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SEISMIC REFLECTION & VSP IN SOME GEOTHERMAL FIELDS IN JAPAN - A CONTRIBUTION TO A KNOWLEDGE OF FRACTURED RESERVOIR CHARACTERIZATION-

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ABSTRACT

To obtain insights into the geological and hydraulic characteristics of fractured reservoirs, seismic reflection survey, VSP survey, and pressure transient tests were conducted in three volcanic fields with different types of fractures, which include streaky active fault type, small scale fracture network, and large scale fracture network. These data were integrated with the existing local geological and geophysical data. The seismic patterns and hydraulic properties corresponding to the three types of fractured reservoirs were characterized. That is, streaky fault type is clear fault pattern-permeable, small scale fracture network is seismic pattern of relatively continuous-flat reflectors - impermeable, and large scale fracture network is weakly-reflective seismic pattern - strongly permeable.

These results may contribute to a knowledge of fractured reservoir characterization.

INTRODUCTION

Geothermal reservoirs are usually found in fractured rock formations. For this reason, it is very important to evaluate geological and hydraulic characteristics of fractures in geothermal exploration.

Mapping the fracture distribution within the reservoir comprises a formidable task, since effective exploration techniques for fractured reservoirs do not exist in the early stages of field development.

Since 1988, the New Energy and Industrial Technology Development Organization (NEDO) and Japan Petroleum Exploration Co., Ltd. (JAPEX) have been conducting a research program to evaluate the use of elaborated seismic exploration technology (e.g., seismic reflection, VSP, tomography) for characterizing subsurface fractures in

geothermal fields.

As part of this program, we have carried out seismic reflection, VSP, crosswell seismic tomography, various loggings, and pressure transient tests in some geothermal fields where are the Tanna and the Kakkonda field (Honshu island), and the Yutsubo field (kyushu island).

As a fractured reservoir forms various different structures caused by various tectonic and volcanic activities, it might be expected to obtain the different seismic and hydraulic responses corresponding to them.

Especially, though we also felt uneasy that surface seismic methods in volcanic areas have often difficulty in imaging the reflections due to strong attenuation and scattering in complex volcanic geology, we have been able to obtain records to image subsurface geological structure by the elaborated specifications of field surveys and data processing.

In this paper, on the basis of seismic reflection and VSP data acquired in the above mentioned fields, we studied seismic response patterns on fractured reservoirs, the relationship between seismic response and hydraulic properties corresponding to some different fracture reservoirs were deduced.

GEOLOGICAL SETTING

Geological setting of the three volcanic field are as follows

1) Tanna field

The Tanna field is located in the northern part of the Izu peninsula, central Japan, and forms small basin (radius ~1.5km). Many volcanoes and hot springs exist around there. Especially, the active strike-slip fault - the Tanna fault which is famous for a large earthquake fault among many seismologists - is straight traced in the center of the basin. It is traced for more than 30km in N-S direction on the surface. The Tanna fault is a kind of a wrench fault. From the drilling data of some

(Nakagome, et al.)

National Railway tunnels crossed this fault, the Tanna field is underlain by lake deposit , brecciated tuff of Pleistocene and basal of Pliocene , and the width or fracture zone of the Tanna fault around the basin center are known to be 50~100m (200m at a depth from the surface), and its dip and strike are 70° , and N-S direction.

The land in this basin moved laterally along this fault about 3m away on the occasion of the Kita-Izu earthquake in 1930 (Magnitude 7.0) . Moreover from geomorphological data, the total land displacement along the Tanna fault has been inferred to be more than 1km since middle Pleistocene ,and it has been formed some small basins like the Tanna field along the fault (NEDO 1988-1991).

2) Yutsubo field

The Yutsubo field is located in the central part of Kyushu island. The largest Hacchobaru geothermal power plant (105 MW) in Japan is sited about 3km southward from this field. Many active volcanoes exist around there ,and the stratigraphy is inferred to be underlain by young thick volcanic product which consists of tuff, brecciated tuff, and andesitic lava, etc., and show the relatively simple stratigraphical structure from some exploration well data of another NEDO project (NEDO 1984) in the wide area including the Yutsubo field.

