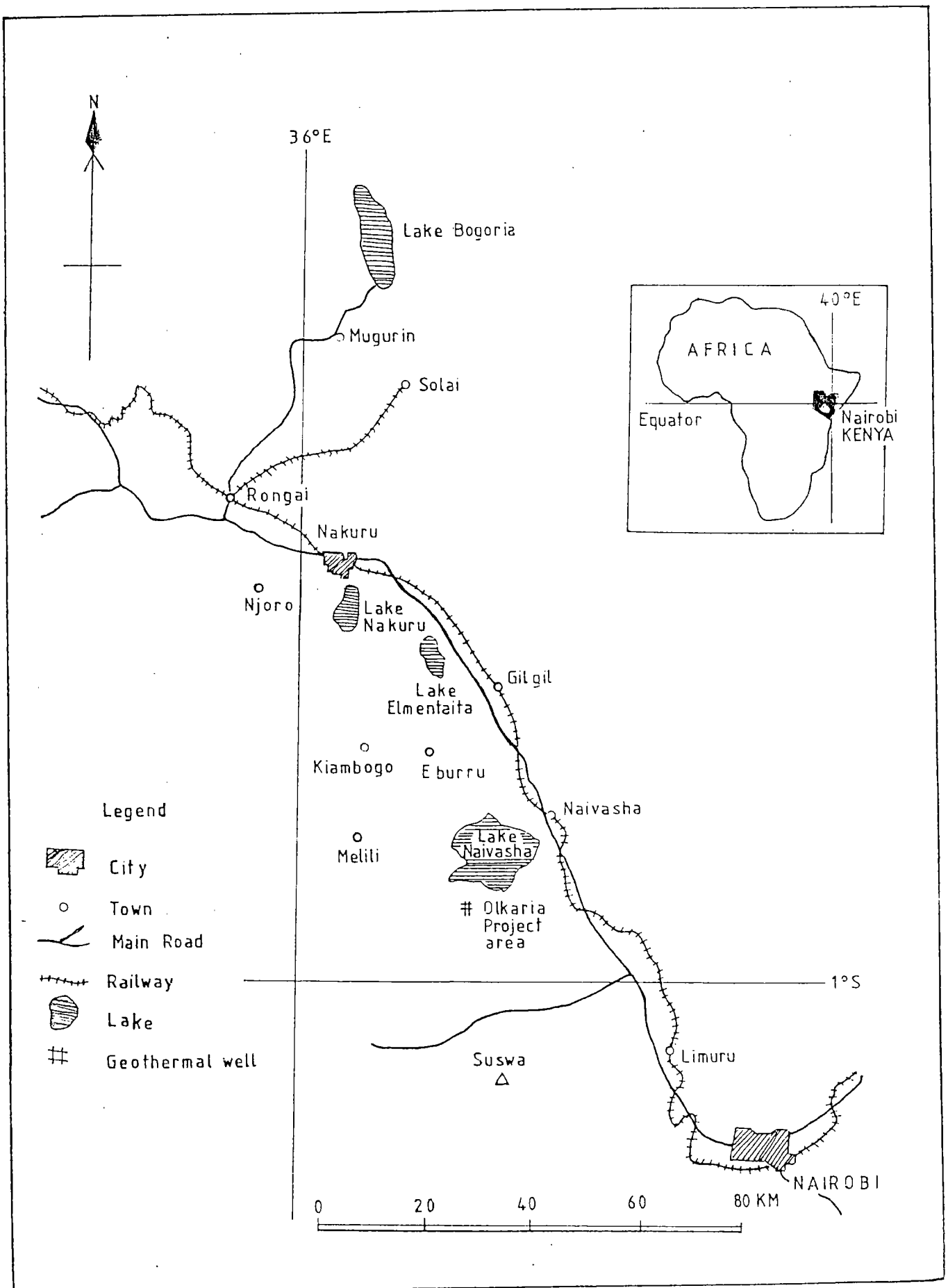


Fig. I Location of Olkaria project area (after JICA, 1983).

