Joint Meeting

T I d 1

Volcanic Reservoirs, Their Characteristics of the Development and Production

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Introduction

Japanese oil and gas fields have been found mainly in the nothern half of the country. Especially, the Japan Sea coastal area accounts for about 99% of Japanese petroleum production.

Japanese oil and gas fields, except for those gas fields of water dissolved type, occur in the Neogene strata.

In this paper, the writers will describe an outline of Japanese oil and gas fields and then explain in detail about those which have volcanic or phyroclastic reservoirs.

Generally speaking, igneous rocks are inferior to sandstones and carbonate rocks as reservoir rock. Knebel and Rodriguez-Eraso (1956) made a statistical study of 236 major oil fields of the free world and stated that "---- sand reservoirs hold 59 per cent of oil found in major fields, with carbonates holding almost the entire remaining 41 per cent. Other fractured rocks such as shales and igneous or metamorphic rocks contain only 0.8 per cent of the oil in major fields."

However, it is true that igneous rocks can form payable reservoir in some places. For example, Thrall oil field in Texas, Lytton Spring oil field in Texas, Dineh-bi-Keyah oil field in Arizona and Djatibarang Shutin gas field discovered recently in Indonesia are famous for the reason that the reservoir is igneous.

As 5 of 11 major oil and gas fields found during the last 15 years in northeast Japan have igneous reservoirs, reservoirs of this type has recently become important in the area.

General Geology and Outlines of Oil and Gas Fields in the Japan Sea Coastal Area of Northeast Japan

Oil and gas fields have been found in the Neogene sedimentary basin extending along the coast of the Sea of Japan. The basin began its depression associated with volcanic activities in early Miocene and continued to subside through the Neogene and Quarternary periods. It is about 700 km long and 80 km wide and the thickness of sediments is estimated to be about 10,000 m at the point of maximum depression. This sedimentary basin is generally called Uetsu geosyncline.

Basement rock of Uetsu geosyncline is mostly composed of slightly metamorphosed Paleozoic formations and granitic rocks. Granitic rocks are presumed to have intruded during the late Mesozoic period. Only small masses of Mesozoic formations are found in the southern part of this basin but no Paleogene formations are found in this area.

Uetsu geosyncline is, as shown in Fig. 1, subdivided into two subbasins. The northern one is Akita subbasin and the southern one is Niigata subbasin.

They are similar in their geological development, however, some differences in the detail of sedimentary facies, amount of sediments, mode and period of volcanic activities and tectonic movements can be seen.

Neogene successions of these subbasin are shown in Table 1. Formations in these subbasins can be correlated in detail chiefly using planktonic and benthonic foraminifers.

As shown in Table 1, oil and gas fields in these subbasins occur in the formations deposited during middle Miocene and early Pliocene.

Most of the oil and gas fields in this area have developed on anticlinal structures with stratigraphic traps such as thinning out of sandstone. However, pure stratigraphic trap has not yet been found here.

From the view point of reservoir rock, many oil and gas fields occur in sandstone reservoir. Only a small oil field was proved to occur in carbonate rock in Akita subbasin. However, the remarkable characteristic in this area is, as described before, that volcanic rocks and pyroclastic rocks form rather good oil and gas reservoirs in many places. As the sandstone reservoirs are usually tuffaceous, it may be generally concluded that reservoir rocks in this basin is strongly affected by volcanisms.

Oil and gas fields which are said to have recoverable reserves of one million kiloliters or more are listed on Table 2 (1000 m^3 of gas is converted to 1 kl of oil). Among them, there are 6 oil and gas fields which occur in igneous rocks.

In Akita subbasin only one oil field with igneous reservoir was found, which happened to be the first in Japan. In Niigata subbasin, 5 major oil and gas fields occur in igneous reservoirs as shown in Table 2. At least 2 gas fields of medium class, namely Kumoide and Fujikawa gas fields, can be added to them. Therefore, Niigata subbasin may be characterized as a sedimentary basin where development of igneous reservoirs is remarkable.

Amount of recovery of hydrocarbon for unit area of a reservoir is compared among major oil and gas fields. Igneous reservoirs are proved to have rather good productivity compared with average productivity of sandstone reservoirs.

In this paper we deal with igneous reservoirs in Niigata subbasin since they have been discovered lately and studied rather carefully.

Characteristics of Igneous Reservoirs and Reservoir Problems for Development

Igneous rocks which form reservoir rocks in this basin range from the end of middle Miocene to early Pliocene.

Igneous reservoirs are composed of lava, agglomerate and tuff breccia. Although tuff is proved to form reservoirs in many fields, it can not be placed under the category of igneous reservoirs due to reasons mentioned in a later section of this chapter.

Formation porosity can be calculated by some kinds of physical logs used in bore holes. Different types of pores respond to these porosity tools in different manners. Depending on this fact, type of porosity can be recognized by using several combination of porosity tools. For example, Formation Density log (FDC) and Neutron log (NL) respond to total porosity in the formation but porosity from Sonic log (SL) is thought to show intergranular porosity only. Consequently, porosity calculated from Formation Density log and Neutron log, if it is adequately computed on well adjusted logs, should be larger than that from Sonic log for reservoirs in which fractures and vugs exist in addition to intergranular pores.

Comparison of porosity from FDC and SL in igneous reservoir in Myohoji gas field and sandstone reservoir in Shintainai gas field is shown in Fig. 2. It indicates that igneous reservoir in Myohoji gas field has fracture and vagular porosities.

It is characteristic of igneous reservoir that fractures and vugs are quite effective. Tuff reservoir is volcanic in origin but it cannot be put into the category of igneous reservoir because its porosity is mainly intergranular like that of the sandstone reservoir.

Basic igneous rocks can be found in this sedimentary basin, but they have not been proved to form good reservoirs for petroleum.

Considering that fractures and vugs play a more important role in movement of liquid than intergranular porosity, it may be a reason why basic igneous rocks can not form good reservoirs as viscosity of basic lavas is too small to yield sufficient fractures and vugs for passages of petroleum.

Igneous reservoirs, roughly speaking, has a resemblance to carbonate rock reservoirs. It is common to both in points of fractures and vugs being predominant, formation resistivity being quite higher than surrounding formations, and the shape being sometimes reeflike. However, the decisive difference between them is that carbonate rocks have a possibility of being source rock as well as reservoir rock and igneous rocks are not able to be source rock.

Therefore it is important that in searching for oil and gas in igneous reservoirs, the source rock must be situated close by.

Some igneous rocks are proved to be good reservoir with well continuing porosities, but others are not so good in continuity of porosity.

A typical example of igneous reservoir with poorly continuing pores is that of Mitsuke oil field. Reservoirs of this field are, as illustrated in Figs. 3 and 4, considered to be mushroomlike bodies of liparite lava. A number of small lava bodies form a reeflike igneous mass being stuffed with impervious tuff. For development of this field, it was a serious problem to presume the location and magnitude of the lava bodies. Problem of well spacing seemed to be a minor one for this field. Reflecting upon the details of development of this field, exploitation planning can not be necessarily said to have been successful.

Fig. 5 is the restored stratigraphic section through Mitsuke oil field. It shows that pyroclastic rocks of middle Miocene age, which are sometimes called "Green Tuff," made a high in the sedimentary basin at that time and they have remained continuously as a high through Neogene and Quarternary ages owing to less subsidence than the surrounding areas. Petroleum is considered to have migrated into these volcanic bodies from contemporaneous mudstone surrounding them. The reason why oil could occur in profitable quantities in igneous reservoir of Mitsuke oil filed may have been because thick mudstone was deposited close to the igneous bodies. At the north of Mitsuke field, some anticlines with igneous rocks have been drilled and proved the accumulation to be non-commercial proportions of petroleum, although igneous rocks showed desirable properties as reservoir rock. It may be caused by lack of large amount of contemporaneous mudstone in the neighborhood of these anticlines.