Some major faults as conduits of geothermal fluid are not recognized in this field, while many such faults exist in the Hacchobaru field.

From Gravity survey data, our field is located in very steep gravity gradient zone, which may indicate that a large fault exists in the deep (NEDO 1984,1992-1994)

3) Kakkonda field

The Kakkonda field is located in the northern part of the Honshu island, and 80MW geothermal power plant is operating there.

This field locates in the young volcanic area where surface geology consists of pre-Tertiary basement whit younger intrusion, tertiary formation, and young volcanics. There are many dikes and intrusions (Dacite) in this area, and of them are observed as outcrops.

While major streaky faults like the Tanna and the Hachoubaru field are not recognized, many fracture zones formed by regional tectonic movement with magma intrusion exist in this field. From many production/injection well data, these fracture zone laterally forms very permeable fracture network zones like a layer from shallow formation to deep

formation (depth from 500m to 3000m). This field is full activity of microearthquake, which hypocenter distribution correlates to the productive / injective in this field (NEDO 1995).

FIELD DATA ACQUISITION

(1) Seismic Reflection

The basic specifications of the field data acquisition in the Tanna , the Yutsubo , and the Kakkonda field are as follows;

- Source : P-wave vibrator (4 vibrators)
- Sweep frequency ; 8~70 Hz
- Source interval ; 10m
- Receiver : Geophone(peak response 10Hz)
- Sample rate ; 4ms
- Receiver interval ; 10m

Survey line

- 1) Tanna ; 5.5 km (5 lines)
- 2) Yutsubo ; 13.0 km (5 lines)
- 3) Kakkonda ; 7km (1 line)

(2) VSP

The basic specifications of the field data acquisition in wells the Tanna , the Yutsubo , and the Kakkonda field are as follows ;

Well condition ;

	total depth	No. of surveyed well	survey depth
Tanna	500m	3	50 ~ 500m
Yutsubo	1700m	2	150 ~ 1670m
Kakkonda	3000m	1	80 ~ 600m

- Source ; P-wave Vibrator (1 vibrator)
- Sweep Frequency ; 8-60Hz

- Receiver ; Three-components Geophone (working temperature ~ 260 °)
- Interval ; 25m
- Sample rate ; 2ms.
- Offset distance ; 0 - 500m

RESULTS

We have analyzed the reflection seismic , VSP data and , pressure transient test data in the Tanna , the Yutsubo ,and the

Kakkonda field, in conjunction with other local geological and geophysical information.

The seismic and hydraulic characteristics on fractured reservoir in these fields are summarized as follows.

1) Tanna field

Seismic reflection and VSP data made it possible to understand the structure of the Tanna fault.

Seismic reflection records are characterized by very clear reflectors deep to about 1.0 sec. two way travel time (Fig.1).

The Tanna fault has been inferred to be a streaky fault, but it was revealed that the Tanna fault was composed of a main major fault and many secondary faults from the main fault, which form V - shaped fault zone which is 150m wide around the center of the Tanna basin on the seismic section (Line88 V-A CDP 100~150), which results agree with the Tanna tunnel drilling data mentioned above.

This V-shaped fracture zone shows pressure-ridge like anticline structure, and is similar to the so-called flower or palm - tree structure caused from a wrench fault movement (Bally1983strike-slip displacement).

VSP was effective to identify the boundary of lithologic changes, and the attenuated amplitude of seismic wave and splitting phenomena in the V-shaped fault zone is recognize on

the offset VSP record, and S-wave VSP data respectively. These facts support that a strongly fractured zone exists.

