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A Case Study of Geometrical Fracture Model for Groundwater Well Placement, Eastern Munsan, Gyeonggido, Korea

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지하수개발을 위한 단열모델 연구사례(경기도 문산 동쪽지역)

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본 연구는 단열지질조사를 통한 대상지역의 지하수 단열 모델을 규명하여 지하수를 개발한 사례이다. 경기도 문산 동쪽에 위치하고 있는 산업시설물에서는 시설물 유지에 필요한 용수 수급용 지하수개발이 요구되었다. 지하수 개발 대상지역은 0.15 Km^2 면적으로 제한되어 있었을 뿐만 아니라, 지하 매설물, 건물 등의 시설물을 피하여 선정, 개발해야 되는 매우 어려운 지리적 조건을 가지고 있었다. 지하수 개발 대상지역은 지하 매설물이 설치되어 있어 지구물리탐사가 불가한 곳으로 지질조사에만 의존하여 지하수개발을 수행하였다. 편마암의 엽리와 암상조사로 엽리 궤적도를 작성하여 조사대상지역에 발달하고 있는 남북방향 습곡축의 향사형 습곡이 인지되었다. 동서방향의 지질단면 분석에서는 아이스크림 스푼 모양의 F2 향사형 중첩습곡이 해석된다. 광역조사에서 인지된 N20°E, N30°W, NS 주향의 단층연장 상에 위치하는 평평한 조사대상지역에 수반성 인장단열들의 존재 가능성을 예측하였다. 우수향 운동감각을 갖고 있는 N20°E 단층은 F2 향사형 습곡에 발달하고 있는 두 조의 요곡성 공액형인 P-전단단층으로 해석된다. NE 주향 지질단면상에서, N20°E 단층과 엽리 간의 교각으로 약 100 m 심도에서 지하수저장이 가능한 삼각 프리즘형태의 공간형성이 가능함을 알 수 있어, 중첩습곡의 서쪽 날개 쪽이 지하수개발 가능지역으로 예측하였다. 또한 N40°E 단층도 지하수공급원이 될 수 있다. 단열지질조사와 단면해석을 기초로 하여 N20°E와 N40°E 단층을 따라서 지하수 개발가능 위치를 선정하였으며, N20°E 단층선 상에 위치한 한 지점을 선정한 결과 이곳에서 145 ton/day의 지하수를 개발하였다. 결론적으로 개발에 성공한 지하수는 중첩습곡에 수반된 요곡단층과 엽리 교차로 형성된 지하수 저장고의 불투수 공간으로부터 공급된 것으로 해석되었다.

주요어 : 단열조사, 편마암, 지하수, 엽리궤적도, 아이스크림 스푼형, 향사형 중첩습곡

This study is the case of groundwater development based on the geometrical fracture model of target area established only through geological fracture mapping technique. A fracture mapping of 9 km^2, eastern Munsan, has been conducted to determine geological and hydrological factors for new water well placement in the Gyeonggi gneiss complex. Geophysical exploration was not applicable because of small restricted area and dense underground utilities at the site. Form line mapping on the basis of foliation orientation and rock type revealed a synform of NS fold axis bearing to the south. An EW geological cross-section passed through the site area shows a F2 synform as a double-wall ice cream spoon shape. Three regional faults of N20°E, N30°W and NS have been dragged into the site to help understand extensional fault paths. The N20°E fault with dextral sense is geometrically interpreted as a western fault of two flexural conjugate type-P shear faults in the F2 synformal fold. The NE cross-section reveals that a possible groundwater belt in the western limb of superposed fold area is formed as a trigonal prism within 100 m depth of the intersectional space between the N20°E fault plane and the weakly sheared plane of transposed foliation. Another possible fault for water resource strikes N40°E. Recommended sites for new water well placement are along the N20°E and N40°E faults. As a result of fracture mapping, 145 ton/day of water can be produced at one well along the N20°E fault line. Exploration of groundwater in the area is

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succeeded only using with geological fracture mapping and interpretation of geological cross-section, without any geophysical survey. Intersection of fault generated with the F2 synformal fold and foliation supply space of groundwater reservoir.

