NATURAL GAS RESOURCES IN KATHMANDU VALLEY

May 1980

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Abstract

Kathmandu valley is a small intra-mountain basin situated in the lesser Himalayas of Central Nepal, and has an average elevation of 1,350 m and an area of 400 km^2. The valley is composed of the Quaternary fluvio-lacustrine desposits, and its basement consists of the Precambrian - Devonian Kathmandu Complex and the Tertiary granites.

The Quaternary fluvio-lacustrine sediments are distributed mainly in an area of about 250 km^2 inside the watersheds encircling the valley. This area constitutes a low hilly land with mild undulations and is dissected by rivers having extensive alluvial plains. The Quaternary sediments are composed mainly of mud, sand and gravel beds in the unconsolidated or half-consolidated state, and include lignite, peat and diatomaceous earth. The coarse sediments are found mainly in the land adjacent to the pre-Quaternary basement rocks and in the northern half of the valley, whereas the muddy sediments prevails in the central and southern part of the valley. The maximum thickness of the Quaternary sediments is unknown. The groundwater exploratory wells in the southwestern part of the valley are drilled to a maximum depth of 457 m, but none have reached the basement. The lake which produced the lacustrine deposits was created by the ascending development of the Mahabharat Lekh (Mountains) in the south of the valley which proceeded at a speed higher than the downward erosion by the southward flow of the antecedent stream, the Bagmati river. It came into existence in the Pleistocene and was perhaps drained up in the Holocene.

Natural gas occurs in the fluvio-lacustrine deposits in the state of dissolved-in-water gas. Gas showings are observed at many water wells with a depth of 20 - 330 m, and these wells are found in Kathmandu city situated in the western part of the valley as well as in Patan city adjoining Kathmandu city on the south. The gravelly sand beds lying below a depth of 200 m are the promising gas reservoirs, and they produce about 70 m^3/day of gas from an artesian well having a casing pipe diameter of $1\frac{1}{2}$ inches. Main gas components are CH_4 (75 - 80%), CO_2 (14 - 23%) and N_2 (1.5 - 6%). Chemical analysis of the muddy sediments indicates the probability that the muddy substances rich in organic matter are the gas source. The gas-water ratio at the casing head of wells is about 1 : 2. In an area of about 4 km^2 located to the south of Kathmandu city, the degree of methane saturation of the groundwater exceeds

100% at depths larger than 200 m from the ground surface. Assuming that the reservoir in this area has a thickness of 60 m and a porosity of 35%, the estimated value of its saturation gas reserves turns out to be $4.2 \times 10^7 m^3$. The gas deposits in Kathmandu valley resemble the Suwa gas field in Central Japan in type and scale, and their early development for supply of domestic fuel is greatly hoped for.

I. Introduction and Acknowledgements

Kathmandu valley in Nepal embraces an area where the Quaternary sediments are distributed and many gas showings are observed*, and a portion of the gas deposits in this area is utilized as domestic fuel.

In view of the growing fuel demand in Kathmandu valley and neighbouring areas, the Department of Mines and Geology, Ministry of Industry and Commerce, His Majesty's Government of Nepal, formulated a plan for the exploration and research of the gas deposits in the aspects of geology, economic geology, geochemistry and geophysics. To provide technical assistance for the implimentation of this exploration plan, the Japanese Government, acting through the Japan International Cooperation Agency (JICA), sent a four-member geological survey team to Nepal consisting of Koji Motojima, Hiro'o Natori, Shozo Nagata, and Fuminori Takizawa. During their one-month stay in Nepal from May 9 to June 8, 1979, the four experts conducted a joint survey and research including field explorations and laboratory tests in collaboration with three officials of the Department of Mines and Geology, namely G.S. Thapa, P.R. Sthapit, and S.K. Giri.

The said survey and research disclosed that a natural gas deposit is in existence in Kathmandu valley and that the gas is of "dissolved-in-water type" (NGW) originated from the Quaternary fluvio-lacustrine sediments.

It was also found that highly potential deposits, of which the main component is methane, are distributed in the southern part of the city area of Kathmandu, and the coarse-grained sediments greater than 200 m in depth are the main reservoirs.

The team wishes to express its deep gratitude to the Ministry of Foreign Affairs, Ministry of International Trade and Industry, Japan International Cooperation Agency and the competent Nepalese authorities for the kind arrangements for making the survey successful. Acknowledgement is also due to Mr. Sadao Higuchi, Japanese Charge d'Affaires in Kathmandu, Messrs. M.N. Rana and T.M. Tater, Director-General and Deputy Director-General respectively

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* Mori, 1968; Tandukar and Pandey, 1969; Bashyal and Joshi, 1973; Vinod, 1973; NDMG, 1977; Thapa, 1977; Sharma, 1978.

of the Department of Mines and Geology, Nepal, and Mr. Nobuyuki Saito, Chief of JICA Kathmandu Office for the helpful assistance offered to the team in the survey area.

II. Outline of Topography and Geology

1. Topography

Kathmandu valley is an oval shaped intra-mountain basin situated in the lesser Himalayas of Central Nepal (Fig. 1), and covers a distance of about 25 km from east to west and about 19 km from south to north.

Kathmandu city, located in the western part of the valley, has an elevation of about 1,300 m. The lowest elevation in the valley, observed near Bagmati gorge in the southern part, is about 1,250 m, and the highest elevation in the flatland area of the valley is about 1,400 m. The valley is encircled by a number of high-rising mountains such as Siwapuri (El. 2,732 m), Manicur (El. 2,403 m), Mahadewpokhri (El. 2,164 m), Phulchauki (El. 2,762 m), Chakhel (El. 2,517 m), Jamacok (El. 2,096 m), and Ahale (El. 2,321 m). The mountainous areas have highly undulated topography, reflecting the differential erosion caused by the differences in lithologic character. Many of the ravines and ridgelines run in the WNW - ESE direction on account of the geological structure. Although the relative height from piedmont to summit reaches a maximum of 1,400 m, most ravines are short in length, descending a very steep gradient to form piedmont fans at the foots of mountains. The water flow rate of the ravines is extremely small except in the wet season and on rainy days (Table 1).

Table 1. Monthly average rainfall of Kathmandu valley in 1961 - 1969

Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
19	22	32	48	69	252	375	352	127	55	8	2	1,361

in mm

Most of the rivers flowing through the valley have a gentle surface slope with fairly wide and horizontal beds. Well-developed erosion terraces are found in the whole valley. The relative height from river-bed to terrace surface is greater in the southern part of the valley than in the central and northern parts. In the southern part, all creeks flow northwards and the terrace surface, which frequently has an elevation of more than 1,400 m, is developed to a height of 1,450 m in some places. Hence, steep cliffs with a relative height of several tens of meters are observed, indicating that the southern area underwent heavier upheavals than the other parts of the valley during the Holocene.

Main rivers flowing through the valley are the Bisnumati flowing from north to south, the Manohara flowing from east to west, and the Bagmati flowing southwards from the confluence of the two rivers. The Bagmati flows out of the valley from Chovar gorge, crosses the Mahabharat Mountains, and joins the Ganges on reaching the Hindustan Plain far in the south.

2. Geology

The basement rocks of Kathmandu valley are composed of the Precambrian – Middle Paleozoic metamorphic and weakly metamorphosed sedimentary rocks and the igneous rocks including the Tertiary granites. They are blanketed with the Quaternary fluvio-lacustrine deposits unconformably (Dhoundial, 1961, 1966; Gandotra, 1968-a, b; Binnie and partners, 1973; Nadgir, 1973). Table 2 shows the succession of these formations.

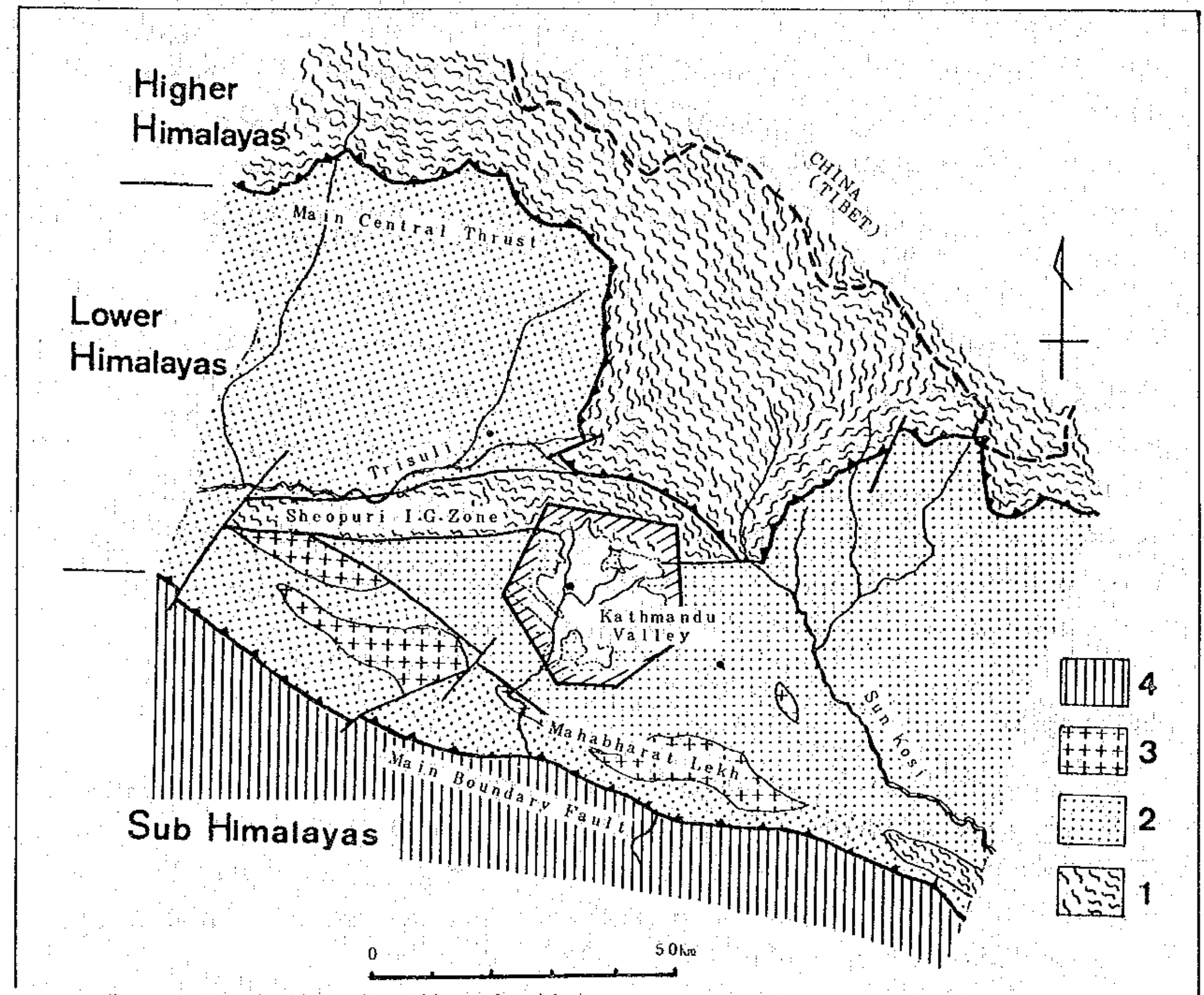
Table 2. Geological succession in Kathmandu valley

Cenozoic	Quaternary	Holocene		Fan gravels Talus Lake deposits (gravels, sands, silts, clays, peats, lignites, diatomaceous earths)
		Pleistocene		Fuvial deposits (gravels, sands, silts, clays, peats, lignites)
Paleozoic		Devonian ~ Ordovician Ordovician ~ Cambrian (?)	Pulchauki Group	Chandragiri Formation (quartzites, quartzose sandstones, shales, limestones with fossils) Chitlang Formation (conglomerates, phyllites, shales, sandstones, limestones)
Precambrian			Bhimphedi Group	schists, quartzites, phyllites, limestones, schistose sandstones
			Gneiss (Sheopuri Lekh)	
Igneous rocks				pegmatites, granites, basic intrusive rocks, tourmaline granite (Tertiary)

Precambrian

Bhimphedi Group:

This group crops out in the peripheral mountainous areas surrounding the northern half of the valley and on the southern neighbouring areas of the valley and consists of schists, phyllites, quartzites and limestones which are generally considered to be the late Precambrian sedimentary rocks. In the Sheopuri Injection Gneiss Zone (Fig. 1), injection geniss is well developed besides schists and more crystalline than in other zones. Intrusion of granites is also often seen in this zone.



1. Precambrian gneiss, migmatite and schist.
2. Late Precambrian to Middle Paleozoic meta-sedimentary rocks
3. Granite
4. Siwalik Series

Sheopuri I.G. Zone: Sheopuri Injection Gneiss Zone

Fig. 1. Map showing the location of Kathmandu valley in Central Nepal. Compiled from Gansser (1964) and Hashimoto (1973)

Paleozoic

Phulchauki Group:

Phulchauki Group in the Kathmandu area is divided into Chitlang Formation and Chandragiri Formation, and crops out in the peripheral mountainous areas encircling the central and southern parts of the valley. Its outcrops are also found within the valley in the form of islets.

Chitlang Formation:

This formation is composed of conglomerates, limestones, sandstones, shales and phyllites, and no fossils have yet been found in any of these rocks. It is considered that the upper part of this formation is formed by the Late Ordovicioian sediments as it has a transitional relationship with the overlying Chandragiri Formation, but the age of its lower part is not clarified yet. It is separated from the underlying formation by fault, and thrusted up by the Bhimphedi Group.

Chandragiri Formation:

This formation is found in the southern part of the valley in the neighbourhood of Mt. Chandragiri and Mt. Phulchauki. It is composed of quartzites, sandstones, shales and limestones, and produces fossils such as trilobites and cephalopods. The lower part of this formation is correlated with the Ordovician, the upper part with the Silurian, and the topmost part with the Devonian by reason of the presence of conodonts.

Igneous Rocks

In the northern part of Kathmandu valley where the Bhimphedi Group is distributed, gneissic granites and pegmatites are found. On the other hand, the Bhimphedi Group in the southern neighbouring areas of the valley has intrusive basic rocks and tourmaline granites which the age is assumed to be the Tertiary (Khan and Tater, 1970).

Quaternary Sediments

The Quaternary sediments are distributed in the low-lying flat area covering a distance of about 25 km from east to west and about 23 km from south to north inside the watersheds encircling Kathmandu valley. The total distributed area is about 250 km^2, which accounts for 62% of the total land area surrounded by the watersheds. In the southern fringe area of the valley, however, a small distribution of the sediments is observed outside the watersheds on the south. Elevation of the distributed area ranges from 1,250 to 1,450 m.

The sediments are composed of clay, silt, sand and gravels, thus presenting various sedimentary environments such as lakes, swamps and marshes, rivers, esturine deltas and piedmont fans, and their facies show a notable horizontal change in the north-south direction. The estimated maximum thickness of the sediments is about 600 m, and a conspicuous facies change is also noted between the fluvial deposits and the overlying lake deposits in depth about 200 m in the southern half of the valley. On the whole, the grain size is coarser in the northern part, becoming finer towards the south.

Geological Structure of Pre-Quaternary

The Precambrian Bhimphedi Group occurs in the north of Kathmandu valley and on the southern neighbouring areas of the valley. The Paleozoic Phulchauki Group distributed between them within a width of about 25 km, are complexly folded, presenting a synclinorium having WNW - ESE trend. The axis of this synclinorium is at the neighbourhood of Godawari - Pharphing in the southern fringe area of the valley, and is enveloped with the limestones of Chandragiri Formation along the axis.

Formation of the Pleistocene lake of the valley is ascribed to the rapid unpheaval of older rocks of the Mahabharat Lekh in the south during the Quaternary time (Boesch, 1974; Sharma, 1977). Specifically, it is believed that the lake was created when the Bagmati, the antecedent stream flowing in the south, was dammed up because its downward erosion proceeded at a speed slower than the rapid upheaval of the Mahabharat Lekh.

III. Quaternary Sediments

The Quaternary sediments accumulated extensively in Kathmandu valley are composed of clastics sediments such as clays,silts, sands and gravels and include diatomaceous earth in a limited quantity. These sediments as observed on the ground surface can be grouped into the following three facies as also shown in Table 3.

Facies I : Fluvial deposits
Facies II : Lake-delta deposits
Facies III : Proper lake deposits

Table 3. Facies classification of Quaternary sediments in Kathmandu valley

	Sedimentary environment	Lithofacies
Facies I	Fluviatile (Alluvial flood-plain)	〈 Fining-upward cycle 〉
Ia	Stream-channel fill	Coarse-grained sand with gravel
Ib	Over-bank (included marsh)	Clay and silt with sand
Facies II	Lake-delta	
IIa	Delta-flont & Delta-slope	Fine-to medium-grained sand
IIb	On-delta marsh	Carbonaceous clay and silt
Facies III	Lake (proper)	
IIIa	Proximal lake	Silt-sand alternation
IIIb	Proximal lake	Laminated clay and fine sand
IIIc	Distal lake (included marsh)	Clay (occasionally diatomaceous or carbonaceous)

In addition to these three facies of continental sediments, there can be also observed piedmont-fan deposits. Fig. 2 shows the approximate distributions of these facies. As seen in the figure, all facies generally show a horizontal change in the north-south direction.

On the whole, the Quaternary sediments are bedded horizontally, but southward dipping within an angle of 5^{o} is observed in certain places of the northern part of the valley where facies I prevails. In the southern part, the sediments are distributed at a height several tens of meters greater than observed in the central part, suggesting that the southern part of the valley was subjected to a relatively greater upheaval.

The maximum thickness of the sediments is estimated to be a little more than 650 m. It is supposed, however, that the base is undulated and the thickness varies considerably from place to place. In the southern part of the valley judging from the graphic well logs, it is probable that the facies distribution to a depth of about 200 m is similar to that observed on the ground surface (Fig. 2).

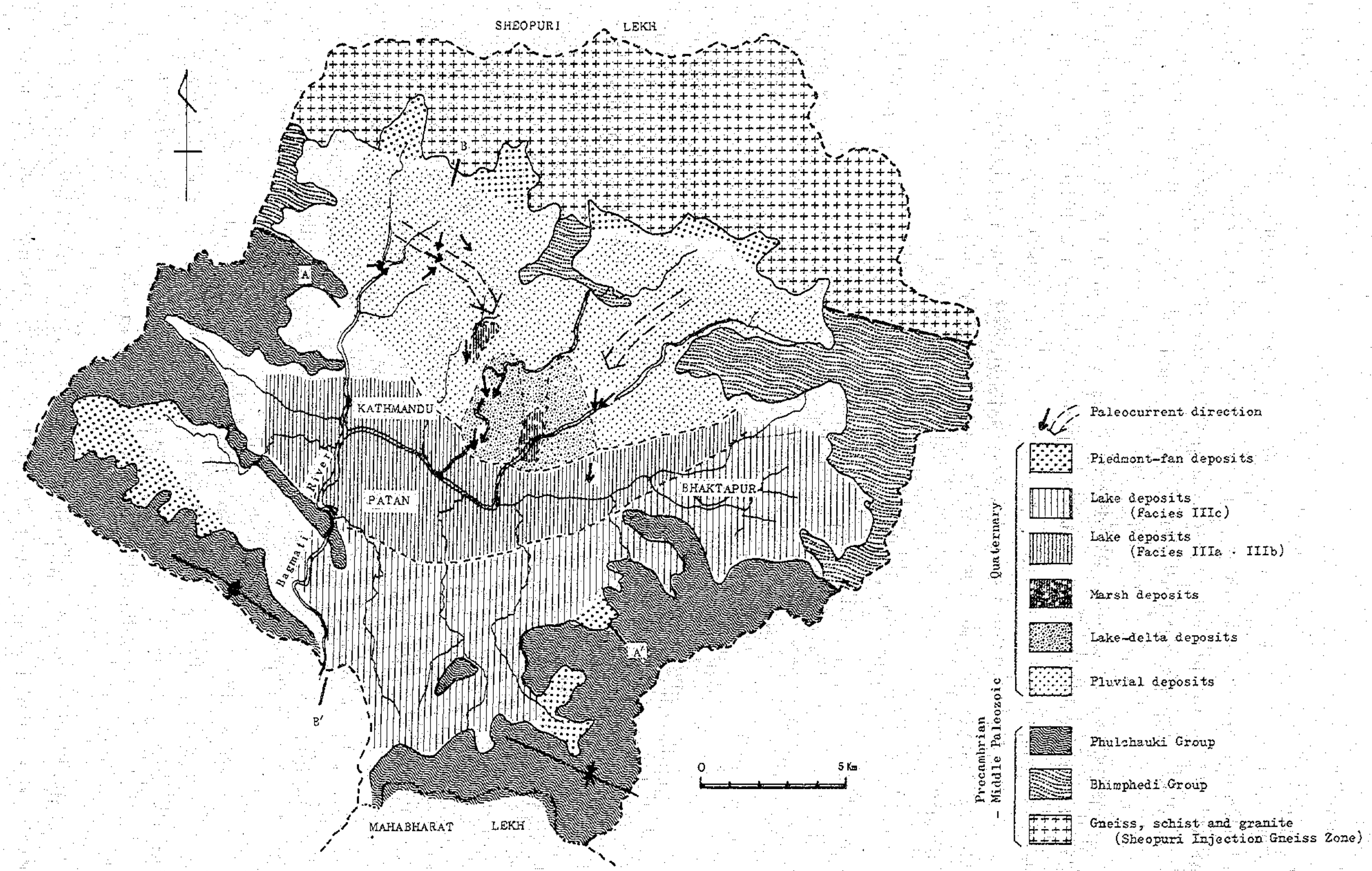


Fig. 2. Facies distribution map of Quaternary sediments in Kathmandu valley. A-A' and B-B' lines show the location of sections in Fig. 12.