Three experimental wells (T.D. 500m) were drilled in the Tanna basin, one of them (well 1S) was drilled in the V-shaped fractured zone, and encountered many major lost circulation zones (deeper than 200m), and other wells (well 2S,3S) were out of this fractured zone.

Pressure transient test for well 1S(in the V -shaped zone) indicated permeability-thickness value 8.0 darcy-meter, outside wells are 0.5 darcy-meter. It was inferred that considerable hydrologic difference existed between the fracture zone and the outside zone.

Judging from the relative magnitude of kh values and seismic pattern, a fracture zone characterized with seismic patten like flower structure might be estimated as a reservoir with ten order darcy-meter value. (NEDO 1988-1991)

2) Yutsubo field

About 10km of seismic reflection data were acquired over four lines, and two experimental wells (T.D. 1700m) for P-wave multi-offset VSP and seismic tomography surveys were drilled in the Yutsubo field.

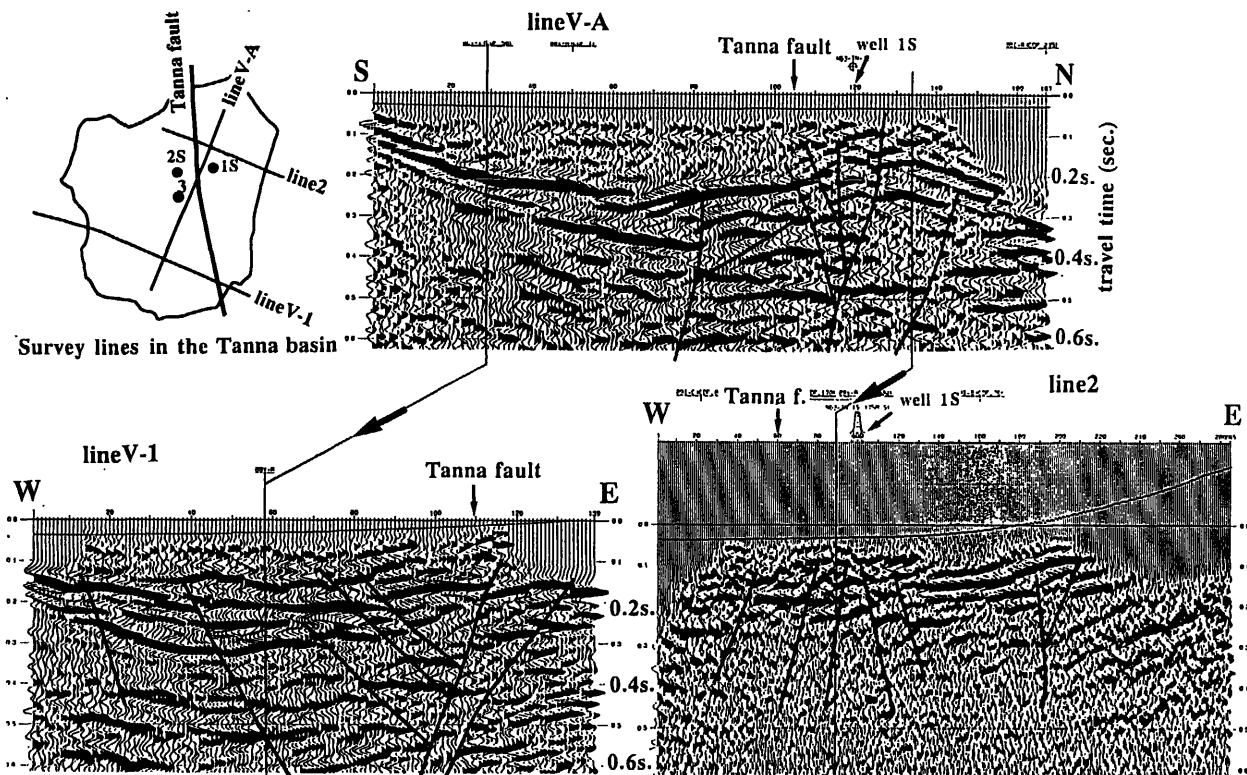


Fig.1 Reflective seismic section in the Tanna field

(Nakagome, et al.)