Key words : Fracture mapping, East Munsan, Groundwater well, Formline map Double-wall ice cream spoon shape, F2 synformal fold

1. Introduction

Fracture mapping for the purpose of future groundwater resource development has been applied to a small area of E. Munsan, NNW, Seoul. A regional reconnaissance bearing the eastern part of Munsan-eup, 126°47'30"~126°50'00"E and 37°50'00" ~37°52'30"N, was conducted to understand the regional geology and characteristics of fracture geometry. The general rock type is the Precambrian gneiss complex named the Gyeonggi massif (Kim, 1973), implying that the superposed fold patterns must have constrained the development of fracture geometry for the survey. The area for a detailed fracture mapping covers about 9 km^2. It appears that 14 groundwater wells have been developed on faults in the studied area.

The aim of the study is to figure out geological and hydrogeological factors and to select new water well placements in the site of 0.15 km^2. Neither electromagnetic nor magnetic surveys were available because of dense underground utilities in the target area. Therefore, the fracture mapping technique is selected to determine the site feasibility for groundwater development, although a fracture mapping method is applied for the first time to determine groundwater resource.

Morphologically, the Munsan area is divided into two parts; a high mountainous part to the east and a hilly part to the west. A regional mountain range is occupied by the Precambrian(?) metasyenite with ENE-WSW trend, while granite and biotite gneiss occupied hilly small mountains or flat topography of 100 to 200 m high. The Imjingang (Rv.), main drainage system of the Munsan area, meanders trending EW to NS. The river joins the Hangang (Rv.) at the west. The second ordered water systems like streams, branch out from the Imjingang (Rv.), also show an EW and NS trend. The third ordered water system, mainly ditches, around the area has generally a SW trend.

The site within a radius of 3 km consists of low hills and wide-open paddy fields. A geomorphologic relief is less than 100 m. Rice paddies widely occupied the Quaternary deposit. The Quaternary deposit, originated from the adjacent gneiss, covers the site without any outcrop. The general elevation of surrounding hills facing the site are approximately 50 m higher than the flat site. Small valleys of NE to EW trends develop to the north of the paddy area. The stream trending southwest flows toward the west of the site. The site is faced with a low ridge 59.1 m high of north-northwestern trend toward the east. The distance from downtown Munsan is about 2.5 to 3.0 km toward the east. The site is divided into two parts; the west and east of downtown Seonyu-ri. In this paper, we focus on describing the site condition and discussing fracture mapping result for the site limited to the eastern part of Seonyu-ri.

2. Geologic Setting

2.1. Lineament

An IRS-1C panchromatic satellite image (5 m

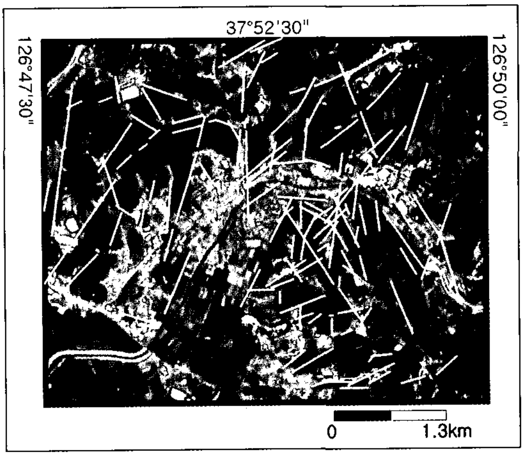

Fig. 1. Lineament of study area on IRS-IC panchromatic image (5 m resolution). NS, N20°E and N30°W directions around the site are detected and accords with faults surveyed in field.

resolution) was used to interpret the lineament pattern related to a possible groundwater belt at the site.

Lineament trends penetrating the site are classified to three directions, e.g. NS, NE and NW (Fig. 1). Among lineaments, strikes of N20°E and N30°W must be closely related to groundwater resources at the site. The detected lineament of N20°E was about 47 to 92 m away from the fault striking parallel with the lineament toward the east. The error limit of the lineament for the detected fault is about 4 to 2 mm on a scale of 1 to 25,000. The accuracy of the lineament was suitable for the fault of N20°E. The lineament of N30°W was about 50 to 90 m away from detected fractures toward the east. Fractures of N30°W generally accord with fracture cleavages and minor faults. The NS lineament was drawn exactly on the NS fault, whose length is shorter toward the south than that of the NS lineament. Another NS fault, 120 m away from the NS lineament toward the west, could not be identified on the satellite image.

A wide-open type arc, like a part of the circular structure and/or fold, was characteristically observed. The curved form shown on the image was expected to reveal foliation and the joint of the Gyeonggi metamorphic complex. Those planes of structural elements apparently seemed to incline toward the concave central part. In view of an aero-photographical interpretation, a wide open-syncline inclining to the south was expected.