1. Sedimentary Facies and Environment

i) Facies I (Fluvial deposits)

Developed in the northern part of the valley, this facies occupies about a third of the surface distribution of the Quaternary sediments. As seen in Fig. 3 (Columnar Sketch of Facies I), it is composed by a combination of two sub-facies, the 5 - 10 m thick coarse clastics (sands and gravels) and the several meter thick fine clastics (clays and silts).

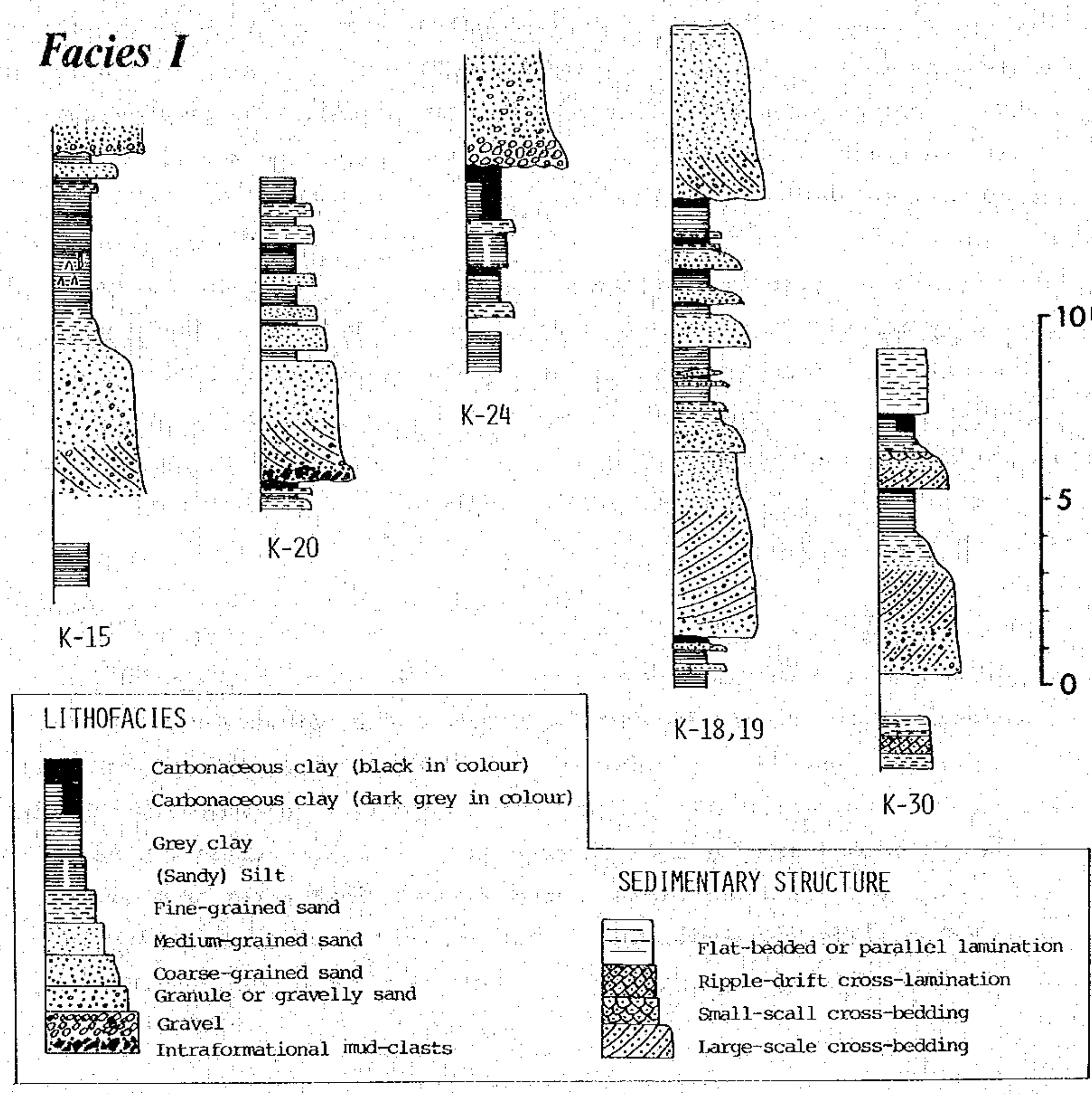


Fig. 3. Columnar sketches of Quaternary sediments (Facies I).
Localities in Fig. 8

With its lowermost part consisting of gravels and gravelly coarse sand, this facies presents a small-scale sedimentary cycle in which grain size shows an upward fining from the lower half composed of coarse sand to the clayey upper half, with a transitional fine sand bed intercalating in between. Its base is constantly bordered by the penecontemporaneous erosion surface. As exemplified in Fig. 3, the lowermost part of the said cycle often includes intraformational mud-clasts. The presence of the intraformational mud-clasts and the penecontemporaneous erosion surface indicates that the sedimentation proceeded with the progress of erosion of lower beds. The sand bed shows poor sorting of sand grains and conspicuous development of cross-bedding or cross-lamination. The grain size in the sand bed presents a gradual upward fining (granular sand --- coarse sand --- medium sand --- find sand). The gradual upward fining in grain size is also observed in the transition zone from the sandy part to the muddy part.

The muddy upper half of the sedimentary cycle consists mainly of grey clay and silt and often includes thin sand beds. Its upper part is occasionally found to include carbonaceous clay* which is black or blackish grey in colour. This dark coloured clay is rich in organic matter and locally known as "Kalimati". The clay bed of facies I, which includes "Kalimati," is often spotted with bluish green vivianite ($Fe_3^2 (PO_4)_2 \cdot 8H_2O$).

It can be concluded that the sedimentary environment of the facies I, which presents the above-mentioned sedimentary cycle of upward fining grain size type, was an alluvial flood plain with rivers repeating lateral migration. As shown in Fig. 4, the coarse clastics in the lower half of the cycle are stream channel-fill deposits, and the fine clastics in the upper half are due to an over-bank flood plain deposits. It is considered that the flood plain included ephemerical water areas such as marsh and often gave rise to the formation of carbonaceous clay.

* Organic carbon content disclosed by chemical analysis is 4 - 5% (See Table 9).

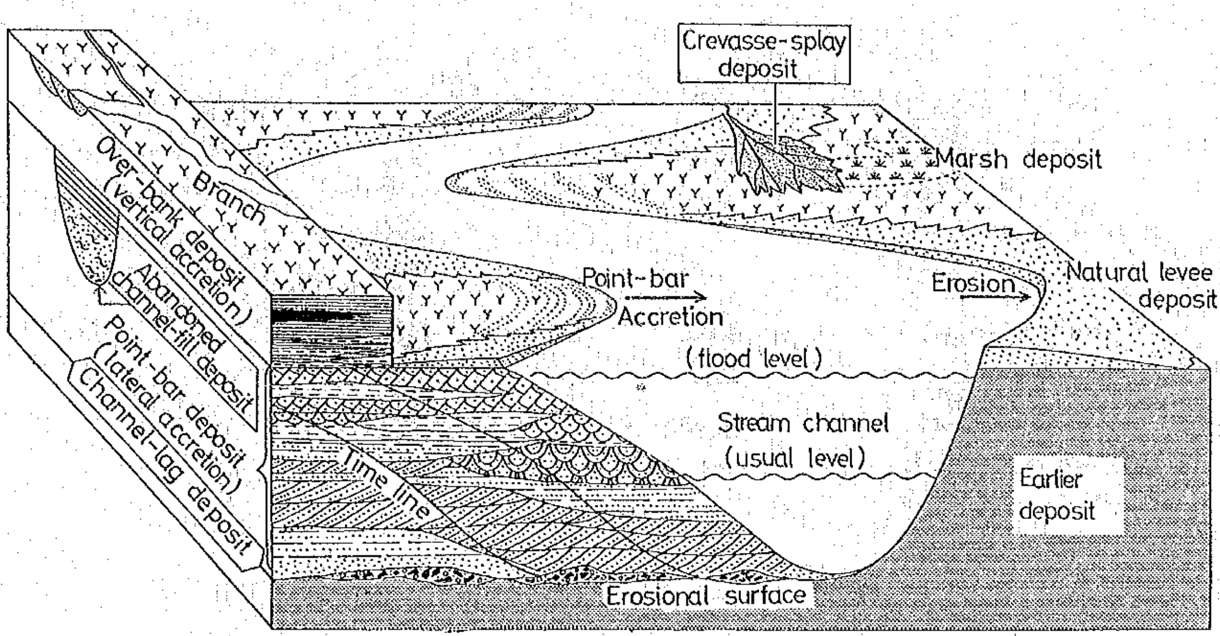


Fig. 4. Illustration showing the formation of a fining-upward sequence in an alluvial flood-plain.

As described later, it is likely that the sediments of the facies I, found mostly in the northern half of the valley, are also distributed extensively in the southern half at depths greater than about 200m. They are the important reservoirs of groundwater and natural gas that can be produced by bore-holes in the city area of Kathmandu.

ii) Facies II (Lake-delta deposits)

This facies is the transition facies between facies I and III, and it crops out in the vicinity of the Tribhuwan airport in the central part of the valley, particularly on the western side of the airport. It consists mainly of bedded sand featured by the well-developed cross-bedding and parallel lamination (facies II-a), and of laminated clay and silt (facies II-b). The former is composed mainly of medium- and fine-grained sand and shows a fairly sorting of sand grain. The latter adjoins the former and contains a considerably large volume of carbonaceous clay (Fig. 5).

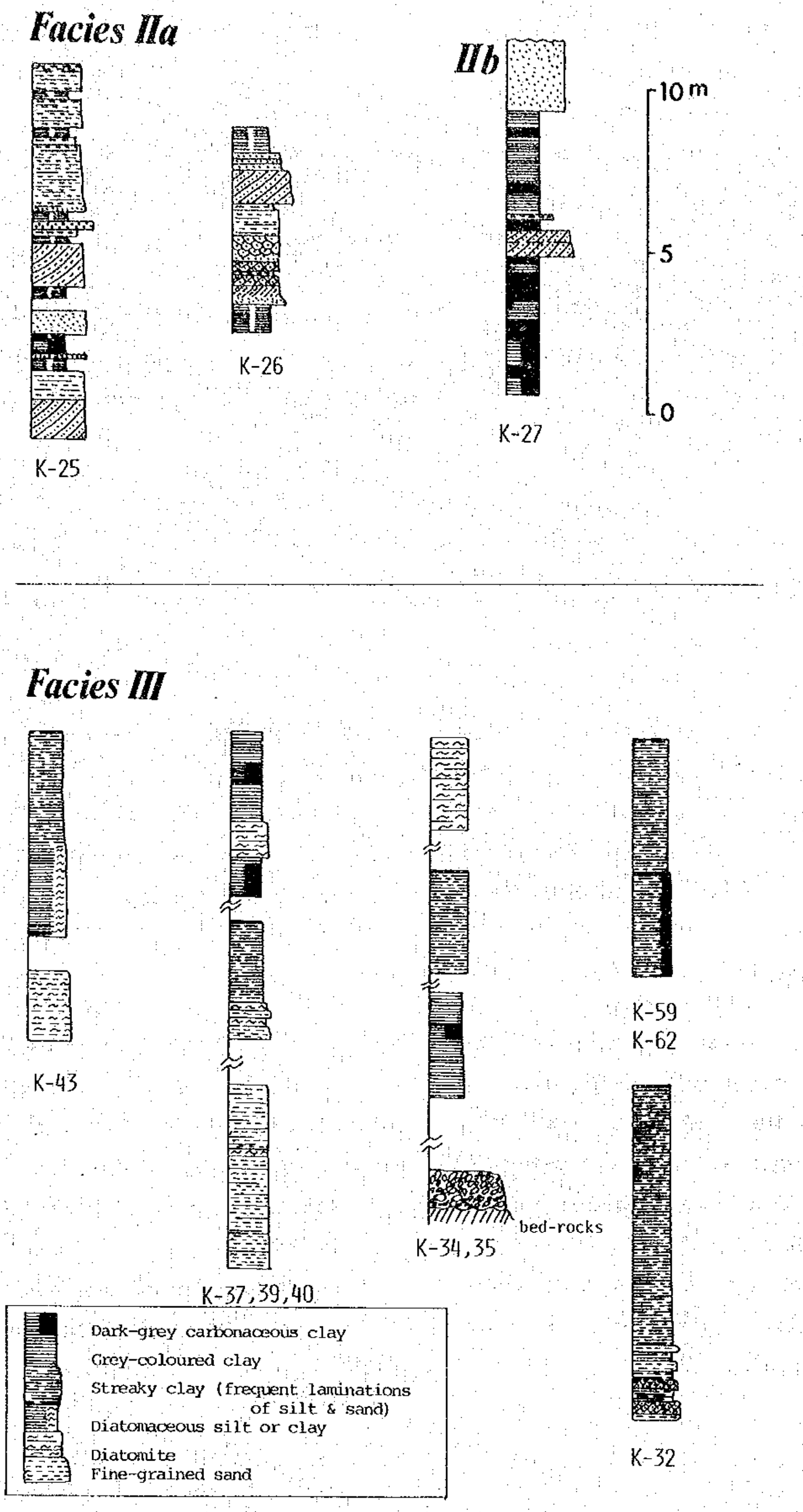


Fig. 5. Columnar sketches of Quaternary sediments (Facies II and III).

It is probable that facies II-a has originated from lake-deltas in an estuary environment. The silty sand bed observed along the Ring Road which runs on the west of the Tribhuwan airport, presents a clinoform which is a characteristic feature of deltas. Facies II-b, on the other hand, is considered to be derived from swamps or marshes near the lake-deltas. In certain places of the area where this sub-facies is distributed, the sedimentary cycle of fining-upward sequence as observed with facies I is found, and this is regarded to be an on-deltaic deposits. It is believed that this sub-facies was formed under the changeable condition of the water level of the Pleistocene lake and of the erosion of the hinterland.

No clear judgement can be passed on the sub-surface distribution of this facies due to the absence of relevant data. Nevertheless, the data of exploratory water wells drilled in the proximity of the said airport suggests the presence of a sand bed at a depth of 75 - 125 m, and this bed is considered to correspond to delta deposits.

iii) Facies III(Proper lake deposits)

This facies crops out in the southern half of Kathmandu valley, and consists mainly of unconsolidated to semi-consolidated mud bed and partly of thin beds of fine sand and diatomaceous earth. It represents the sediments on the bottom of the ancient lake, and is classified into three sub-facies. Fig. 5 shows typical columnar sections of its outcrops.

Facies III-a consists mainly of sandy mud with frequent sand bed intercalations and includes fairly thick sand beds. It's appearance is featured by sand-mud alternation. The sand beds are composed mainly of fine sand and have well-developed cross-lamination and parallel lamination. The mud beds are mostly silty or sandy. This sub-facies is distributed from the neighbourhood of Thimi to the northern part of Kathmandu city, adjoining facies II on the north.

Facies III-b is composed of silty clay which forms a muddy streak due to frequent intercalations of very thin layers or laminations of very fine sand and silt. It has a greater organic matter content than facies III-a, and it's outcrops expose sporadically in the western and southern parts of Kathmandu city. It adjoins facies III-a on the north.

Facies III-c is composed of grey (partly dark grey) clay which frequently includes light yellow diatomaceous earth. It shows few sand bed partings. Development of lamination is not notable in the clay bed, but often found to be conspicuous in the diatomaceous earth. This sub-facies crops out extensively in the southern part of the valley, including "Kalimati" clay in certain places, in particular, the southern fringe area. It is considered that this sub-facies was formed in the sedimentary environment created where the flow of the ancient lake was suspended.

According to the logging data, the deposits of facies III are distributed uniformly, with a thickness of about 200 m, in a considerably wide area embracing Kathmandu city and extending from the central to southern part of the valley. It is also known that the clay of this facies is developed to a depth of 300 m from the ground surface in a small area stretching from Dhapakhel to Harisidhi, both located at the southern fringing area of the Quaternary sediments.

iv) Characteristics and Provenance of Coarse Clastics

Notable prevalence of sands and gravels is observed in the Quaternary sediments distributed in the northern half of Kathmandu valley. The sediments are typical arkosic clastics of presenting leucocratic colour and consisting mainly of quartz, feldspar and muscovite. Quartz and muscovite are conspicuous because of their large grain size. Besides these main mineral components, minor components such as tourmaline and biotite are also observed in small quantities. Fragments of granite and gneiss constitute a dominantly large portion of these gravels, and fragments of meta-sandstone, quartzite and phyllite are also found in small quantities.

Sand beds of facies I are often found to be gravelly and ill-sorted. Sand grains are not rounded, indicating that their transportation distance is short. Sand beds of facies II and III are composed of fine or medium sand. They are fairly well sorted, but include some ill-sorted parts. These sand beds often present yellowish brown colour due to weathering of mica which is contained in large quantities.

Fig. 2 shows some palaeocurrents obtained from the current structures often found in the said sand beds. The figure indicates the notable fact that facies I (fluvial deposits) presents palaeocurrents flowing from WNW to ESE in the northwestern part of the valley, a flow direction quite divergent from that of the Bisnumati river system. An inference can be drawn from this fact that in the northern half of the valley where coarse clastics prevailed, the ancient streams from the north converged into an area near the existing airport, and then emptied into the proper lake.

On the basis of the above-mentioned facies of coarse clastics and the data of palaeocurrents, it can be concluded that the granites and gneiss, distributed in the Siwapuri mountains area extending along the northern fringe of the valley, were the principal provenance of the Quaternary seidments. Bhimphedi Group and Palaeozoic rocks are also considered to have contributed to the formation of the Quaternary sediments, but to a far less degree. It is probable that the Siwapuri mountains was composed of coarse crystalline rocks which were susceptible to deep weathering, and these rocks strongly heaved up and eroded in the Quaternary time.

2. Sub-surface Geology

In Kathmandu valley there are many water-wells drilled for goundwater supply (Binnie and partners, 1973; Nautiyal and Sharma, 1961; Sharma and Singh, 1966; Unpublished graphic well logs of Nepal International Drilling Company), and they cover nearly the entire distribution area of the Quaternary sediments.

Fig. 6 shows bore-hole logs arranged to present a section in the approximate north-south direction with Kathmandu city at the centre. As seen in the section, a thick clay bed extends uniformly to a depth of 200 m, and there is no doubt that this clay bed belongs to sub-facies "a or b" of facies III (proper lake sediments) which is observed on the ground surface. As can be

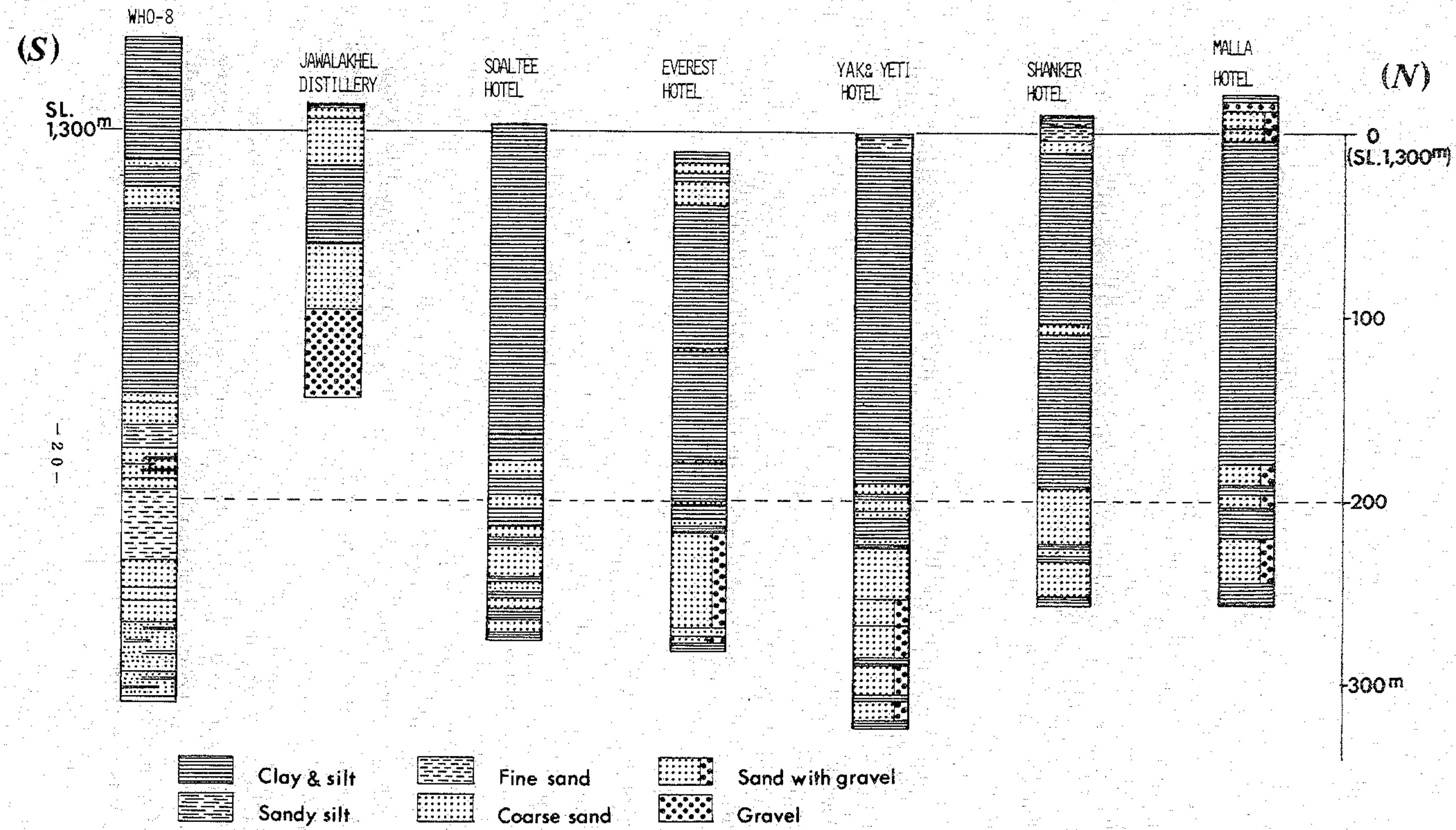


Fig. 6. Bore-hole geologic sections of Quaternary sediments - I - Localities in Fig. 8.

confirmed from electric resistivity logs, the said clay bed is distributed continuously to Thimi, Bhaktapur and Phaidhoka located in the eastern part of the valley.