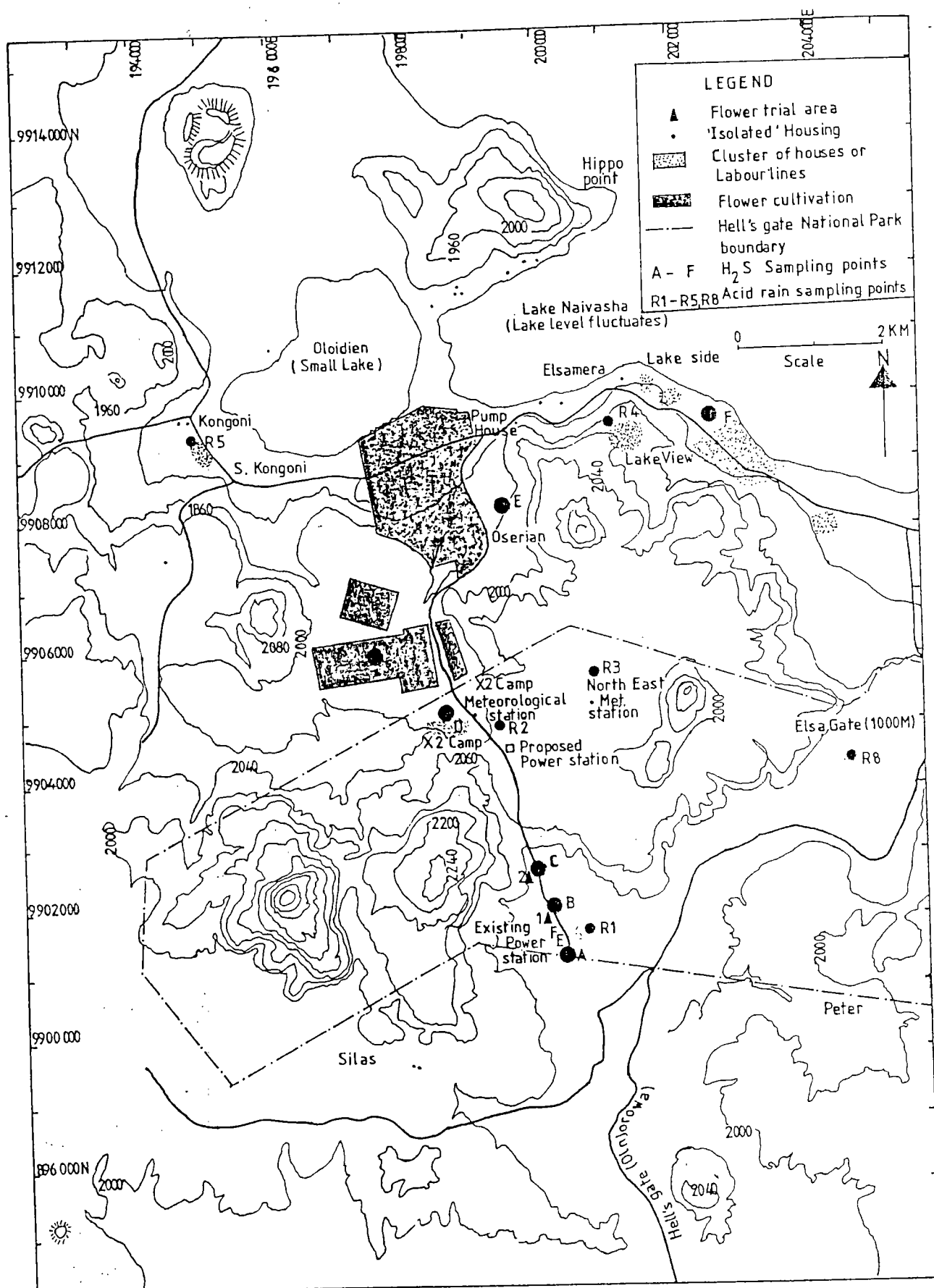


Fig. 2 Hydrogen Sulphide and acid rain sampling points.