In the cases of Katagai gas field and Fujikawa gas field, shown in Figs. 6 and 7, characters of igneous rocks for reservoir are rather uniform. Depending on open flow capacity of producing wells, potential of reservoir is a little higher at the top of structure than at the wing area. Shape of these anticlines became distinct and igneous rocks of the axial area were fractured by tension stress as these anticlines suffered tectonic movement during the depositing of the overlying formations. Well spacing is the most important problem for development in the fields of such type. The former was developed with well spacing of about 700 m along anticlinal axis and the latter was with that of about 500 m.

As Yoshii gas field, shown in Fig. 8, is now in the early stage of exploitation, properties of igneous reservoir have not been fully studied. Depending on well data now available, continuity of igneous reservoir may be classed as in between those of Mitsuke oil field and Katagai- Fujikawa gas fields. Fig. 4 illustrates, distribution of volcanic rock content obtained from lithologic log and electric log. Volcanic rocks seem to be distributed around some centers and their magnitude is larger than volcanic bodies in Mitsuke oil field. Yoshii gas field is now under exploitation with 700 - 1000 m spacing. Mode of development of igneous rock should be further investigated at the advanced stage of exploitation.

According to restored stratigraphic section through Yoshii gas field, it shows that igneous rocks forming reservoir is not a clear anticlinal rise when the volcanic rocks were piled up. Migration and accumulation of gas may have ended in or after late Miocene when the anticlinal shape of igneous rocks became clear. Gas should come from the overlying mudstone of the Nanatani and Teradomari formations. It has not been proved whether gas migrated primarily into igneous rock and migrated secondarily to the crestal area of the anticline or gas was generated after a considerably long time of the deposit of the source rocks. Mode of migration and accumulation in Yoshii gas field may differ from that in Mitsuke oil field where oil and gas are considered to have accumulated just after the source rocks were deposited.

Characteristics of Oil and Gas Production from Igneous Rock Reservoirs

The characteristics of oil and gas production from igneous rock reservoirs come mainly from the fact that the pore structure is of vug and fissure type. Accordingly, those reservoirs of different mineral origin, the pores of which consist of vug and fissure, will show very similar characteristics. As already described, almost of all igneous reservoirs which have been found so far, are located in Niigata Prefecture. Mitsuke oil field which is one of those igneous reservoirs has a production history as long as 10 years and is now almost depleted. On the other hand, Yoshii gas field which is now of development stage and is adding new proved reserves year by year, is also one of igneous reservoirs. The various performance those reservoirs show have an intimate relationship with the nature of reservoir rock. We would like to see hereafter some of these peculiar performances in terms of relation to reservoir rock.

As you understand, an oil or a gas reservoir will have a certain pressure distribution at a certain depletion, depending mostly on its permeability and well distribution, the production of each well, and the encroachment of edge or bottom water. Table-3 and Table-4 show pressure vs. cumulative production of Katagai gas field and Fujikawa gas field respectively. The one is a dry gas reservoir with no water drive and the other is a gas-condensate reservoir with active water drive. The physical nature of each field is fairly uniform over its structure. The one is of Agglomerate and the other is of Breccia.

Table-3 and Table-4 show that there is hardly any scattering of datum plane pressures. The standard deviations of these field pressures are 0.38 Kg/cm^2 and 1.71 Kg/cm^2 to Katagai and to Fujikawa gas field respectively. In Katagai gas field, wells have nearly equal producing capacity and cumulative production, whereas each well has its pretty distinctive characteristics in Fujikawa gas field. As to Yoshii gas field, the standard deviation of datum plane pressures obtained from the static bottom pressure survey in October '71 is as high as 4.72 Kg/cm^2. As this field which is apparently a gas-condensate reservoir, has been producing only 2 1/2 years, neither the existence of water encroachment nor its future performance can be predicted. However, datum plane pressures of wells at a certain time are slightly scattered, possively due to the heterogeneity of reservoir rock as already pointed out. Besides the said heterogeneity of reservoir rock, this will indicate the areal separation of the lava body. Supposing the separation into two divisions, say Yasuda District (which is southern part of the field) and Yoshii District (which is central part), datum plane pressures of the former district lie below those of the latter district, and the standard deviation of each district comes out to 2.35 Kg/cm^2 to the former and 0.98 Kg/cm^2 to the latter, each of which is far less than that of as a whole.

The standard deviation of datum plane pressures observed in Oct. '64 in Mitsuke oil field, is of relatively high value of 4.05 Kg/cm^2. Although this field could be divided into the southern and northern section, the standard deviation of each section would be still as high as 5.19 Kg/cm^2 and 2.66 Kg/cm^2 respectively. This will show the poor continuity of the igneous reservoir rock of Mitsuke oil field. Referring to Higashi-Niigata gas field which is a typical sandstone reservoir, its standard deviation of 2900 M D Layer's datum plane pressures as of September '71, is 7.08 Kg/cm^2.

It is needless to say that the time required to reach the straight line portion of B.U.C. depends upon the amount of after flow and skin effect, that the slope of the straight line is controlled by the producing rate before shut-in and that the time to start to deviate from the straight line is effected by the distance to the boundary. The shape of pressure build up curve may also depend upon the pore type and homogeneity of reservoir rock. The B.U.C. features of Katagai gas field is that the pressure builds up instantly to a certain value and levels off. As to Fujikawa gas field, every B.U.C. has an apparent straight line portion and shows the behavior peculiar to a bounded reservoir. In Yoshii gas field and Mitsuke oil field, complete pressure build up occurs instantly after shut-in, in some wells and in other wells, pressure build up behavior is similar to those of bounded reservoirs.

Both Fujikawa gas field and Mitsuke oil field are accompanied with fairly strong water drive, although the way of water encroachment is different for each of the fields. In Fujikawa gas field, water seems to encroach from north-east side of the field and the gas-water contact is suspected to dip down from north to south from the inspection of the relationship between the structural position and the time of water cut rise. Fujikawa SK-9 which began to produce much water early in its life and water cut of which rose rapidly is a well completed structually deep in the reservoir and near to the northern boundary. (See Fig. 10.) Fujikawa SK-4, the time of which to commence water production was early, and water cut of which rose gradually, is located east side of the structure, and completed over a long interval from top to bottom of the reservoir. Encroached water has reached to the west side of the structure in the northern area, and in wells which are completed near the present water-gas contact, the water cut depends heavily upon the gas production rate. (See Fig. 9.) Production rate is very sensitive to the height of water coning. So far as Mitsuke oil field is concerned, water comes verticaly from the bottom, so that drowned wells are located structually higher, irrespective of their areal position. Once water is produced, the water cut rises rapidly and oil production declines sharply, and as a result, the reduction of production rate does not contribute much to the water cut reduction. (See Fig. 12.) However there are some wells, the water cut of which rises gradually and is very sensitive to oil production rate. (See Fig. 11.) Generally speaking, the higher the P.I. is, the more easily the well is cut with water. These behavior is supposed to have much relation to the state of fissure development.

It comes to the conclusion that the performance of an igneous rock oil or gas reservoir seems to reflect well the type of pore structure and its distribution.