On the other hand, it is known from many bore-hole data that the underground geology of the northern half of the valley is represented by the prevalence of coarse clastics with minor muddy beds. It is probable that their facies corresponds to facies I observed on the ground surface of the area.

As seen in Fig. 6 showing the columnar section of Soaltee Hotel and Yak and Yeti Hotel, the underlying beds of the above-mentioned clays consist of alternation of sand beds with a thickness of several to 20 m and thinner clay or silt beds. It is highly probable that this facies presents a sedimentary cycle being similar to the one seen in the fluvial deposits of facies I. This can be substantiated by the bore-log data from a number of wells including WHO-8 which indicate that the fine grained beds contain dark clays, lignites, carbonaceous matters and even peats in general. The above inference can be supported by the fact that the conspicuous fluctuation of electric resistivity shown in Fig. 7 (Selected electric resistivity logs) for each several to several tens meters in thickness at depths greater than 200 m shows a close resemblance to the pattern of the electric resistivity logs of facies I distributed in the northern part of the valley.

The bore-hole logs shown in Fig. 9 indicate that the aforementioned proper lake deposits are developed to a depth of 300 m or more from Harisidhi to Dhapakhel, both located in the southern part of the valley, as well as in some other places including Lagan-Toll in Kathmandu city. It is probable that during sedimentation of the bed existing a depth of 300 m at present, most part of the valley was an alluvial flood plain and there existed a narrow lake extending from south to north, i.e., from the southern fringe of the valley to Lagal Toll. It may be said that this state was maintained until the start of sedimentation of the mud bed above the depth of 200 m.

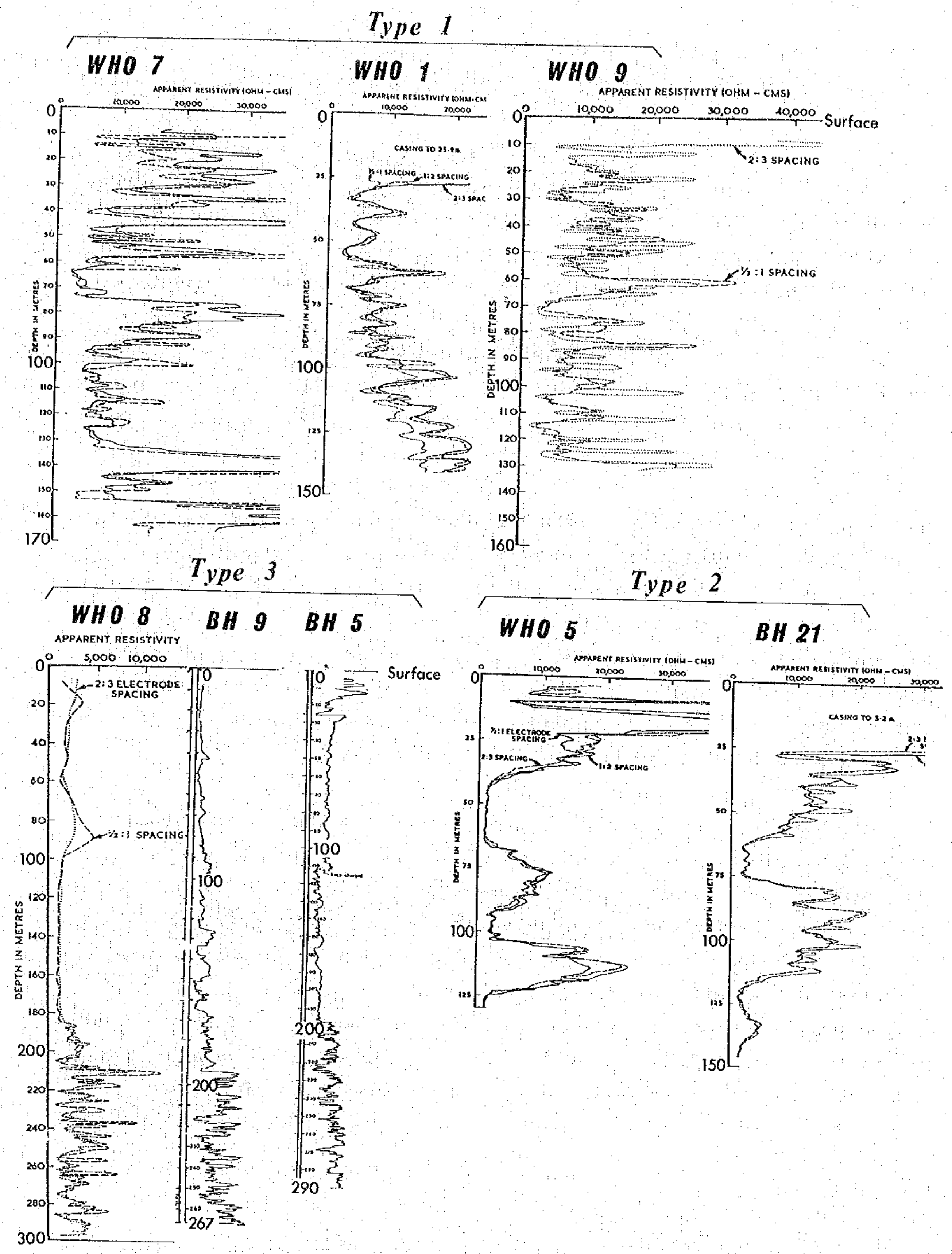


Fig. 7. Selected electric resistivity logs on the Quaternary sediments.

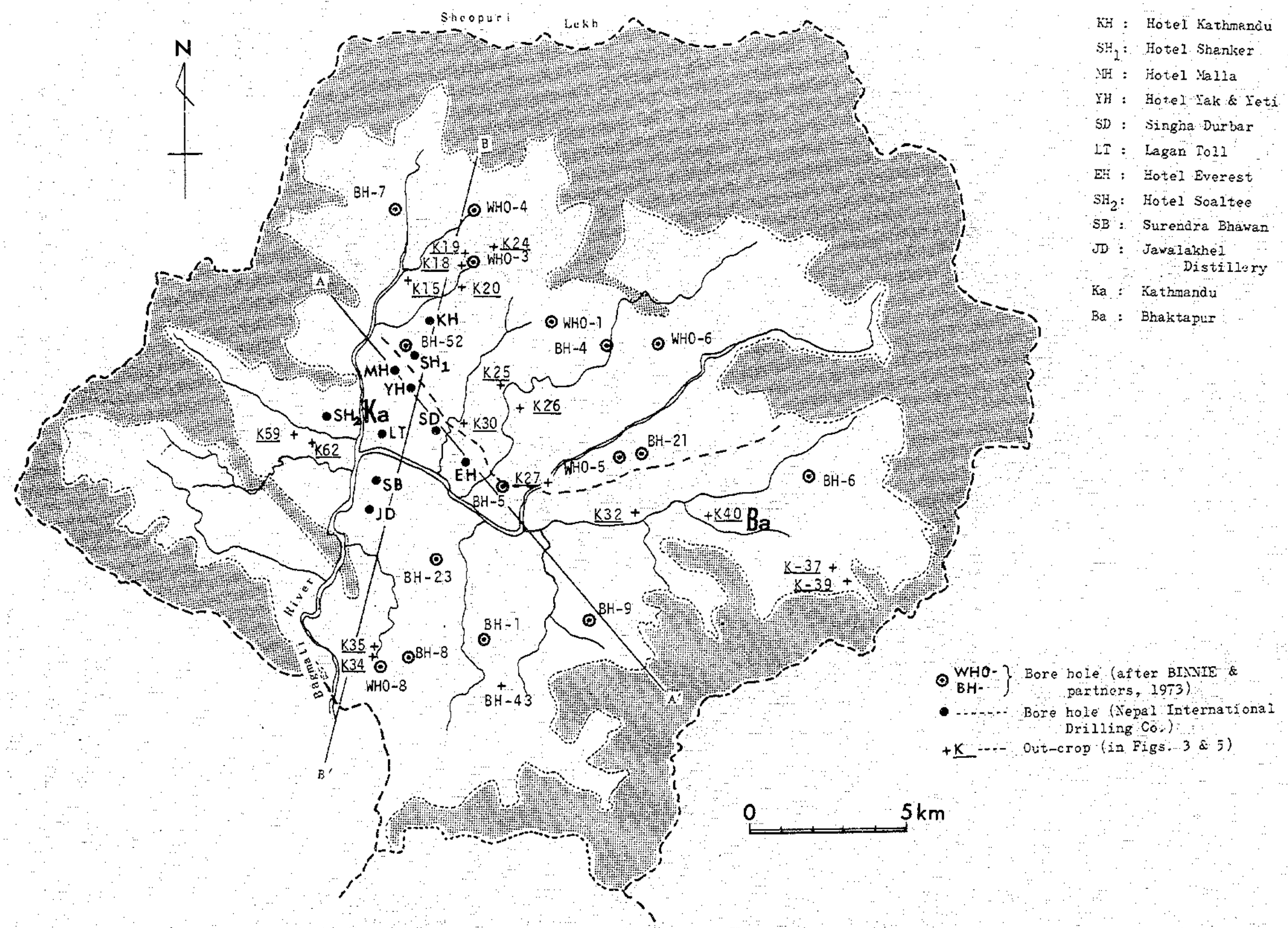


Fig. 8. Location map of the bore-holes in Figs. 6, 7 and 9, and rock-samples in Table 8.

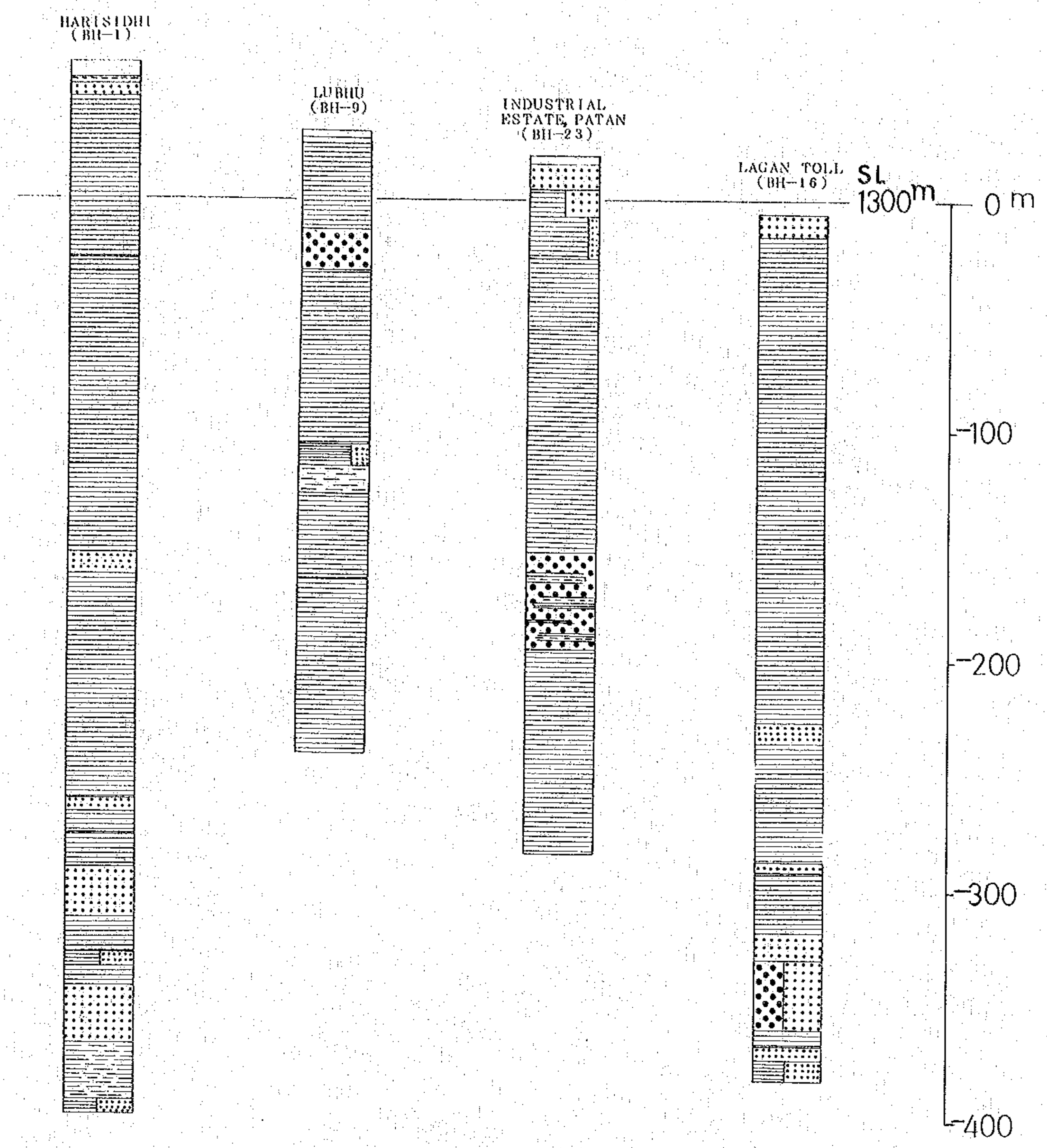


Fig. 9. Bore-hole logs of the Quaternary sediments - II -
Note the thickness of clay beds in comparison with Fig. 6.
Legend in Fig. 6.

There are no drilling data available for the thickness of the Quaternary sediments because none of bore-hole drilled in the past reached the basement in the valley except its marginal parts. The groundwater exploratory well at Harisidhi, shown in Fig. 7, is the deepest of all boreholes in the valley. It has a depth of 457 m but has not reached the basement.

In the data of gravity analysis of Moribayashi and Maruo (1980), the thickness of the Quaternary sediments is estimated to be a little more than 650 m. In this gravity analysis, which was made on the basis of the gravity map with contours 1 mgal interval (Fig. 10), the basement depth was calculated with the density contrast between the basement rocks and the Quaternary sediments taken at 0.8 g/cm^3. Fig. 11 shows the depth contours of the base-level of the Quaternary sediments as obtained by this analysis, and indicates that the thickness of the sediments is the largest between Kathmandu city and the airport and the base-level configuration conforms to the facies obtained from the bore-hole geologic data.

Fig.12 shows the geologic cross-sections of the valley prepared on the basis of the surface geology, well logs and gravity analysis. These cross-sections are accurate to a depth of 300 m because the facies to that depth are clarified by abundant well logs, but the portions deeper than 300 m were drawn arbitrarily using data of a few bore-holes. It is estimated that the sediments in the lower part exceeding 300 m in depth are composed mainly of coarse clastics of facies I, but proper lake sediments of facies III may also be present, though in a small scale.

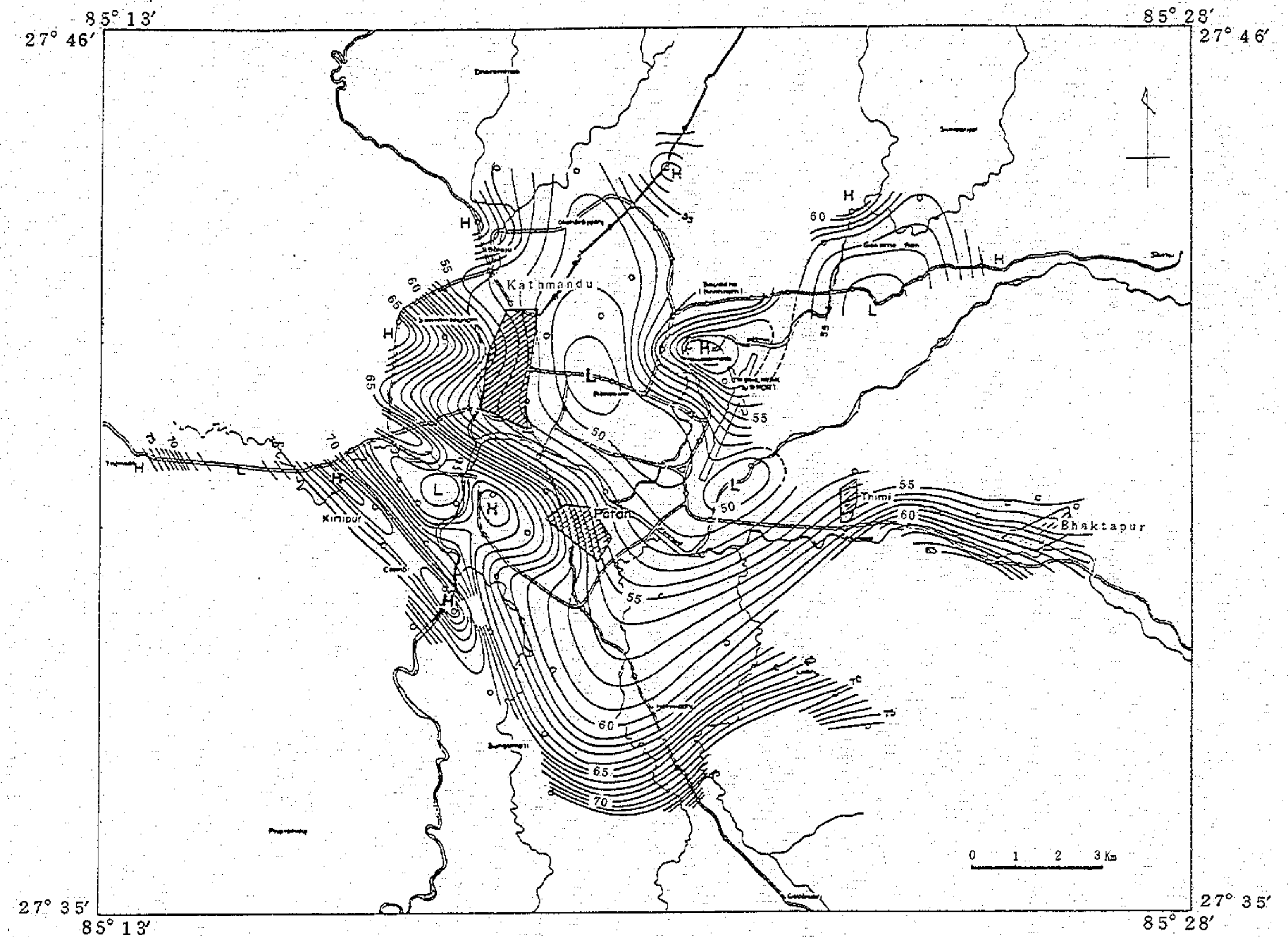


Fig. 10 Gravity contour map in the Kathmandu valley. Contour interval 1 mgal. Circles show localities of gravity station. (after Moribayashi and Maruo, 1980)

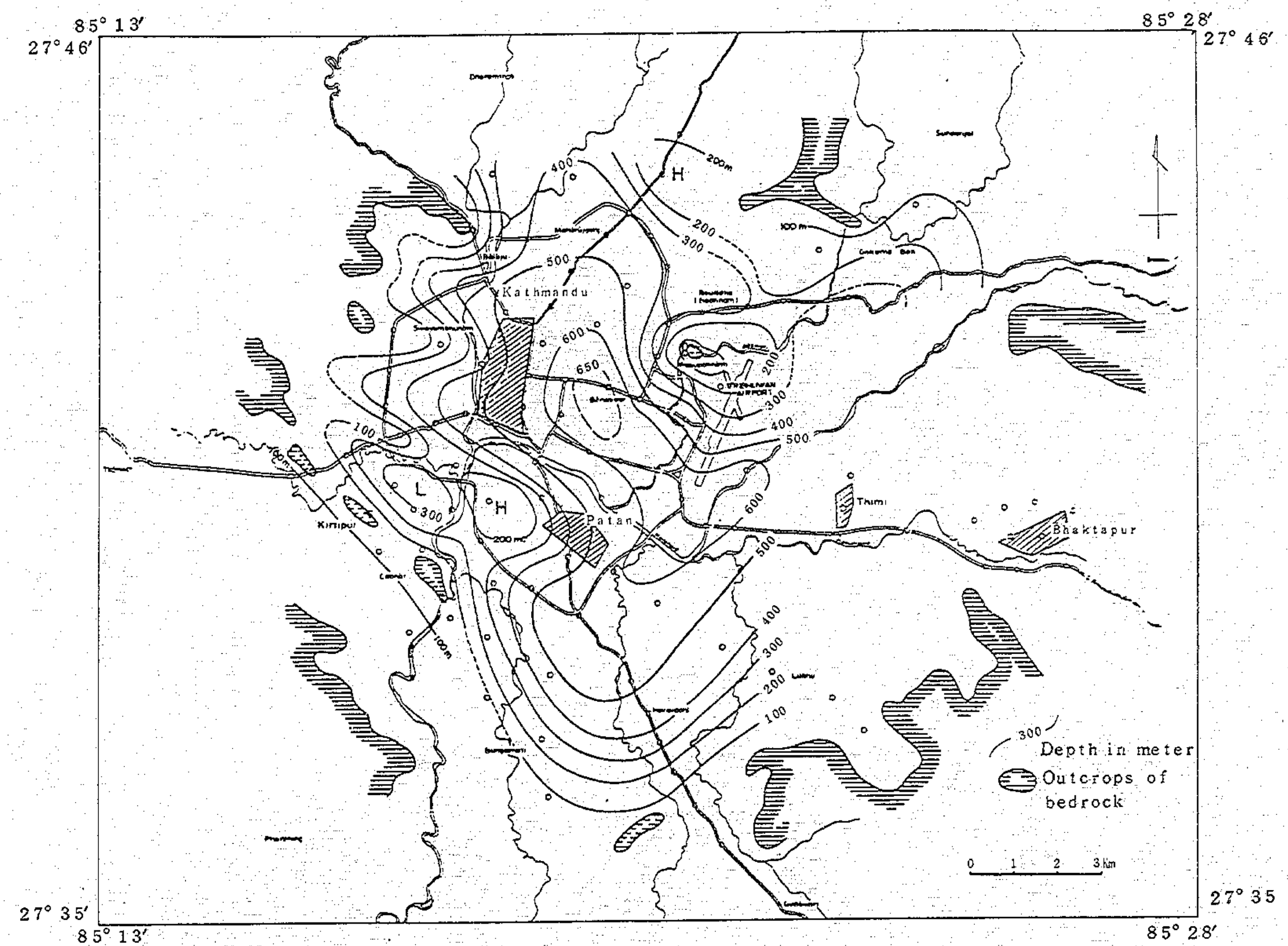


Fig. 11 Basement contour map in the Kathmandu valley estimated from the density difference of 0.8 g/cm^3. Contour interval 100 m. (after Moribayashi and Maruo, 1980)

