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The Alluvial Fan Surface Deformation of the Northern Part of the Ulsan(Bulguksa) Active Fault System in the Southeastern Korea

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Abstract : The geomorphic deformation of the alluvial fans by tectonic movement was investigated along the lineaments of the northern part of the Ulsan(Bulguksa) fault system. Based on the aerial photographs interpretation and field surveys Ulsan fault system was identified as an active reverse fault which has displaced the Quaternary fan deposits. Bulguksa fault system strikes for the direction of NW-SE and N-S. These two lineaments of active fault are crossing at Jinty village in Gyeongju city and the fault plane forms here almost vertical dip. The lateral pressures from the two directions have possibly influenced on the formation of the vertical dip at Jinty village. It should be resulted from that the two pressures responsible for the active reverse fault at which the one with the NW-SE strike thrusts the hanging wall of Tohamsan block southwestward and the other pressure with the N-S strike thrusts it westward over the foot wall of the fan deposits. The marine oxygen isotope stage 8(0.30-0.25 Ma. BP) and stage 6(0.20-0.14 Ma. BP) are presumed to be the ages of high and middle surfaces of the alluvial fan, repectively. The vertical displacements on the high surfaces along the Bulguksa fault system are about 10.5 m at Ha-Dong, 9.5-10.5 m at Jinhyun-Dong, and about 10 m high at Jinty village. And the vertical displacement on the middle surface was measured about 6 m high at Ha-Dong. The average slip rate of vertical displacements is calculated about 0.03-0.043 mm/y.

Key Words : Ulsan(Bulguksa) fault system, the Quaternary, active fault, reverse fault, crossing of lineaments, vertical displacement of alluvial fan

I. Introduction

The existence of active faults and investigation of its displacement have been reported in Korea as one of the most important issues during the last 10 years in the relation to the construction of nuclear power plant or expressway. There exist several raws of lineament on the southeastern part of Korea in the direction of NNE-SSW, collecting at county Yeongdeok as the pivot from south to north like a folding fan. East block of Yangsan fault line is supposed to have moved about 25km to the south by right-lateral slip fault in Tertiary (Woo, 1984), also vertically with the rate of displacement of 0.02-0.03mm/y. in Quaternary by Okada *et al.*(1994).

The Ulsan fault system, occasionally called as Bulguksa- or Hyungsangang fault system, is recently recognized as a typical example of reverse active fault in Korea during the Quaternary. Okada *et al.*(1998) reported it extending with a wide zone of more than 50km and slightly sinuous NNW-SSE trend. It is adjacent to Yangsan fault, also well known as Quaternary fault. Therefore their geomorphological characteristics of alluvial fans, especially the deformation of surfaces by tectonic movement are maybe very similar each other. But the rates of displacement have been