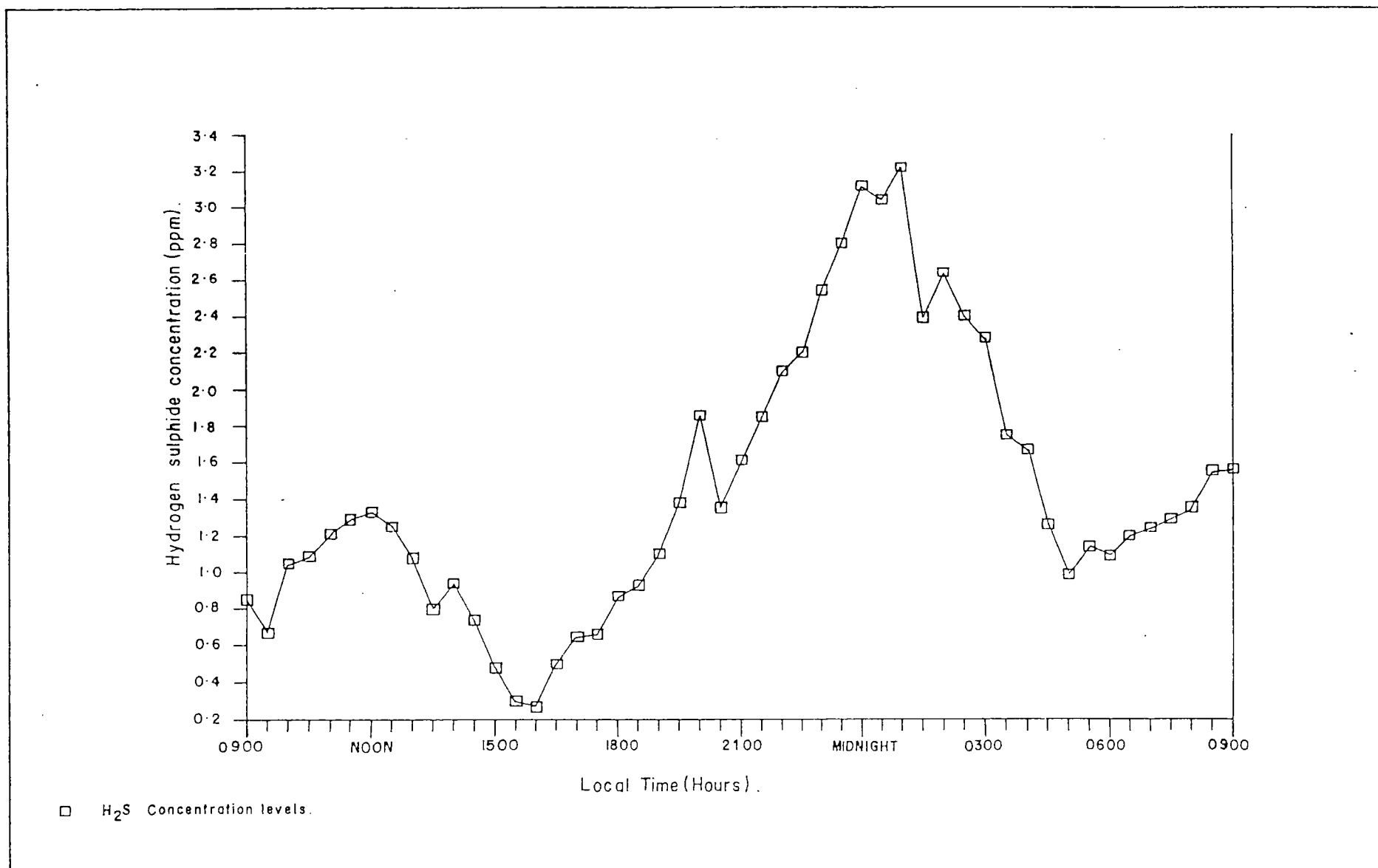


Fig.3 Diurnal trends of half-hour H₂S data at site B.