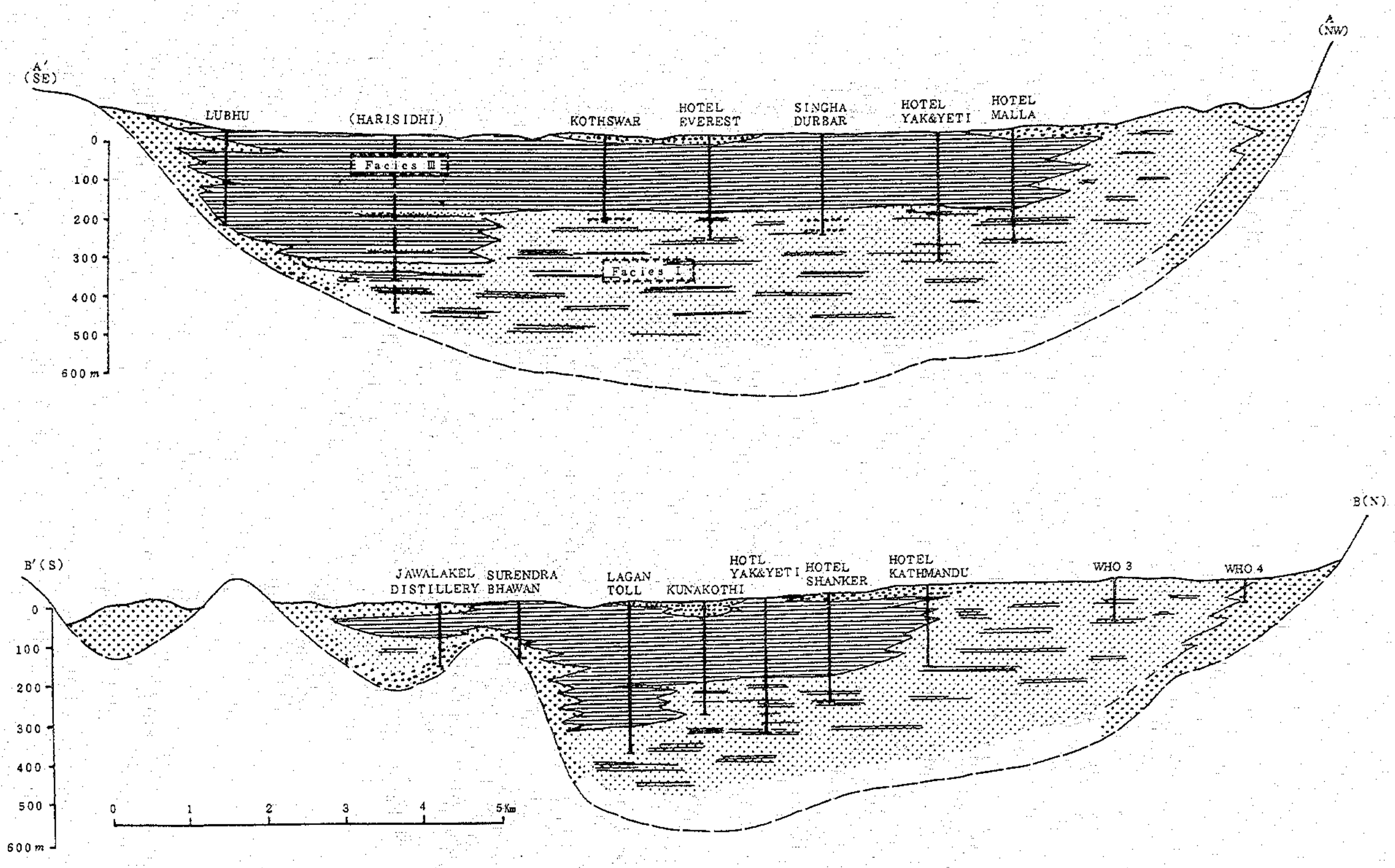


Fig. 12. Geologic cross sections of the Quaternary sediments for the location of the sections given in Fig. 8.

As indicated in Fig. 12, the following three sedimentation stages can be conceived of for the Quaternary sediments in Kathmandu valley.

a) Sedimentation of the 600 - 300 m deep beds: Basal facies and facies I (details unknown).

b) Sedimentation of the 300 - 200 m deep beds: The most part of the valley covered with facies I, with small-scale sedimentation of facies III in the southern part.

c) Sedimentation of the 200 - 0 m deep beds: Facies distribution resembling the present surface distribution, with the southern half of the valley covered with facies III and the northern half with facies I and II. Temporary linguiform development of deltaic deposits occurred in facies III during sedimentation of about 100 m deep beds.

Of the above three stages, stage b) is considered to have produced the largest volume of the sediments which are rich in organic matter and can provide the gas source rocks. In this stage, the greater part of the valley was an alluvial flood-plain in which rivers changed their stream course whenever they were flooded. As a consequence, ephemerical marshes and swamps were formed at many places on the flood-plain, resulting in the sedimentation of carbonaceous clays which eventually turned into gas source rocks. Accordingly, these clays present a lenticular shape and lack in continuity. The stream-channel deposits adjoining these clays are an excellent aquifer because of their large porosity, so that they are considered to be working as the reservoir of dissolved-in-water gas. These deposits have a small areal distribution and tend to present a belt-like distribution. In addition, their cross-section presents a lenticular shape in places where they meet river channels at right angle. These characteristics of the stream-channel deposits must be taken into careful account in developing dissolved-in-water natural gas.

IV. Natural Gas Deposits Based on the Reservoirs of Dissolved-in-Water Type (NGW)

Deposits of dissolved-in-water natural gas are created when natural gas containing methane as main component dissolves in groundwater due to hydrostatic pressure. Their formation calls for the availability of sediments rich in organic source material and a gas reservoir composed of coarse sediments which are high in porosity and permeability. Pressure of the reservoir at a suitable depth is another essential factor because the gas volume that can be dissolved in water increases in proportion to depth.

In Kathmandu valley, sediments which are rich in organic matter and could become the source rocks are found in the marsh deposits of facies I and the lacustrine deposits of facies III. Of these two kinds of deposits, the former is of particular importance. Coarse sediments which could become gas reservoirs exist in any of the three facies observed in the valley, and those in facies I are most important.

As detailed in Chapter V (Geochemistry of Natural Gas Deposits), the survey disclosed the presence of natural gas deposits with high productive potential in the coarse sediments distributed at a depth of more than 200 m in an area of about 4 km^2. These gas reservoirs, consisting mainly of coarse sediments including deposits rich in organic matter, are considered to have been formed with fluvial and marsh deposits of facies I.

Since none of the existing bore-holes are deep enough to reach the basement excepting those drilled in the fringe area of the valley, there are no direct data on the thickness of the sediments. However, the calculation based on the data of gravity analysis, which was worked out with the density contrast taken at 0.8 g/cm^3, indicates that the sediments have a thickness of 600 m or more in the deepest part of the valley and about 600 m in the southern part of Kathmandu city (Moribayashi and Maruo, 1980) where the presence of gas deposits was confirmed. This means that hopes are laid on the discovery of gas deposits in the deeper part of the area as well.

In the southern part of Kathmandu city, most of bore-holes violently blow out gas-laden mud water when they reach into the reservoirs of dissolved-in-water natural gas. However, the gushing force dwindles rapidly, giving place to stabilized artesian flow in a day or two. Although no accurate observation data are available, it is said that manually drilled wells with a casing pipe of $1\frac{1}{2}$ inch diameter gains stabilized artesian flow after the water flow rate and gas production are reduced to about 200 kl/day and 100 m^3/day, respectively. Violent initial jetting indicates the presence of free gas in the reservoir. The top surface of such reservoirs is covered with lacustrine mud deposits which work as a cap rock that retains free gas in the upper part of dissolved gas deposits.

The groundwater exploratory well No. 8-1 (Fig. 23) at Kopudol about 2 km to the west of Patan is known as one of the most vigorous artesian wells in the whole valley. This well, having a casing diameter of $1\frac{1}{2}$ inches, was drilled by manual labour in 1974. When the well reached on a depth of 185 m, it jetted out an enormous volume of mud water and gas. The mud water caused heavy damages to the farmland and houses in the neighbouring area because the gushing force was uncontrollable and could not be reduced even after sand and mud were thrown into the well to shield it. When the violent artesian flow subsided in a few days, a pool of water with a diameter of several meters emerged due to the erosion of the wall of well. The flow has continued to date and when the team observed the well in May 1979, it recorded a daily production of more than 100 kl of water and several tens cubic meters of gas. According to the gravity survey data of Moribayashi and Maruo (1980), this well is located at the northern foot of a buried hill of basement rocks. In the neighbourhood of the well, there is a small domical stratigraphic trap, and this may explain the formation of the gas reservoir which existed with free gases under an extraordinary high pressure.

In Kathmandu city, gas showings are observed at depths smaller than 200 m, apart from those of deeper deposits. To cite an example, well No. 14 (Fig. 23), a water well drilled in January 1979 by manual labour using a casing pipe with a diameter of $1\frac{1}{2}$ inches, reached a gas reservoir at a depth of 17 m. The well jetted out gas with a metallic sound, shooting up sand to a height of more than 10 m, but no water flowed out. It is considered that this well hit a gas pocket in a small lenticular sand bed lying in marsh or lacustrine deposits.

Formation of dissolved-in-water gas deposits does not call for very specific geologic structure, but it does presuppose the presence of a basinlike structure which prevents outflow of gas-dissolved groundwater or a closed system of groundwater except in cases where smooth and sufficient gas supply from the organic matter in the deposit or from underlying beds is ensured.

In so far as can be judged from the basement configuration, it can be said that the groundwater in the Quaternary sediments over Kathmandu valley becomes less fluid and more closed with the increase of depth. Hence, it can be expected that natural gas deposits exist extensively at deeper parts of the valley.

As regards natural gas deposits of geologic structure type or pocket gas, there is little likelihood of their being in existance with exceptionally high productive potential because of the small scale of the sedimentary basin and the frequent changes in facies.

Most of wells drilled in the southern part of Kathmandu city stop artesian flow in several years after reaching the gas deposit. This can be attributed to a number of causes such as pressure decrease in the reservoir, sand deposition in the well, loading of the strainer or perforated pipe, and breaking of the bore-hole wall, and the later three causes are considered to be most prevalent in the valley. Most of the artesian wells are manually drilled using $1\frac{1}{2}$ inch diameter iron casing pipes or spindle drilled using 6 - 8 inch diameter iron casing pipes. It seems that they are not given repair services when they stop artesian flow. The small diameter of manually drilled wells not only makes the repair work impossible but even raises difficulty in installing a pump. However, large-diameter wells that have decreased production of gas and water should be repaired to restore them to their original service condition.

V. Geochemistry of Natural Gas Deposits

1. General

After examining and compiling the data stored at the Department of Mines and Geology, Ministry of Industry and Commerce, His Majesty's Government, the team determined to adopt the hydrogeochemical method for exploration of the natural gas resources in Kathmandu valley, because it was supposed that the natural gas of the area was confined in the reservoirs of dissolved-in-water type in the Quaternary aqueous sediments. It is known from experience that the said method is quite expedient in such a gas area if some previously drilled wells are available.

Eighteen water wells previously drilled to the depth of about 20 to 330 m were selected for geochemical observation and sampling. In addition, seven outcrops were selected as sampling sites from which one Paleozoic sedimentary rock and six Quaternary sediments were collected for organic geochemical exploration.

2. Field and Laboratory Operations of Hydrogeochemical Exploration

Well-side operation

The following items were conducted at each of the eighteen well sites and the results obtained are shown in Table 4. The localities of the wells are shown in Fig. 13.

Table 4. Hydrogeochemical data in Kathmandu valley.

May – June 1979

Loc. No.	Location	Approxim. Res. Depth (m)	Vg (m³/d)	Vw (Kℓ/d)	GWR	Tw (℃)	HCO_3^- (mg/ℓ)	Free CO_2 (mg/ℓ) (mℓ/ℓ)	diss O_2 (mℓ/ℓ)	free gas: He (%)	H₂ (%)	O₂ (%)	N₂ (%)	CH₄ (%)	CO₂ (%)	H₂S (ppm)	C₂H₆ (%)
GC-01	Nagasthan	190	42	70	1:1.7	26.5 f	732	165 (84)	0.00	0.006	0.004	0.23	2.26	74.19	23.30	20	0.003
02	Kathmandu Mo.Co.	180	61	137	1:2.2	26.2 f	708	132 (67)	0.01	0.000	0.000	0.27	2.87	76.96	19.90	13	0.003
03	Patan Nat.Ind.Est.	200	tr	0	not determined					0.000 (0)	0.000 (0)	9.67 (0)	37.34 (0.27)	49.27 (92.73)	3.72 (7.00)		0.000 (0)
04	East of Soaltee Hot.	190	20±	100±	1:4.1	26.4 f	683	110 (56)	0.00	0.000	0.000	0.18	2.85	75.63	21.34	12	0.003
05	Tripureshdwar	180	67	119	1:1.8	26.2 f	780	154 (78)	0.10	0.002	0.000	0.17	2.64	74.48	22.72	8	0.003
06	USSR Embassy	40			1:20	21.5 p	293	102 (52)	0.03	0.000	0.001	0.14	1.73	81.02	17.11	7	0.000
07	Thapathali	175	44	157	1:3.6	25.9 f	768	154 (78)	0.16	0.000	0.000	0.21	2.51	76.09	21.19	11	0.002
08	N of Ring Road	100	20	471	1:25	23.5 f	146	20 (10)	0.00	0.001 (0.002)	0.001 (0.002)	11.14 (0)	56.81 (28.38)	28.61 (63.00)	3.94 (8.68)	1	0.000 (0)
09	Kupandol	190	5.5	162	1:39	26.3 f	647	60 (31)	0.00	0.000	0.040	0.21	5.07	78.80	15.88	0	0.003
10	Malla Hotel	200	not determ		1:3.2	25.8 p	427	92 (47)	0.10	0.000	0.000	0.23	6.10	76.26	17.40	10	0.000
11	Yak & Yete Hotel	180	8±	150	1:2.0	25.9 f	280	65 (33)	0.00	0.000	0.000	0.20	6.29	82.03	11.48	0	0.000
12	Leo Hotel	115	1.7	4.3	1:2.6	23.9 f	464	140 (71)	0.00	0.000	0.000	0.73	6.84	74.87	17.57	10	0.002
13	Bank in Kalimati	110	3.9	6.2	1:1.6	23.8 f	760	106 (54)	0.19	0.000	0.000	0.16	3.67	78.48	17.69	tr(<1)	0.003
14	Jyatha Tole	20	0.4	200	1:500	20.7 p	61	57 (29)	0.00	0.000 (0)	0.000 (0)	2.10 (0)	20.65 (14.13)	68.30 (75.93)	8.94 (9.94)	2	0.000 (0)
15	RSS Office	200	7.0	161	1:2.3	26.6 f	708	141 (72)	not determined	0.012	0.002	0.51	4.39	73.78	21.30	6	0.002
16	Patan, Whisky Fac.	150	27	1500	1:56	25.0 p	330	66 (34)	0.00	0.001	0.000	0.18	17.00	75.24	7.13	6	0.000
17	Patan, University	120	not determ		1:38	24.1 p	488	88 (45)	0.00	0.000	0.000	0.17	8.23	77.66	13.94	12	0.000
18	Minor Thimi	90	1.4	200	1:140	23.0 p	159	11 (5.6)	0.32	0.002 (0.004)	0.000 (0)	12.18 (0)	62.24 (38.84)	25.07 (59.89)	0.51 (1.22)	3	0.000 (0)

Vg …… flow rate of natural gas
Vω …… flow rate of groundwater
GWR … gas – water ratio
Tw …… temperature of groundwater
f ……… natural out – flow
p ……… pump up

( ) …… calcurated gas composition under no atomospheric contamination ($O_2 = 0.00$)

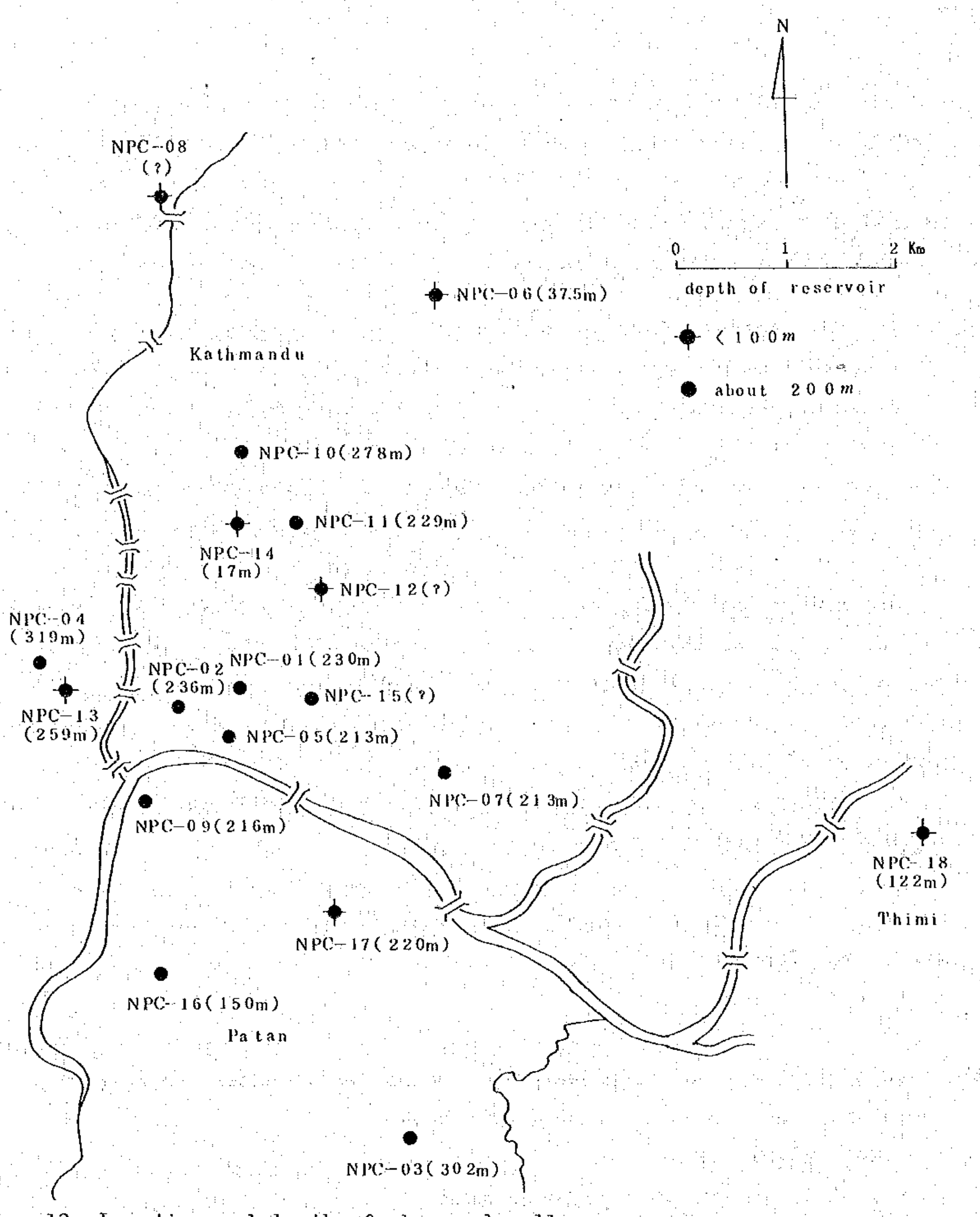


Fig. 13. Location and depth of observed wells.

Measurement of the volume of gas production by volumetric and/or flame-length method ----- Vg (m^3/day)

Measurement of the volume of water production by volumetric method ----- Vw (kl/day)

Sampling of free gas and water at the casing head

Measurement and calculation of the gas-water ratio at the casing head ----- GWR (value of the ratio expressed in m^3/day and kl/day)

Determination of gas potentiality ----- A factor of gas potentiality has been well expressed by the ratio of Ra/Rt (%) as shown in Fig. 14.