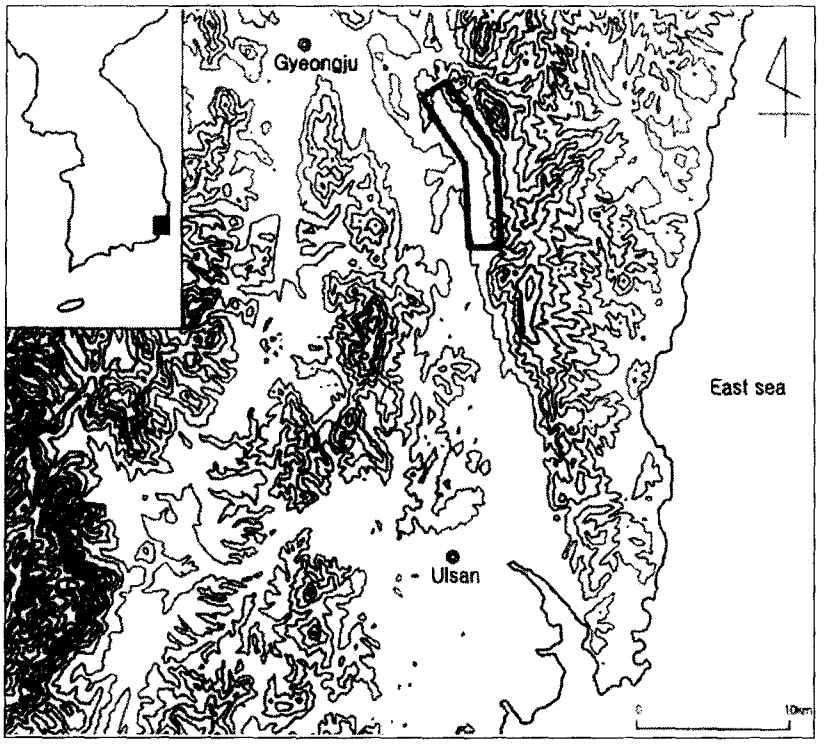

Fig. 1. Study Area.

reported differently each other such as 0.02-0.03mm/y. at Yangsan fault line(Okada, 1994) in spite of 0.08-0.1mm/y. at Ulsan fault line(Okada, 1998). Hwang(1998) and Yoon&Hwang(1999, 2001) have clarified the geomorphic development of alluvial fans at the northern part of this fault system and investigated the displacement of reverse fault system based on the outcrop survey of the sediment layer.

The study area is extended to longer distance from northern Ha-dong to southern Malbang-ri along the lineament of the northern part of the fault system for a distance of 9km, and investigated the geomorphic deformation of the alluvial fans by tectonic movement based on the aerial photographs interpretation and field surveys. And the research is aimed to identify the route and the local differences of fault system and direction of lateral pressure from East Sea by the measurement of the vertical displacement on the fan surface(Fig. 1, 2).

II. The Distributional Characteristics of Alluvial Fans Along Yangsan- and Ulsan Fault Systems

The alluvial fans along the Ulsan- as well as Yangsan-fault line were classified as three geomorphic surfaces such as Higher-, Middle- and Lower surfaces based on the characteristics of their spatial distribution and formation processes, for example, relative height from the riverbed,

Fig. 2. The distribution of alluvial fans along the Ulsan Fault System at study area(compiled by Hwang &Yoon, 2001 and Yoon & Hwang, 2001).

surface slope, conservation or erosion degree of the surfaces, and weathering degree of gravels in sediments(Okada *et al*, 1994, 1998; Jo, 1997; Hwang, 1999; Hwang & Yoon, 2001).

Higher surfaces with the oldest age are mostly covered with pine tree forest and often used as dry field farming on these days. Original surfaces are shaped in fragment of a river terrace rather than a fan. They are 20-25m high from the riverbed and 5-15m from middle surface at the apex, and lowered gradually to the apron. It means lots of sediments made Higher surfaces had been delivered from the

hills and mountains behind and covered on the middle surface during the glacial age.

Middle surfaces are the largest one among the surfaces, distributed widely and continuously, almost keeping a whole fan shape. They were also eroded by some streams flowing from the mountains behind. The lower surfaces are distributed narrowly in small scale along the streams. The Mts Bulguksa with a summit of Mt. Tohamsan(745m) is located on the east hillside of Ulsan fault line, connected to it continuously. Therefore the fans are distributed confluently on the west side of Mts Bulguksa. Rivers Nam and Dong flow as subsequent streams northwards and southwards respectively along the Ulsan fault line. And alluvial fans are developed on the western steep slope of the Mts Bulguksa by the resequent streams flowing into them(Fig. 2).

There exists a great difference on the thickness of gravel layer between east- and west blocks of the fault line on the fans, especially on the higher surfaces. That is, the gravel layer on the east side is 7-10m thick on the bedrock and that of west side is very thick that couldn't be identified, but supposed over 20m thick.

The major factors contributed to the fan formation on the study area are summarized as four in major(Hwang & Yoon, 2001). First, long terms of freeze-and-thaw cycle during the glacial period, second, the steep hill slopes of Mts. Bulguksa, and third, the tectonic movement by reverse fault along the Ulsan fault line during the Quaternary, and lastly, the erosion-labile characteristics of bedrock, such as Bulguksa granite and the Cretaceous sedimentary rock, could make easy the fan formation.

III. Deformation of Geomorphic Surfaces by Active Fault System

The fan surfaces at study area were displaced vertically by the active reverse fault during the Quaternary. The deformation of the fan surfaces could be confirmed from the outcrops and its magnitude were measured on the longitudinal profiles of the surfaces for the investigation of local difference by active fault along the lineament.