Seismic reflection records are characterized by disturbed and discontinuous reflectors with several diffractions deep to about 1.0 sec., probably produced by fractured and rough surfaces with sudden lithological variations, but these reflectors relatively mark contacts among geological units (Fig.2). These contacts are nearly flat, having no discontinuities that would indicate faults.

On the other side, VSP data (Fig. 3) showed some clear reflectors which well correlate to well geology. These reflectors are flat and continuous.

However, the big fault system like the Tanna field is not recognized from VSP and seismic reflection data.

Both wells did not encountered major circulation zones, but encountered many small circulation loss zones from a depth of 1640m to 1770m, and relatively permeable or fractured zone is about 130m or less in thickness. This permeable circulation loss zone lies among the flat reflective horizons in seismic sections.

A pressure transient tests were carried out in the above mentioned two wells. These pressure data analysis indicates that both wells are completed in a low permeability and low storage formation.

The permeability-thickness (kh) value is about 0.5 darcy-meter, and is about an order of magnitude larger than that of the Tanna field.

Moreover seismic reflection, VSP, and pressure data were integrated with Schlumberger's Formation Micro scanner Log. The circulation zones coincide with fracture zones analyzed from FMS data .

Further from seismic tomography survey , the circulation zone corresponds to the relatively low velocity anomaly zone in velocity tomogram, which not extends so far, limited to several ten meters.

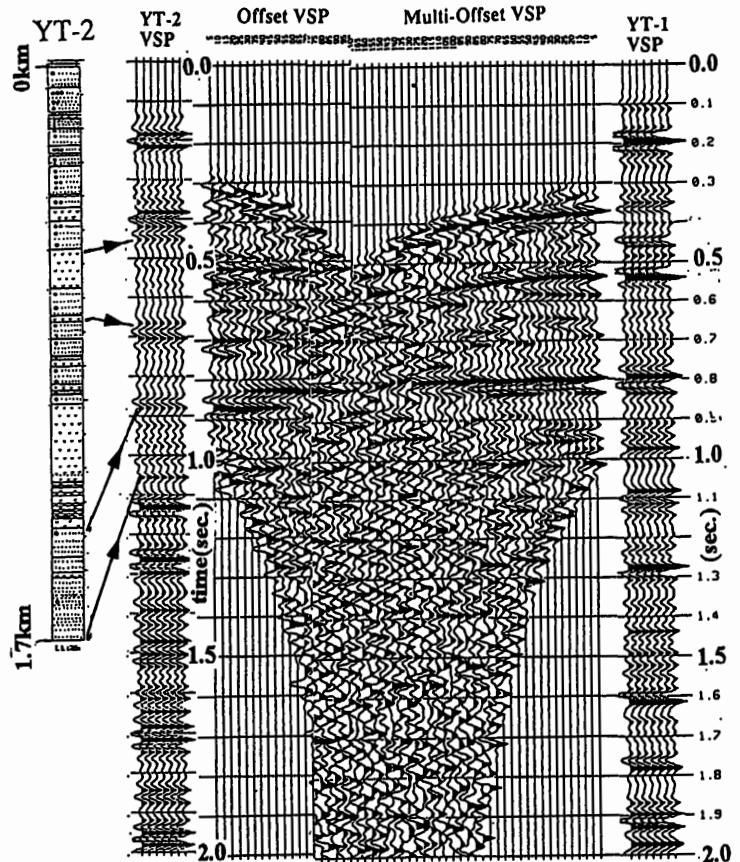


Figure 3 : VSP record section between wells YT-1&YT-2, and well geology (Distance between YT-1&YT-2 ; 270m)

