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AN OVERVIEW OF GEOTHERMAL RESOURCES OF PAKISTAN.

Malik Sikander Bakht
Geological Survey of Pakistan

84, H-8/1, Islamabad, Pakistan.

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ABSTRACT

This paper deals with geologic and tectonic features associated with the surface manifestation of geothermal activity in Pakistan. Major tectonic elements during the cenozoic and mesozoic have shaped the Geological structures observed in Pakistan today. These structural elements are indicators for delineating and developing the potential geothermal resources of the country. The zone of deformation extends from the Makran region in the southwest, to the Hazara-Kashmir syntaxial bend in the north. These features are produced by interaction of the Indian, Arabian and Eurasian Plates. Tectonic movements along these plates give rise to localisation of hotsprings. The Arabian plate underthrusted the Eurasian plate and has resulted in the formation of Chagai volcanic arc which extends into Iran (Fig 1). In the northern areas the rock units represent Indian mass Kohistan Island arc, and Eurasian mass. The rocks exposed in the area are metamorphic to granitic, and range from pre-cambrian to tertiary in age. Numerous hotsprings are found along the Main Mantle Thrust and Main Karakoram Thrust in Chilas and Hunza areas respectively. In Sindh province thermal springs are concentrated in the vicinity of Karachi and are broadly divisible into hilly terrain in northwest and plain areas in southeast. In Punjab province thermal springs and seepages follow the alignment of syntaxial bend. In Baluchistan province "Hamun-e- Mashkhel" a graben structure also shows geothermal affinity on the basis of results obtained by an aeromagnetic study.

1. INTRODUCTION

1.1 Purpose and Scope

Pakistan has been facing an energy crisis for the last several years. The need for development of alternate energy sources has been felt after the oil crisis of 1973. Despite its best efforts, Pakistan barely produces about 30 % of its required energy. The rest of the needs are met by importing oil, hence spending huge amounts from the meagre foreign exchange reserves. Geothermal energy has been developed in over thirty countries of the world , such as China,US, Japan, Italy, Iceland etc. A systematic study of the geothermal resources is necessary to supplement the energy needs of Pakistan. In this part of Asia, the Peoples Republic of China has fully developed its geothermal resources in Tibet. India has also set up a geothermal station at Puga valley. Nepal is also engaged in exploration programmes to exploit its geothermal potentials. As is evident from the tectonic framework of the Middle East (Fig. 1) geothermal activity in Pakistan owes its origin to the collision of the Indian Plate with the Eurasian Plate, whereby the Main Mantle Thrust (MMT) and the Main Karakoram Thrust (MKT) have been produced. Geothermal manifestations are concentrated along these features. It may be noted that hotsprings occur in the Gilgit , Hunza and Yasin valleys in the Northern areas. The highest surface temperature recorded in the Hunza valley is 21^0C and preliminary studies indicate higher subsurface temperatures. In the south the subduction of the Arabian Plate beneath the Indian platehas resulted in the emergence of Chagai volcanic arc where Quaternary volcanics are found with evidence of recent tectonism. The third geothermal zone as shown in Fig 2 extends from NE to SE of the country as a narrow belt along the Indus basin margin, down to Karachi. A large concentration of geothermal manifestations occurs in Dadu District of the Sindh province. The zone also extends into the Main Boundary Thrust (MBT) which constitutes the northern limits of the geothermal system. (Fig 2).

1.2 Methodology and Techniques

The field study covered the Gilgit, Hunza and Skardu areas in Northern Pakistan, the Chagai area in Baluchistan and Karachi and its vicinity , in the Sindh province. Water samples were collected applying different geothermometres such as Na/K, Na-K-Ca, and SiO_2. Chemical data was also interpreted with the help of qualitative geothermometres. Water samples were collected from the points where the water naturally oozes out from the surface. There we made side measurements such as pH, eH, water conductivity and air temperatures, using digital electronic instruments. Flow rates were determined by using calibrated containers and a chronometer where spring waters could be collected. For sampling, heat-resistant bottles

are rinsed with sample water before they are completely filled. On site, alkalinity was measured using 0.1 N HCl. One ml of concentrated HCl was added to 250 cc water washed with sampling water. The water was used to determine Ca, Mg, and Silica. Same size bottles containing 50 ml $BaCl_2$ and NH_4OH were used to determine CO_2. For H_2S gas determination, 250 ml solution of which 3% is cadmium acetate was used. A 50 cc bottle was used for the analysis of stable isotopes and a 1000cc bottle for tritium analysis

1.3 Study areas

The distribution of the geothermal study areas is shown in Fig. 2. The conceptual model of the geothermal system and the results of the evaluation of geothermal resources of Pakistan are briefly described in the following text.