The height differences by deformation were measured on the profile A-A′ and X-X′ of the Middle surfaces at Ha-Dong and Malbang-Ri, and on the profiles B-B′ at Ha-Dong, C-C′ at Ma-Dong, D-E′ and E-E′ at Jinhyun-Dong, F-F′ at Jinty village and Y-Y′ at Malbang-Ri of the Higher surfaces(Fig. 3).

The outcrops indicating surface deformation by tectonic movement could be found clearly from the breccia- or gouge zone along the lineament crossing on the fan surfaces(Fig. 4-9). Ulsan fault system at study area has moved to the directions of NW-SE and N-S strikes. The outcrops with NW-SE strike were found at Ha-Dong, Ma-Dong and Jinhyun-Dong and with N-S strike at the Jinty village and Malbang-Ri separately. The characteristics of each outcrop at 5 sites are explained as follows.

1. Outcrop at Southern Side of Ha-Dong

Fig. 4 shows northern side of outcrop at Ha-Dong of the higher surface caused by the dissection of a streamlet. The gouge zone or breccia zone of reverse fault was confirmed with a narrow width under 0.5m. The fan surface on the foot wall is using as a crop field with 17-20m

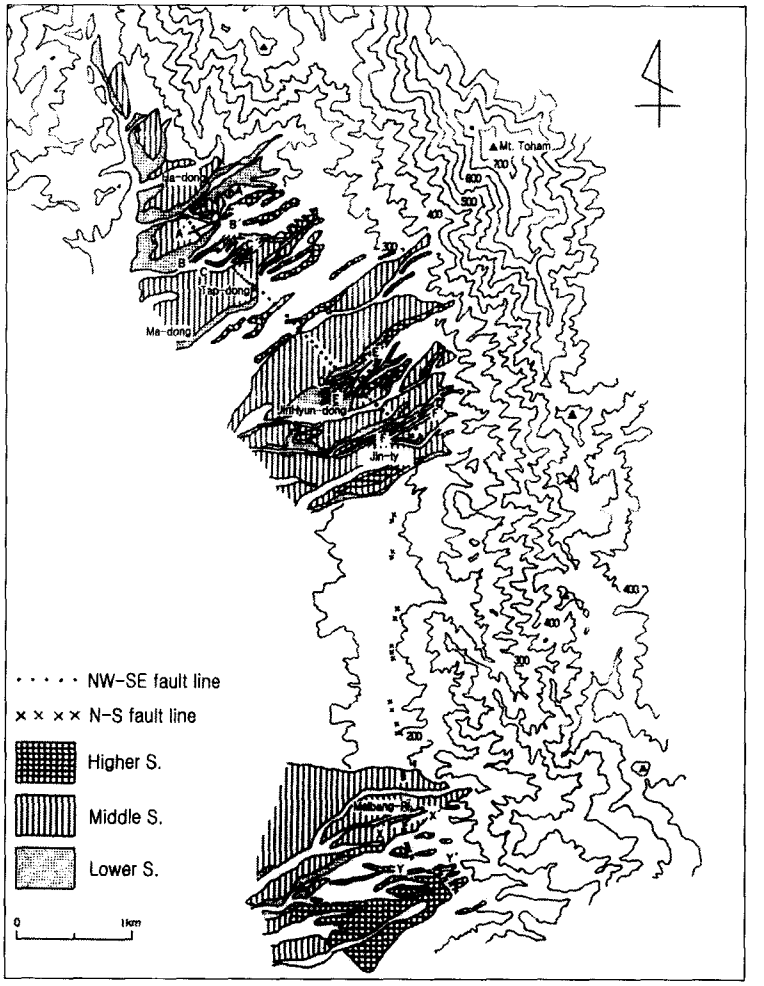

Fig. 3. The distribution and longitudinal profiles of alluvial fans along NW-SE and N-S directions of Ulsan Fault System.