2.2. Geology

The study area consists of Proterozoic biotite gneiss, Jurassic granite and Quaternary deposit (Fig. 2).

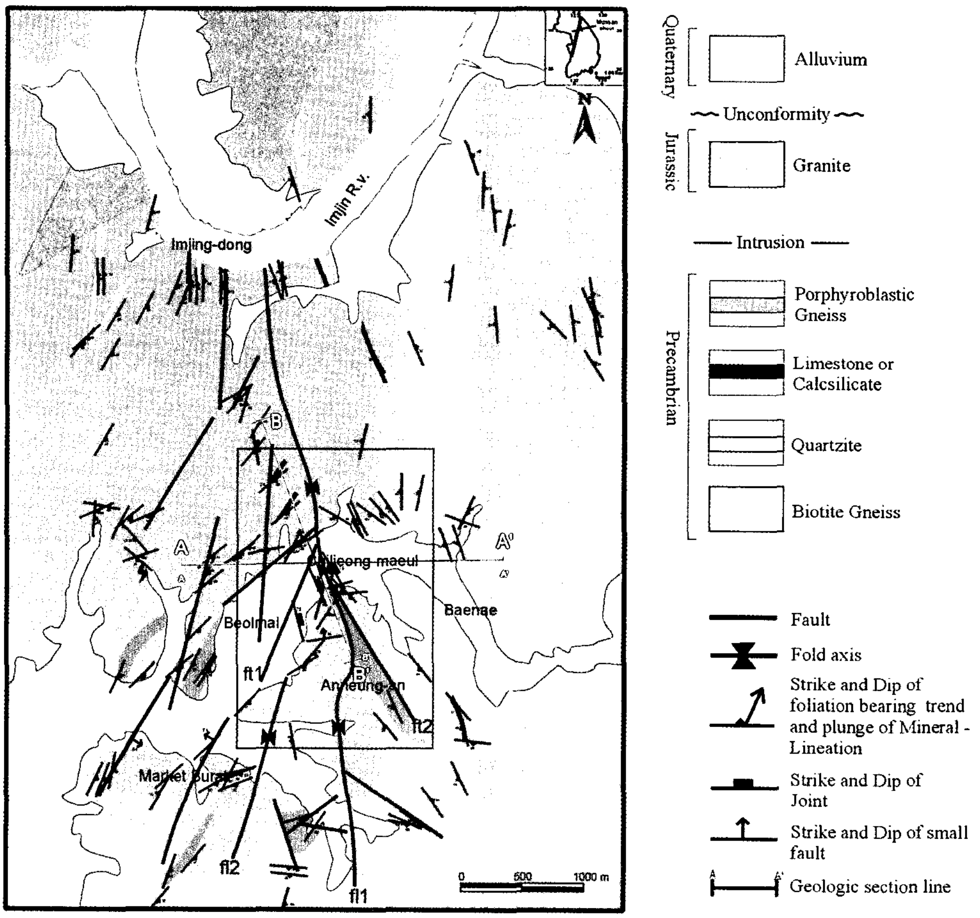

Fig. 2. Geologic map of E. Munsan eup.

The biotite gneiss of the Gyeonggi gneiss complex is the representative rock type in and around the area. The biotite gneiss within the area is divided into leucocratic gneiss and banded gneiss. The porphyroblastic gneiss in small amount is intercalated in the biotite gneiss. Porphyroblasts of feldspar are elongated, stretched and/or rotated. Accompanied Proterozoic rocks such as quartzite, crystalline limestone to calc-silicate and quartzofeldspathic schist are intercalated in the gneiss. The Jurassic granite is distributed in the north of the Munsan district and is a part of the Gaeseong granite body. The coarse grained granite consists mainly of mega crystal quartz and feldspar. Dykes intruding the Proterozoic basement have two trends of intrusion. On the eastern side of the site, the intrusion trend is generally northwest, while the east-west trend is predominant on the western side of the site. The Quaternary deposit is vertically inferred to the Middle Pleistocene at the bottom and the upper Pleistocene to Holocene on the top. The deposit seems to be the valley fill sediments rather than the general river terrace one. The size of the stream westward from the site is not too small to assess the river terrace. However, there is not any evidence of the step type river terrace, but the apron type fan deposit. According to well logs of the existing wells, the depth of the alluvial deposit is in the range of 4 to 8 m. If the range of the depth of the Quaternary deposit involves the highly weathered bedrock, the estimated thickness of the deposit may be thinner than that of the range.