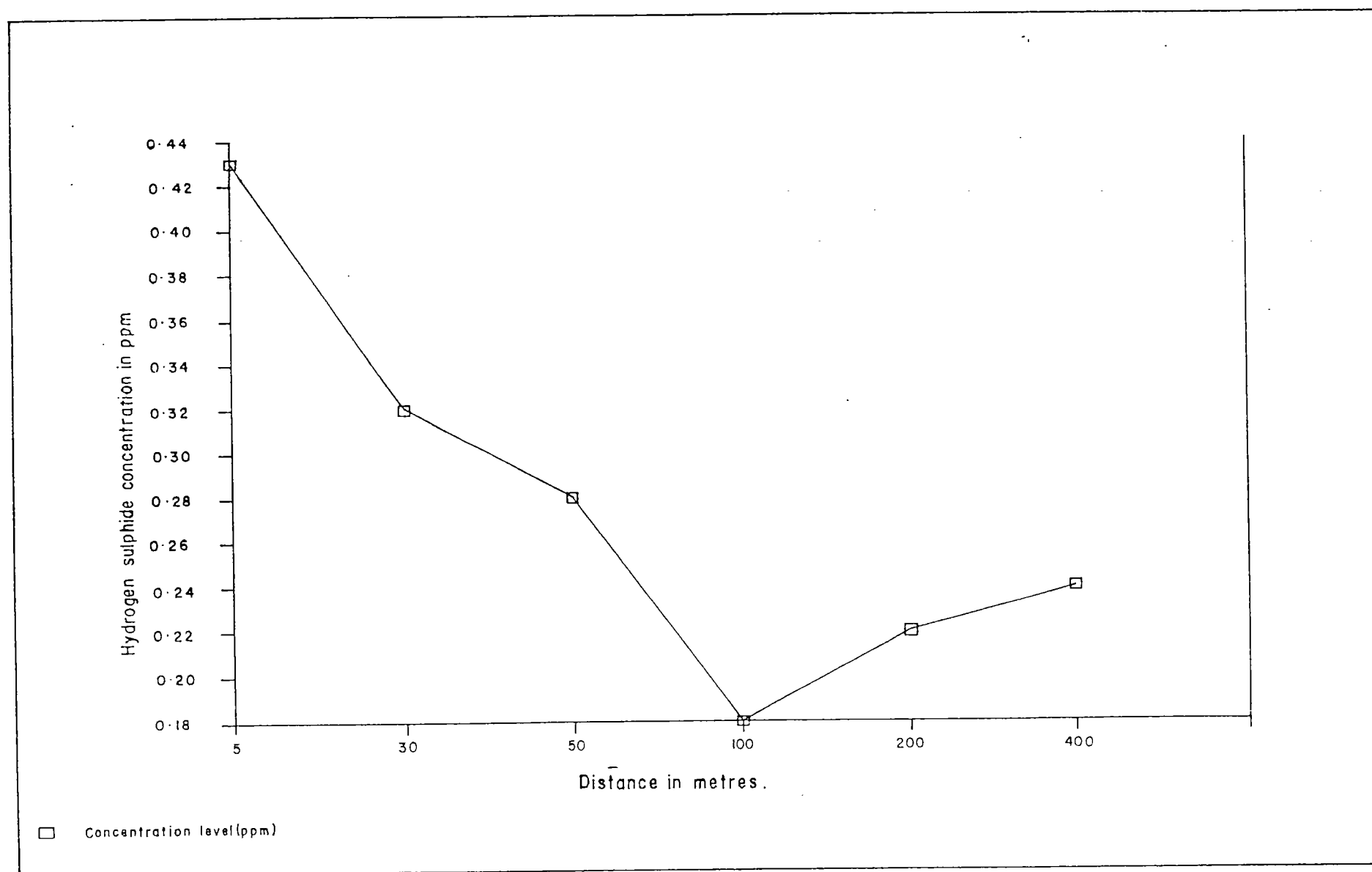


Fig.4 Hydrogen sulphide concentration variation with distance from the wellhead.