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Remarks: * Written in Japanese with English abstract

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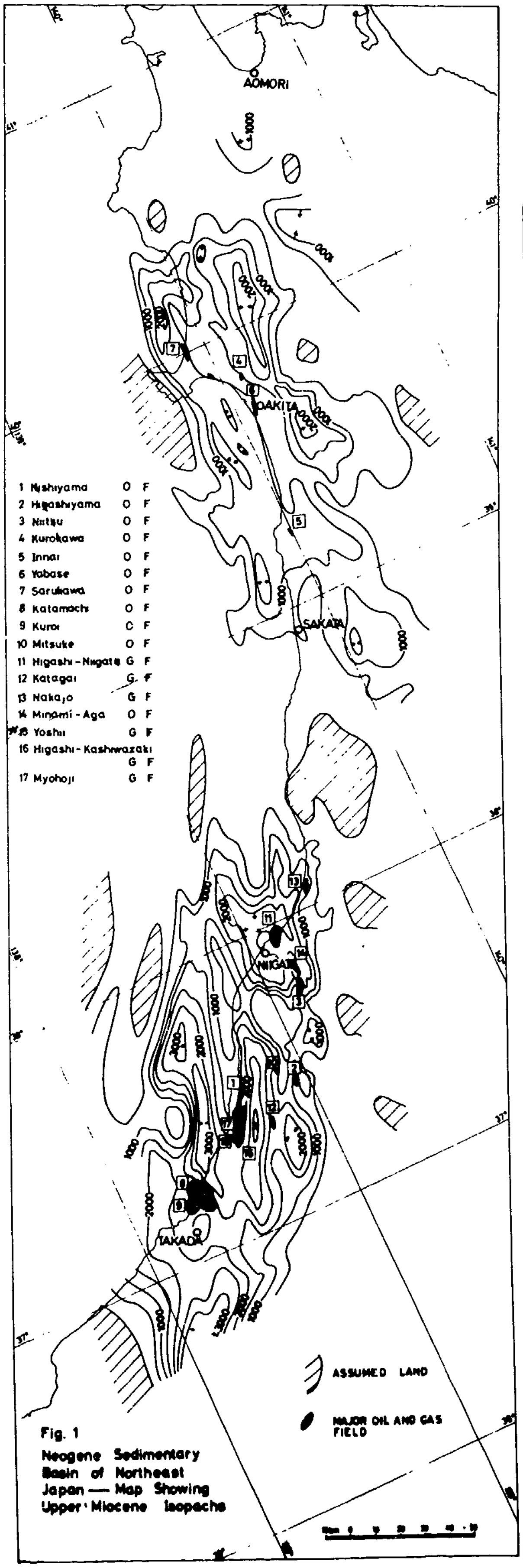


Fig. 1
Neogene Sedimentary Basin of Northeast Japan — Map Showing Upper Miocene Isopachs

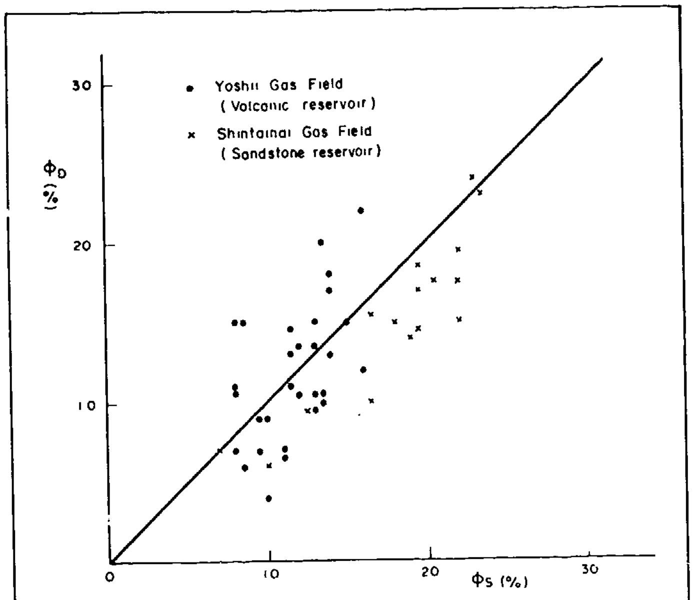


Fig. 2 ϕ_D vs ϕ_S plots

(Yoshii Gas Field & Shintainai Gas Field)