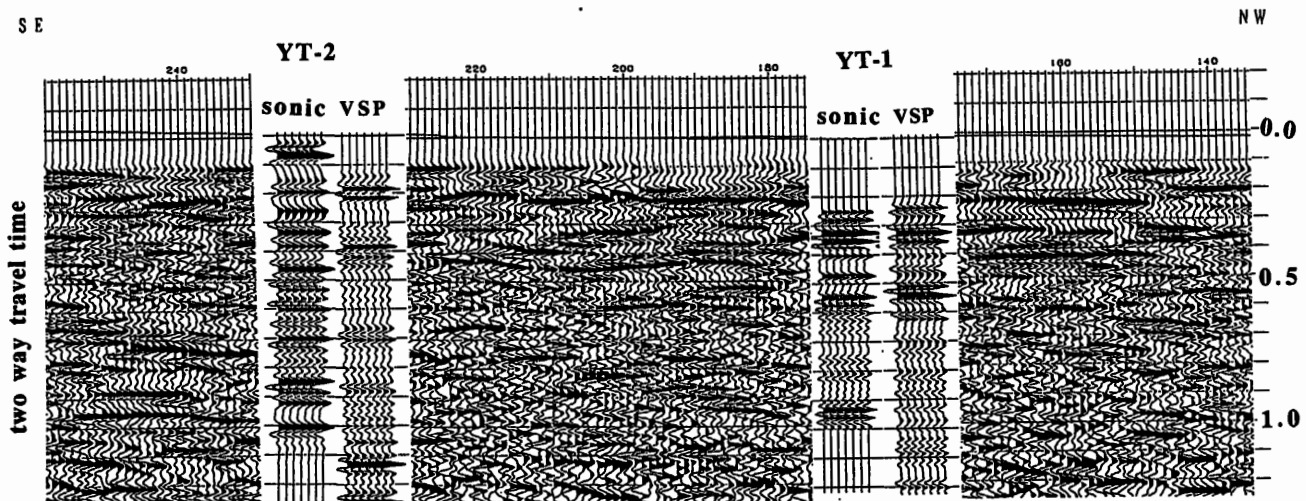


Fig.2 Reflective seismic section in the Yutsubo field

Judging from the relative magnitude of kh values and seismic pattern, a fracture zone characterized with relatively flat and discontinuous reflective pattern might be estimated as a reservoir with zero point five order daecy-meter value.(NEDO 1992-1994,Nakagome 1994,1995)

3) Kakkonda field

A seismic reflection survey was carried out along the Kakkonda river in order to confirm the possibility for the seismic method to detect the large scale fracture network reservoir. Many production / injection wells (drill depth ; 1000m ~ 3000m) are drilled near the seismic survey line. Some deep wells (total depth~3000m) reached pre-Tertiary basement rock (dacite) around a depth of ~3000m from a surface .

On the seismic section , a well-developed discontinuous reflectors are recognized at 1.0sec. two way travel time overall (Fig. 4). This reflective horizons correspond to a depth of approximately 2.5 km which marks at the top of pre-Tertiary basement from sonic log and VSP data conducted in well WD-1 (TD 3500m) sited at CDP No. 90, which form gentle dome structure from CDP 5 to CDP 800 and descends eastward , which is also in accord with pre-Tertiary basement structure inferred from some other deep wells (~ 3000m) drilled in the Kakkonda field . As reference ,the geological cross section along the seismic survey line inferred from well data is indicated below the seismic section (Fig.4). Structural pattern on the seismic section seems to be relatively concordant with the geological model.