Ra is the observed gas-water ratio at the casing head of a well. Rt is the theoretical gas-water ratio for methane (CH_4) under saturation condition. When the reservoir has a depth of 200 m, the value of GWR is about 0.5(1:2), because the solubility of methane in water under room temperature and 1 atm is 36 ml/l, and the hydrostatic pressure for 200 meter aquifer is about 20 atm. Therefore, Rt under these conditions is 36 x 20 = 720 ml/l. This value is decreased because of the super saturation of dissolved gases in water at the casing head, the increasing salinity, and the temperature rise in the underground, etc. Thus, the expected value of Rt at the casing head is to be around 0.5. When the reservoir depth is 100 m, the value of Rt is about 0.25. Therefore, the value of Rt can be calculated from two factors, the solubility of methane in water and hydrostatic pressure of the aquifer in which natural gases are reserved.

Measurement of groundwater temperature ----- Tw (^oC)

f--natural flow-out

p--pumping up

Estimation of the depth of groundwater producing bed (aquifer) by water temperature measurement at the casing head

$d = (Tw - 20.1) \times 30$

where, d(m) -- depth of aquifer in meter

Tw ---- water temperature at the casing head in ^oC

20.1 -- average annual temperature in Kathmandu in 1970 given by the Meteorological Station of Kathmandu (^oC)

30 ---- geothermal gradient (1^oC/30 m)

Measurement of casing diameter ---- inch

Determination of pH value of water at the casing head by colorimetric method ---- pH

Determination of RpH value at the well side by colorimetric method ---- RpH

RpH is the value of pH after attaining equiribrium between water sample and atmospheric air. The value of RpH - pH has been used as one of the indicators for geochemical exploration of natural gas deposits.

Measurement of hydrogen carbonate in water by methylorange alkalinity ---- HCO_3^- (mg/l)

Measurement of free carbon dioxide in water by phenolphtalein acidity ---- free CO_2 (mg/l and ml/l)

Measurement of dissolved-in-water gas, diss. O_2 and diss. N_2, etc. ---- ml/l

Measurement of chlorine in water by Mohr method ---- Cl^- (mg/l)

Measurement of ammonium in water with Nessler reagent both in Kathmandu and Tokyo ---- NH_4^+ (mg/l)

Determination of the content of carbon dioxide in free gas at the casing head with a detector tube. A free natural gas sample was introduced into the detector tube, and the original colour of packed powder was changed. The length of changed part showed the content of carbon dioxide ---- CO_2 (%)

Determination of hydrogen sulfide content in free gas with a detector tube. H_2S (ppm)

Operation in the laboratory

A set of gaschromatograph, Shimazu GC-4CPT, was donated to the Department of Mines and Geology by the Japan International Cooperation Agency (JICA) and was set up for the purpose of gas analysis.

The carrier gases of argon, nitrogen, and helium were used and as a detector only a thermal conductivity detector (TCD) was used for both qualitative and quantitative analyses of free gas samples separated at the casing heads of water wells. Because of the difficulty of air transportation of compressed hydrogen gas from Tokyo to Kathmandu, the flame ionization detector (FID) was not used for hydrocarbon detection with high sensitivity. Thus, the approximate sensitivity of gas analysis is as follows:

methane (CH_4)	0.01	volume %
ethane (C_2H_6)	0.01	"
helium (He)	0.001	"
hydrogen(H_2)	0.001	"
oxygen (O_2)	0.01	"
nitrogen(N_2)	0.01	"
carbon dioxide (CO_2)	0.01	"

The following quantitative analyses were carried out at the laboratory of the Department:

He in free gas ----- Helium content in free gas was determined with gas-chromatograph in the laboratory in Kathmandu (%).

H_2 in free gas ----- Hydrogen content in free gas was determined with gas-chromatograph in the laboratory in Kathmandu (%).

O_2 in free gas ----- Oxygen content in free gas was determined with gas-chromatograph in the laboratory in Kathmandu (%). The oxygen content in free gas is a measure by which air contamination can be recognized.

N_2 in free gas ----- Nitrogen content in free gas was determined with gas-chromatograph in the laboratory in Kathmandu (%).

CH_4 in free gas ----- Methane content in free gas was determined with gas-chromatograph in the laboratory in Kathmandu (%).

C_2H_6 in free gas ----- Ethane content was determined with gaschromatograph in the laboratory in Kathmandu at the first step, but no ethane was detected with TCD. The second step determination was conducted in the laboratory of the Geological Survey of Japan, Tokyo, with the gas-chromatograph having a flame ionization detector, which resulted in the detection of a minor content of ethane in the free gas samples.

CO_2 in free gas determined with gaschromatograph ----- Carbon dioxide content was determined with gaschromatograph in the laboratory in Kathmandu, and the value was compared with that of detector tube. As a result, the detector tube could be successfully adopted for determination of CO_2 content in the free gas at the casing head.

3. Results of Chemical Analyses and Field Observation

i) Location of observed wells

Some of previously drilled water wells were selected as observation sites for geochemical exploration of the natural gas deposits in Kathmandu valley. Eighteen wells were selected for survey as shown in Fig. 13. These wells are distributed in Kathmandu city, Patan city, and Thimi town.

According to the depth of gas reservoirs the wells were grouped into two types, one shallower than 100 m and the other about 200 m deep.

ii) Gas flow rate (Vg)

As shown in Table 4, the maximum flow rate of natural gas was observed at Loc. No. 15 (Army headquarters). The value reached 70 m^3/day and the gas-water ratio was 1 : 2.3. This is an artesian well and natural gas flows out with groundwater having pale brownish grey colour. The next largest flow rate was observed at Loc. No. 5 (Tripureshwar) by 67 m^3/day and the gas-water ratio was 1 : 1.8.

In the high gas productive area, the gas flow rate from a well with $1\frac{1}{2}$ inches of casing diameter was around 20 to 70 m^3/day. The estimated total production of natural gas from the 18 observation wells was approximately 500 m^3/day.

iii) Gas-water ratio

Considered from the technical standpoint, the value of gas-water ratio is one of the most important factors for natural gas exploration. The values of observed gas-water ratio are tabulated in Table 4.

The areal distribution of the values of Ra/Rt (see page 36) is shown in Fig. 14. It is clearly shown that in the southern part of Kathmandu city, the value of Ra/Rt ratio is high, more than 100%, and

50% is recorded in an area of about 4 km^2 (2 km x 2 km) for the "200 m reservoir". As for the reservoirs shallower than 100 m, the 100% area measures approximately 3 km x 4 km, which is larger than that of the "200 m reservoir".

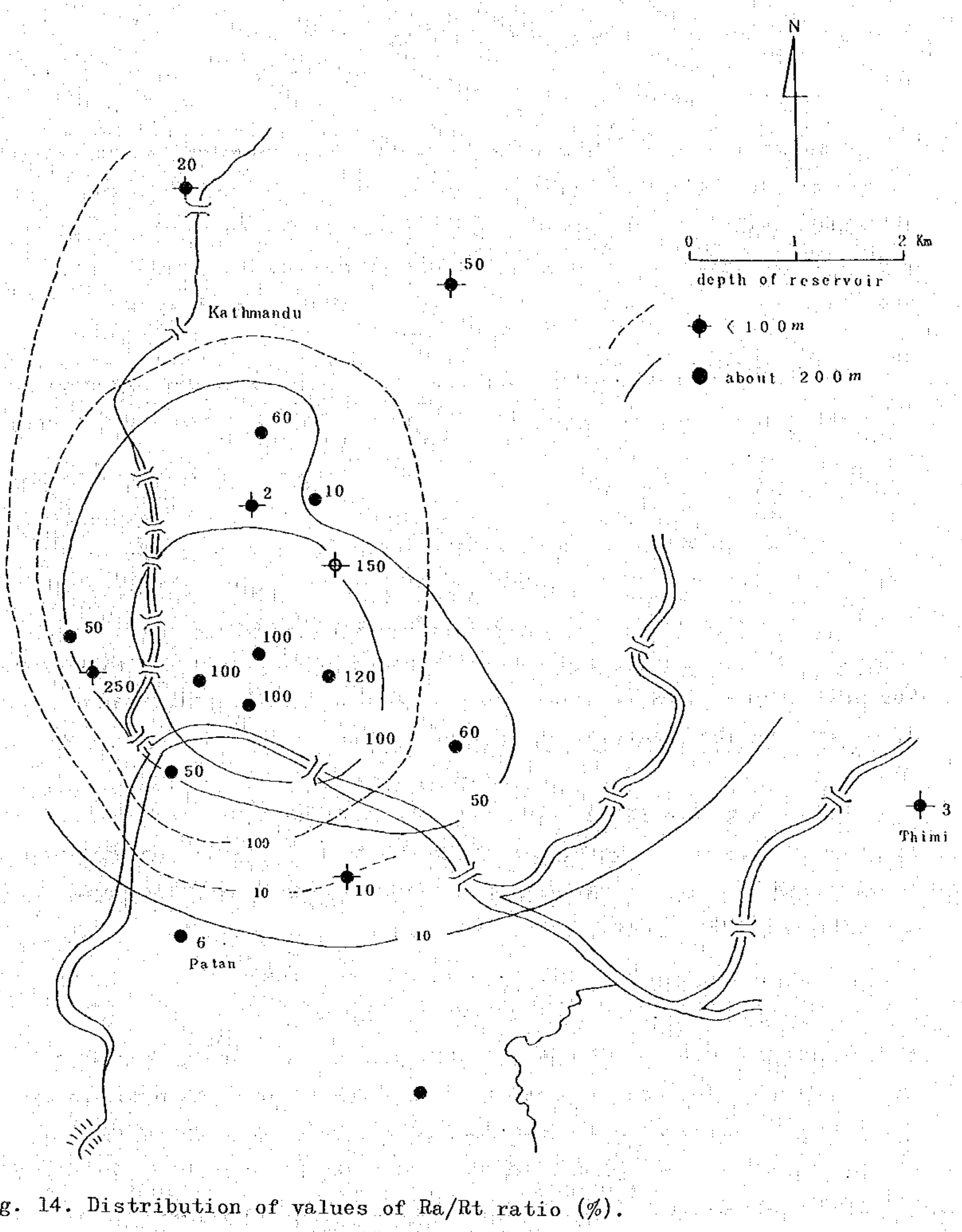


Fig. 14. Distribution of values of Ra/Rt ratio (%).

Ra.....Observed gas-water ratio

Rt.....Theoretical gas-water ratio for methane under saturation condition

iv) Hydrogen carbonate (HCO_3^-) in groundwater

The areal distribution pattern of HCO_3^- (mg/l) in groundwater is shown in Fig. 15. The organic material has been decomposed into CH_4, N_2, CO_2, H_2O, etc., and in some steps of the alteration of groundwater, CO_2 changes into HCO_3^-. Therefore, the content of HCO_3^- is correlated to that of CH_4 in groundwater. Thus, HCO_3^- is one of the most important indicators of hydrogeochemical prospecting for natural gas.

The areal distribution of HCO_3^- shows clearly the high productive potential of gas reserves in the southern part of Kathmandu city. The distribution pattern perfectly coincides with that of gas-water ratio which is shown in Fig. 14. (see Fig. 15) In certain cases, some difficulty is encountered in determining the exact value of gas-water ratio at the observation site. For determination of the gas potentiality (gas-water ratio), therefore the content of hydrogen bicarbonate was used. Besides, there is a close relationship between the content of hydrogen bicarbonate in water and the chemical composition of free gases. Thus, the content of hydrogen bicarbonate in water usually indicates the two geochemical factors of vital economic importance, the gas-water ratio and the chemical composition of free gas.

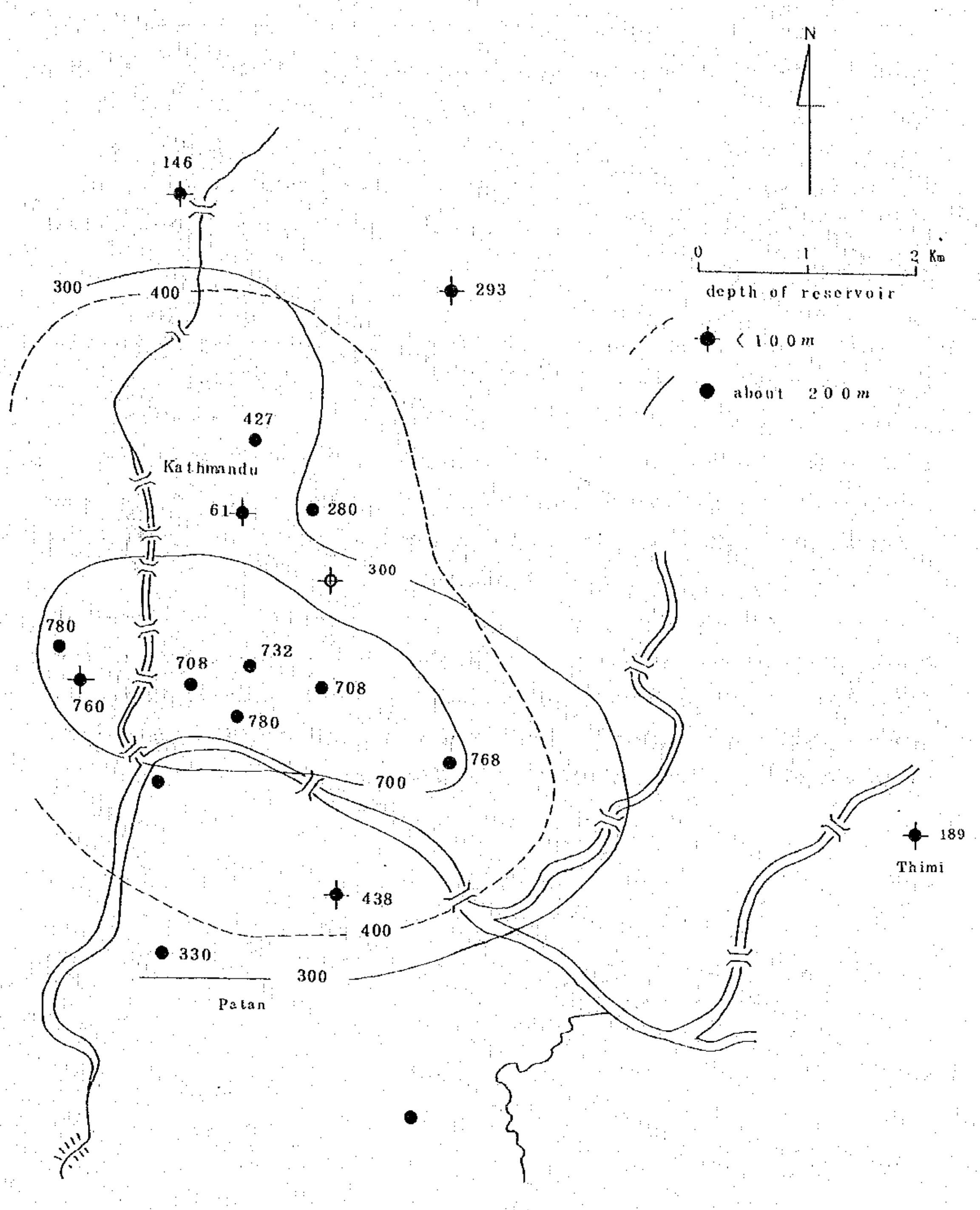


Fig. 15. Distribution of hydrogen carbonate (HCO_3^-) in ground water (mg/l).

v) Free carbon dioxide in groundwater (free CO_2)

The distributional trend of free CO_2 in the survey area is shown in Fig. 16. It is quite clear that in the southern part of Kathmandu city, the CO_2 content exceeds 50 ml/l, and the distribution pattern coincides with that of gas-water ratio.

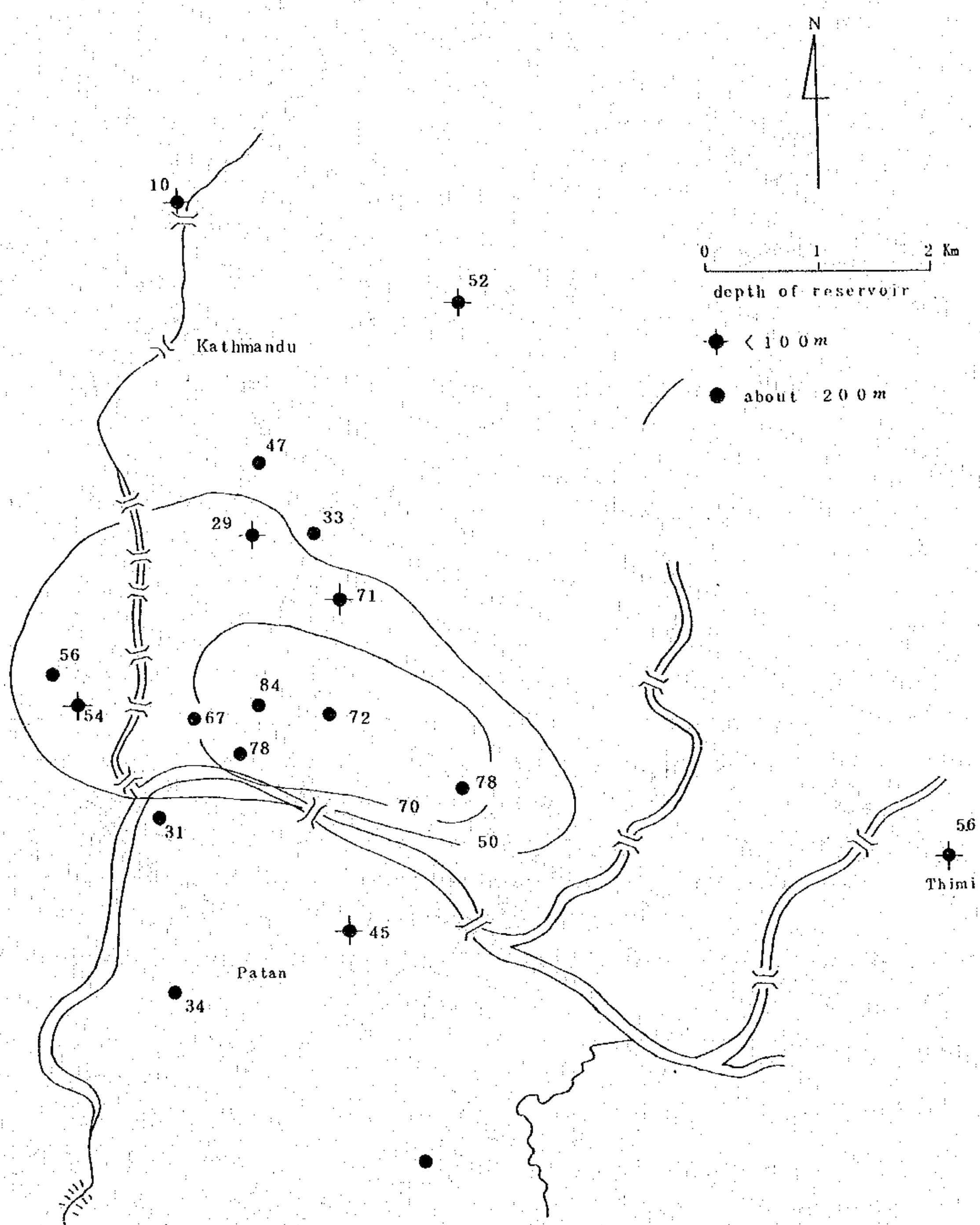


Fig. 16. Distribution of free CO_2 in groundwater (mg/l).

vi) Hydrogen sulfide in free gas (H_2S)

Fig. 17 shows the areal distribution of hydrogen sulfide in free gas samples from the casing head of the wells. The distribution pattern coincides with that of gas-water ratio. Hydrogen sulfide may be the product of decomposition of organic matter in the sediments.

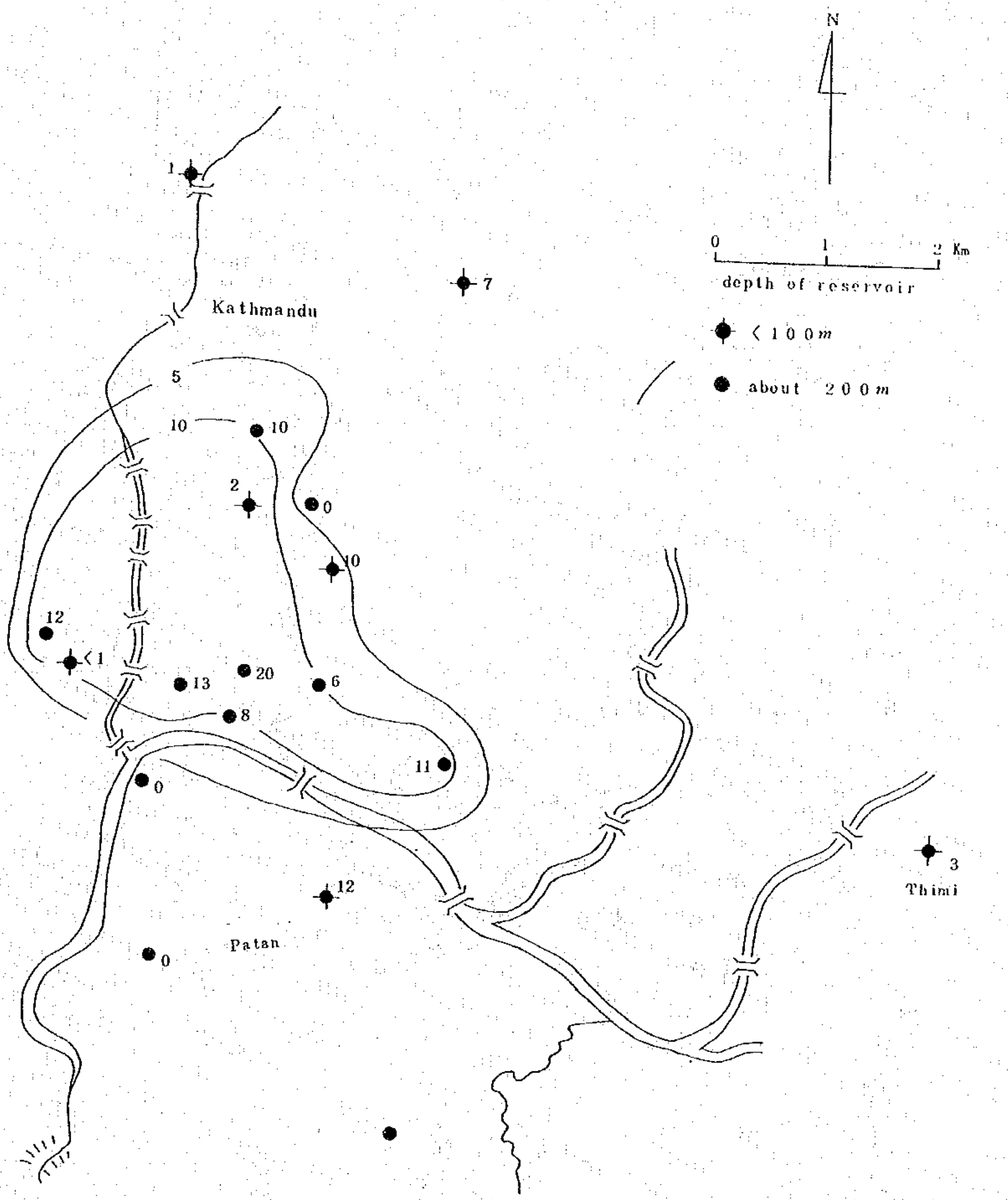


Fig. 17. Distribution of H_2S in free gas from casing head (ppm).

vii) Dissolved oxygen in groundwater (diss. O_2)

The content of dissolved oxygen was determined at the sampling sites. As shown in Table 4, the values of diss. O_2 content are usually smaller than 0.10 ml/l, and these values indicate both the gas potential in the field and the degree of atmospheric contamination of gas samples during sampling, storage, and chemical analysis.