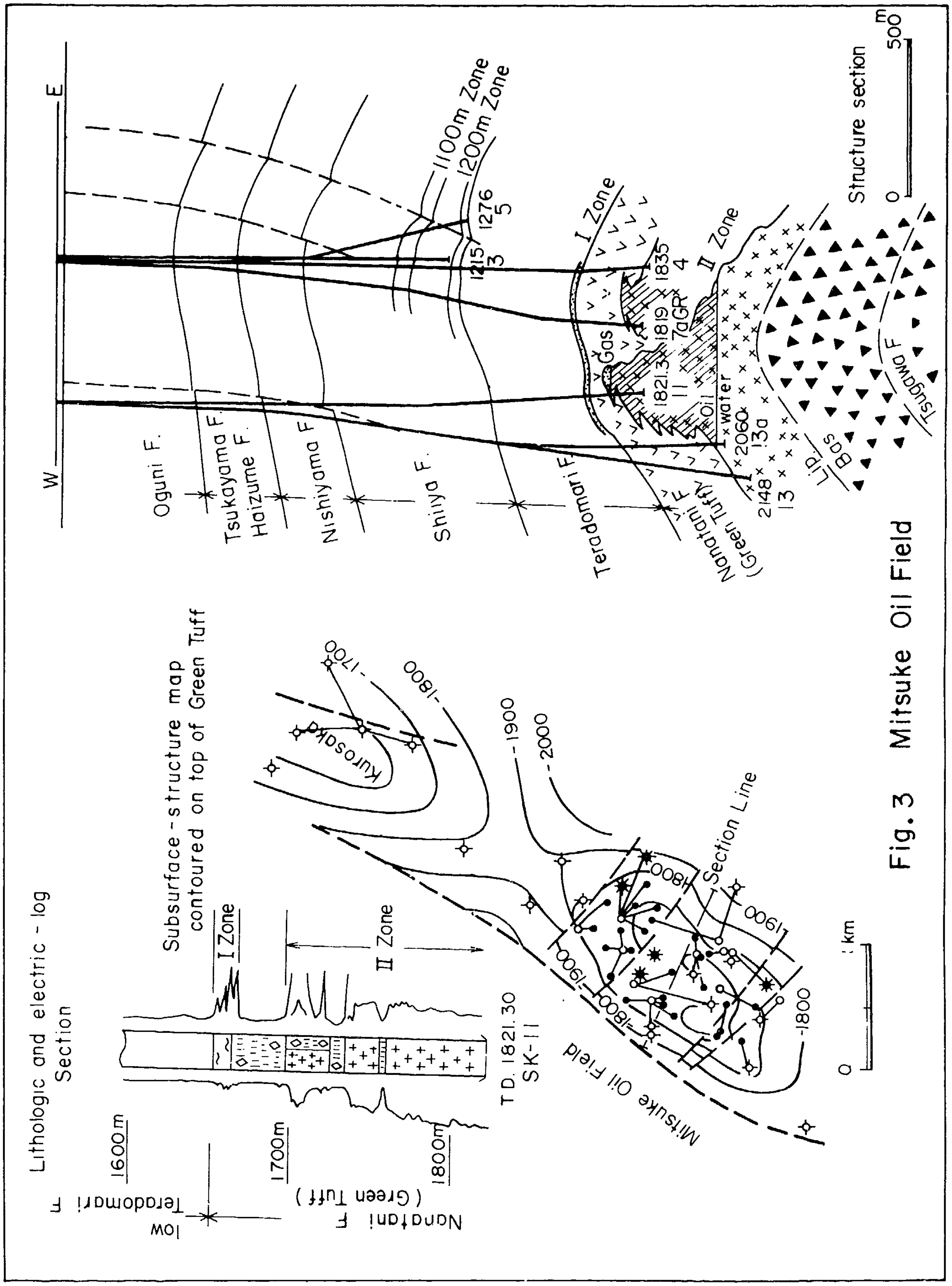


Fig. 3 Mitsuke Oil Field

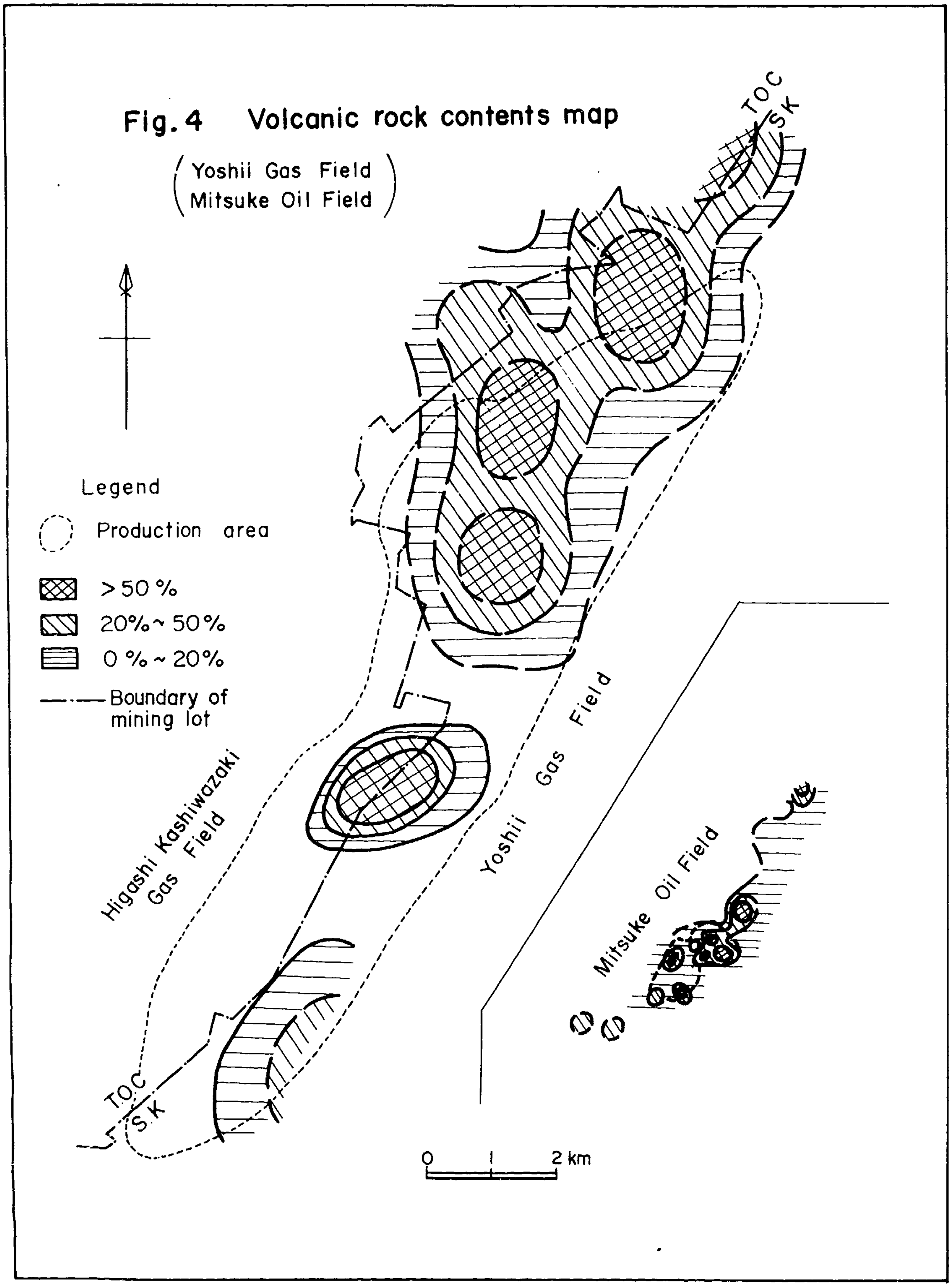


Fig. 4 Volcanic rock contents map
(Yoshii Gas Field
Mitsuke Oil Field)
Legend
Production area
> 50 %
20% ~ 50 %
0 % ~ 20%
Boundary of mining lot
TOC
SK
Yoshii Gas Field
Higashi Kashiwazaki Gas Field
Mitsuke Oil Field
0 1 2 km

