ON THE RELATIONSHIPS BETWEEN ACTIVE FAULTS AND BASIN-FORMING MOVEMENT

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Abstract In this paper, the relationships between the active faults in the western part of the Kanto Plain and the Kanto basin-forming movement are considered. The active faults in this region show five tectonic features common to them. From these features, following conclusions are deduced. The active fault movement is not related directly to the downwarping of the basin, but to the relative movement at the boundary between the tilting blocks. The active faults are the rejuvenation of the preexisting fault beneath the plain.

1. Introduction

The Kanto Plain, the largest plain in Japan, is a tectonic basin that has been caused by a conspicuous downwarping since the Pliocene called the Kanto basin-forming movement. The maximum thickness of the Quaternary strata exceeds 1000m at the central part of the basin.

In the western part of this plain, several NW-trending active faults are recognized from the displacements of the terraces (Matsuda *et al.*, 1975). All these faults are reverse faults without lateral component. The activities of these faults are classified to the B class of Matsuda's criterion (Matsuda, 1975).

The active faults in the marginal area of a large plain are recognized not only in the Kanto plain but also in other large tectonic basins such as the Niigata Plain in central Honshu and the Ishikari Plain in Hokkaido. In many cases, the senses of faults in the marginal area are discordant with the downwarping of the each plain. The relationships between the faulting and downwarping is necessary to be studied in detail.

The author examines the fault movement and related tectonic features in the western part of the Kanto Plain. Based on the evidences, the role of the active faults in the Kanto basin-forming movement is considered. Recently, Tada (1983) has investigated the subsurface structure along the active faults in the Kanto Plain based on the geophysical measurements. His data provides us useful and helpful information for the fault movement.

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2. Active Faults in the Western Part of the Kanto Plain

The western part of the Kanto Plain mainly consists of hills and terraces. The hills are the relic of the middle Pleistocene terraces and are composed of the Miocene to lower Pleistocene strata overlain by middle Pleistocene gravels. They are distributed along the piedmont line and some of them are isolated as the residual hills in the plain. The late Pleistocene terraces that were formed mainly by the fluvial process of streams from the western mountains consist of the S surface (ca. 120,000 years ago), the M surface (ca. 80,000–60,000 years ago) and the Tc surface (ca. 20,000–15,000 years ago).

The active faults in this region can be clearly distinguished from the obvious displacements of these hills and terraces (Fig. 1). The fault displacements and their slip rate have