Geologic sequence at the study area is as follows;

Quaternary	Alluvium ~~~ Unconformity ~~~	
Age unknown	Dikes	
	—— Intrusion ——	
Jurassic	Coarse grained granite	Daebo granite
	—— Intrusion ——	
Early Proterozoic	Biotite Gneiss (Porphyroblastic gneiss, Quartzite & Limestone)	Gyeonggi Gneiss Complex

3. Fracture Geometry for Hydrogeological Application

3.1. Fold

Ductile deformation is distinct in the studied area. Superposed folding is the fundamental factor to determine a geometrical pattern of the area prior to finding the accompanied fault.

Foliation orientations are various along fold shape and range from N10°E/SE~N10°W/SW and N40°E/SE~N40°W/SW. A form line map (Fig. 3) on the basis of foliation orientation and rock type

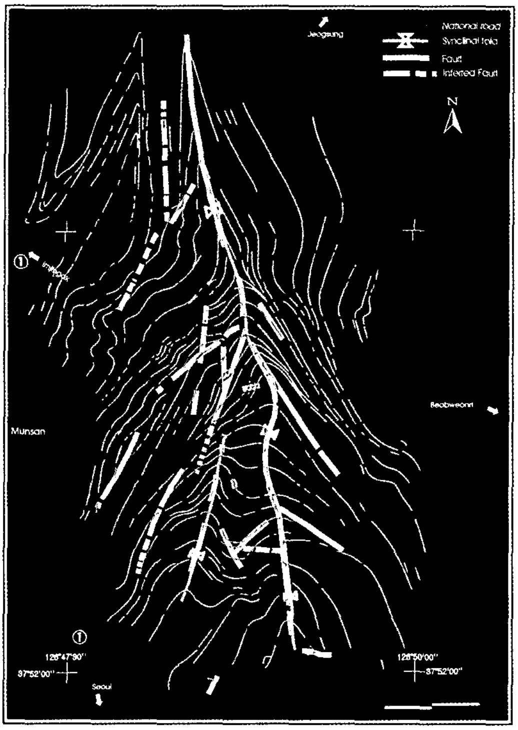

Fig. 3. Form-line map based on foliation orientation in and around the boxed area in Fig 2.

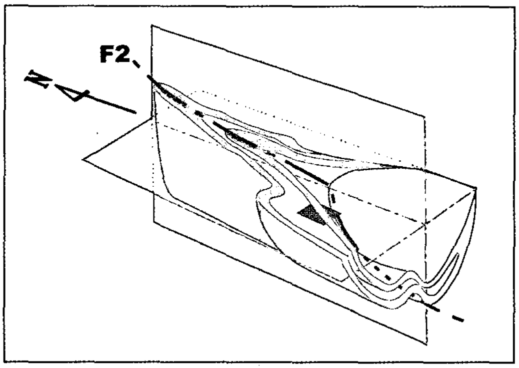

Fig. 4. Schematic 3-D model of the eastern Munsan area. Note ice-cream spoon shape. F2: Trajectory of NS synclinal fold axis (green dot and partial line) plunged to south. Blue quadrangle: site.

shows a synformal fold with NS axis. Two F2 fold axes (fl-1 & fl-2) pass through the northeastern part of the site and plunge toward the south. The major synclinal fold (fl-1) changes its form from open type in the southern part to an isoclinal type in the northern part, like a double-wall ice-cream spoon shape (Fig. 4). The trajectory of the NS synformal fold axis shows a southern plunge.

The open type fold in the southern part has another accompanied fold axis (fl-2) on the western limb of the major synclinal fold (fl-1). The axis (fl-2) develops in the open type fold area and terminates its life in the northern part of the open type fold, so that the axis (fl-2) is discontinuous prior to reaching the north of the site (Fig. 2 & 4).

A generally intrafolial minor fold pattern is observed on the gneiss outcrop. Minor fold axes of the intrafolial folds bear plunges toward the south-southeast, south and south-southwest from westward to eastward. The variety of minor fold axes, foliation orientations and stretched mineral lineations are indicators to understand the wide open-syncline bearing plunge to the south. The occurrence of the porphyroblastic gneiss and the intercalated quartzite bed is another key horizon to determine the synclinal form. On the NS cross section (Fig. 5a) plunges the foliation of gneiss toward the south, and seems to lay as a conformable formation without folding, while the EW cross-section passing through the site shows a wide open type, F2 synform (Fig. 5b).