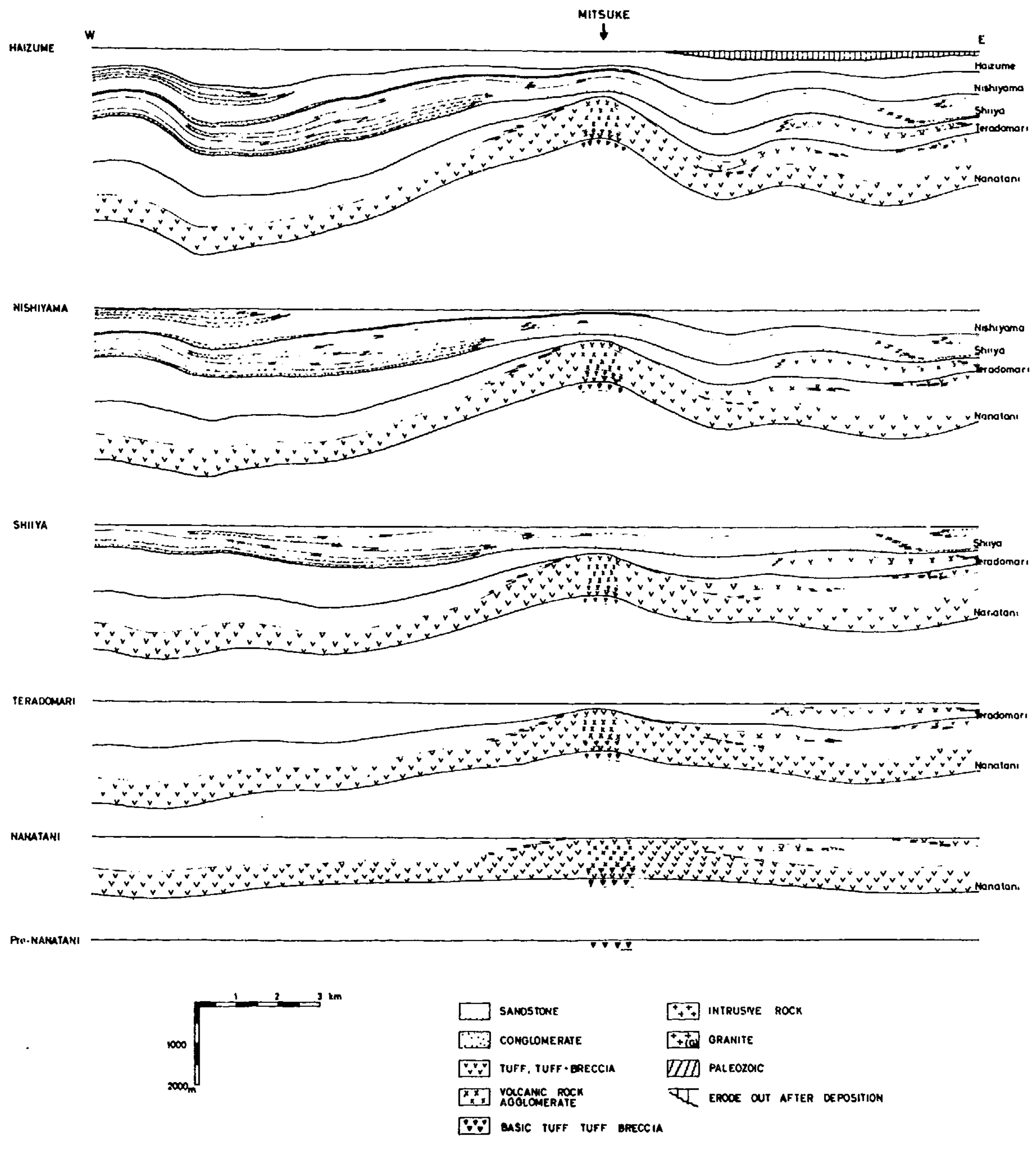


Fig. 5 Restored Stratigraphic Section Through Mitsuke Oil Field

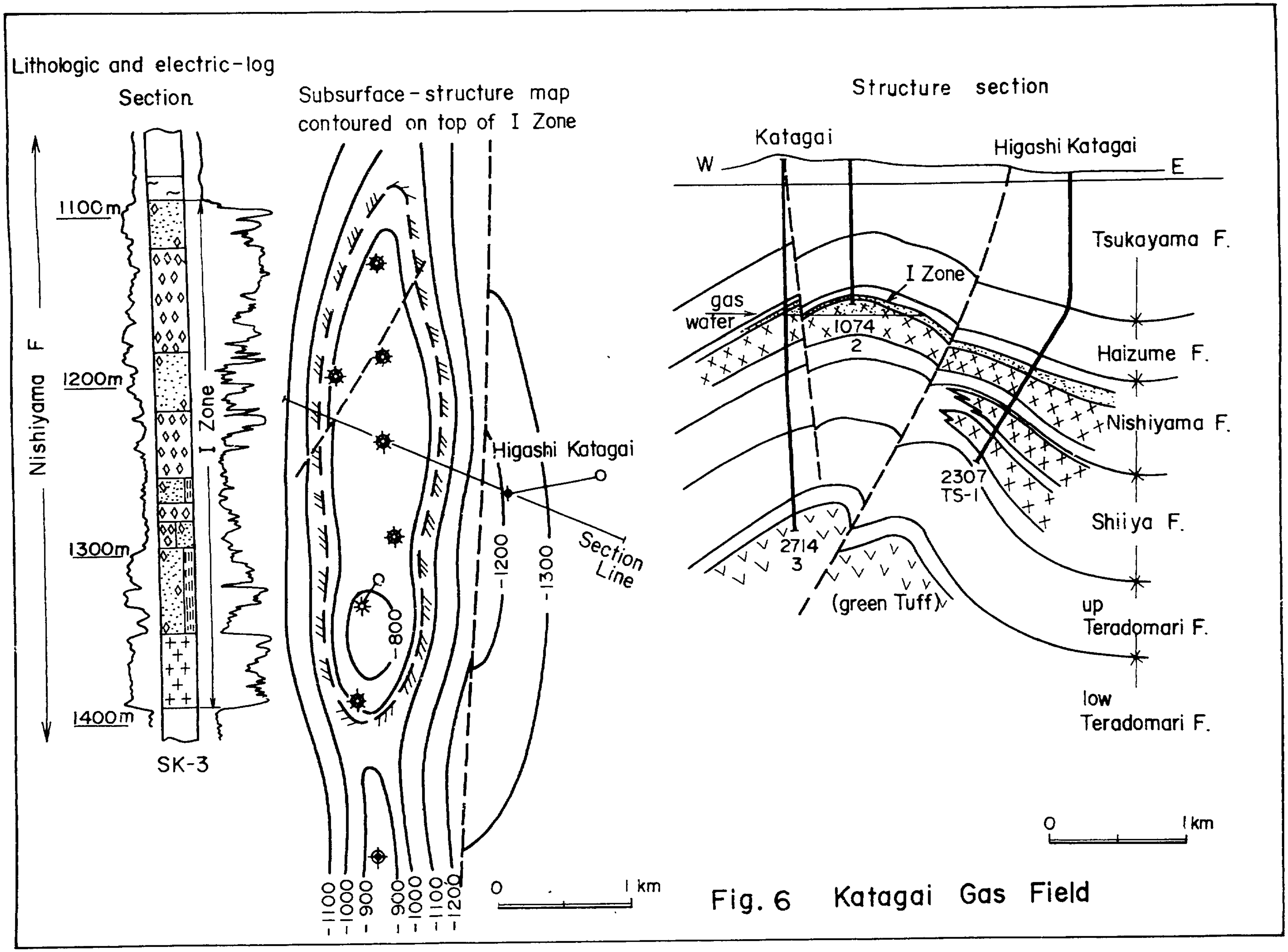


Fig. 6 Katagai Gas Field

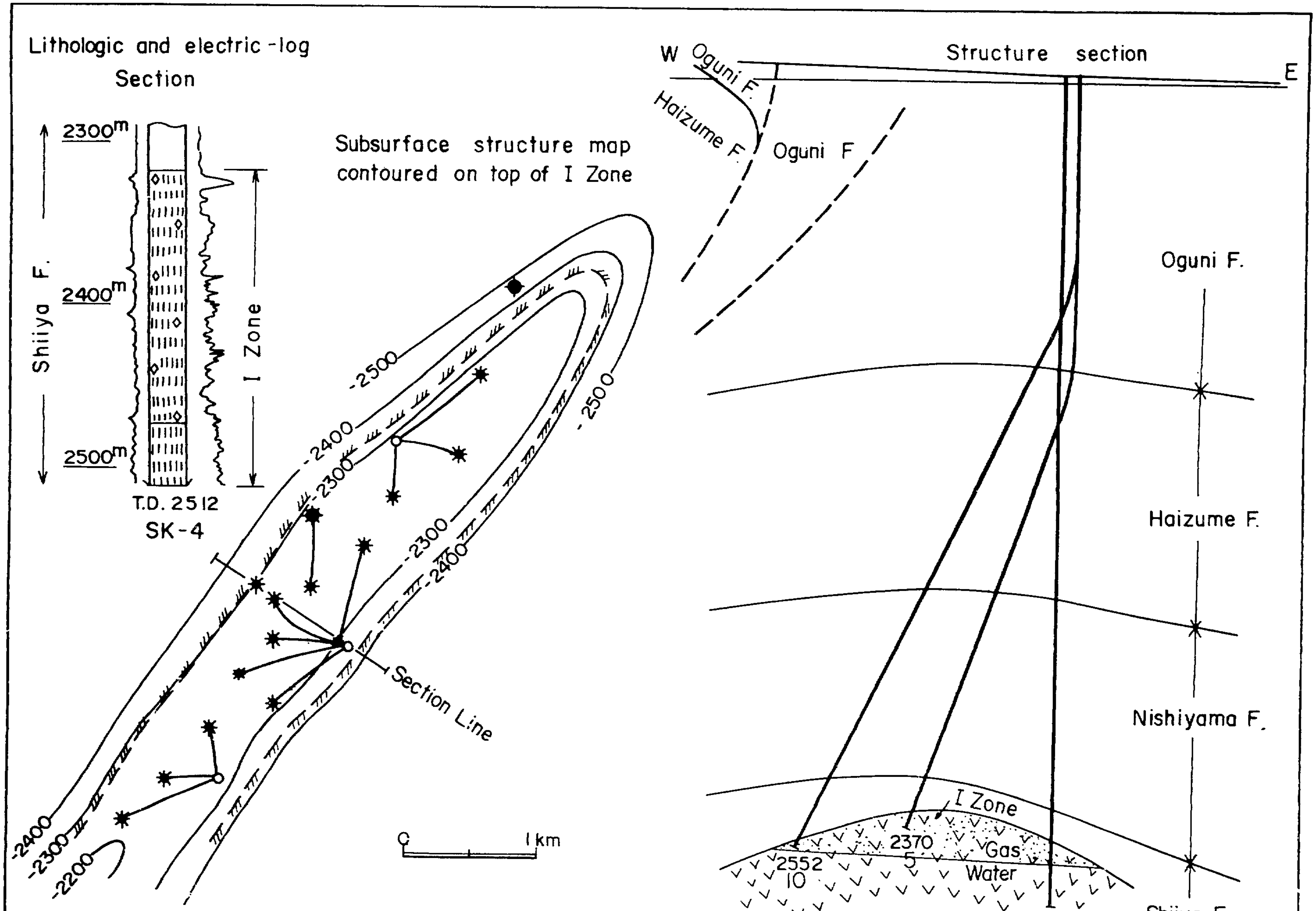


Fig. 7 Fujikawa Gas Field

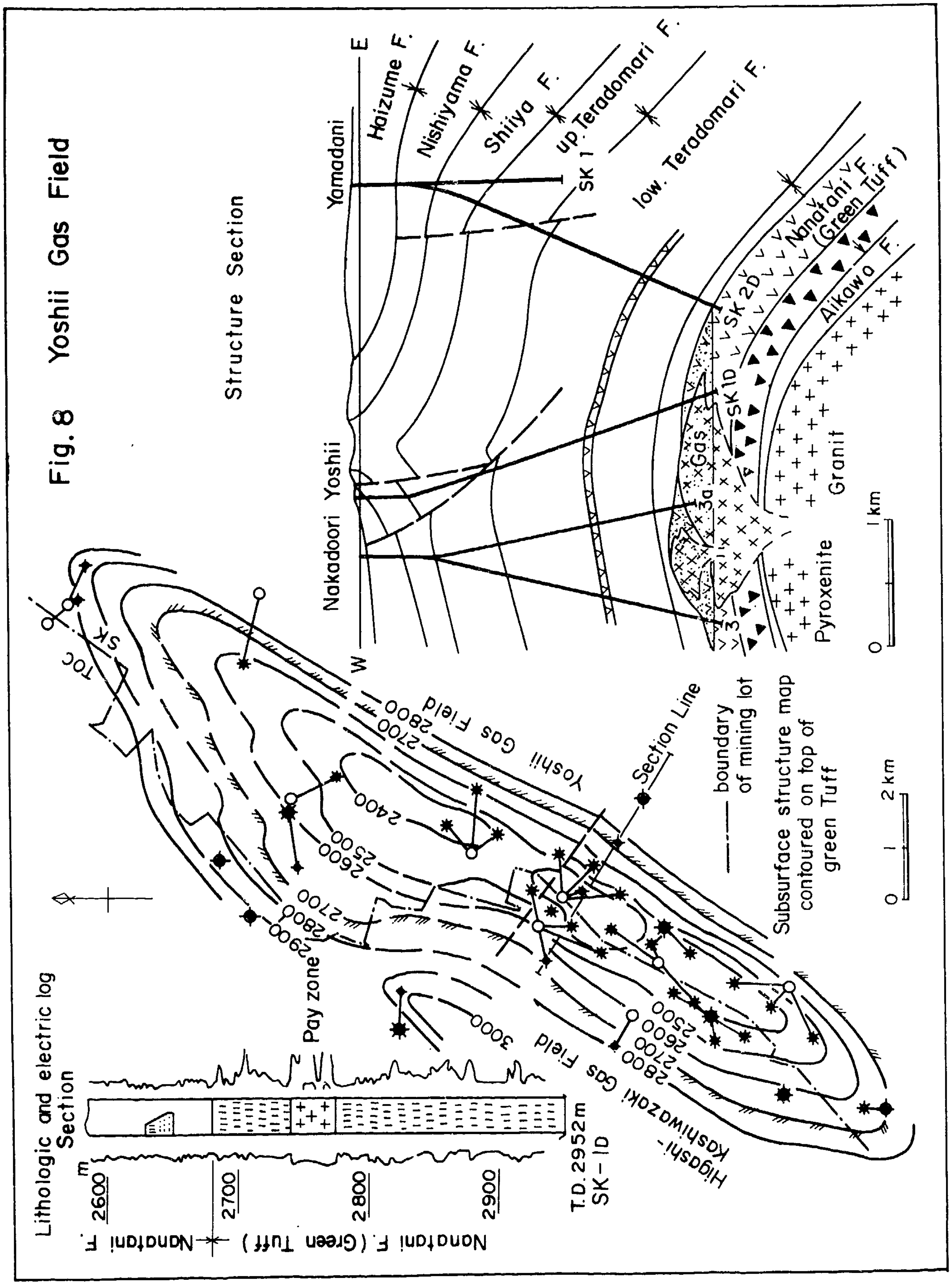


Fig. 8 Yoshii Gas Field

Table 1.

Cenozoic Stratigraphy of Oil Fields in Northeastern Japan

Geologcal Age			Stratigraphy: Akita	Stratigraphy: Niigata	Foraminiferal Zonules: Benthonic Forms	Foraminiferal Zonules: Planktonic Forms	Oil and Gas Producing Zones
Quaternary	Holocene		Terrace Deposit	Terrace Deposits			Akita Sub-basin; Niigata Sub-basin
Quaternary	Pleistocene		Katanishi F	Oguni F			
Quaternary	Pleistocene		Shibikawa F	Tsukayama F			
Tertiary	Pliocene	Late	Sasaoka F	Haizume F	Protoelphidium clavatum - Pseudorotalia gaimardii	Globigerina pachyderma (sinistral) Globigerina incompta	
Tertiary	Pliocene	Early	Jobutentokuji F	Nishiyama F	Uvigerina akitaensis -	Globigerina pachyderma (sinistral) Globigerina quinqueloba	
Tertiary	Pliocene	Early	Kabutentokuji F Katsurane Fc	Nishiyama F	Islandiella japonica	Globigerina pachyderma (dextral) Globorotalia inflata	