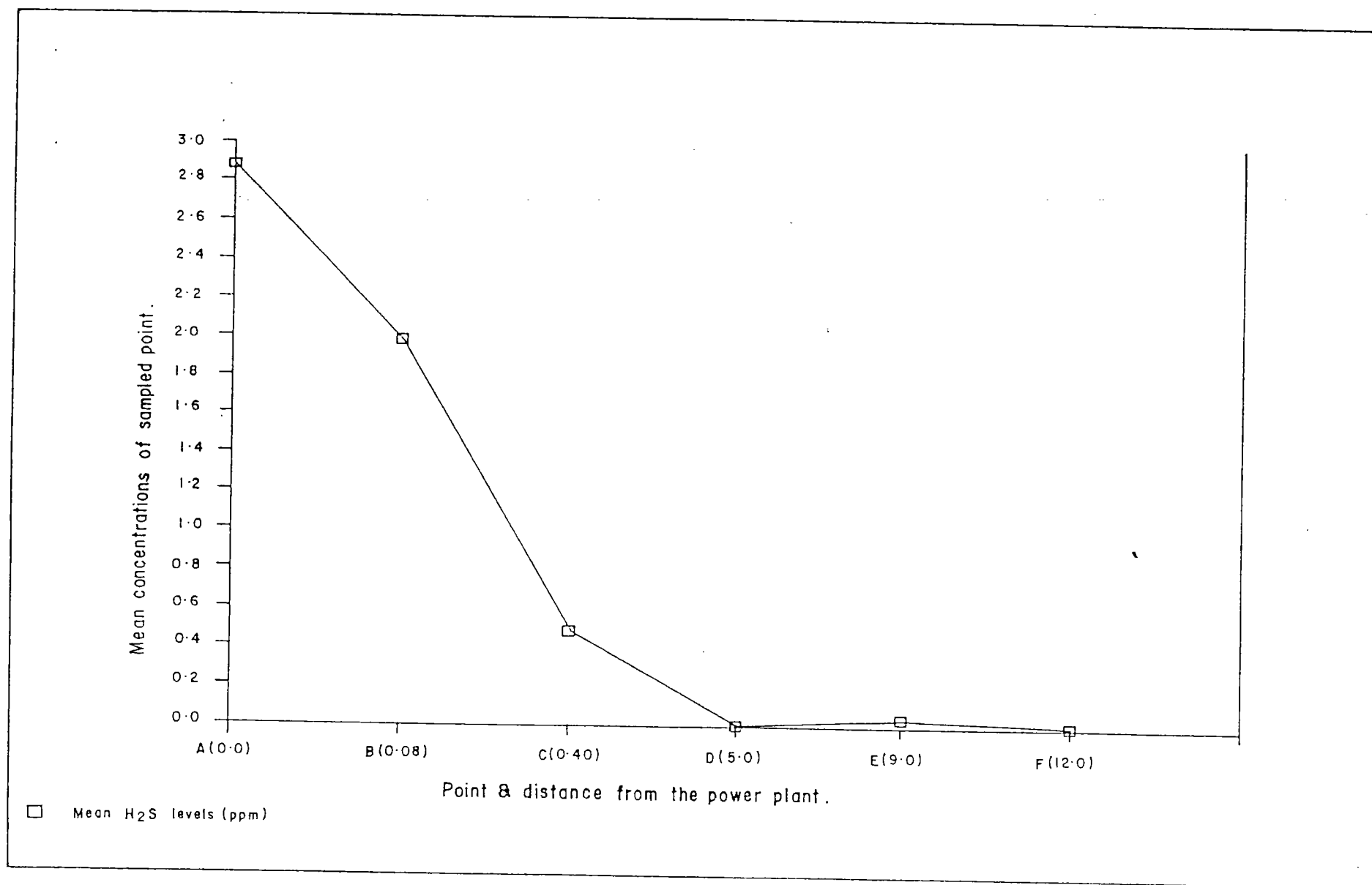


Fig. 5 Mean H₂S versus distance from the power plant.