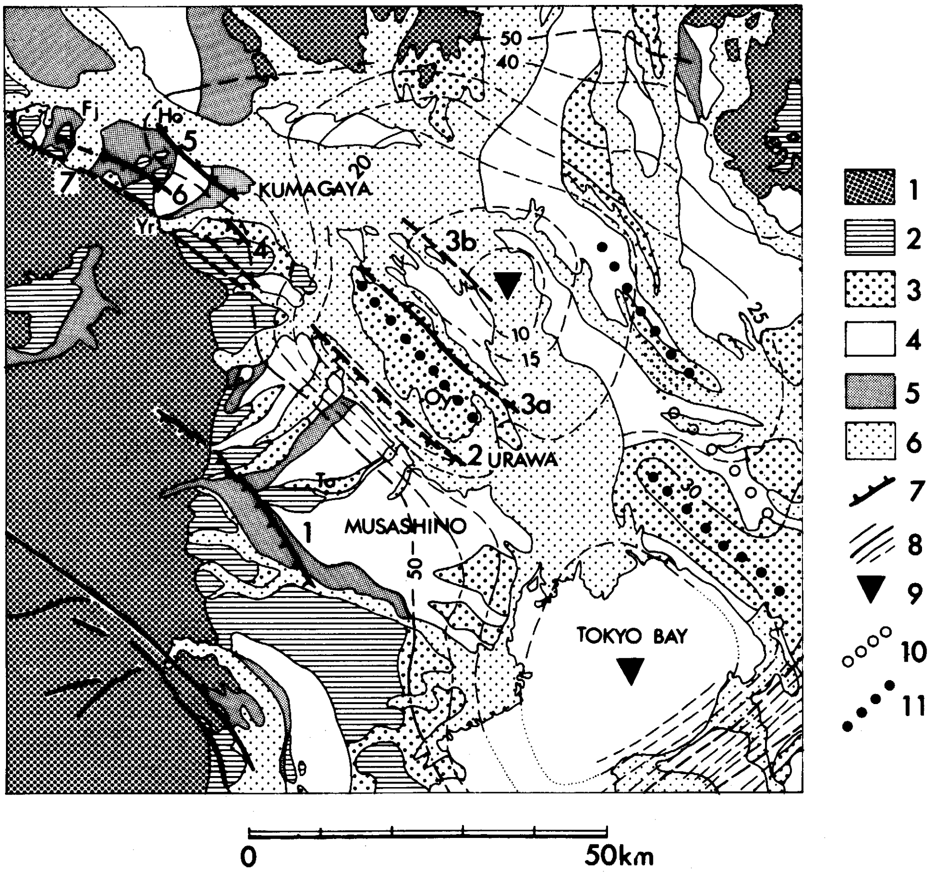

Fig. 1 Geomorphological and active fault map of the western part of the Kanto Plain (revised Kaizuka, 1981).
1: mountain; 2: hills; 3: S surface; 4: M surface; 5: Tc surface; 6: alluvial surface; 7: active fault (ticks on downthrow side); 8: generalized contour line of the S surface; 9: center of relative subsidence; 10: axis of subsidence zone; 11: axis of uplift zone. To: Tokorozawa; Oy: Oomiya; Yr: Yorii; Ho: Honjo; Fj: Fujioka. Fault numbers correspond to that in Table 1.

Table 1 Main active faults in the western part of the Kanto plain

Fault name	Strike	Length (km)	Sense of Displacement V	Sense of Displacement H	Displacement (m)	Displacement (surface)	Mean slip rate ($m/10^3$ y.)	Reference
1. Tachikawa f.	N40W	20	NE		70	Kazusa g.		Matsuda *et al.* (1975)
					35	hills	0.07	Yamazaki, (1978)
					7–8	S	0.06	
					3.0	M	0.04	
					5.8	Tc2	0.36	
					3.8	Tc3	0.27	
					1.4	A		
2. Arakawa f.	N45W	20+	NE		10–15	S–M	0.1–0.2	Kaizuka, (1975)
3. Motoarakawa tectonic belt								Shimizu & Horiguchi, (1981)
a. Ayasegawa f.	N45W	30	SW		6	S–M	0.08	
b. Kuki f.	N45W	15+	SW			M		
4. Konan f.	N45W	3	NE		10	S	0.08	Maruta, (1975)
5. Fukaya f.	N45–60W	13+	SW		4.5–14	M	0.28	Matsuda *et al.* (1975)
					3.6–6.0	Tc	0.4	
6. Kushibiki f.	N55–70W	17	NE		3.6	M	0.08	Matsuda *et al.* (1975)
					2.3	Tc	0.16	
					1.3	A	0.14	
7. Hirai f.	N55–70W	15+	NE		10	S	0.1	Matsuda *et al.* (1975)
					1.8	Tc	0.12	

(Tc2 and Tc3 are subdivision of the Tc surface) been reported by many researchers as shown in Table 1.

Tachikawa fault

The NW-trending Tachikawa fault which obliquely traverses the Musashino upland displaces the hills and the several terraces of the River Tama. In the hill area, this fault is recognized as a topographical discontinuity of the summit plane and on the terraces, it is expressed by a monoclinal scarplet extending for over 15km. The upthrown side of the fault is northeast. The reverse faulting without lateral slip is inferred from the microtopography of the deformed terrace surfaces along the fault (Yamazaki, 1978).

Figure 2 shows the distribution of the vertical displacement and its slip rate along this fault. The maximum rate of $0.4\text{m}/10^3\text{y}$. appears in the middle part of the fault trace and the rate decreases toward the both ends.