Tertiary	Miocene	Late	Funagawa F (up)	Shiiya F	Miliammina echigoensis - Martinottiella communis	"Orbulina universa" Globigerina woodii (s l)	
Tertiary	Miocene	Late	Funagawa F (low)	Teradomari F (up)	Spirosigmoilinella compressa -	Barren Planktonic Foraminifera	
Tertiary	Miocene	Late	Onnagawa F	Teradomari F (low)	Spirosigmoilinella compressa -	Globigerina pachyderma (dextral) Globigerina woodii (s l)	
Tertiary	Miocene	Middle	Nishikurosawa F	Nanatani F; Tsugawa F	Haplophragmoides sp	Globorotalia peripheroacuta Globorotalia scitula gigantea	
Tertiary	Miocene	Middle	Nishikurosawa F	Nanatani F; Tsugawa F		Globorotalia peripheroronda Globorotalia scitula praescitula	
Tertiary	Miocene	Middle	Nishikurosawa F	Nanatani F; Tsugawa F		Praeorbulina curva Globigerinoides sicanus	
Tertiary	Miocene	Middle	Daijima F	Iwafune F; Tsugawa F			
Tertiary	Miocene	Early	Monzen F	Aikawa G			
Tertiary	Miocene	Early	Akashima F	Aikawa G			
Pre Tertiary			Paleozoic and Granitic Rocks	Paleozoic and Granitic Rocks			(◊ shows volcanic reservoir)

Table 2.