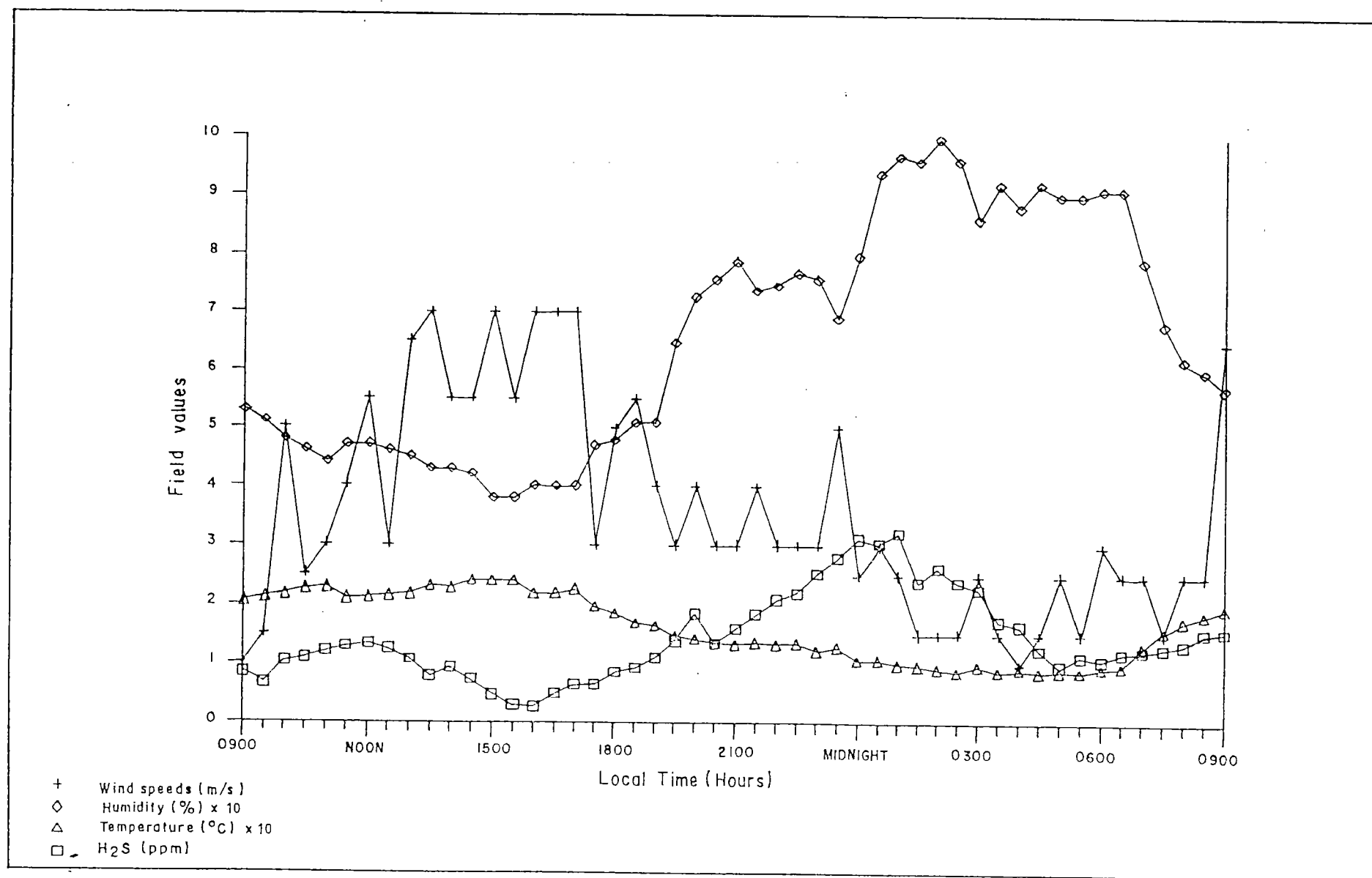


Fig. 6 Diurnal trends between H₂S and meteorological parameters at site B.