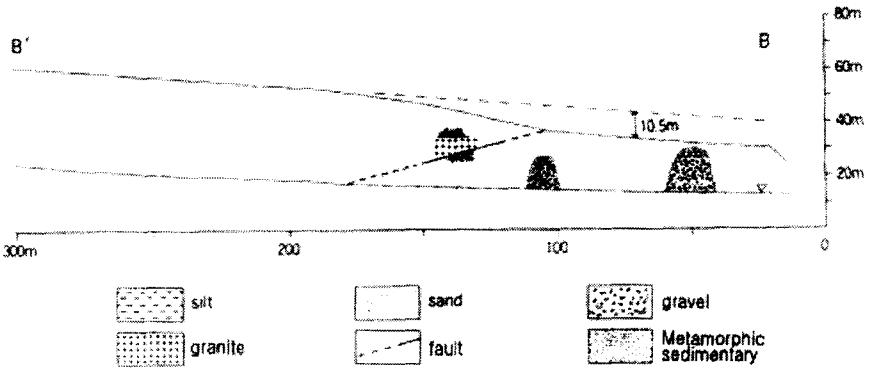

Fig. 4. longitudinal profile of B-B′ and outcrop of reverse active fault at Ha-Dong in the northern part of Bulguksa alluvial fans.

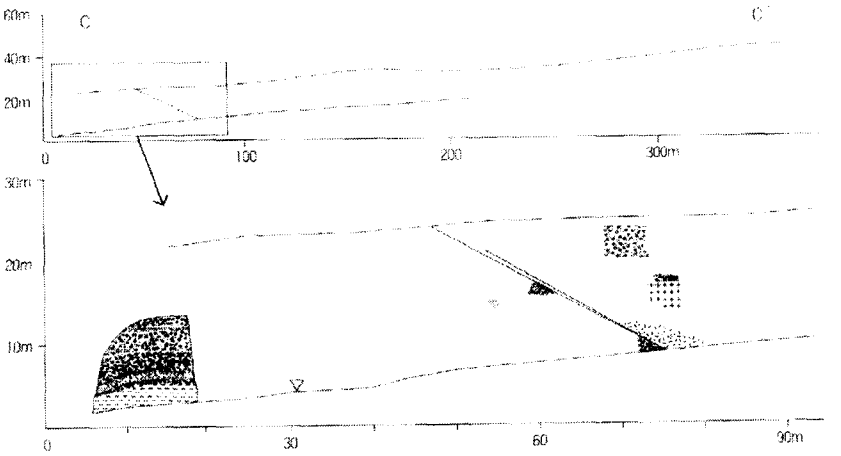

Fig. 5. longitudinal profile of C-C′ and outcrop of reverse active fault at Ma-Dong in the northern part of Bulguksa alluvial fans.

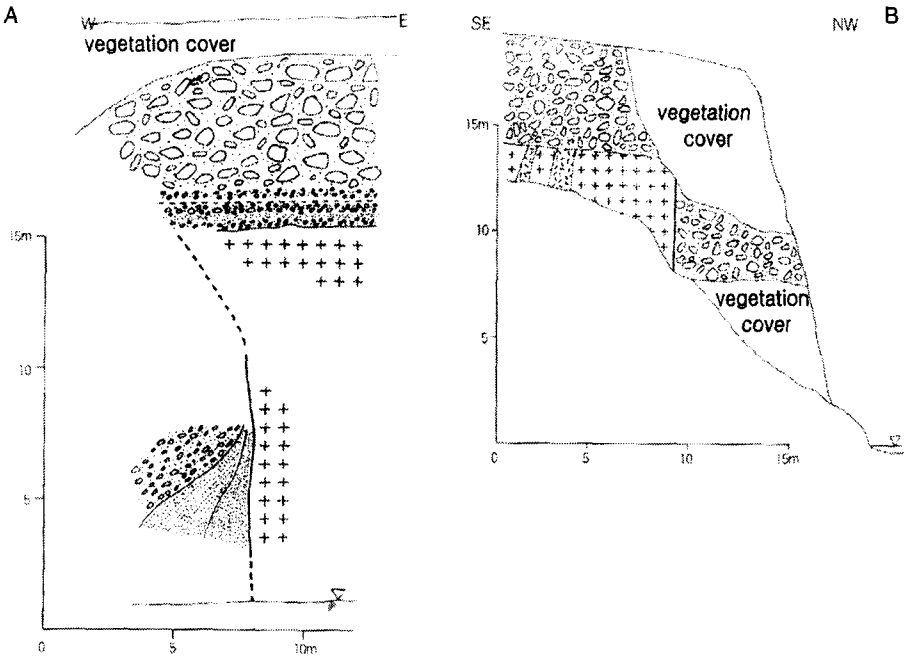

Fig. 6. outcrops of Jinhyun-Dong (A: profile E-E') and Jinty village(B: profile F-F') of Bulguksa alluvial fans.