2. GEOTHERMAL AREAS

2.1 Himalayan Collision zone

It is located in extreme north of Pakistan (Fig 2). It extends from $34^0$40' to 37^0 04 N and 72^0 30' to 77^0 50' E. It is bounded in the north by Afghanistan and China and in the East by Jammu and Kashmir. The area is connected with Islamabad through air and road links. The area is characterised by steep topography and U shaped valleys. Some of the highest peaks like K-2 (8611m), Gashabrem (6068 m) and Rakaposhi are the significant tectonic features of the area. The Baltoro, Batura and Ratro are amongst the largest glaciers of the area. The main water source of the area is the Indus river, with the Shigar, Shiyok and Yasin rivers as its tributaries. The geothermal system here is the result of the collision of the Indian and Eurasian plates. Hotsprings are scattered and its temperatures ranges up to 91^0 C (Table 1, Shuja and Iqbal 1983). In the Gilgit area there are two well known thermal springs, one is near Turboto das and the other is located 3 km near Darkot pass (Bakr 1965). Quite a number of thermal springs are located in a place called Garam Chashma where the subsurface temperature ranges from 85^0C to 252^0 C, based on silica and Na-K geothermometres respectively.

2.2 Geology

The rock units of the area are metamorphic togranitic and range in age from Pre-Cambrian to recent. They represent the Indian mass, Kohistan Island arc and Eurasian mass. The paleozoic sequence comprise igneous metamorphic and sedimentary assemblages. In the Indian mass the Salkhala series is the oldest unit and constitutes the substantial part of the massif (Tahirkheli, 1962). The main rock types are slate phyllite and schists sandstones and quartzitic crystalline conglomerate which are intruded by basic and igneous rocks. The rock types of the Salkhala series are predominantly pelitic and indicate an excessive carbonaceous association. The Kohistan Island arc sequence comprise thick calc-alkaline plutonic and volcano-sedimentary rock sequences which are cretaceous in age. The Eurasian mass obducted onto the Kohistan Island arc, which is characterised by low to high metamorphism and plutonic rocks. The Baltit group is the oldest unit in the Eurasian mass which has a tectonic contact with the Main Karakoram Thrust. Its thickness is more than 2000 m and consist of marble schists and gneisses intruded by pegmatite, aplite, and quartz. The Karakoram granodiorite forms a linear belt which extends from Shiyok valley in Baltistan and terminates south of Mastuj in Chitral in the west. On the northern side of the Karakoram granodiorite six lithological units have been identified. They are Pasu slate, Gircha formation, Kilke formation, Misghar slates, the Gujal dolomite and Shahnoz conglomerate which extends to the Hindukush range towards the west.

2.3 Murtazabad hot springs

The Murtazabad hotsprings are located in the toposheet No. 42 L/11. These springs emnate from the steep cliff which is made up of fluvial deposits, largely comprising gravel sand and silt. Chemical data was also interpreted with the help of qualitative geothermometres. Water samples were collected from the point where the water naturally oozes out from the surface. There on-site measurements were made using digital electronic instruments. The flow rate was determined by using a calibrated container and a chronometer, where spring water could be collected. For sampling, heat resistant bottles were rinsed with sample water before they were completely filled. Alteration zones cover an approximate dimension of 50 m by 20 m. The alteration zones commonly comprise white some sublimated sulphur with traces of mudpots. The country rock is talus. Some cracks with direction $N45^0$ W are observed in this zone. Steam at 90^0C is issuing from the cracks. Its pH is between 3 and 4 by pH and test paper.