Although the Tachikawa fault does not make any major topographical boundary, the Sayama and the eastern half of Azuyama hills composed of the uplifted Plio-Pleistocene strata and the middle Pleistocene gravels are situated only on the northeastern side of the fault. The northern half of the Musashino upland including the area of northeastern side of this fault tilts toward northeast intensively. This tilting has proceeded cumulatively through the Quaternary period. The older strata and surfaces in this region show steeper gradient than the younger. In consequence, the hills are covered by surfaces younger than the S surface in the west and north of Tokorozawa, and the S surfaces are buried under the M surfaces in further northeastern side of the upland. Kaizuka (1957) pointed out that the tilting of the northern half of the Musashino upland as a result of the downwarping of the Kanto basin.

The underground structure of the Musashino upland obtained from the compilation of the bore hole data indicates the offset of the Plio-Pleistocene strata with 70m of northeast upthrown of the northeastern side (Yamazaki, 1978). The 500m discontinuity of the base-

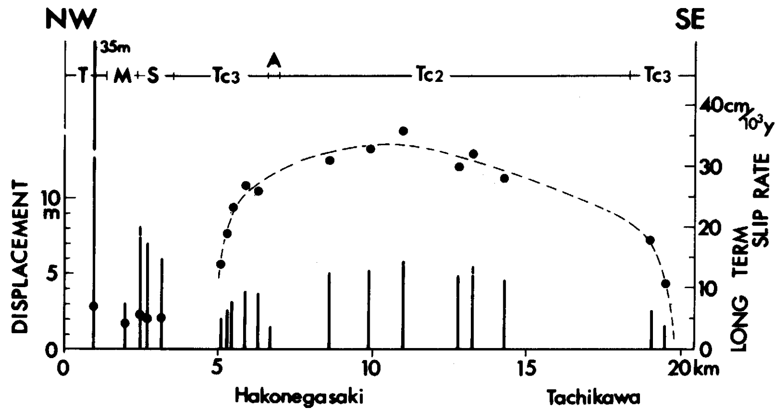

Fig. 2 Distribution of fault displacement and long term slip rate along the Tachikawa fault (Yamazaki, 1978).
vertical line: vertical fault displacement; solid circle: long term slip rate.

ment depth is estimated along the fault from the gravity survey (Tada, 1983). The upthrown side of this basement discontinuity is southwestern side of the fault. This southwest upthrow of the basement is the reverse to the sense of the recent fault movement deduced from the shallow underground structure. Tada (1983) concluded that the recent movement of the Tachikawa fault was the rejuvenation of old fault in response to the Quaternary tectonic stress field.

Arakawa fault

Existence of the Arakawa fault beneath the Arakawa alluvial plain is inferred from the difference of the topographical features and the movement pattern between the Musashino and the Oomiya upland (Kaizuka, 1957). This fault extends for over 20km along the western margin of the Oomiya upland and shows the northeast side upthrow. The Arakawa alluvial plain is thought to be a fault angle-basin caused by the upheaval of the Oomiya upland on the northeastern side of the Arakawa fault (Kaizuka, 1981).

Although evident fault topography are not found in and around the Arakawa alluvial plain because of the thick accumulation of alluvium, the underground structure obtained from the geophysical measurement indicates the existence of the fault in the basement but upthrow of the fault is southwestern side (Tada, 1983).

Motoarakawa tectonic belt

The existence of the Ayasegawa and the Kuki faults (Fig. 1) is assumed from the discontinuity of the height of terrace surface in the area of eastern part of the Oomiya upland (Shimizu and Horiguchi, 1981). Both faults show the southwest upthrow and parallel to the strike of the Tachikawa and the Arakawa faults. The terrace deposit including the TP fall (ca. 50,000 years ago), is displaced 6m vertically along the Ayasegawa fault. Shimizu and Horiguchi (1981) considered that these two faults lay in the tectonically active belt because many topographical lineaments and scarplet were recognized in the zone between these two faults. They designate this fault zone the Motoarakawa tectonic belt.