height from the river bed. And that on the hanging wall with 35-36m had been used as a field till early 1990, but covered with pine trees and acasia forest at present. As a result of reverse fault, hanging wall covered with graver layer of 10m thick on the granite bedrock was

overthrusted on the foot wall of gravel layer as a whole. The breccia zone of fault plane has a dip slope 15° to the horizon.

2. The Outcrop at Northern Side of Ma-Dong

The breccia zone by reverse fault was confirmed at the northern outcrop at Ma-Dong of Fig. 5. The fan surface of hanging wall is 16-18m high from the river bed. Its area exists so narrow to be used only as graveyard or pine forest. And the height difference between hanging wall and foot wall didn't be recognized on the border of fan surface. It was very different from Ha-Dong, because the uneven surface around the breccia zone was changed to be smooth by artificial erosion like plowing for a long time. As a result, the magnitude of deformation by the fault activity wasn't measured for on the longitudinal profile. The higher fan surface of the hanging wall is covered with gravel layer with 8m thick on the bedrock of saprolite gneiss. The gravels of foot wall as well as hanging wall were also weathered deeply. The gouge zone of reverse fault was very narrow under 0.1m with clay of soil color, grayish yellow brown 10YR 6/2. And dip angle became to 35-40° at Ma-Dong, which was 20-25° larger than Ha-Dong.

3. The Outcrop at Jinhyun-Dong

Fig. 6a shows the outcrop of the higher surface deformed by reverse fault at Jinhyun-Dong. The breccia zone could be confirmed along the fault plane to about 7m high, although the surface is about 20m high. The fault plane stands almost vertically, but leaned slightly reflecting a reverse fault on the upper part of the outcrop. It seems like a pattern that eastern hanging wall pushed up to the western foot wall.

The outcrop was exposed around the fault plane caused by development of the dissected valley. And we could confirm "the drag phenomena", which 1.5m of gravel and sand layers composed of well sorted and bedded granule and pebble were drawn upward along hanging wall on the weathered granite bedrock with 14-15m high from river bed. The boundary of the fault plane was appeared clearly and leaned over 45° to the horizontal plane by drag action

4. The Outcrop at Jinty Village

Fig. 6b shows the outcrop of the Higher surface deformed by reverse fault at Jinty village. It is however exposed at the northeastern end on the direction of N-S strike, where is curved from the strike N-S to NE-SW.

The outcrop is exposed by a dissection valley on crossing the narrow and long shaped Higher surface along the boundary of fault plane. The angle of fault plane indicates 90° vertical to the horizontal plane. The gouge zone of about 10cm width composed of clayey soil, 10YR 5/2, grayish yellow brown color was confirmed from it. The gravel layer of deeply weathered cobbles and boulders is sedimented 4-5m thick with the matrix color of yellowish red or brown 5YR 5/8 or 7.5YR 6/8.

5. The Outcrop at Malbang-Ri

Fig. 7 shows the outcrop of the Higher- and Middle surfaces deformed by reverse fault at Malbang-Ri.

The outcrop at Malbang-Ri is located on the way passing to the direction of N-S strike by the reverse fault(X-X'). It is exposed on the Middle surface facing on the artificial reservoir by erosion of small stream, which was found and reported by Okada *et*

al.(1998). The hanging walls on the Middle- and Higher surfaces are shaped in protruded westwards by reverse fault, however, preserved well without erosion as a whole. Therefore the magnitudes by vertical displacement could be confirmed clearly to 5m and 15m separately on the both surfaces. The dip angle by the reverse fault indicates 25-30° at this place, which is changed to acuter angle than at Jinty village, about 4km far away.