Intrafolial folds observed on outcrops show two discrete types of Z and S shapes, respectively. The Z type minor fold is detected in the west limb of SE dip direction and verges to the southeast. With this Z sense, an inclined isoclinal type antiform is expected to the southeast. On the contrary, the vergence of a S type-minor fold in the eastern limb of the SW dip direction is to the southwest. The S sense would indicate an antiform to the northeast. Two vergings revealed that the earlier flat F1 fold had been refolded to a F2 synclinal fold (Fig. 6). Consequently, the present synform is interpreted to the superposed F2 fold. The synform shows the composite characteristics of the dome-crescent-mushroom shape on the surface. The surface fold type belongs to a type II of Ramsay's classification of interference fold pattern (Ramsay and Huber, 1987). This fold type has been mentioned in the Munsan geological sheet on a scale of 1:50,000

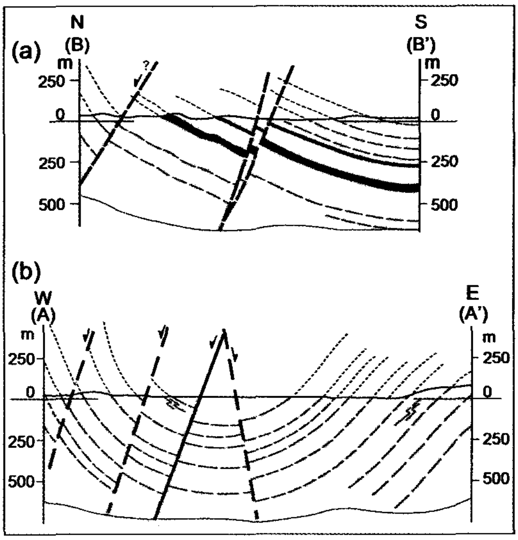

Fig. 5. Geologic cross-sections of an N-S (a) and E-W (b) strikes. On the E-W section detected the F2 synclinal fold.

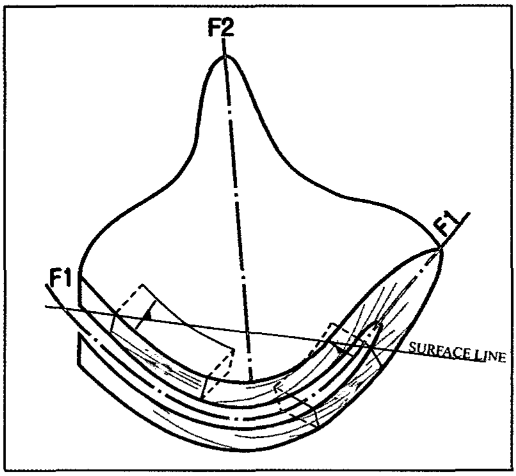

Fig. 6. Simplified cartoon showing verging of intrafolial folds (Z and S types).

(Choi *et al.*, 1998). The site is situated on the west limb of the F2 syncline, close to the discontinuous F2 fold axis (fl-2).

3.2. Fault Geometry

Fractures related to the folding structure show two trends, NS and EW faults are accompanied by secondary fractures as the joint. These secondary also have NS or EW trends and are concerned to the fault strike. Within a radius of 3 km of the site, examined faults have almost a normal movement sense with a north-south trend, except for an ENE or WNW fault in the southern part of the studied area. Normal faults must have brought out from the synclinal folding.

The NS fault has been observed in Imjin-dong at the northnorthwest of Munsan and is oblique to the direction of synclinal fold axis. In an adjacent area of the site, observeded faults are of N10°~30°E (W)/55°~75°NW (NE). Further south of the site, around Baenae, Beolmal and Market Burak, N10°~30°E faults are on the west limb of F2 synclinal fold. One of these faults, N20°E/70°NW (ft1), passes through the site. The east limb includes a fault of N20°W/70°NE (ft2) extended from Chiljeong-maeul to Anneung-an (Fig. 2). This NNW fault joins to the major fold axis of syncline. These faults are a kind of flexural shear fracture formed by an EW compression that is perpendicular to the NS axial fold. Faults of N55°W (or N56°E) develop in Saengmal of the south of the studied area. Strikes are perpendicular to the axis of F2 fold. These faults are a kind of compressive conjugate set and are formed in the inner arc of folded layers. Two of these faults (ft1 and ft2), N20°E to N20°W, penetrate into the site and may be the extensional path for the groundwater.