In general, the groundwater contains 0.3 to 0.5 ml/l of dissolved oxygen in most of the potential gas area, while in the transitional zones between the highly oxidized area and the natural gas area, it shows the lowest value of dissolved oxygen content (0.00 - 0.06 ml/l). This general trend was noted to be prevalent in Kathmandu valley.

viii) Helium in free gas (He)

Helium is a daughter product of radioactive disintegration of uranium (U) and thorium (Th). It was detecred in the free gas samples from six wells. The maximum content was 0.012% at Loc. No. 15, and the second highest was 0.006% at Loc. No. 1. The other four wells record extremely small values of helium content, namely,

Loc. No. 5	0.005%
Loc. No. 8	0.002%
Loc. No.16	0.001%
Loc. No.18	0.004%

In the Tripureswar area located in the southeastern part of Kathmandu city, the free gases contain 0.002 - 0.012% of helium. This area has the highest gas potential, and the fact that helium was recognized in the area may indicate the following two points; the excellence in gas reservation of the sediments against the landsurface including the meteoric water invasion, and/or the existence of crushed zones in the basement rocks underneath the Quaternary gas-bearing sediments.

The depth of the well at Loc. No. 8 is relatively small, about 100 m, and the free gas has 0.002% of helium. It is supposed that a fault in NW-SE direction in the basement rocks passes through this area and helium might be supplied through the fault zones into the overlying gas reservoirs.

The wells at Loc. No. 16 and No. 18, in the western Patan and Minor Thimi, were drilled in the area where the basement rocks are relatively shallow, about 200 m. Thus, it can be reasonably presumed that helium in free gases was derived from the basement rocks and migrated into the overlying water and gas reservoirs.

A noticeable fact was observed at Loc. No. 5, that is, helium was recognized only in the free gas from the "200 m reservoir", while no helium was detected in the free gas from the reservoirs shallower than 100 m.

To sum up, the helium content is controlled by the relationship between the basement rocks and the gas reservoirs of young sediment, and especially, the fractures in the basement rocks have an important and intimate bearing upon the chemistry of the overlain gas reservoirs. Thus, the structural studies on the above stated sites will become important.

ix) Hydrogen in free gas (H_2)

Hydrogen in free gas is the product of chemical reaction between iron of casing pipe and anaerobic groundwater. In Kathmandu valley, no hydrogen was noticed in groundwaters.

x) Oxygen in free gas (O_2)

Oxygen content in the free gases from Kathmandu valley is about 0.15 - 0.20%. The oxygen content is a measure for atmospheric contamination of gas samples. In the case of highly contaminated samples, the original gas composition was calculated standing on the air composition to obtain the numerals shown in Table 4 in brackets.

xi) Nitrogen in free gas (N_2)

Nitrogen content in the free gases from Kathmandu valley ranges from 1.73 to 8.23% depending on the value of gas-water ratio. The nitrogen content is one of the contamination indicators of air into gas samples. Natural gas from the low potential area usually shows a high percentage of nitrogen content in both free gas and dissolved-in-water gas.

xii) Methane in free gas (CH_4)

Methane content in the free gases from Kathmandu valley ranges from 82 to 39% depending on the potential of gas reservoir. The percentage of methane in free gas decides the calorific value of the gas. Loc. No. 3 is the exceptional well for sampling.

xiii) Carbon dioxide in free gas (CO_2)

Carbon dioxide content in the free gases ranges from 23 to 1% depending on the potential of gas reservoir. Loc. No. 3 is the exceptional well to get gas sample, because the sample was taken from the inside of casing with no water and not from the casing head.

xiv) Ethane in free gas (C_2H_6)

In free gas samples from the centre of gas deposit, ethane was recognized by 0.002 - 0.003%, as shown in Fig. 18.

Very noticiable facts in the vertical and areal distribution of ethane were recognized: (1) In spite of the fact that the sediments in Kathmandu valley were deposited under the Quaternary lacustrine and fluvial conditions, ethane exists in free gases. (2) In the area where ethane was detected in the free gases from the "200 m reservoir", it was also detected in the free gases from the "100 m reservoir".

As already stated, helium was detected in the free gases from the "200 m reservoir" but not in those from the "100 m reservoir", whereas ethane was detected in both reservoirs. Ethane might have been generated from the organic materials in the neighboring sediments of each reservoir.

xv) Summary of chemical composition of free gases

The chemical composition of the free natural gas in Kathmandu valley has been well expressed on the triangular diagram (Fig. 19). The natural gases from the high productive area occupy the bi-compositional part of CH_4 - CO_2, while those from the low productive area occupy that of CH_4 - N_2. The following are some of the noticeable chemical characteristics of the natural gases in Kathmandu valley:

(1) Relatively high content of CO_2.

(2) Relatively low content of N_2.

(3) Moderate content of CH_4.

(4) Calorific values are from 6,200 to 7,000 $Kcal/Nm^3$.

(5) Some gases contain C_2H_6 by 0.002 - 0.003%.

(6) At the newly drilled well, a high content of H_2 was observed, as a reaction product between the casing and groundwater.

(7) Helium was detected at some wells.

(8) Hydrogen sulfide was detected in the high productive area.

(9) In the high productive area, the southern part of Kathmandu city, the chemical composition of free gases is characterized by relatively high contents of ethane, helium, carbon dioxide, and hydrogen sulfide, a moderate content of methane, and a low content of nitrogen.

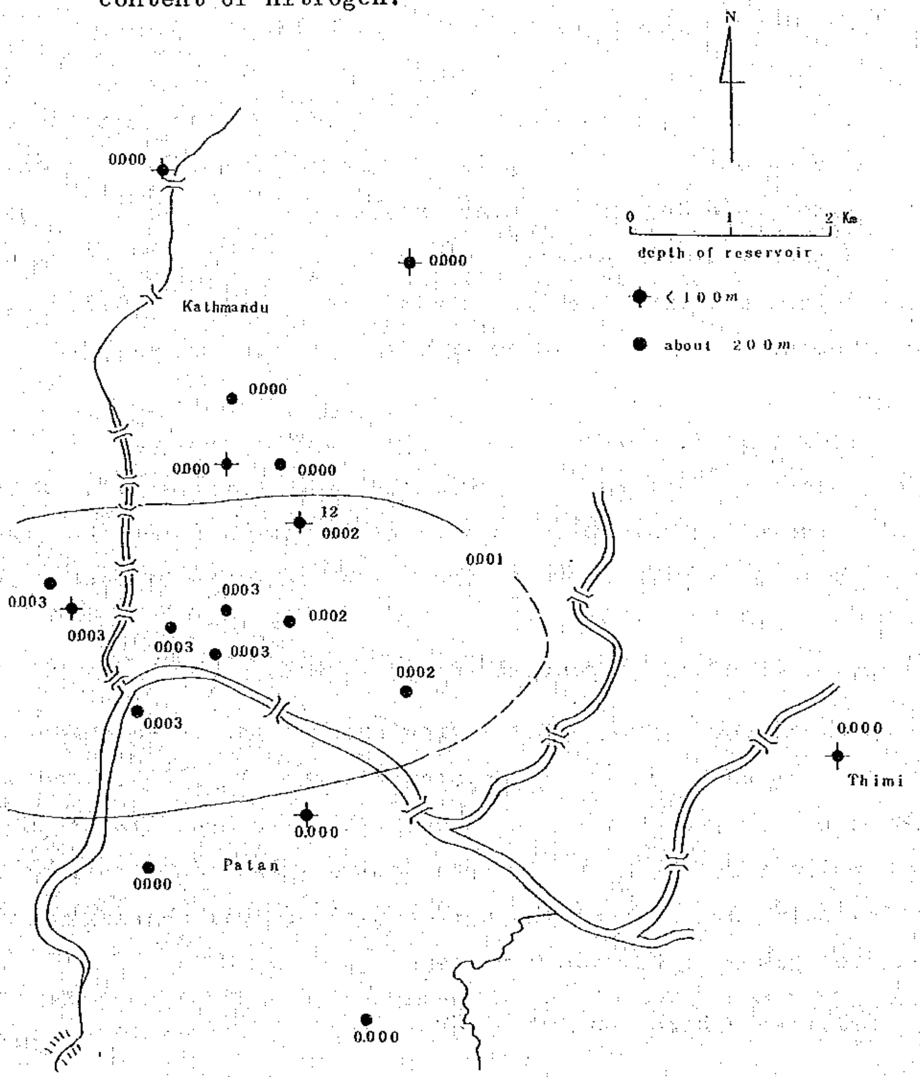


Fig. 18. Distribution of ethane in free gas (%).

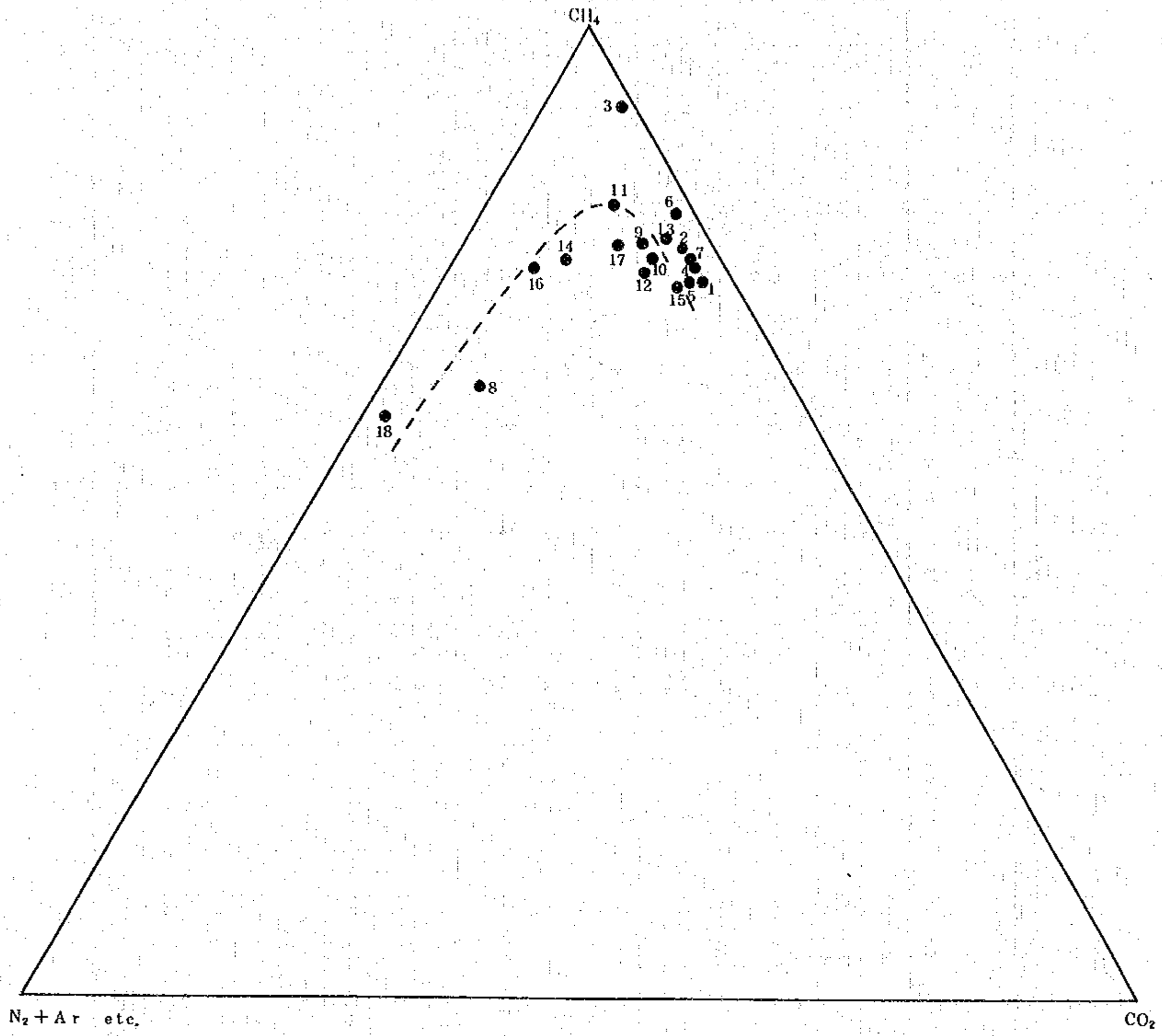


Fig. 19. Chemical composition of free natural gas on triangular net (vol. %).

4. Additional Geochemical Data

Some samples of rocks, groundwater, and gases were analysed supplementarily in the laboratory of the Geological Survey of Japan in 1979. Tables 5, 6, 7, and 8 show the analytical and calculated data.

Table 5. Analytical data of groundwater, free gas, and dissolved-in-water gas.

Loc. No.	Location	ground water											
		pH	RpH	Cl^- (mg/ℓ)	SO_4^{2-} (mg/ℓ)	Ca^{2+} (mg/ℓ)	Mg^{2+} (mg/ℓ)	Na^+ (mg/ℓ)	K^+ (mg/ℓ)	NH_4^+ (mg/ℓ)	Total Fe (mg/ℓ)	$KMnO_4$ cons. (mg/ℓ)	HBO_2 (mg/ℓ)
1	Nagasthan	6.5	7.2	4.4	1.1	89.7	15.6	68.0	6.2	70	4.9	84	24.5
2	Kathmandu Mo. Co.	6.5	7.1	5.2	3.1	84.3	13.1	61.2	5.2	50	7.7	95	29.8
3	Patan Nat. Est.	—	—	—	—	—	—	—	—	—	—	—	—
4	East of Soaltee Hotel	6.5	7.1	1.2	0	66.7	12.8	58.6	5.0	52	7.6	68	40.6
5	Tripureshawar	6.6	7.2	2.6	0	87.4	21.1	62.3	6.9	61	4.6	65	40.0
6	USSR Embassy	6.4	7.0	2.3	1.9	29.0	6.7	20.9	3.0	21	7.9	91	13.3
7	Thapathali	6.6	7.1	2.1	0	105	13.1	60.1	5.4	53	7.9	72	52.4
8	N of Ring Rand	6.8	7.4	0.8	0	22.8	3.4	19.7	1.8	5.6	6.5	18	9.2
9	Kupandol	6.6	7.2	1.8	0	72.6	11.5	59.0	5.8	48	4.6	53	35.8
10	Malla Hotel	6.4	7.0	2.7	0	48.5	5.8	37.1	3.4	20	6.9	57	11.3
11	Yak & Yeto Hotel	6.4	7.0	1.7	1.1	32.6	9.5	34.9	3.0	0.6	6.3	42	7.1
12	Leo Hotel	6.4	7.0	1.7	0	33.6	10.7	37.1	4.0	52	8.4	61	42.1
13	Bank in Kalimati	6.5	7.2	2.7	2.1	125	14.1	68.4	5.8	34	3.5	51	31.8
14	Jyatha Tole	6.0	6.8	18.4	0.2	10.0	2.2	10.5	2.2	1.1	8.8	4.3	1.0
15	RSS Office	6.6	7.3	3.8	3.2	102	15.0	67.7	5.8	43	0.2	159	25.7
16	Patan, Whisky Fac.	6.7	7.2	7.4	3.1	29.8	8.3	16.3	3.4	47	5.9	37	11.3
17	Patan, University	6.7	7.3	3.8	2.7	49.8	10.4	59.0	5.3	29	0.1	108	9.2
18	Minor Thimi	7.0	7.3	2.6	0	17.0	4.6	19.6	2.1	3	4.0	8.8	3.0

Analyst , S.Nagata
Dec. 1979

Loc. No.	free gas Ar (%)	free gas C_2H_6 (%)	free gas N_2/Ar	dissolved-in-water gsa He (%)	H_2 (%)	N_2 (%)	CH_4 (%)	Ar (%)	C_2H_6 (%)	dissolved N_2/Ar	diss. N_2, etc. (ml/l)
1	0.057	0.003	40	0.001	0.001	10.86	88.82	0.32	0.003	33.9	38.0
2	0.068	0.00	42	0.000	0.000	4.75	95.08	0.16	0.000	29.9	45.2
3	—	0.00	—	not determined		—	—	—	—	—	7.
4	0.076	0.003	38	0.000	0.002	15.27	84.35	0.39	0.000	39.6	27.9
5	0.055	0.003	48	0.001	0.000	14.08	85.56	0.34	0.002	41.4	36.8
6	0.042	0.000	41	0.000	0.002	20.50	79.08	0.42	0.000	48.8	39.1
7	0.060	0.002	42	0.000	0.000	17.08	82.50	0.42	0.002	40.7	36.2
8	1.01	0.000	56	0.000	0.002	45.75	53.07	1.18	0.000	38.8	36.5
9	0.115	0.003	44	0.000	0.000	15.40	84.22	0.34	0.002	45.3	45.1
10	—	—	—	0.000	0.000	17.59	81.95	0.46	0.000	38.2	42.0
11	0.146	0.000	43	0.000	0.000	15.93	83.67	0.40	0.000	39.8	30.9
12	0.149	0.002	41	0.000	0.000	17.59	81.97	0.43	0.000	40.9	31.1
13	0.072	0.003	51	0.000	0.000	20.56	79.02	0.42	0.003	49.3	30.8
14	0.043	0.000	48	0.000	0.000	23.68	75.63	0.66	0.000	36.0	42.1
15	0.100	0.002	44	not determined		—	—	—	—	—	—
16	0.370	0.000	46	0.000	0.000	14.62	84.95	0.45	0.002	32.5	33.3
17	0.179	0.000	46	0.000	0.000	14.49	85.09	0.42	0.000	34.5	45.4
18	1.150	0.000	54	0.000	0.000	24.57	74.85	0.57	0.000	43.1	23.2

Table 6. Calculation to make up the Key diagram.