Major Oil and Gas Fields in Japan

Name of Field		Sub-basin	Year of Discovery	Producing Horizon	Lithology of Reservoir	Depth of Reservoir
Nishiyama	O F	N	1883	Sy - Td	Tuffaceous Sandstone	-400 ~ -900 m
Higashiyama	O F	N	1888	Sy - Td	Sandstone	+400 ~ -700
Niitsu	O F	N	1896	Sy - Td	Tuffaceous Sandstone	-50 ~ -850
Kurokawa	O F.	A	1913	On	Liparite	-250 ~ -300
Innai	O F	A	1923	Kn - Fn	Tuffaceous Sandstone	-600 ~ -1300
Yabase	O. F	A	1933	Kn - On	Tuffaceous Sandstone	-350 ~ -1700
Sarukawa	O. F	A	1958	Kn - On	Tuffaceous Sandstone ~ Tuff	-600 ~ -1500
Katamachi	O F	N	1958	Td	Tuffaceous Sandstone, Tuff	-400 ~ -1600
Kuroi	O. F.	N	1958	Td	Tuffaceous Sandstone, Tuff	-500 ~ -1900
Mitsuke	O. F	N	1958	Nt	Dacite, Dacitic Tuff-breccia	-1500 ~ -2000
Higashi-Niigata	G F.	N	1959	Ny	Sandstone, Tuffaceous Sandstone	-1200 ~ -3000
Katagai	G. F	N	1960	Ny	Andesitic Agglomerate	-800
Nakajo	G F	N	1961	Ny - Sy	Sandstone	-800 ~ -2000
Minami-Aga	O. F	N	1964	Sy	Tuffaceous Sandstone	-2250
Yoshii	G F	N	1968	Nt	Dacite, Dacitic Tuff-breccia	-2600
Higashi-Kashiwazaki	G. F	N	1969	Nt	Dacite, Dacitic Tuff-breccia	-2600
Myohoji	G F	N	1969	Nt	Dacite, Dacitic Tuff-breccia	-2600

A : Akita Sub-basin
N : Niigata Sub-basin
Kn : Katsurane F
Fu : Funakawa F
On : Onnagawa F.
Ny : Nishiyama F.
Sy : Shiiya F
Td : Teradomari F
Nt : Nanatani F.

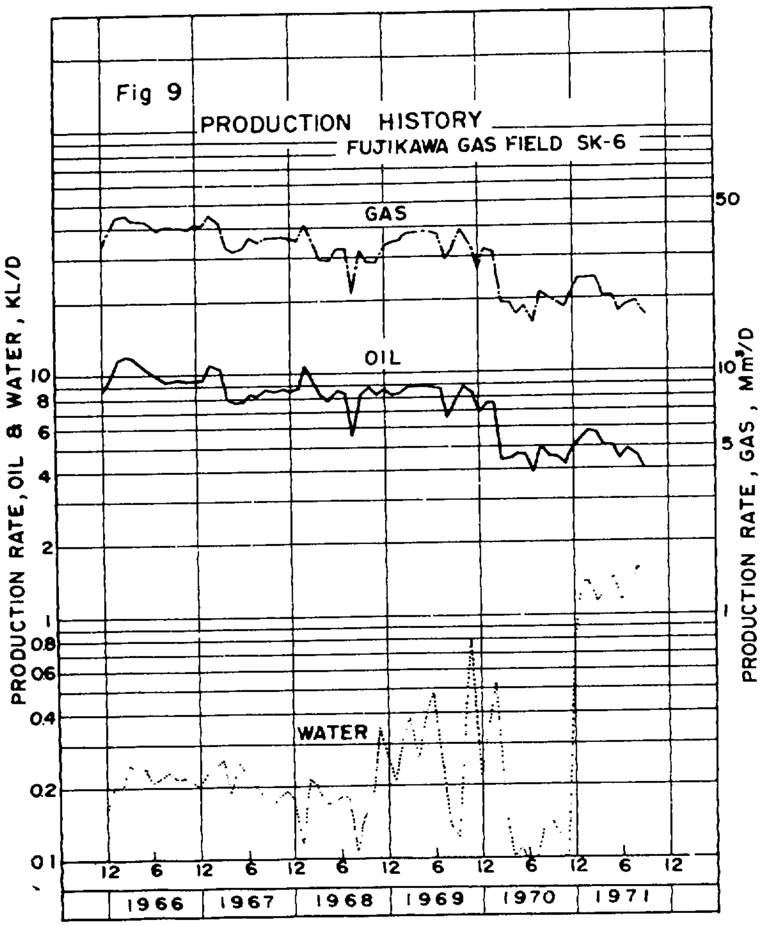


Fig 9
PRODUCTION HISTORY
FUJIKAWA GAS FIELD SK-6
GAS
OIL
WATER
PRODUCTION RATE, OIL & WATER, KL/D
PRODUCTION RATE, GAS, Mm³/D
10
8
6
4
2
1
0.8
0.6
0.4
0.2
0.1
50
10
5
1
12 6 12 6 12 6 12 6 12 6 12 6 12
1966 1967 1968 1969 1970 1971