As stated, there is no outcrop in the site. However, in view of structural geology, the method of geometrical extensive projection from obtained data of the surrounding areas on all sides was induced into the site. Since it has been determined that the site lies high on the western limb of the open syncline, a large amount of groundwater couldn't be expected in the area. The best placement is geometrically recommended to the synclinal fold axial trace on the surface, rather than the inclined limb part. Generally, the intersection space between vertical to high angle fault and inclined foliation could be a groundwater reservoir. If there was not any fault with a high angle on the western limb, a groundwater belt may not be available in the site.

The extension of three faults has been dragged into the site from outside to find out a possible ground-water belt.

First, the north-northeastern (N20°E) fault is an extension from right lateral step type faults on the adjacent southern area. Two intercalated quartzite beds were selected for the key horizon to understand

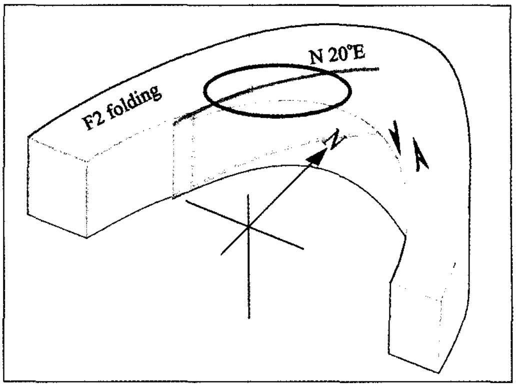

Fig. 7. Cartoon illustrating the flexural brittle fault (post F2 fold) of N20°E (the site lies on the left fault; ellipsoidal shape).

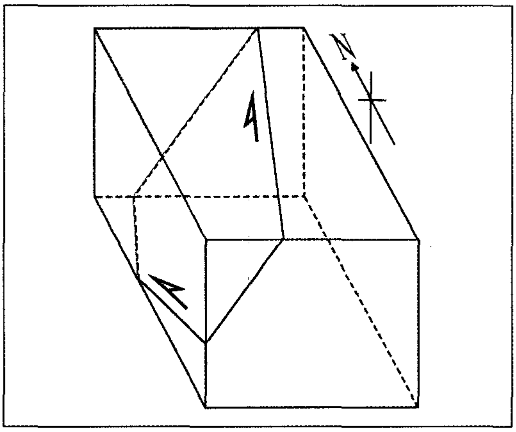

Fig. 8. Schematic block diagram of transtensional fault of N20°E, showing right lateral movement sense on the horizontal surface. On the vertical left plane, the fault movement reveals dextral sense. In 3-D sense, the fault plane (white color) dips to west-northwest.

the NNE fault. The initial form of the NNE fault is geometrically interpreted to as a flexural type-P shear in the synclinal F2 folding (Fig. 7). The dextral movement sense of the fault and the dextral shear sense of the c-fabric of gneiss foliation evidently fit the fold pattern. The extension of the NNE fault toward the north-northeast should be terminated at the junction of the synclinal fold axial trace on the surface because the NNE fault develops within the west limb of the concave fold. As the northern extensional tip of the major F2 fold axial trajectory lies relatively higher than the southern bottom due to the ice-cream spoon type-interference fold shape, the attitude of the western limb with apparent horizontal surface thickness, like a rectangle, maintains an inclination toward the east-southeast as a part of a F2 fold shape. The horizontal dynamic pressure from south-southwest to north-northeast, sub-parallel to the foliation trend, gives an effect of the development of a transtensional fracture (F2 fault) within the inclined rectangle together with a flexural fault (P shear) originated from folding. In view of the coupling mechanism, the attitude of the fracture plane has to be suitable for the transtensional force in a three-dimensional way (Fig. 8). The attitude of the fracture plane preserves the vertical trend of NNE to SSW, and lies high at the southwestern side and low at the northeastern side at the same time. As a result, the orientation of the fault plane keeps the north-western dip (Fig. 8). The dip of the NNE fault is geometrically expected to incline westward.

Second, the north-northwestern (N30°W) fault is approximately equivalent to the major fold axial plane. Here, only fracture cleavages and several minor faults are observed at the site. These fractures are parallel to the syncline fold axis. However, in the extended area toward the south-southeast, faults of N30°W were observed. Hence, the junction area between the fold axis and the fault of N30°W is regarded to as a terminated zone of NNW faulting.

Third, the NS fault on the western side of the NNE fault is a second-order fault. Therefore, the NS fault is not expected to penetrate the NNE fault toward the south.

Last, the N40°E/NW fault that might be another second-order fracture of NNE fault has been inferred to pass to the southeastern margin of the site, as a small flexural shear fault developed in inner part of the F2 fold.