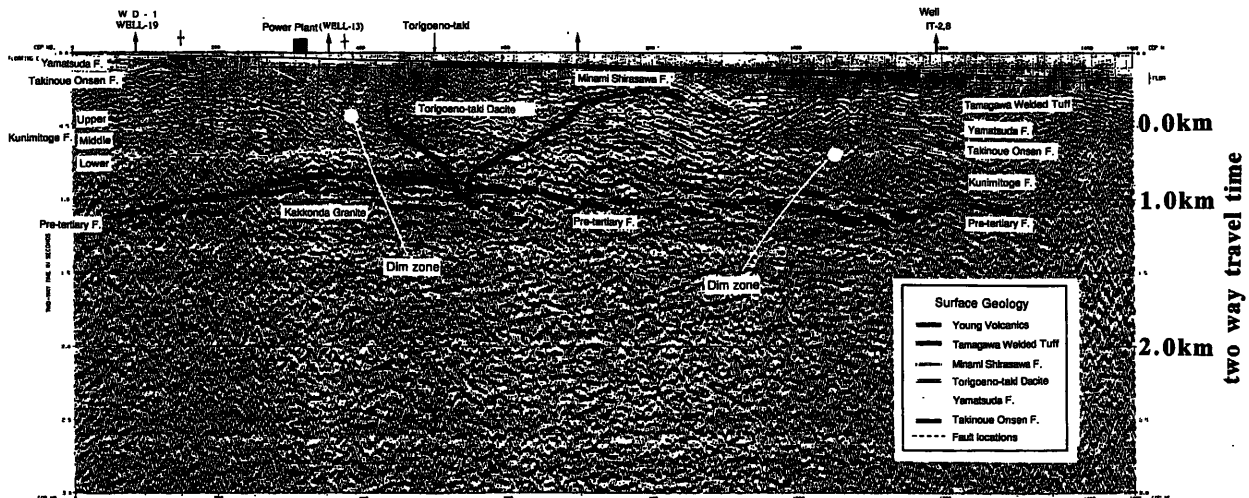


Fig.3 Reflective seismic section in the Kakkonda field

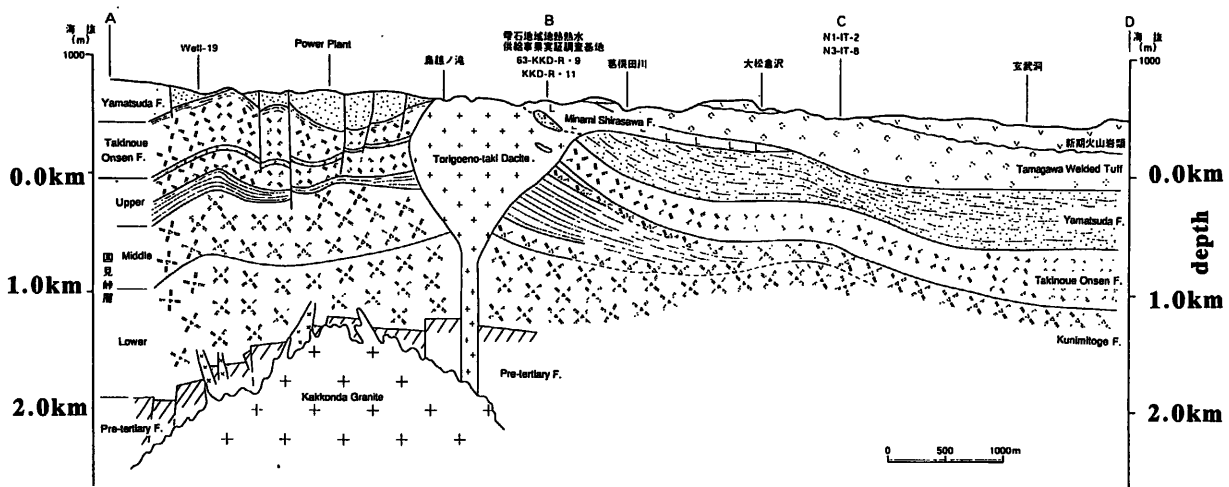


Fig.4 Geological cross section in the Kakkonda field

(Nakagome, et al.)