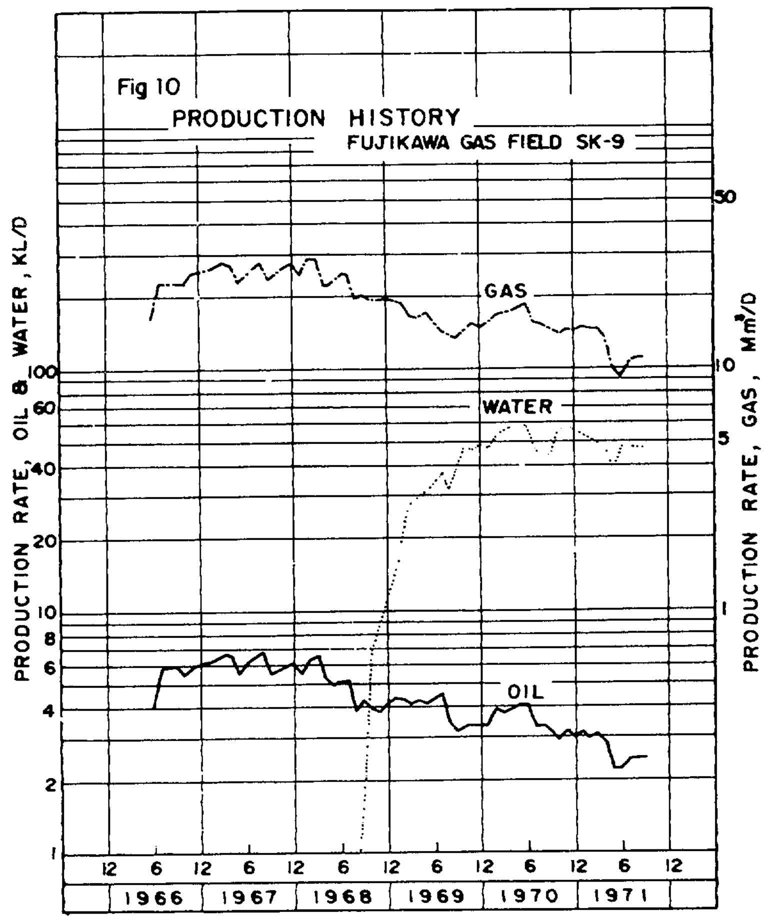
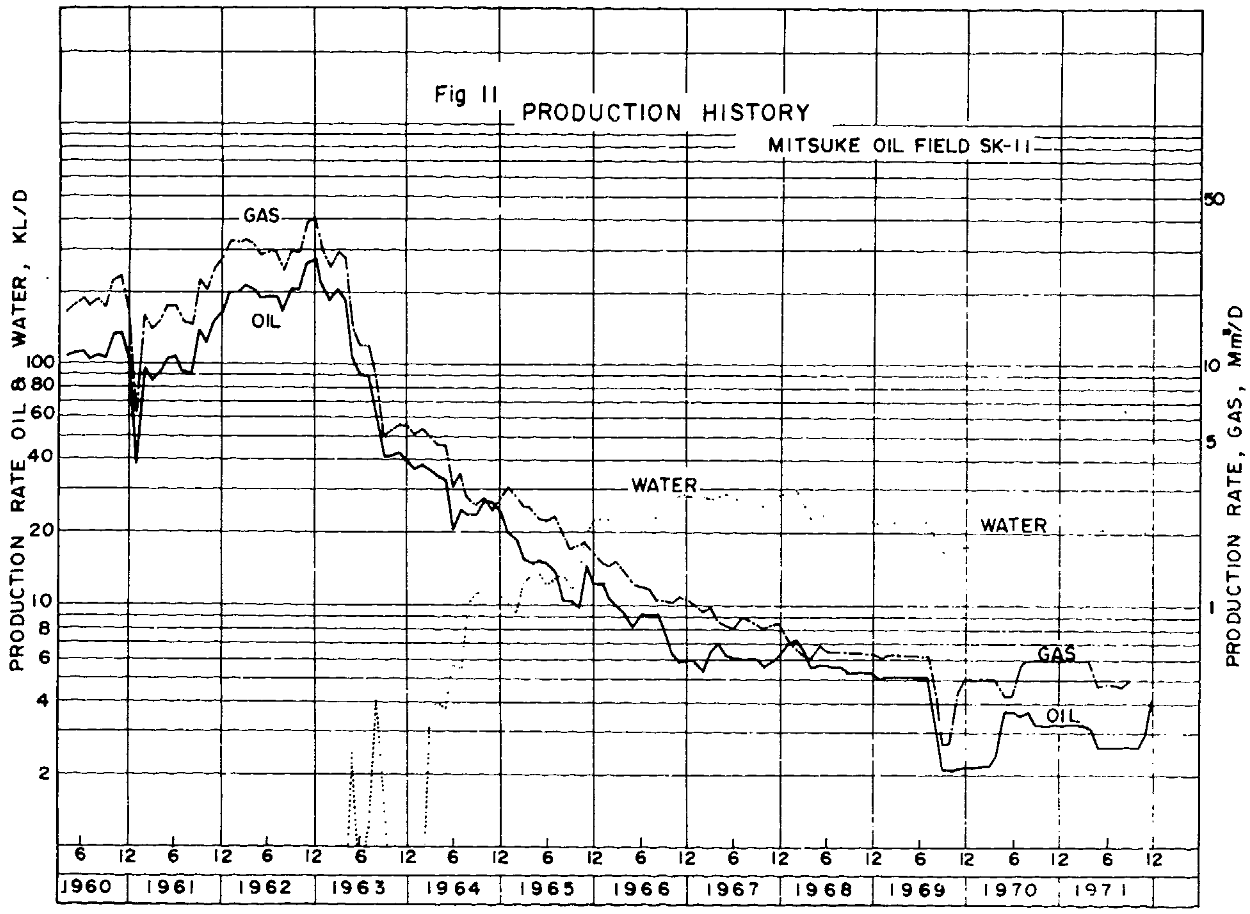


Fig 10
PRODUCTION HISTORY
FUJIKAWA GAS FIELD SK-9
GAS
WATER
OIL
PRODUCTION RATE, OIL & WATER, KL/D
PRODUCTION RATE, GAS, Mm³/D
100
60
40
20
10
8
6
4
2
1
50
10
5
1
12 6 12 6 12 6 12 6 12 6 12 6 12
1966 1967 1968 1969 1970 1971



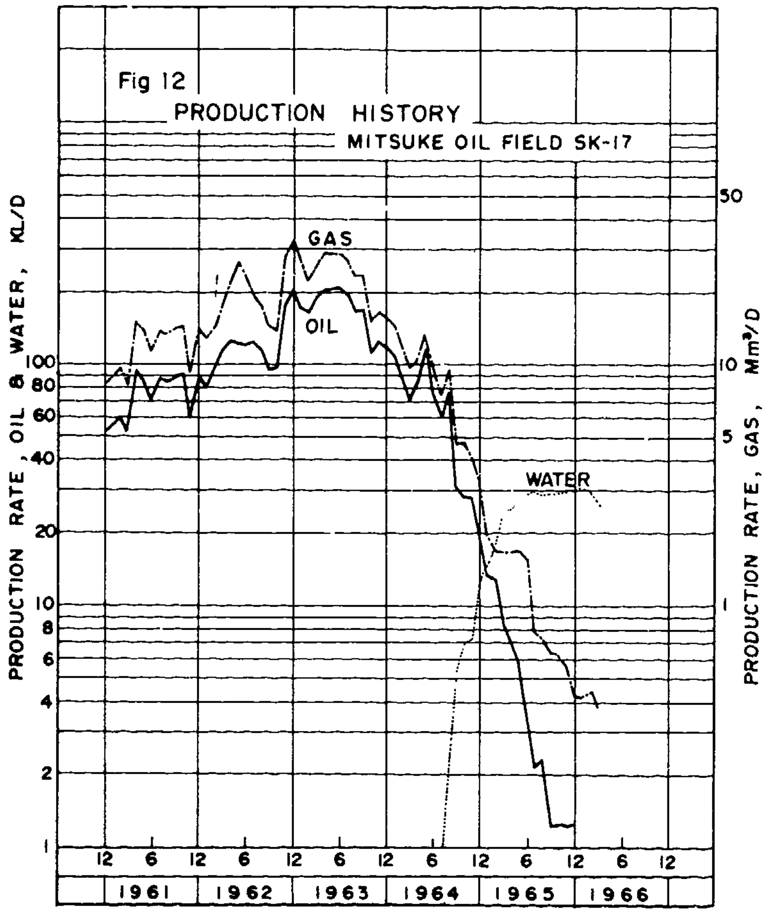


Table-3 Datum plane pressure in Katagai Gas Field(1970.9)

Well	Datum plane pressure	Cumulative gas production
SK-1	66.72 kg/cm²	131.8 MM m³
SK-2	67.79	142.4
SK-5	67.32	149.4
SK-6	67.15	133.0

Table-4 Datum plane pressure in Fujikawa Gas Field(1971.12)

Well	Datum plane pressure	Cumulative gas production
SK-1	297.9 kg/cm²	21.1 MM m³
SK-2	299.5	86.3
SK-5	297.0	60.0
SK-7	297.4	75.6
SK-8	300.9	65.4
SK-10	302.0	0.6
SK-11	299.1	50.6