Loc. No.	HCO_3^- meq/ℓ	Cl^- meq/ℓ	SO_4^{2-} meq/ℓ	Ca^{2+} meq/ℓ	Mg^{2+} meq/ℓ	Na^+ meq/ℓ	K^+ meq/ℓ	HCO_3^- meq/ℓ	$Cl^- + SO_4^{2-}$ meq/ℓ	$Ca^{2+} + Mg^{2+}$ meq/ℓ	$Na^+ + K^+$ meq/ℓ	HCO_3^- meq/ℓ %	$Cl^- + SO_4^{2-}$ meq/ℓ %	$Ca^{2+} + Mg^{2+}$ meq/ℓ %	$Na^+ + K^+$ meq/ℓ %
1	12.00	0.12	0.02	4.48	1.28	2.96	0.16	12.00	0.14	5.76	3.12	98.85	1.15	64.86	35.14
2	11.61	0.15	0.06	4.21	1.08	2.66	0.13	11.61	0.21	5.29	2.79	98.22	1.78	65.47	34.53
3	not determined														
4	11.20	0.03	0.00	3.33	1.05	2.55	0.13	11.20	0.03	4.38	2.68	99.73	0.27	52.04	37.96
5	12.79	0.07	0.00	4.36	1.74	2.71	0.18	12.79	0.07	6.10	2.89	99.46	0.54	67.85	32.15
6	4.80	0.06	0.04	1.45	0.55	0.91	0.08	4.80	0.10	2.00	0.99	97.96	2.04	66.89	33.11
7	12.59	0.06	0.00	5.24	1.08	2.61	0.14	12.59	0.06	6.32	2.75	99.53	0.47	69.68	60.32
8	2.39	0.02	0.00	1.14	0.28	0.86	0.05	2.39	0.02	1.42	0.91	99.17	0.83	60.94	39.06
9	10.61	0.05	0.00	3.62	0.95	2.57	0.15	10.61	0.05	4.57	2.72	99.53	0.47	62.69	37.31
10	7.00	0.08	0.00	2.42	0.48	1.61	0.09	7.00	0.08	2.90	1.70	98.87	1.13	63.04	36.96
11	4.59	0.05	0.02	1.63	0.78	1.52	0.08	4.59	0.07	2.41	1.60	98.50	1.50	60.10	39.90
12	7.61	0.05	0.00	1.68	0.88	1.61	0.10	7.61	0.05	2.56	1.71	99.35	0.65	59.95	40.05
13	12.46	0.08	0.04	6.13	1.16	2.97	0.15	12.46	0.12	1.78	3.12	99.05	0.95	70.03	30.07
14	1.00	0.52	0.00	0.50	0.18	0.46	0.06	1.00	0.52	0.68	0.52	65.79	34.21	56.67	43.33
15	11.61	0.11	0.07	5.09	1.23	2.94	0.15	11.61	0.18	6.32	3.09	98.47	1.53	67.16	32.84
16	5.41	0.21	0.06	1.49	0.68	0.71	0.09	5.41	0.27	2.17	0.80	95.25	4.75	73.06	26.94
17	8.00	0.11	0.06	2.49	0.86	2.57	0.14	8.00	0.17	3.35	2.71	97.92	2.08	55.28	44.72
18	2.61	0.07	0.00	0.85	0.38	0.85	0.05	2.61	0.07	1.23	0.90	97.39	2.61	57.75	42.25

Table 7. Content of $Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}$ (mg/l) in groundwaters

Loc. No.	Ca+Mg+Na+K (mg/l)
1	179.5
2	163.8
3	no water sample
4	143.1
5	177.7
6	59.6
7	183.6
8	47.7
9	148.9
10	94.8
11	80.0
12	85.4
13	213.3
14	24.9
15	190.5
16	57.8
17	124.5
18	43.3

Table 8. Calculation of total amount of gaseous nitrogen (N_2) and argon (Ar) in groundwaters

Loc. No.	total N_2 in water (ml/l)	total Ar in water (ml/l)	tot. N_2/tot. Ar
1	17.42	0.12	145
2	15.20	0.07	217
3			
4	11.21	0.11	102
5	19.85	0.13	153
6	8.87	0.16	55.4
7	20.12	0.15	134
8			
9	19.97	0.15	133
10	26.45	0.19	139
11	8.07	0.12	67.3
12	31.31	0.13	241
13	29.27	0.13	225
14	10.38	0.28	37.1
15			
16	7.86	0.15	52.4
17	8.75	0.91	9.62

Note:

Dissolved nitrogen and argon in water under an equilibrium with atmosphere at 20°C and 0 meter elevation

diss. N_2 = 12.02 ml/l

diss. Ar = 0.301 ml/l

diss. N_2/diss. Ar = 39.9

i) Operation

a) Groundwater

pH ---- Determined with pH meter.

RpH --- Determined with pH meter.

Cl^- --- Determined by Mohr method (mg/l).

SO_4^{2-} -- Determined by nephelometry (mg/l).

Ca^{2+} -- Determined by atomic absorption method (mg/l).

Mg^{2+} -- Determined by atomic absorption method (mg/l).

Na^+ --- Determined by atomic absorption method (mg/l).

K^+ ---- Determined by atomic absorption method (mg/l).

NH_4^+ --- Determined by colorimetry with Nessler's reagent after distilling NH_4^+ as NH_3 into dilute H_2SO_4 solution by circulating air (mg/l).

total Fe --- Determined by dipyridyl method (mg/l).

$KMnO_4$ consumption --- Determined by titration under acidic condition (mg/l).

HBO_2 -- Determined by mannitol method (mg/l).

b) Free natural gases and dissolved-in-water gases

Ar ---- Determined with gaschromatograph using TCD.

C_2H_6 -- Determined with gaschromatograph using TCD with argon carrier and silica gel column. In addition to this, check analysis was carried out using FID.

c) Rocks

Ext. -- Total soluble organic matter (bitumen) extracted with mixed organic solvent (benzene 50%, acetone and alkohole 25% each).

P + Cp --- Determined by column chromatograph method. The column was filled with activated alumina powder. Paraffin and cyclo-paraffin hydrocarbons of hexane eluate.

Ar ---- Aromatic hydrocarbons of benzene eluate.

O-N-S compounds --- Hetero-organic compounds of pyridine eluate.

Res. -- Residue on alumina column.

HyR --- Total hydrocarbons (P + Cp + Ar).

Co ---- Organic carbon content determined with a C-H-N coder.

Ch/Co --- Degree of hydrocarbonization calculated from the data of HyR and Co.

ii) Results

a) Groundwater

Fig. 13 shows the location of water sampling sites.

Chlorine (Cl^-)

The groundwater from Loc. No. 14 (Jyatha Tole) shows the highest value of Cl^- content among the 17 water samples. As the depth of the aquifer is only about 20 m and the well is located at almost the centre of Kathmandu city, about 15 mg/l out of 18.4 mg/l might have been supplied by human excretion.

Areal distribution of Cl^- in water has no distinct characteristics, and in the high potential area of gas production the Cl^- content ranges from 2.1 to 5.2 mg/l. In areas outside the high potential area, the Cl^- content is about 1.2 - 2.6 mg/l except in the southern area where 3.8 - 7.4 mg/l is recorded.

The low concentration of Cl^- in groundwater accords with the depositional environment of the Quaternary sediments in Kathmandu valley.

Sulfate (SO_4^{2-})

Because of the low redox potential of the groundwater from the gas producing area, the groundwater associated with natural gases has low values in SO_4^{2-} content, approximately 0.0 mg/l. In some cases, SO_4^{2-} is supplied into the water samples from the construction materials of the well such as cement. However, standing on the detailed examination of the physical condition of sampling sites, it is concluded that the groundwater associated with gas has no SO_4^{2-}, 0.0 mg/l.

Calcium (Ca^{2+}) and magnesium (Mg^{2+})

It is true that in some cases, calcium is moved into groundwater from the construction materials. According to the data in Table 5, however, that of the content of calcium shows no intimate relation with SO_4^{2-} and pH value. Thus, the approximate calcium content in the groundwater from the high productive area is estimated to be about 70 to 105 mg/l as against 30 to 50 mg/l in that from the surrounding area.

A relatively high concentration of Mg^{2+} is also noticed in the gas productive area with a value of 13 to 21 mg/l. The roughly estimated value of Ca^{2+} mgl^{-1}/Mg^{2+} mgl^{-1} in the gas productive area is 4 to 7.

Sodium (Na^+) and potassium (K^+)

In the gas productive area, the approximate content of Na^+ ranges from 60 to 70 mg/l, and that of K^+ from 5 to 7 mg/l. Thus, the value of Na^+/K^+ in mg/l is about 10.

Ammonium (NH_4^+)

A high concentration of NH_4^+ in groundwater was recognized in the gas productive area. The ammonium ion content was determined at the laboratory in Kathmandu on some samples, and in Tokyo on the rest of the samples. In general, NH_4^+ decreases with increasing NO_2^- during storage and transportation of water samples. However, according to the data of the rapid estimation of NH_4^+ content at the sampling sites and those of the check analysis at the Geological Survey of Japan, three months after sampling, no fundamental difference was recognized. Hence, it is possible to use the data in Table 5 for estimation of chemical properties of groundwater in nature in Kathmandu valley.

In the gas productive area, the NH_4^+ content in groundwater is more than 50 mg/l, which is higher than the value in the groundwater associated with natural gas in the Quaternary fresh water sediments in Japan. This fact reflects the rapid or strong disintegration of organic matter in the sediments as already indicated in the data of high CO_2 content in the gases and water from Kathmandu valley.

Total iron (total Fe)

The greater part of iron in groundwater associated with Quaternary natural gas is Fe^{II} because of the low Eh (oxidation-reduction potential) value Fe^{II} in water exists, in general, as $Fe(HCO_3)_2$.

In Kathmandu valley, about 5 to 10 mg/l of total iron was noticed in the gas productive area.

Potassium permanganate consumption ($KMnO_4$ cons.)

After oxidizing groundwater samples with air, the approximate amount of soluble organic materials in water can be determined by $KMnO_4$ consumption.

In the water samples from the gas productive area, the value of $KMnO_4$ cons. ranges from 50 to 160 mg/l, which is higher than observed for groundwater from the ordinary Quaternary gas reservoirs in Japan. This fact also indicates the rapid decomposition of organic matter in sediments into natural gas.

The water sample from Loc. No. 17 (University) had a high degree of muddiness and hence, the value of $KMnO_4$ cons. was high.

Metaboric acid (HBO_2)

In the gas productive area, the content of metaboric acid in the groundwater ranges from 25 to 52 mg/l, and in the surrounding area it is about 1 to 25 mg/l. In general, the content of HBO_2 relates to that of carbon dioxide, so that the metaboric acid was one of the indicators for hydrogeochemical exploration of natural gas.

Type of groundwater quality

Fig. 20 shows the type of groundwater quality on the "Key diagram". All the groundwaters in Kathmandu valley are plotted in the section of $Ca(HCO_3)_2$ type. Table 6 shows the result of calculation for the "Key diagram" preparation.

Fig. 20 has the axes of anion expressed by SO_4^{2-} + Cl^- and HCO_3^-, and those of cation expressed by Ca^{2+} + Mg^{2+} and Na^+ + K^+. Sixteen points for water samples out of the seventeen samples are on the linear band of $HCO_3^- \geqslant 95\%$, and these points shift on the line of Na^+ + K^+ and Ca^{2+} + Mg^{2+}. On the figure, only Loc. No. 14 occupies a point slightly separated from the area having sixteen points in it, because the Cl^- content in the water from Loc. No. 14 is extremely high compared with the values at other sampling sites.

In Fig. 20, seventeen points are divided into the following six groups:

Group A --- Loc. No. 17, 18
Group B --- Loc. No. 4, 8, 9, 10, 11, 12
Group C --- Loc. No. 1, 2, 5, 7, 13, 15
Group D --- Loc. No. 16
Group E --- Loc. No. 6
Group F --- Loc. No. 14

Group A is the most abundant in alkali elements (Na^+ + K^+), Group B is the next, and Group C is the least alkaline or the most abundant in alkali-earth elements. Generally, when meteoric water penetrates into the ground, the water quality is relatively rich in alkali elements at the first stage, and tends to change gradually to the type abundant in alkali-earth elements following the movement in the underground. Thus, it is supposed that the groundwater of Group C has been reserved under the most stagnant condition. The result of this geochemical assumption coincides with the distributional pattern of natural gases.

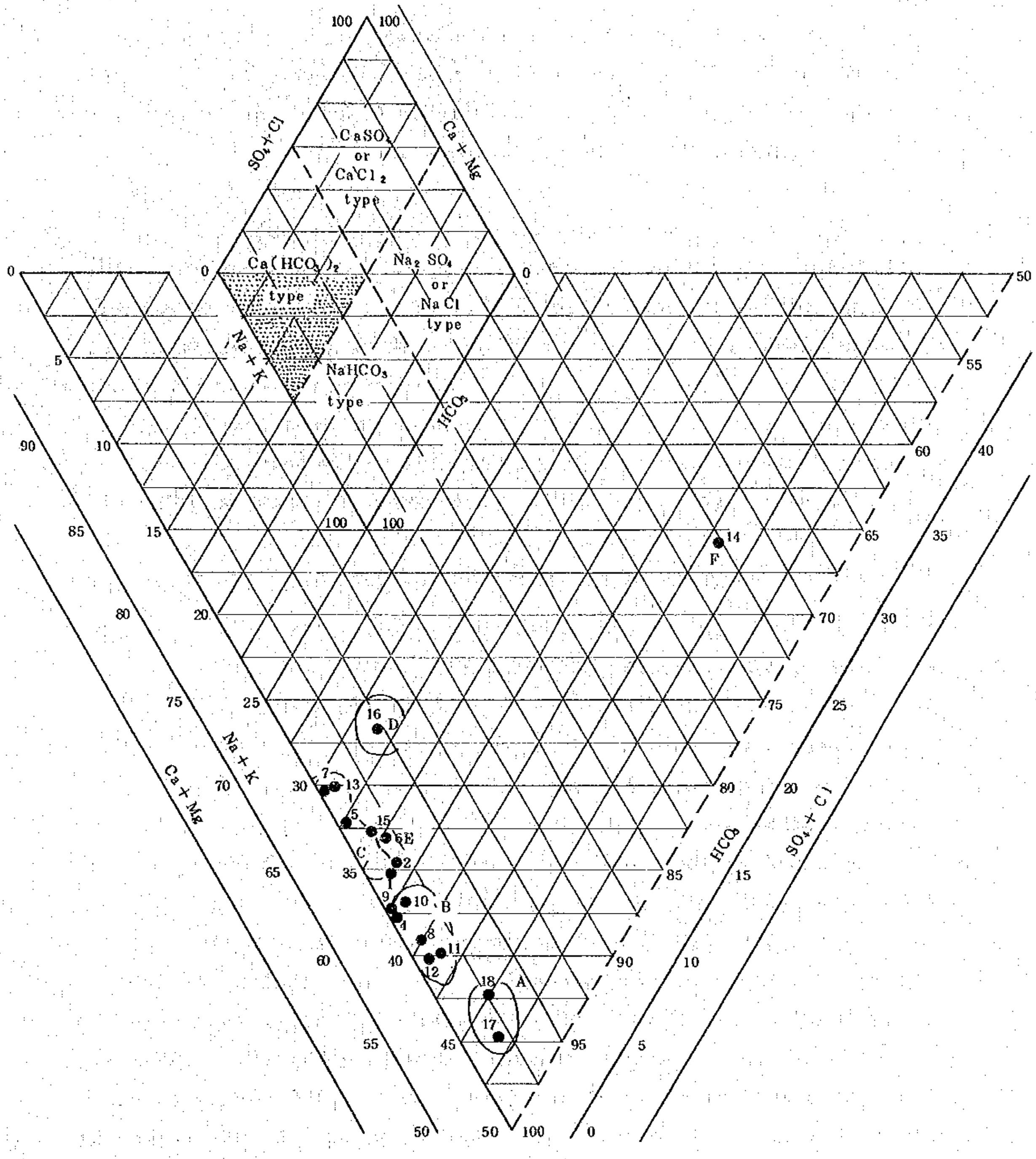


Fig. 20. Key diagram for groundwaters from Kathmandu valley.

Fig. 21 shows the areal distribution of the type of groundwater and the supposed flow direction of groundwater on the basis of the above explanation.

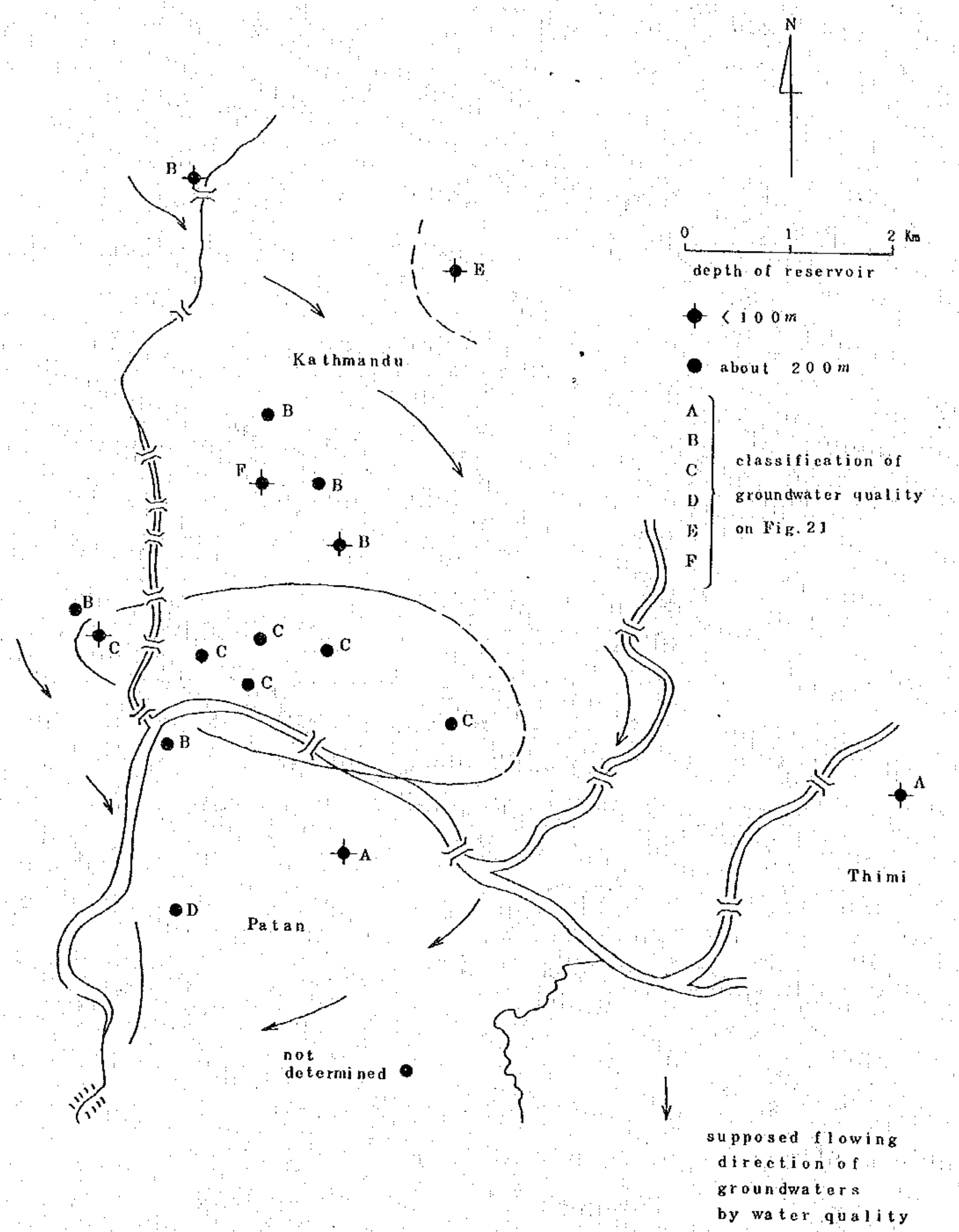


Fig. 21. Areal distribution of groundwater quality.

$Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}$

Table 7 shows the content of $Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}$ in mg/l, and Fig. 22 shows its areal distribution. In the gas productive area, the groundwater has more than 150 mg/l of $Ca^{2+} + Mg^{2+} + Na^{+}$

$+ K^+$. The supposed flow direction of groundwater is shown in Fig. 22.

The distribution pattern of the type of waters and that of the content of $Ca^{2+} + Mg^{2+} + Na^+ + K^+$ of groundwater coincide with each other.

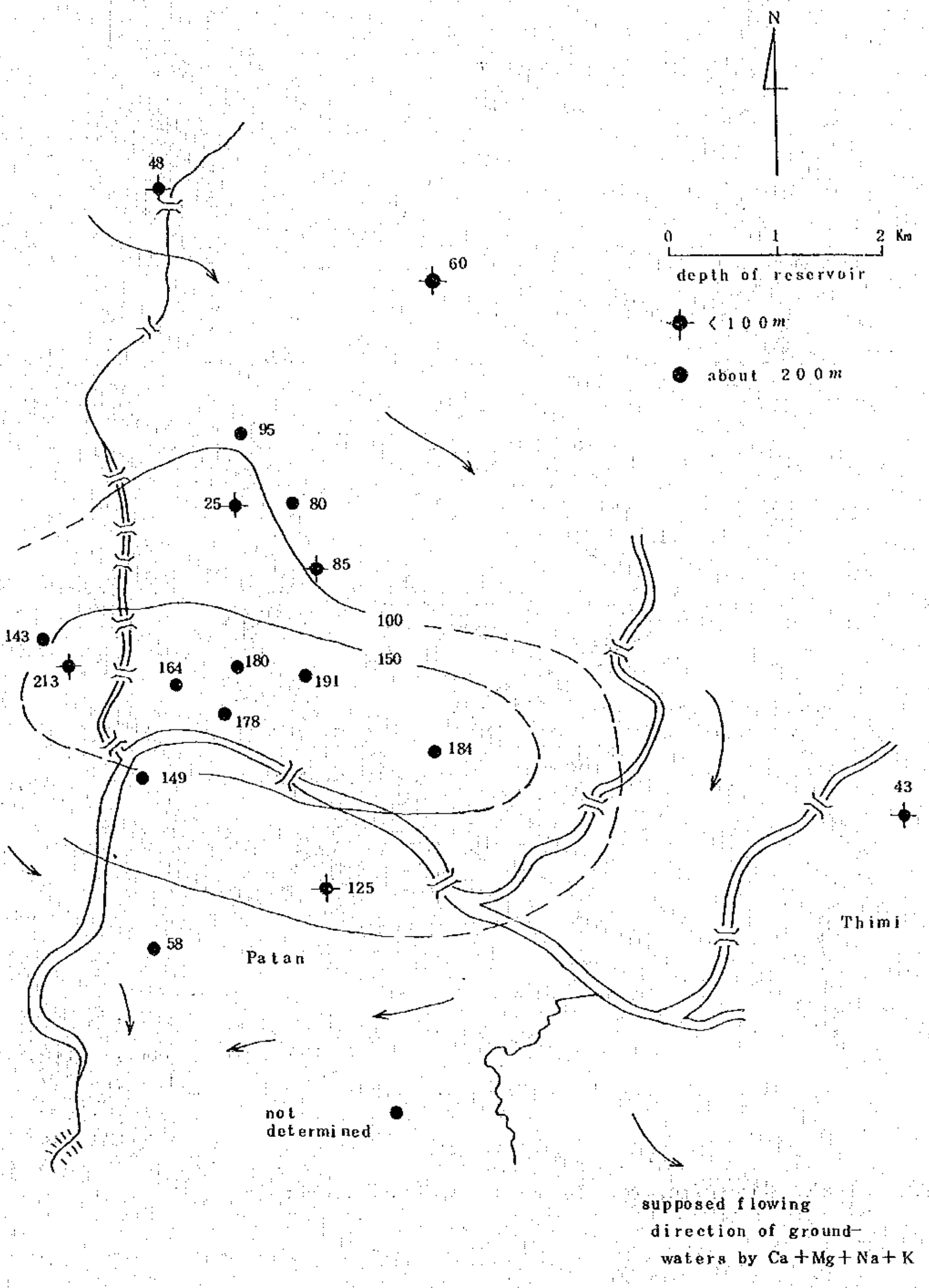


Fig. 22. Distribution of $Ca^{2+} + Mg^{2+} + Na^+ + K^+$ (mg/l) in groundwaters.

b) Gases

Argon in free gas (Ar)

The argon percentage in free gases ranges from 0.042 to 1.150 (%) depending largely on the degree of contamination of air into gas samples. Two free gas samples from Loc. No. 8 and 18, whose argon contents are 1.01% and 1.150% respectively, clearly show a high degree of air contamination, because as shown in Table 4, the values of oxygen content in the samples are 11.14% and 12.18% respectively.