3.3. The Well Status

In the Korean peninsula, there are highly frequent tectonic fractures and fold compared with her land size. The depth of drilling for the purpose of potable groundwater is generally recommended to be 150 m below the surface except in the unusual case of fault and/or fold geometry.

Fourteen exploratory holes were drilled to get groundwater in the site and 12 holes produced water. Recently, only three of 12 wells are in use and the others were abandoned due to low yield or/and contamination. Wells in use are 100 to 238 m in depth and offer a small quantity of water of about 91 to 218 ton/day (16 hours) from each well (Table 1).

The distribution of water wells is obliquely crossing foliation strikes with an east-northeast trend. As a result, the ENE belt of water wells of the area gave good information to raise the geometrical accuracy of NNE and NW faults bearing groundwater. The archived well log data for two existing wells (No. H and M) of both edges in the site were re-interpreted. However, data have no particular meaning for the interpretation of mapped fractures.

In addition, bore hole camera logging was

Table 1. Well log of existing wells of the study area (depth from the surface) after FED's data.

Well No.	Well depth (m)	Top of bedrock (m)	Pump intake (m)	Pump rate (ton/day)	Current statues
A	238			No water	Abandoned
B	213			18	Abandoned
C	244	4.6	99	109	Abandoned
D	98	7.6	80	181	Abandoned
E	184	4.6	99	73	Abandoned
F	54	7.6	48	109	Abandoned
G	172	6.1	99	73	Abandoned
H	122	5.5	101	218	In-Use
I	184	7.0	99	73	Abandoned
J	166	4.6	106	145	Abandoned
K	130	6.1	99	181	Abandoned
L	140	4.6	86	91	Abandoned
M	100	4.6	70	181	In-Use
N	238	4.3	81	91	In-Use

performed to identify fracture pattern in the existing wells. The observed fracture was very weak and tiny. Distinctive fractures of the well-H were detected at 61, 87 and 110 m deep. A dike was observed at 107m deep. The well-M has fractures more frequent than in the well-H. The most distinctive fractures were at 10, 62, 67 and 94 m deep.

4. The evaluation of ground water

After comprehensive analysis of regional and detailed mapping, structural geometry, well logging and a review of the existing wells at the site, a favorable hydrologic view was possibly determined as follows:

If considering the occupied area by faulting, the fault of N20°E keeps the widest area in the site. The three other available faults are striking N40°E, N30°W and NS (Fig. 9). The NS fault system, defined as a small branch fault, is not recommended to get a proper groundwater resource. The NW fault crosses the eastern margin including well-M in the site. The N40°E fault has been inferred to pass the southeastern margin of the site and might supply the water resource for the well-M and well-L. As stated above, a possible groundwater belt in the site is recommended along two faults of N20°E and N40°E from a geometrical point of view (Fig. 9).

If comparing the well status (Table 1) to the well location on the separate map (Fig. 9), it reveals that good yield of water wells in use or used do not lie on the fault, but apart from the fault line toward the hanging wall side. The general horizontal distance from fault line ranges from 37~40 m to 55 m. In the case of 21.3~24.4 m, it is the horizontal distance between well-M and another extended NW fault (ft 2-2). Failed or poor yield of water wells are on the fault line or very near to the line, no matter which side from the fault, e.g. hanging wall side or foot wall side. Another feature of barren case is the central area between NE fault and NW.

The separate map of 14 wells, faults and contour lines was drawn out to project each point of water well vertically onto the optional cross-section between well-K and well-M. From the cross-section between well-H and well-M (Fig. 10), it reveals that the possible groundwater belt in the deformed gneiss area is formed within the intersectional volume between the fault plane and more or less sheared plane of transposed foliation.