IV. Direction of Lateral Pressure by the Tectonic Movement

By the observation of each outcrop, we could identify some tendency among the dip angles of fault plane. The angle of fault plane tends to be larger from north to south gradually along the NW-SE strike of the reverse fault, from Ha-Dong to Jinhyun-Dong. It varies from 15° at Ha-Dong at the most northern site, 35-40° at Ma-Dong at more southern site, almost vertical at Jinhyun-Dong of the most southern site. On the other side, a dip angle has been also changed to be smaller again, to 25-30° at Malbang-Ri, while Jinty village indicated 90° on the same direction N-S of the fault.

There exists Bulguksa fault system by reverse fault which strikes for the direction of NW-SE and N-S at the study area. Usually dip angle of the fault plane by reverse fault reflects the degree of compressive force. The smaller the angle of the fault plane is the more powerful the force by reverse fault is. The angle of the fault plane is usually controlled by compressive force of lateral pressure. The acute angles were maybe maintained at all the places if the two strikes of reverse fault moved parallel to each other. But the pressure by reverse tectonic movement is estimated to be interfered at the crossing point of two lineaments of active fault at Jinty village. Finally the compressive forces from the two different directions have formed the vertical dip angle at Jinty village as a result of confliction.

Southeastern part of Korean Peninsula is influencing by the compressive force from East Sea Plate caused by two lineaments near the Strait of Korea by Otsuki and Ehiro(1978). It should be

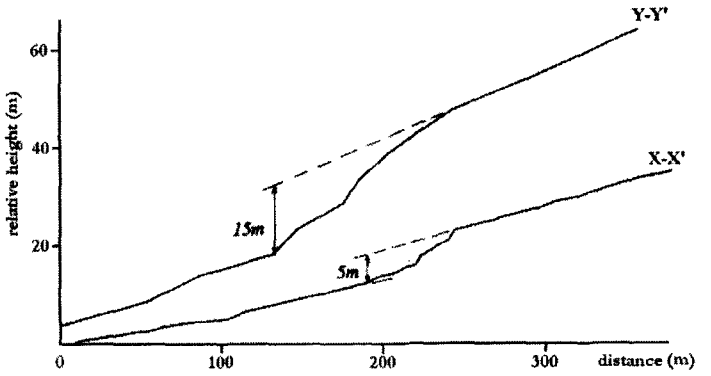

Fig. 7. longitudinal profile and vertical displacements of X-X′ ,Y-Y′ at Malbang-Ri in the N-S direction of Ulsan fault system (Okada et al., 1998).

resulted from that the two pressures responsible for the active reverse fault at which the one with the NW-SE strike thrusts the hanging wall of Tohamsan block southwestward and the other with the N-S strike thrusts it westward over the foot wall of the fan deposits.

V. Deformation of the Fan Surfaces by Lateral Pressure on the Relation to Tectonic Movement

The fan surfaces at the study area were displaced vertically by the active reverse fault during the Quaternary. The longitudinal profiles were measured to investigate local differences of fault activity along each fault line(Fig. 8). The Deformation height at Ha-Dong is 6m on the profile A-A′ of the Middle surface. And vertical height difference of the Higher surface is 10.5m on the profile B-B′ at Ha-Dong. But the vertical height difference of the Higher surface couldn't be confirmed on the profile C-C′ at Ma-Dong caused by previous cultivation. The deformation heights of the Higher surface are estimated to 9.5m on the profile D-E′ and also 10.5m on the profile E-E′ separately at Jinhyun-Dong. The deformation height at confliction point of Jinty village indicates 10m on the profile F-F′ of the Higher surface. The deformation heights at Malbang-Ri were reported as 5m on the profile X-X′ of the Middle surface and 15m on the profile Y-Y′ of the Higher surface.