Based on the explosion seismic data across the Kanto Plain, Tada (1983) pointed out the existence of a NW- trending fault in the basement, namely the Yashio-Chiba fault, along the Motoarakawa tectonic belt. The Yashio-Chiba fault makes up the eastern margin of a basement graben which extends in a NW direction from the northeastern part of Tokyo Bay to Kumagaya-Fukaya region through the central part of the Kanto Plain.

Fukaya fault

The Fukaya fault appears on the M and the Tc surfaces in the Kushibiki upland between Kumagaya and Honjo as a monoclinal flexure (Matsuda *et al.,* 1975) (Fig. 3). This fault shows the NW trend and the SW side upthrow. The movement sense of this fault accords with the sense of the basin-forming movement. On the northeast side of the fault, the downthrown M surface is covered by the alluvial plain of the River Tone.

Figure 4 shows the distribution of the fault displacement and its slip-rate along the Fukaya fault. The maximum displacement reaches 14m on the M surface and 6m on the Tc surface. The long-term slip rate along this fault is $0.3–0.4 m/10^3 y.$, which is the maximum value among active faults in the Kanto Plain. The gradual increase of the slip-rate toward the

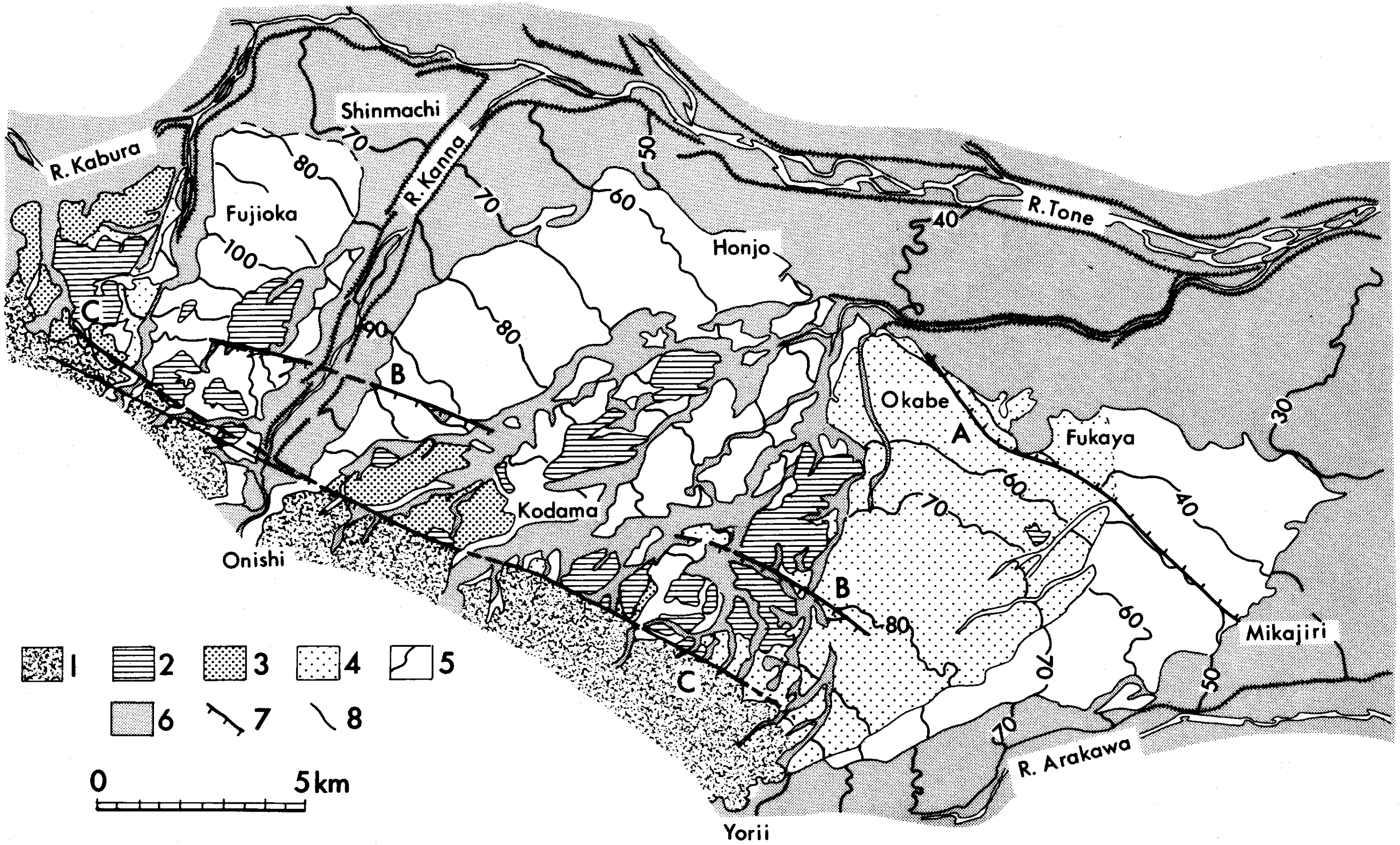

Fig. 3 Geomorphological and active fault map of the northwestern part of the Kanto Plain.
1: mountain; 2: hills; 3: S surface; 4: M surface; 5: Tc surface; 6: alluvial surface; 7: active fault (ticks on downthrow side); 8: inactive fault.
A: Fukaya fault; B: Kushibiki fault; C: Hirai fault.