On the other hand, some very weakly-refractive zones (dim zone) are recognized . One of them exists below the distribution of the Torigoeno-taki intrusion (dasite) which crops out near the surface(CDP430~750). Its outline of the dim zone appears like mushroom shaped pattern . The other one is distributed under the power plant from the surface to 0.7 sec (corresponding depth ~1800m). two way time between CDP 180 to CDP 420 , which dim zone extend eastward to the deep . This dim zone corresponds to the hypocenter distribution zone of very active microearthquake.

Moreover many wells drilled in this active microearthquake zone also encountered major circulation loss zones, - that is, major production zone in the Kakkonda field - ,and comparing with the various existing data, this zone corresponds to the faulting and folding zone, and supposed to be fractured zone discussed in the existing study.

Pressure transit tests conducted in this zone indicated permeability-thickness value 20 darcy-meter, which is the largest value of three study fields - Tanna, Yutsubo, Kakkonda-.

Judging from the relative magnitude of kh values and seismic pattern in the production zone, fracture zone characterized with weakly-refractive zone (dim zone) might be estimated as a reservoir with several ten darcy-meter. (NEDO 1995)

These results corresponding to the three fields are summarized in Table1.

CONCLUSION and DISCUSSION

To obtain insight into the character of the fractured reservoirs from a point of structural and hydraulic view, seismic reflection, VSP data and pressure transient data acquired at there volcanic fields with different types fractured reservoirs were analyzed with other geological and geophysical data.

While the same rule cannot be applied to estimate fracture characterization due to the difference of survey specification and measurement depth range , and a few case-studies, their

characteristics corresponding to different types - fracture-streaky active fault, discontinuous small scale fracture network, large scale fracture network-, might be able to make rough estimation.

1) streaky active fault type

The fracture related to a streaky active fault (strike slip type fault) like the Tanna field is characterized as clear seismic fault pattern (individual discrete fracture) in contrast to the confused or dim pattern on the seismic section , and considerable hydraulic heterogeneity - high permeability limited in a fault zone kh value ten order darcy-meter in a fault and outside 0.5 darcy-meter.

The fractured reservoir controlled by streaky major fault composed of individual discrete faults which interval is as long as it is indicated as seismic reflection response - longer than several ten meters. As such a fractured reservoir are restricted to a fault zone , considerable hydraulic heterogeneity existed.

2) small scale fracture network type

The fracture related to small scale fracture network like the Yutsubo field is characterized as relatively continuous reflective horizons not to be recognized as clear gaps of the horizons and weak-refractive zone (dim zone) on the seismic reflective sections and VSP section ,and relatively low permeable zone as a whole.

kh value of the formation showing such reflective pattern is estimated 0.1 darcy-meter.

The fracture like Yutsubo field is composed of discontinuous and small fractures set and does not extend so far. While the spacing between fractures from Formation Microscanner log is short, It would appear that the continuous fractures extended so far have a smaller aperture than the discontinuous fractures judging from kh values. The width or aperture of fracture is as short as it is not indicated as seismic reflection response - less than several meters.

3) large scale fracture network type

The fracture related to large scale fracture network like the Kakkonda field is characterized as confused or very weakly-refractive or non reflector zone not to recognize

Table 1 Fractured Reservoir Characteristics of the three fields

Field	Type of Reservoir	Seismic Pattern	Permeability – Thickness
Tanna	active fault	clear fault pattern	~10 darcy-m
Yutsubo	small fracture network	flat continuous	~0.01 darcy-m
Kakkonda	large fracture network	dim	several~ tens darcy-m

geological structure on the seismic reflection and VSP sections , and relatively very high permeable zone as a whole. kh value of the formation showing such reflective pattern is estimated over several ten darcy-meter.

The fracture like the Kakkonda field is composed of many continuous and small fractures set and forms fractured zone over a wide area. The spacing between fractures from Formation Microscanner log is very short, the fracture rock mass can be treated as continuum mechanics provided by the so-called double-porosity model.

-the fracture and the porous blocks are regarded as two separate but overlapping continuation - this zone is not indicated as seismic reflection response - less than several centimeters.

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