Table 1: Hydrogen sulphide concentration levels at site B

Time (hrs)	Hydrogen sulphide concentration for point monitoring(taken for 11 24-hour cycles(ppm)										
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11
	01-11-93 to 02-11-93	08-11-93 to 09-11-93	09-11-93 to 10-11-93	10-11-93 to 11-11-93	11-11-93 to 12-11-93	16-11-93 to 17-11-93	17-11-93 to 18-11-93	18-11-93 to 19-11-93	22-11-93 to 23-11-93	23-11-93 to 24-11-93	24-11-93 to 25-11-93
0900	0.98	1.99	0.95	0.66	1.19	0.79	1.74	2.45	0.19	0.42	0.85
0930	0.89	1.94	0.70	0.54	0.89	0.60	1.60	2.30	0.22	0.54	0.67
1000	0.76	1.96	1.00	0.84	1.01	0.51	1.64	1.68	0.21	0.70	1.05
1030	0.72	1.70	1.40	1.22	0.75	0.52	1.52	1.02	0.16	0.86	1.09
1100	1.00	1.48	1.81	1.59	0.39	0.34	1.40	0.82	0.14	1.04	1.21
1130	1.04	1.25	2.01	1.82	0.64	0.36	1.19	0.96	0.35	1.10	1.29
1200	1.19	1.01	2.21	2.05	0.90	0.29	0.98	0.51	0.51	1.15	1.33
1230	1.34	0.91	2.29	1.43	0.52	0.32	1.04	0.48	0.44	1.40	1.25
1300	1.41	0.81	1.98	2.81	0.54	0.27	0.71	0.47	0.18	1.58	1.08
1330	1.46	1.59	1.73	2.92	0.46	0.26	0.59	1.32	0.18	1.76	0.80
1400	2.32	0.37	1.02	3.02	0.38	0.25	0.48	0.24	0.22	1.84	0.94
1430	1.44	0.28	0.67	2.63	0.44	0.38	0.31	0.19	0.28	1.94	0.74
1500	1.67	0.19	0.28	2.24	0.41	0.24	0.25	0.14	0.15	1.44	0.48
1530	1.85	0.35	0.26	1.23	0.63	0.22	0.35	0.49	0.25	1.20	0.30
1600	2.02	0.42	0.22	2.22	0.46	0.28	0.18	0.68	0.38	0.98	0.27
1630	2.18	0.44	0.21	2.08	0.58	0.32	0.20	0.74	0.65	0.89	0.50
1700	1.43	2.42	0.24	1.94	0.64	0.37	0.23	1.17	0.84	1.02	0.65
1730	2.67	2.37	0.42	2.06	0.75	0.44	0.37	1.50	1.04	0.90	0.66
1800	2.70	2.32	0.61	2.18	0.87	0.46	0.53	1.25	1.06	0.96	0.87
1830	2.89	2.08	0.82	1.87	0.80	0.55	0.61	2.44	1.16	0.67	0.93
1900	2.95	1.83	1.07	1.36	0.83	0.67	0.76	0.88	1.24	0.62	1.10
1930	3.01	2.36	1.58	1.76	1.65	0.82	1.10	2.58	1.30	0.84	1.38
2000	2.91	2.38	2.02	0.15	1.67	0.74	1.23	1.64	1.26	1.00	1.86
2030	2.80	2.79	1.88	0.13	1.35	0.92	1.62	1.56	1.11	1.14	1.35

Table 1 continued.