southeastern end of this fault indicates that the Fukaya fault probably extends into the alluvial plain.

The basement height beneath the north western part of the Kanto Plain lowers toward northeast with steep gradient (Kakimi *et al.*, 1973). All active faults in this region are situated on this steep slope of the basement.

The result of the gravity survey conducted crossing the faults at right angle indicates that each fault has clear and large displacement of the basement which is conformable to the sense of recent fault movement. According to Tada (1983), the displacement of the basement height reaches 200m along the Fukaya fault and 500m along the Kushibiki fault which will be mentioned in the following.

Kushibiki fault

The Kushibiki fault running in the southwest of the Fukaya fault traverses the middle part of Kushibiki upland and displaces several landform surfaces in the upland area (Matsuda *et al.*, 1975). The fault can be traced from east of Yorii to south of Fujioka for 17km in length, though the fault scarplet in the middle part of this fault trace is obscured by the cover of the recent sediments. The characteristic fault scarplets appear along the southeastern part of this fault as shown in the profiles (Fig. 5). The scarplet appears on the landform surface with NE-side upthrow as a narrow rise which is similar to an asymmetrical pressure ridge in shape.

It is similar to the case of the Tachikawa fault that several dissected residual hills are situated on the northeast side of the fault. They are composed of the Miocene to Pliocene