Budelas hot springs

Budelas hotsprings fall in toposheet No. 42L/7. These geothermal manifestations are located NW of Chalt on the bank of the Budelas river. An unmettalled branches off towards NW from the Gilgit Hunza near Sikanderabad locality. The nearest thermal spring is B-8, about 12 km from the main road. The spring issues from talus. Other manifestations i.e. B-9 and B-10 are located 7 km and 10 km further north on the right and left banks of the river. The springs are located between the Main Karakoram Thrust and the Karakoram granodiorite. The physical features of these manifestations are shown in Table 2.

Tatta pani hot springs

The Tatta pani hotsprings are located in the right bank of the Indus river along the Karakoram Highway. The springs and seepages are numerous and strech along a 2-3 km wide zone located approximately SW of the Gilgit town. The springs emanate from unconsolidated to semiconsolidated fluvial deposits. Amphibolites which are fractured by the Main Mantle Thrust constitute the hard rocks exposed along these thermal manifestations. These springs are located at the altitude of 1200 m. Brief characteristics are shown in Table 2.

Mashkin hot springs

This geothermal mnifestation is located on the toposheet No. I/11 on an unmetalled road off the Karakoram highway on the left bank of the Astore river at an altitude of 2135 m. The valley is very narrow with steep sides, and the exposed rocks around the spring are Nanga parbat gneisses.

Reservoir Temperature

Temperaturse measured by silica and Na-K-Ca are shown in Table 1. The estimated temperature of Budelas is excluded because of the effect of mixing of fresh water with the geothermal water. The temperature inferred by the silica geothermometre is generally lower than the temperature measured by the Na-K-Ca geothermometre. This is considered to be due to the influence of mixing of non-thermal water. The temperature estimated at Tatta pani ranges from 93 to 128^{0}C, and at Mashkin it is about 169^{0}C. On the other hand the silica geothermometre indicates temperatures from 51 to 97^0 C at Tatta pani, 86^{0}C at Mashkin and 40^{0}C at Sassi . It is noted that most of them are considered to be mixed with non-thermal waters.

Geothermal System and Main Mantle Thrust

The geothermal system at Tatta pani and Sassi lies along the Main Mantle Thrust.The hotsprings come from the Quaternary talus deposits. The linear arrangement of the hotsprings indicate the MMT and the subfault system. It is possible that meteoric water is heated up by the frictional forces along the MMT. However the role played by the granitic rocks in the vicinity is uncertain. It is also seen that the massive amphibolite sequence of the Kohistan Island arc is fractured by the MMT. The small opening cracks are most likely to be occured further, the strike of the MMT changes at Tatta pani , the strike ENE-WSW on the west and NNE-SSW on the east. It is assumed that the permeability of the zone with changes in strike is relatively high and that the MMT plays a vital role in transmitting the geothermal fluid. The hotsprings waters at Tatta pani are classified as the boundary of HCO_3 and SO_4 type. The hotsprings waters have somewhat rich Cl composition in comparison with the chemical composition of Murtazabad water. It is possible that the water is derived from the deep reservoir source where the temperature is 100^{0}C. As to Mashkin area it is felt that more geological and geochemical studies than available at present will be required for the complete understanding of the geothermal system.

3. CHAGAI VOLCANIC ARC

The area comprises a narrow belt which extends eastwards and truncates against the Chaman transform fault. This structure is formed as a result of subduction of the Arabian plate beneath the Eurasian plate (Fig 2) and is likely to be the important geothermal system. Due to the subduction a trench has been formed south of Makran and a volcanic arc has emerged. The Koh-e-Sultan volcano and other volcanic cones in the Chagai area are the result of subduction. The water from the thermal springs in Koh-e-Sultan area has been analysed and subsurface temperatures from 150^0 to 170^0 were reported (Schoppel, 1977).

3.1 Geology of the area

The Chagai area presents three structural and tectonic zones. These are marked by topographic features such as Chagai hills, Ras-Koh hills and Mirjawa Dalbandin ranges. The western part of which extends from the Pakistan- Iran border to the east of Koh-e-Sultan and is characterised by igneous and sedimentary rock assemblages from Cretaceous to Quaternary age. The

stratigraphic classification of the area is Sinjrani volcanic group, subrecent and recent deposits and Chagai intrusions.