Time (hrs)	Hydrogen Sulphide Concentrations for point B(taken for 11 24-hour cycles)										
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11
2100	3.45	3.20	1.74	0.17	1.04	1.20	2.02	2.78	1.08	1.20	1.61
2130	2.10	3.62	1.31	0.44	1.30	1.43	1.98	2.52	1.01	1.11	1.85
2200	1.97	4.04	2.89	0.72	1.57	1.66	1.94	1.90	0.97	0.98	2.10
2230	1.79	3.95	3.44	1.03	1.69	1.46	2.20	2.84	0.68	1.12	2.20
2300	1.66	3.85	4.05	1.33	1.02	2.07	2.40	2.60	0.89	1.06	2.54
2330	1.52	2.93	3.91	1.49	1.35	2.03	2.69	3.20	1.02	1.23	2.80
0000	1.50	4.01	3.88	1.65	1.05	1.99	2.98	3.40	1.13	1.41	3.12
0030	1.51	4.22	4.15	2.25	1.50	2.10	2.03	3.26	1.48	1.40	3.04
0100	2.43	4.02	4.42	2.92	1.97	2.19	2.68	2.21	1.40	1.38	3.22
0130	1.55	3.90	3.60	2.71	2.05	2.21	2.81	3.60	1.36	1.46	2.39
0200	1.28	4.98	4.66	2.51	1.94	2.35	2.92	2.84	1.46	1.60	2.64
0230	1.61	3.73	4.85	2.49	2.02	2.24	2.42	2.92	1.34	1.81	2.40
0300	1.68	3.41	5.04	2.47	1.91	2.26	2.77	2.24	1.20	2.02	2.28
0330	1.73	3.52	3.45	2.55	2.06	1.97	2.38	1.92	1.00	1.65	1.75
0400	1.75	3.62	3.86	3.24	2.22	2.20	2.89	1.76	1.10	1.91	1.67
0430	1.78	3.61	3.57	3.27	2.12	2.42	2.84	1.42	1.18	1.59	1.26
0500	1.84	3.58	3.09	3.11	2.07	2.28	2.80	2.22	1.14	1.47	0.99
0530	1.95	3.22	2.75	3.19	1.96	1.67	2.64	2.28	0.98	1.18	1.14
0600	2.06	2.86	2.44	3.28	1.84	1.86	2.38	2.10	0.92	0.90	1.09
0630	2.21	1.98	1.64	2.84	1.90	1.75	1.91	1.87	0.81	1.10	1.20
0700	2.16	1.11	2.46	2.40	1.95	1.62	1.85	0.85	0.79	1.36	1.24
0730	2.00	1.53	1.36	2.14	1.85	1.80	1.70	1.70	0.55	1.22	1.29
0800	2.51	1.94	1.16	1.86	2.10	1.96	1.51	0.75	0.35	1.01	1.35
0830	1.10	1.45	0.95	1.26	1.55	0.85	1.88	0.54	0.32	0.92	1.55
0900	1.10	0.95	0.66	1.19	1.21	1.74	2.45	0.55	0.42	0.85	1.56

Table 2.4: Results for rainwater analysis for pH and sulphate at seven collection points around the geothermal production area.

	P/S		X-2		OLK-NE		OLK-W		KGN		L-HSE		NSA	
DATE	pH	SO ₄ ²⁻ (ppm)	pH	SO ₄ ²⁻	pH	SO ₄ ²⁻	pH	SO ₄ ²⁻	pH	SO ₄ ²⁻	pH	SO ₄ ²⁻	pH	SO ₄ ²⁻
30.09.93	-	-	-	-	-	-	-	-	-	-	-	-	5.71	6.05
01.10.93	-	-	-	-	-	-	-	-	-	-	6.80	2.6	-	-
03.10.93	-	-	-	-	-	-	-	-	-	-	-	-	5.80	5.9
14.10.93	-	-	-	-	-	-	5.44	4.3	-	-	-	-	-	-
15.10.93	-	-	6.43	6.4	-	-	-	-	-	-	-	-	-	-
16.10.93	7.40	45.0	6.60	5.6	6.59	5.8	6.08	5.1	-	-	-	-	-	-
17.10.93	7.08	10.6	5.99	3.6	5.84	4.9	5.35	7.4	-	-	-	-	-	-
22.10.93	7.24	5.70	5.73	4.2	5.63	6.5	6.40	2.5	-	-	-	-	-	-
31.10.93	6.10	8.80	-	-	5.10	5.1	5.42	9.5	-	-	7.50	2.9	-	-
01.11.93	6.70	13.0	5.60	3.2	5.10	2.9	-	-	-	-	-	-	-	-
02.11.93	5.80	22.0	7.20	3.7	5.20	14.0	5.40	1.4	-	-	-	-	-	-
03.11.93	5.86	3.00	-	-	-	-	-	-	6.65	0.91	-	-	-	-
07.11.93	6.01	21.0	6.60	1.6	7.29	5.0	-	-	-	-	-	-	-	-
09.11.93	6.52	38.4	6.82	5.4	-	-	-	-	-	-	-	-	-	-
10.11.93	5.87	44.8	6.68	5.7	6.76	6.7	6.42	7.0	7.07	1.6	-	-	-	-