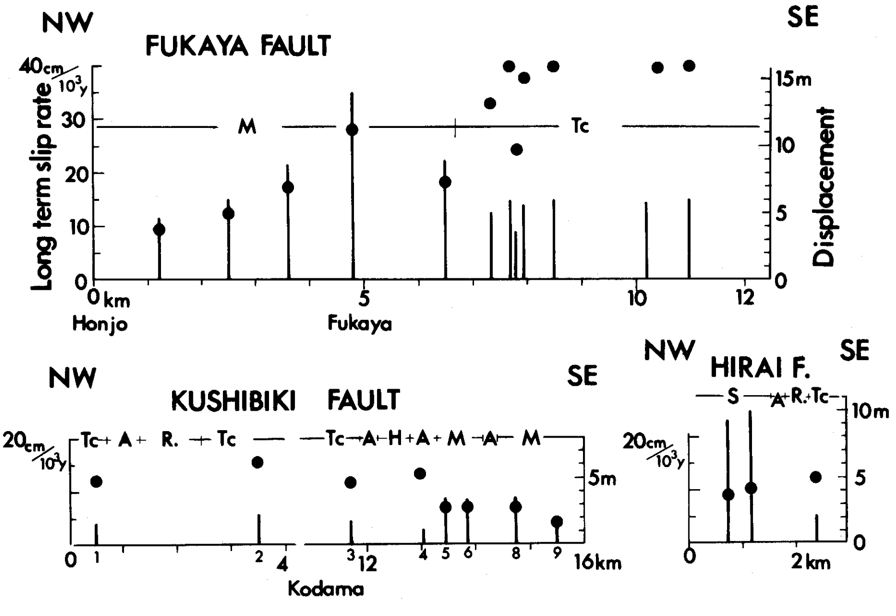

Fig. 4 Distribution of fault displacement and long term slip rate along the active faults in the northwestern Kanto Plain.
vertical line: vertical displacement; solid circle: long term slip rate.

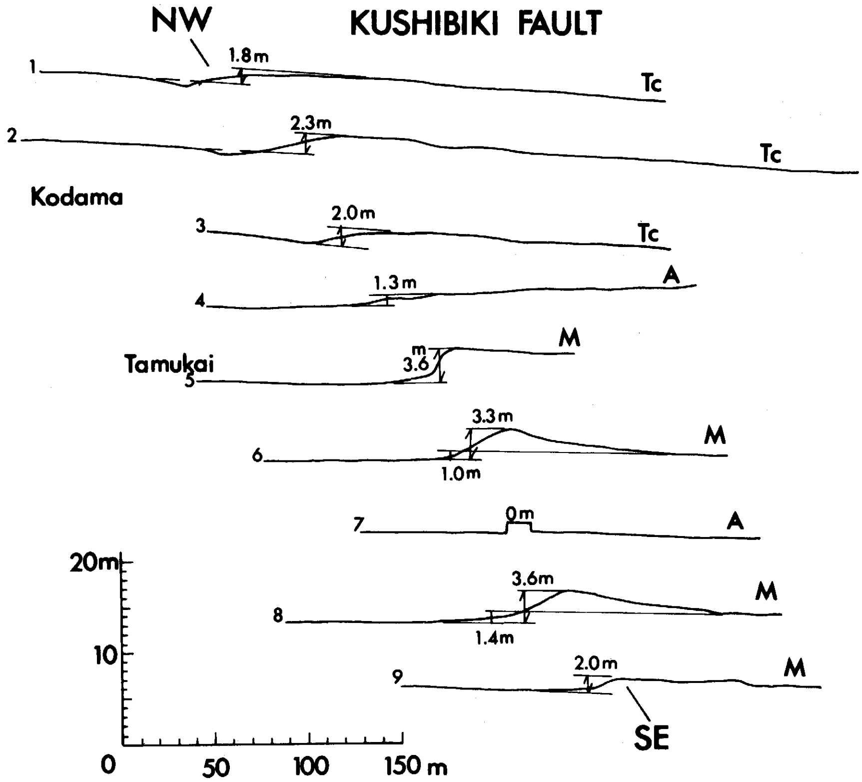

Fig. 5 Topographic profiles across scarplet of the Kushibiki fault

strata and the early to middle Pleistocene gravels (Matsumaru, 1977). These hills tilt toward northeast with steeper gradient than that of adjacent terraces and alluvial surfaces. In consequence, the hills sink into the younger landform surfaces.

As mentioned previously, the discontinuity of the basement height along the Kushibiki fault is larger than that along the Fukaya fault. The recent fault activity of the Kushibiki fault, however, is less than that of the Fukaya fault. From these facts, Tada (1983) concluded that the activity of the Kushibiki fault had been much greater than that of the Fukaya fault in Tertiary and early Pleistocene period.