3.2 Chiken dik spring

The Chicken dik spring is located 7.8 km southeast of Mashki Chah (Toposheet No. 35I/5). It is located at an altitude of 830 m. The water is discharged from holes about 100 m deep which Pakistan Industrial Development Co. has drilled for Iron ore in Mashki Chah. The water table was 2.3 m at the sampling time. The surface rocks are recent deposits, however they may penetrate the Chagai intrusions or the rocks of Sinjrani volcanic group (Arthurton et al., 1979). The physical features of the springs are shown in Table 3.

Koh-e-Sultan springs

The Koh-e-Sultan springs are located in the vicinity of the Miri crater (Toposheet No. 30 G/16). The hotsprings seep from the river bed which consists of lava and agglomerate. The water temperature ranges from 25-32^{0}C. The temperature is lower than the ambient temperature in the summer season. The springwaters in the alteration zone are strongly acidic. Their brief physical features are shown in Table 3.

Chemical properties of Geothermal water

Four water samples from thermal springs and one from the well in the vicinity of Koh-e-Sultan were collected and analysed in Karachi Laboratory of the Geological Survey of Pakistan. Table 3 shows the results of analysis of the water samples. There is a high concentration of salts in the water. The electric conductivity is more than 10,000µs/cm and the TSM ranges from 13,700 to 67,540 mg/l. Gas is continuously dissolved into the very little amout of groundwater available in the area, resulting in a concentrated water. It is assumed that the SO_4 type water flows horizontally into a shallow zone and is mixed with Cl type water fom the deeper levels. By this way the water changes fron SO_4 type to Cl SO_4 type.An Anion Index proposed by Noda (1982) is shown below:

$$A.I. = 0.5 _ \frac{SO_4 + Cl\,SO_4 + SO_4 + HCO_3}{Cl}$$

Higher values of A.I. indicate higher geothermal activity in a volcanic area. The reservoir temperaturecalculated by application of geothermometres may not reflect the true reservoir temperature. It is assumed that the process of mixing of ground water with the gases does not show the reservoir temperature at all.

Geothermal Structure

The Koh-e-Sultan volcano is the youngest volcano of the area. Hunting Survey Co. of Canada assigned pleistocene age to this eruption. Alteration zone is widely distributed in southwestern slopes of the Koh-e-Sultan volcano (Iqbal M., 1988) that the hydrogen sulphide gas and steam were discharged from within the crater which can be observed in the winter. However the temperature of the steam water is low(25-35^{0}C). The southern part of the area is located in the low gravity anomaly zone. The axix of the low anomaly is ENE-WSW to the east of Nokkundi and NW-SE to the west. It appears that the Koh-e-Sultan area is located in the high gravity anomaly area which corresponds with the uplifted area of Chagai volcanic arc. The distribution of Chagai intrusions and Sinjrani volcanic group in Mashki Chah corresponds with high anomaly gravity area. The present uplifted structure is presumed to be formed in the Neogene time (Arthurton et al 1979). Further the Koh-e-Sultan eruption in the Quaternary has produced a number of faults in the older rocks.

4. INDUS BASIN MARGIN

A narrow zone extending NE-SW runs along the eastern margin of the Indus basin where it merges into the Indus plain. Thermal springs occur along the faults and may well have been the resut of deep circualtion of meteoric waters.

4.1 Karachi and Dadu areas

The offshoots of the Kirthar range run as a series of parallel ridges between the boundaries of Karachi and Dadu Districts. In the Dadu area there is a large concentration of thermal springs where the average surface temperature is 40^{0}C (Bakr, 1965). The surface temperature of the springs in the Mangopir area at Karachi is 48^{0}C.

4.2 Salt Range Area

Rocks in the Salt range area range from Pre-Cambrian to recent. However the majority of the rocks are tertiary. Temperatures of the thermal springs are from 25-32^{0}C . The spring water is sulphurous and is known to have therapeutic value for skin disease (Rafique-uz-

zaman and Mehdi Hassan, 1964).

5. CONCLUSIONS AND SUGGESTIONS

From the preceding paragraphs it can be seen that a number of thermal springs exist in Pakistan. Studies of these springs are far from complete. It is suggested that detailed geochemical and radiometric studies should be carried out. After the data is collected and the therapeutic value of these springs is ascertained some of them can be developed as spa as in France, Italy , Japan New Zealand, USA and Iceland. Exploration may be undertaken in order to ascertain the underground source of energy.