As a result, the vertical displacements on the Higher surfaces along the Bulguksa fault system are about 10.5m at Ha-Dong, 9.5-10.5m at Jinhyun-Dong, and about 3m high at Jinty village. And the vertical displacement on the Middle surface was

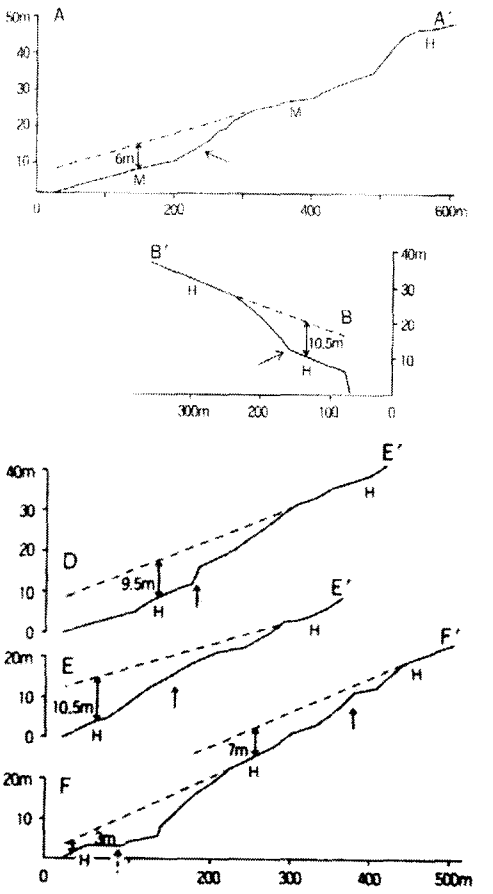

Fig. 8. longitudinal profiles and vertical displacements of A-A′, B-B′, D-E′, E-E′ and F-F′ along the NW-SE strike in the northern part of Ulsan fault system.

measured about 6m high at Ha-Dong.

The magnitude of the deformation in Higher surface was estimated about 10m corresponding NW-SE direction in the northern part and that of N-S direction 15m in the southern part of study area. The Middle surface of NW-SE direction is about 6m in the northern part and that of N-S direction is about 5m at Malbang-Ri. The vertical displacement of NW-SE is 5m lower than that of N-S in the Higher surface, but 1m higher in the Middle surface.

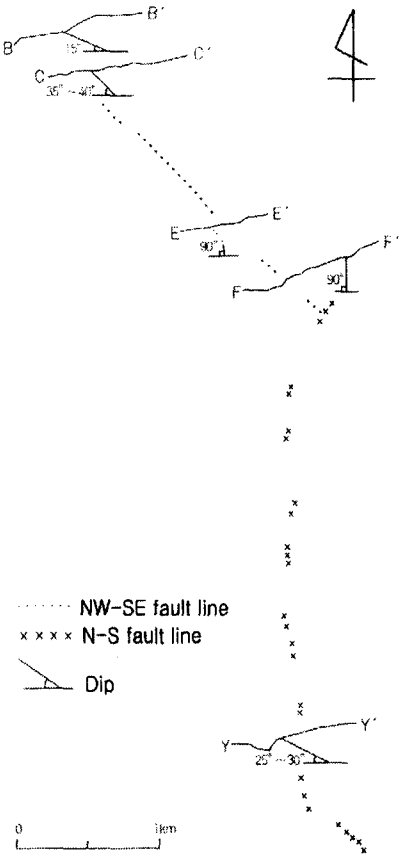

Fig. 9. distribution of fault lines and dips in the NW-SE and N-S directions of Ulsan fault system.

VI. The Chronology of Alluvial Fan Surfaces

Higher surfaces at Malbang-ri of Ulsan fault system are corresponded to the others of the study area very well by the distribution characteristics. The Higher surfaces are usually located on the highest level, shaped in narrowest ridge with many dissected valleys. By the way, Okada *et al.*(1998) has inferred the higher surfaces at Malbang-ri had developed during Riss Glacial stage(MIS 6, 200-140ka BP), on the other hand, those of Yangsan fault during Mindel/Riss Interglacial(MIS 13-8 or 500-250ka BP). In fact, it is difficult to understand such a different formation age by Okada *et al.*(1994, 1998).