The argon content in the free gases from the wells in the high productive area is 0.06 to 0.10%. As atmosphere has the content of argon by 0.93% and that of nitrogen by 78.09%, the value of N_2/Ar ratio is 84. Comparing this value with those of the free gases from the productive area, 40 - 51 as shown in Table 5, it can be seen that the values of free gases are high.

Dissolved-in-water nitrogen and argon (diss. N_2 and diss. Ar)

The contents of dissolved nitrogen and argon in the underground waters in the depths were calculated using the chemical composition of free and dissolved-in-water gases as well as the values of gas-water ratio obtained at the casing head of the wells, and the results are shown in Table 8.

In the bottom of Table 8, the contents of dissolved nitrogen and argon in water under an equilibrium with atmosphere at 20°C and 0 meter elevation are also shown.

According to the data of Table 8, the content of dissolved argon in the groundwater from Kathmandu valley ranges from 0.07 to 0.28 ml/l except for the sample from Loc. No. 17 (University). The physical condition of the well at Loc. No. 17 is quite different from that of other wells. Specifically, the water sample from this well was taken with a bore-hole pump and mixed strongly with sucked atmosphere in the casing when sampling. Therefore, it is supposed that has an extremely high content of argon, 0.91 ml/l. Except for this sample, the other 13 samples have a lower value in argon content than the newly invaded water into the underground.

In general, the content of dissolved-in-water nitrogen ranges from 10 to 30 ml/l. However, the water from the shallow wells and the wells outside of the gas productive area has a low value in nitrogen gas content, about 7.9 - 8.9 ml/l.

The approximate nitrogen gas content in meteoric water is supposed to be 12 ml/l as shown in Table 8. Thus, an increase of nitrogen gas in the groundwater from the gas productive area was noticed.

Ratio of diss. N_2/diss. Ar

In Table 8, the values of diss. N_2/diss. Ar ratio are shown. The values in the gas productive area, 133 - 241, are higher than that of ordinary meteoric water, 39.9. As already stated, these high values in the gas productive area have been caused by both the decreasing of argon and increasing of nitrogen. It is supposed that the argon content in the groundwater in the Quaternary sediments has gradually been decreased following the migration of natural gases generated by the decomposition of organic matter in the sediments. This is because in the geologically young sediments, any addition of argon by the radioactive disintegration of potassium cannot be expected. On the contrary, nitrogen gas has been added by the anaerobic disintegration of the organic matter in the depths.

In the groundwater from outside of the gas productive area, both nitrogen and argon contents decrease because of the migration of the two gases following the slight increase of the generated natural gas which is mainly composed of CH_4 and CO_2. This fact was noticed at Loc. No. 6, 11, 16, and 17.

iii) Sediments and rocks

From the outcrops shown in Fig. 23, seven samples were taken, of which six were Quaternay carbonaceous clays and one was Paleozoic shale. On these samples, the contents of bitumen, paraffin and cyclo-paraffin (naphthene) hydrocarbons, aromatic hydrocarbons, hetero-organic compounds

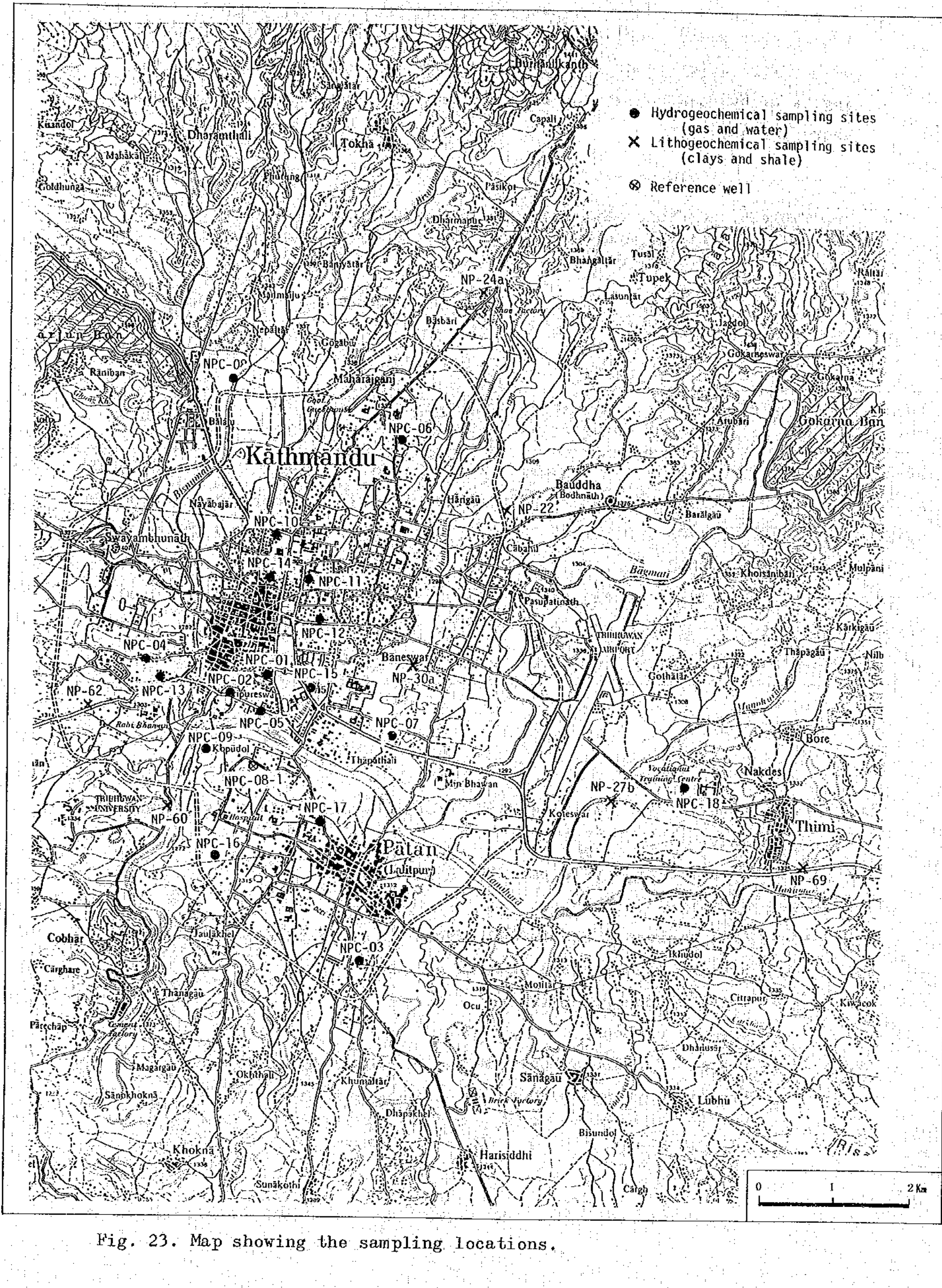


Fig. 23. Map showing the sampling locations.

(O-N-S compounds), residues on activated alumina column, and organic carbon were determined, and the content of total hydrocarbons and the degree of hydrocarbonization were calculated. The results obtained are shown in Table 9.

Table 9. Organic matter in six Quatermany carbonaceous clays and a Paleozoic shale from Kathmandu valley

Analysis: Shozo Nagata
Tomiko Nishimura
(GSJ)

Loc. No.	Geologic age	Ext. (%)	Liquid chromatograph				HyR (ppm)	Co (%)	Ch/Co
			P+Cp(%)	Ar(%)	O-N-S(%)	Res(%)			
NP-22	Quaternary	0.2804	1.46	5.32	14.42	78.80	190.1	0.70	0.00348
NP-24a	"	0.1790	1.79	4.58	18.42	75.21	114.0	4.74	0.00207
NP-27b	"	0.1408	2.10	5.18	20.99	71.73	102.5	2.59	0.00340
NP-30a	"	0.0868	0.71	7.36	27.86	64.07	70.0	2.04	0.00295
NP-62	"	0.1319	0.43	6.33	14.96	78.28	89.2	4.18	0.00184
NP-60	Paleozoic	0.0026	0.90	0.00	12.06	87.04	0.23	0.03	0.0007
NP-69	Quaternary	0.0392	23.28	14.27	20.99	41.46	147.2	0.73	0.0173

Ext. ------- Bitumen content (total extractable organic matter by organic solvent)

P + Cp ---- Paraffin and cyclo-paraffin hydrocarbons

Ar -------- Aromatic hydrocarbons

O-N-S ----- Hetero organic compounds (oxygen-nitrogen-sulfur compounds)

Res ------- Residue on activated alumina column

HyR ------- Total hydrocarbons (P + Cp + Ar)

Co -------- Organic carbon

Ch/Co ----- Degree of hydrocarbonization = carbon in hydrocarbons/organic carbon = 0.86 x hydrocarbons/organic carbon

Fig. 24 shows the position of each surface sample using the analytical results of organic matter, organic carbon and hydrocarbon contents, on the evaluation chart for hydrocarbon source rocks which was determined by Kudo et al. (1976).

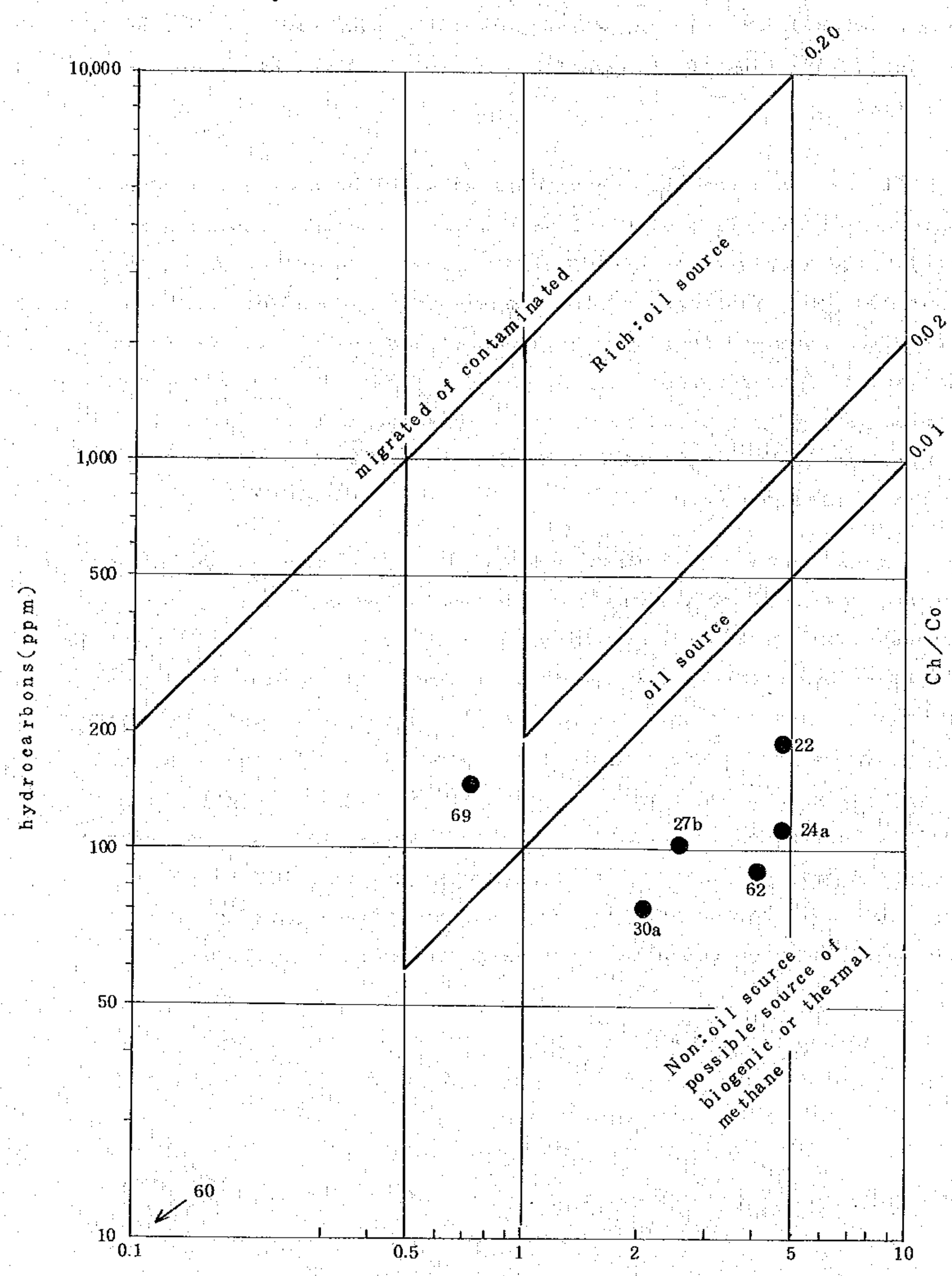


Fig. 24. Position of each rock sample on the analytical result of organic matter on the evaluation chart.

Fig. 24 indicates clearly that five Quaternary samples (NP-30a, 27b, 62, 24a, and 22) have relatively high gas generation potential because of their high organic carbon contents, and one Quaternary sample (NP-69) has oil generation potential. However, one Paleozoic sample (NP-60) from the basement has neither oil potential nor gas potential.

It must be noted that when compared with the ordinary Japanese Quaternary sediments having the same depositional environments all (six) Quaternary samples have a higher value in hydrocarbon content, about 100 ppm. The value of 100 ppm has been recognized in the samples having the boundary character between oil and non-oil source rocks. The degree of hydrocarbonization (Ch/Co) of the analyzed Quaternary samples ranges from 0.002 to 0.0173. These organic geochemical characteristics coincide well with the distribution pattern of ethane in the natural gas (Fig. 18).

Fig. 25 shows the chemical composition of bitumen on the triangular diagram, having three terminals expressed by hydrocarbons, O-S-N compounds, and residues on alumina column. As NP-69 sample has a high content of hydrocarbons, the point is situated at about the centre of the diagram, and expresses the most advanced character for maturation of organic matter in the course of oil generation. On the other hand, the remaining five Quaternary samples are plotted in the area with abundant residue on the column. This fact shows that the five samples have a low degree of maturation for organic matter. One Paleozoic sample (NP-60), having very low contents of hydrocarbons and O-N-S compounds, shows no potential for heavy hydrocarbon generation.

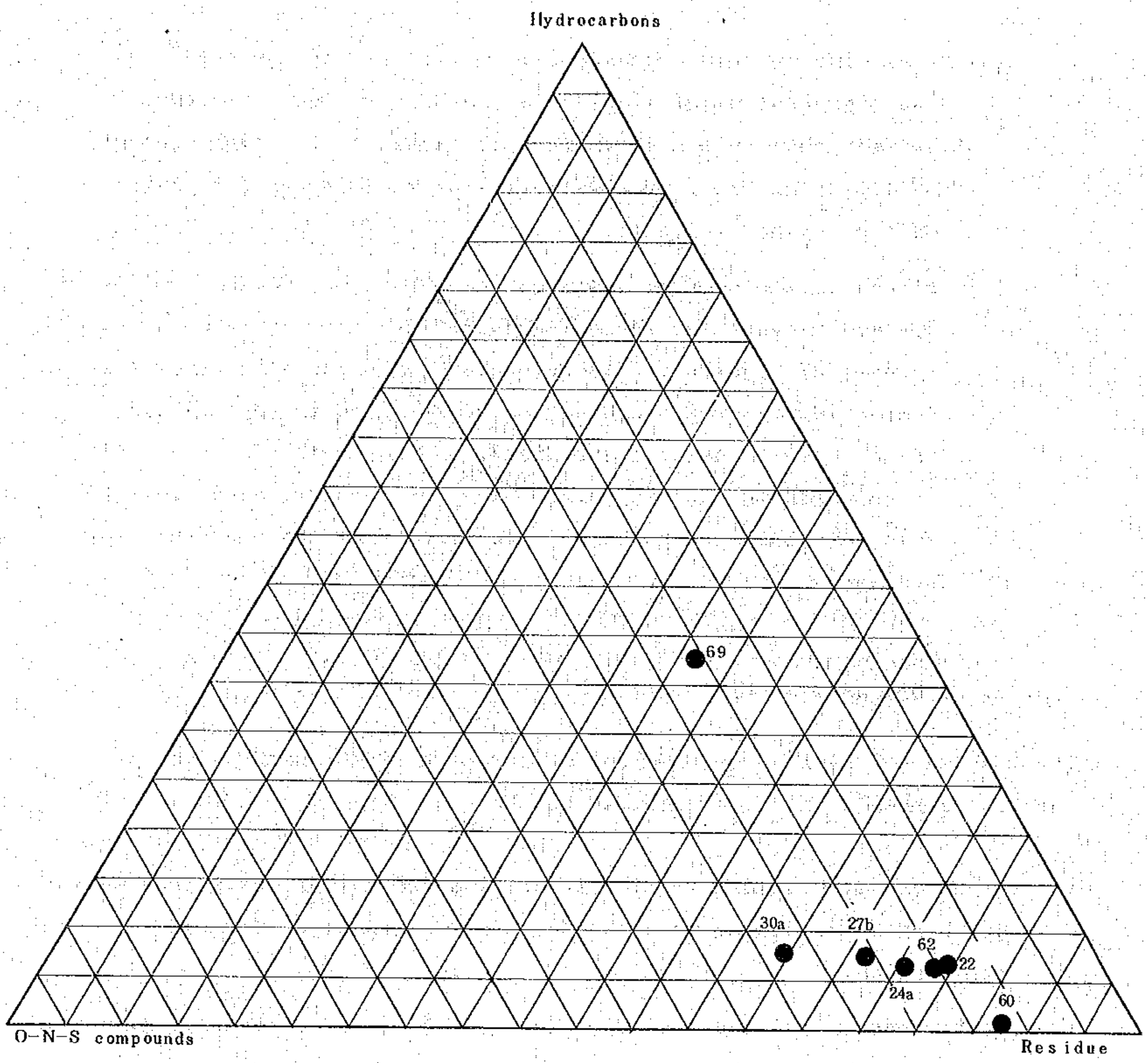


Fig. 25. Chemical composition of bitumen in rock samples on triangular net.

The following are the major findings of the organic geochemical examination on the surface rock samples of the Quaternary and Paleozoic ages.

(1) Quaternary samples have the potential for oil and gas generation.

(2) Paleozoic rock sample has no potential for hydorcarbon generation.

(3) According to the landscape examination of the surveyed area, the high content of liquid hydrocarbons in the Quaternary surface sediments might have been caused by the high content of lipids in the source materials of the dispersed organic matter in the sediments.

(4) Ethane in the natural gas might have been generated from the lipids, because the present groundwater temperature does not exceeds 27°C which is far below 40°C, the lowest groundwater temperature at which ethane can be found in the natural gas in the Niigata natural gas field, 300 km north of Tokyo. It is supposed that ethane might have not been migrated from the Paleozoic basement rocks but generated from the Quaternary sediments.

5. Summary of Geochemical Exploration

The results of the hydrogeochemical exploration of the natural gas resources in Kathmandu valley are summarized below.

(1) Eighteen water wells, previously drilled and having the approximate depth of 20 to 330 m, were used as observation sites for gas exploration.

(2) It has been concluded that the gas reservoirs are of dissolved-in-water type.

(3) The gas reservoirs can be divided into two groups according to the depth of wells, one has the depth of less than 100 meters and the other has the depth of about 200 meters.

(4) The so called "200 m reservoir" has higher productivity and potentiality than the shallower reservoir.

(5) In the gas productive area, located in the southern part of Kathmandu city, the observed gas-water ratio of the "200 m reservoir" is almost equal to the theoretical value 1 : 2 (0.5).

(5) The gas productive area, having high values of gas-water ratio, covers about 4 km^2 of land.

(7) The maximum production rate of natural gas from a flowing well with a diameter of $1\frac{1}{2}$" reaches 70 m^3/day.

(8) The chemical composition of free natural gases is as follows; about 75 - 80% of methane, 14 - 23% of carbon dioxide, 1.5 - 6% of nitrogen, less than 0.3% of oxygen, 0.000% of hydrogen, 0.000 - 0.003% of ethane, 0.000 - 0.012% of helium, and 0 - 20 ppm of hydrogen sulfide.

(9) The calorific value of the free gases ranges from 6,200 to 7,000 Kcal/N m^3, which is sufficient for ordinary usage.

(10) The total gas production rate from the ten observation wells in Kathmandu city was calculated to be about 500 m^3/day.

(11) Natural gas produced at several out of the ten wells has been used for a household fuel.

(12) It is supposed that the components of natural gas, except for helium and argon, might have been generated by the anaerobic decomposition of organic materials dispersed in the Quaternary sediments.

(13) The mineral contents in the groundwater associated with natural gases are low, and this fact is advantageous to the exploitation of gas resources.