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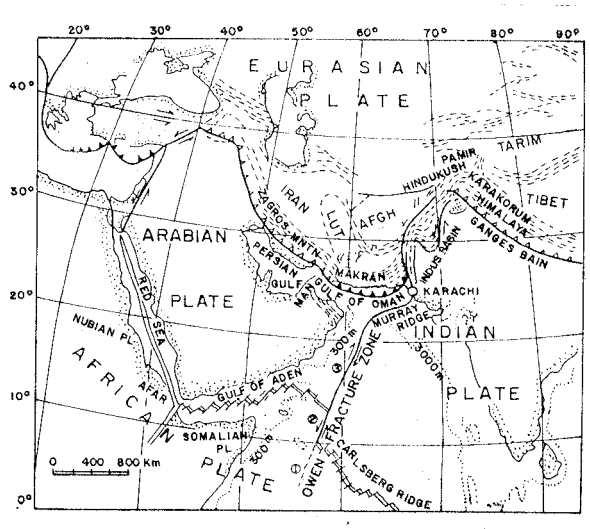

FIGURE 1: Plate tectonic sketch map of the Middle East showing the positions of Arabian, Indian and Eurasian plates.

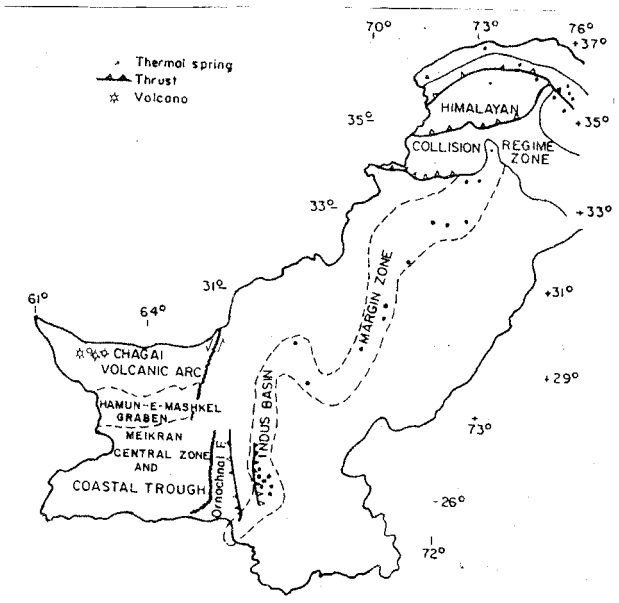

FIGURE 2: Map of Pakistan showing geothermal zones and areas.

TABLE 1: Temperature estimates based on different quantitative geothermometres.

S.No	Location	SiO_2 Adiabatic	SiO_2 Conductive	Na-K	Na-K-Ca β=1/3	Na-K-Ca β=4/3	Na-K-Ca (Mg Corrected)	Surface Temp (°C)
1.	Chilas	83.0	79.4	215.5	171.7	75.3	66.6	20
2.	Jaglot	85.4	82.1	56.9	56. 9	127.7	84. 8	65
3.	Jaglot	88 .7	85 .9	85.0	148. 6	160.1	43.2	20
4.	Jaglot gah	Surface water sample.						
5.	Murtazabad	93.8	91.7	212.7	220.4	235.3	133.0	75
6.	Murtazabad	110.0	110.5	240.6	226.8	221.3	8.9	80
7.	Murtazabad	119.6	121.7	312.7	235.2	175.4	72	26
8	Murtazabad	122.5	125.1	209.3	219.3	236. 9	76.0	91
9.	Hakuchar	115.6	116.7	252.3	191. 3	97. 9	53. 4	50
10.	Hakuchar	116.6	118.2	251.2	0.0	0.0	95.3	49
11.	Budelas	113.4	114.2	159.1	116.6	116.6	23.7	39
12.	Budelas	119.0	121.0	153.8	104.5	104.5	75.6	40