On the other side, the higher surfaces were supposed to have been constructed during the Mindel Glacial stage corresponding to the Elster Glacial stage(560-430ka BP; MIS 14, 13, 12) by Kobayasi(1982). But some problems also exist in this assumption. At first, duration period of 130ka is too long for the construction of higher surface. And secondly, the middle surface was supposed to have been constructed 200ka. It means that 230ka passed away after that the higher surface had been constructed 430ka BP, is too long term in comparison on the formation period of middle surface. Thirdly, the duration period from Late Riss to Elster Glacial stage, there existed Holsteinian Interstadial(430-300ka BP, MIS 11, 10, 9), Drenthe interstadial(300-250ka BP, Early Riss, Early Illinoian, MIS 8), Saale/Drenthe Interstadial (250-200ka BP, MIS 7). Therefore it is proper that the formation period of higher surface is inferred to the age of Drenthe interstadial(300-250ka BP, MIS 8).

MIS 8(0.30-0.25 Ma. BP) and 6(0.20-0.14 Ma. BP) are presumed to be related to the formation stages of the Higher and the Middle surfaces, respectively.

The average slip rate of vertical displacements is calculated about 0.03-0.043mm/y based on it.

VII. Results

1. Bulguksa fault system was identified as an active reverse fault which has displaced the Quaternary fan deposits.

2. But Bulguksa fault system on the study area strikes for the direction of NW-SE and N-S. These

Table 1. Correlation to the Several Geomorphic Surfaces.

Geomorphic surfaces	Higher S. of terrestrial river terrace(Jo, 1997; Okada *et al.* 1994)	Higher S. of Malbang (Okada *et al.*, 1998)	Marine terrace Chilbo (Hwang, Yoon, 1996)	Higher S. of Gyeongju (Hwang, Yoon, 2001)	Middle S. of terrestrial river terrace(Jo, 1997; Okada *et al.* 1994)	Middle S. of Malbang (Okada *et al.*, 1998)	Marine terrace, Kumgok (Hwang, Yoon, 1996)	Middle S. of Gyeongju (Hwang, Yoon, 2001)
Formation period	M/R(500-250ka BP)	Riss glacial (200-140ka BP)	M/R	Early Riss (MIS8, 300-250ka BP)	Riss(200-140ka BP)	Early Wurm (50-60ka BP)	R/W(130-70ka BP)	Late Riss (MIS 6, 200-140ka BP)
Paleoshoreline			35-40m.a.sl.				19-24m.a.s.l.	
Magnitude& rate of displacement	12m 0.024-0.048 mm/y	15m 0.08mm/y		10m 0.033-0.042mm/y	5-7m 0.05-0.07 mm/y	5m 0.1mm/y		6m.a.s.l. 0.03-0.043 mm/y
Soil color	orange(2.5 YR 6/6) bright reddish brown(2.5YR 5/8; 5YR 4/8)		bright reddish brown (5YR 5/8) bright brown (7.5YR 5/8)	Yellow orange (10YR 7/8) orange(7.5YR 6/8) bright reddish brown(2.5Y 7/6)	Yellow orange (7.5YR 8/8), Yellow orange (7.5YR 7/8), orange(7.5YR 7/6)		bright reddish brown(10YR 6/8)	
Weathering degree	severely weathered	severely weathered	severely weathered	severely weathered	weathered		weathered	
	Patterned gravel layer			Patterned gravel layer				

two lineaments of active fault are crossing at Jinty village in Gyeongju city and the fault plane forms here almost vertical dip.

3. The lateral pressures from the two directions have possibly influenced on the formation of the vertical dip at Jinty village. It should be resulted from that the two pressures responsible for the active reverse fault at which the one with the NW-SE strike thrusts the hanging wall of Tohamsan block southwestward and the other pressure with the N-S strike thrusts it westward over the foot wall of the fan deposits.

4. MIS 8(0.30-0.25 Ma. BP) and 6(0.20-0.14 Ma. BP) are presumed to be the ages of the Higher and the Middle surfaces of the alluvial fan, respectively.

5. The vertical displacements on the Higher surfaces along the Bulguksa fault system are about 10.5m at Ha-Dong, 9.5-10.5m at Jinhyun-Dong, and about 3m high at Jinty village. And the vertical displacement on the Middle surface was measured about 6m high at Ha-Dong. The average slip rate of vertical displacements is calculated about 0.03-0.043mm/y.

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