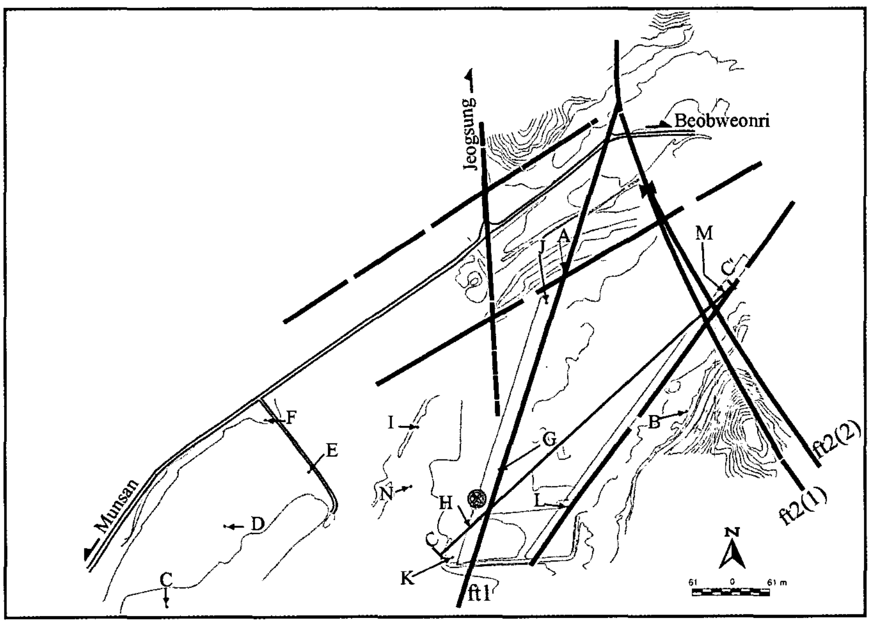

Fig. 9. Locality map of 14 water wells (∘← A) and new well site (⊛) showing the relationship with faults and fold. Light blue area shows the estimated groundwater reservoir. C-C': cross section line. ╪ Fold axis, ── Fault, ─ ─ Inferred fault.

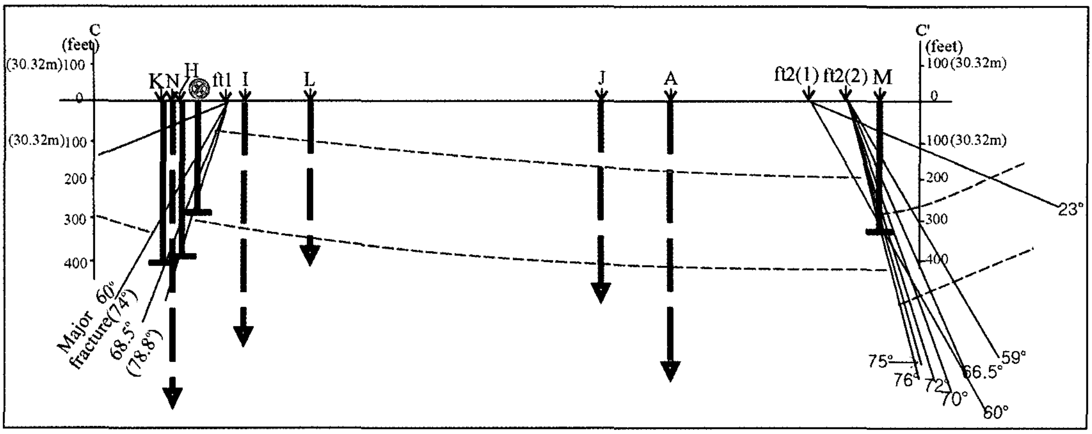

Fig.10. Cross-section of N48°E-strike passed through the well-H and-M at site. Light blue area: estimated groundwater reservoir. Red dotted line: foliation, 60°: fracture dipping angle. ⊕ : New well.

Based on result of this study, a site (Fig. 9) for groundwater was recommended along the N20°E fault and one well with yield of 145 ton/day has been developed.

5. Conclusion

1) The study area is located on the west limb of F2 syncline showing the double-wall ice cream spoon shape. Fractures related to the folding are four faults; N20°E, N30°W, NS and N40°E.

2) A possible groundwater belt is along two faults of N20°E and N40°E. Therefore, the recommendation for the new water well placement is along two faults. The new water well placement should keep the proper horizontal distance of 40-43 m to 60 m apart from fault line toward the hanging wall side.

3) As a result of fracture mapping, 145 ton/day of water was produced at one well by the N20°E fault line.

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Reference

Choi, S.-J., Lee, S.R., Kim, K.B., Kim, J.R. and Kim, B.C. (1998) Geological Report of the Munsan sheet (1:50,000). Korea Institute of Geology, Mining and Materials, 76p.

Kim, O.J. (1973) The stratigraphy and geologic structure of the metamorphic complex in the northwestern area of the Gyonggi massif. Journal of Korean Institute of Mining Geology, v.6, p. 201-218.

Ramsay, J.G. and Huber, M. (1987) The techniques of modern structural geology. Vol. 2: Folds and Fracture, Academic press, p.476-504.

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