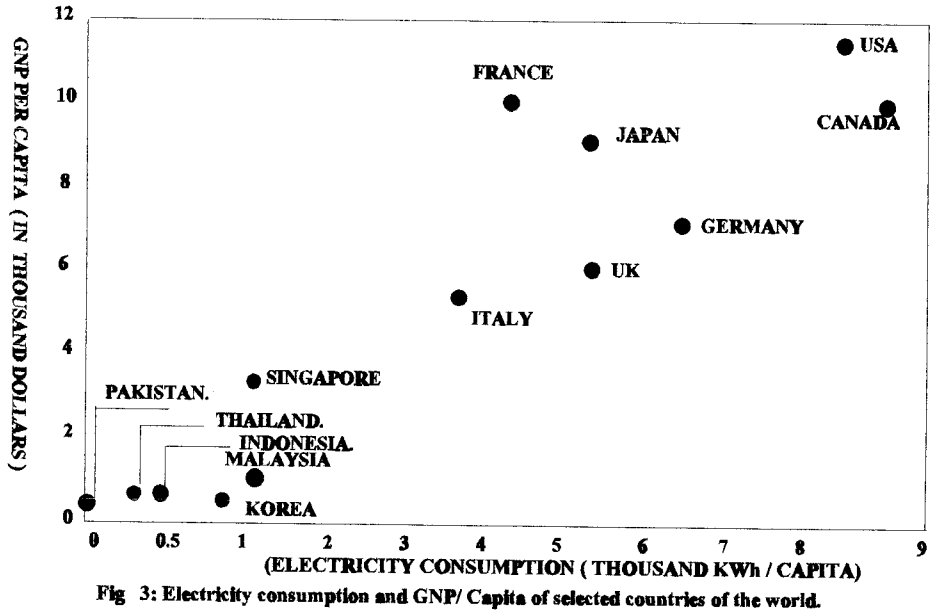

Fig 3: Electricity consumption and GNP/ Capita of selected countries of the world.

TABLE 2:Table showing the different parameters recorded on the **Murtazabad**(M), **Budelas** (B)and **Tatta pani** (TP) hotsprings in Northern Areas of Pakistan.

Hotspring	Temp. (^{0}C)	Flow rate	pH	Electronic Conductivity (μs/cm)	Hot water Properties	Geological Associations.
M 1	42 Amb 35	33 l/min	7.50	1720	Colorless Tasteless.	Terrace deposits Granite-Staurolite.
M2	37 Amb 33. 5	67 l/min	7.8	1856	Colorless, H_2S smell and sour.	Baltit Group Rocks.
M3	30 Amb 28	500 l/min visual Est.	9.21	2470	Colorless H_2S smell.	Terrace deposits Baltit Group rocks.
B1	46 Amb 32	100 l/min visual Est.	7.85	1540	Colorless H_2S smell	Talus-garnet mica schist(Baltit group)
B2	36 Amb 17	100 kl/hr visual Est.	7.49	776	Colorless H_2S smell.	Talus-garnet-staurolite schist.
TP 1	83 Amb 17	> 62 l/min	8.83	1060	Colorless H_2S smell, salty,hot	Terrace deposits Fracture Amphibolites
TP 2	65.5 Amb 36.5	800 l/min	8.57	1540	Colorless, H_2S smell,salty,hot.	Talus/Fractured Amphibolites(Kamila)

TABLE 3: Some measured physical physical charcteristics of hotsprings in Chagai area.

S.No	Locality	Temp (^{0}C)	Flow Rate	pH	Hot water Features.	Electric Conductivity	Geological Charateristic
C1	Chiken Dik.	29.9 Amb 40. 9	<2 l/m	6. 58	Colorless, odourles, salty.	> 10,000 μs/cm	Recent Deposits.
KS 1	Koh-e- Sultan	29.5 Amb 34.7	> 1 l /min	7. 44	Colorless, odourless, salty.	1060 μs/cm	Basal agglomerates.
KS 2	do	23. 2 Amb 36. 9	< 1 l /min	6. 89	Col or less, odourless, salty.	> 10,000 μs/cm	Koh-e-Sultan Volcanics.
KS 3	do	32. 0 Amb 36. 9	< 1 l /min	6.7	Colorless, odourless, salty.	2021 l /cm	Koh-e-Sultan Volcanics.
KS 4	do	26. 9 Amb 31. 1	< 1 l/ min	2.77	Colorless H_2S smell	>10000 μs/cm	Altered andesitic lavas.
KS 5	do	25.6 Amb 31.9	< 1 l/ min	2	Colorless H_2S smell	> 10000 μs/cm	Altered andesitic lavas.