Hirai fault

The WNW trending Hirai fault extends from Yorii to the east of Yoshii for over 15km (Matsuda *et al.*, 1975). This fault defines a boundary between the Kanto Mountains and the Kanto Plain. The fault gradually diverges from the piedmont line toward northwest and turns its strike to north on the west side of the River Ayu. The displacements of the terraces by this fault are conspicuous in the northwestern part of the fault where the S and the Tc surfaces are displaced to 10m and 1.8m (Fig. 4), respectively. The upthrown side of the fault is northeast. Along the southeastern half of the fault, wide shear zone along which crystalline schist of the Kanto Mountains contacts with the Tertiary in the piedmont area is observable. The SW-side upthrow deduced from the geological structure discords with the sense of recent fault movement which is inferred from the displacement of the terraces.

Tectonic features of the active faults

Following features are recognized and are considered to be closely related to the basin-forming movement from the above description of the faults.

1. Active faults in the western part of the Kanto Plain show NW strike.
2. All of active faults are reverse faults and lateral slip components of them are obscure. Activity of them are estimated to the B or C class of Matsuda's criterion.
3. As for the sense of the vertical fault movement, both southwestern side upthrow and northeastern side upthrow are recognized. The former type of the fault appears in the place closer to the center of the basin while the latter develops in the region closer to the piedmont line.
4. Along all of the active faults in this region the large discontinuity of the basement height in their underground structures is recognized. However, the amount of displacement of the basement rocks are not in proportion to the slip-rate of the active fault. And the displacement sense in the basement does not always accord with that of the active fault.
5. In the upthrown northeastern side of the fault, several residual hills such as Sayama, Suwayama and Ikunoyama hills exist. The faulted blocks including the residual hills tilt to the northeast with steep gradient. Cumulative displacements are recognized on many fault references in these blocks.

3. Discussion

From the several features of the active faults mentioned in the previous section, followings are discussed.

Tilting and fault movement

As the active faults which have NE side upthrow component show the movement sense reverse to the sense of basin forming movement, it is difficult to explain that these fault are related to the downwarping directly. The faults of SW-side upthrow have the slip-rate $0.4m/10^3y$. in maximum at most cases. The movement of these faults is considered to have less important role on the downwarping in comparison with the subsiding rate of $1-2m/10^3y$. (Horiguchi, 1981) in the center of the basin.

As for the tilting of the Musashino upland, the gradients of the S and the Tc surfaces are measured to be about 10‰ and 7‰, respectively. As the S surface which was formed in the last interglacial period and have had more gentle gradient originally than the dip of the present Tc surface, the difference of these two gradients shows the maximum value of the tilting during 100,000 years. The tilting rate is estimated to be over $0.3‰/10^4y$. From this tilting rate, even if the effect of the fault displacements was ignored, the rate of subsidence at the central part of the plain would be estimated to be over $1.2m/10^3y$. Therefore, it is proved that the tilting in the marginal region of the plain represents the downwarping of the basin much greater than the active fault movement on the basin-forming movement.

Block movement and stress field

Horiguchi (1974) assumed that the tilting movement on the marginal region in the plain was caused by the block movement and proposed the several blocks, such as the Musashino-Iruma block and the Kushibiki-Honjo block, in the Kanto Plain. Many active faults mentioned in this paper coincide with the edges of these tilting blocks in location. Each block shows the NE tilting with the hinge at the middle part of the block. Active faults showing the NE side upthrow are the expression of the tilting and upheaval of the south-western edge of the block. It is considered that the accumulation of the tilting and upheaval at the edge of the block causes the uplift of the old strata and makes the residual hills.

If the downwarping in the plain and the relative upheaval in the surrounding mountains are the main forces which cause the tilting in the marginal region of the plain, it is expected that the tilting blocks which show the normal faulting at their boundaries occur in that region. As a matter of fact, all the active faults in the western part of the Kanto Plain are reverse faults. This fact means that the blocks in the marginal region of the plain have been affected by the strong compressional stress besides the downwarping in the plain. The strikes of the reverse faults indicate the stress field of the NE-SW horizontal compression.

Relationships between active faults and basin forming movement

Figure 6 shows a schematic E-W cross section in the western part of the Kanto Plain. The tilting of blocks and the movement of active faults in the western part of the Kanto Plain

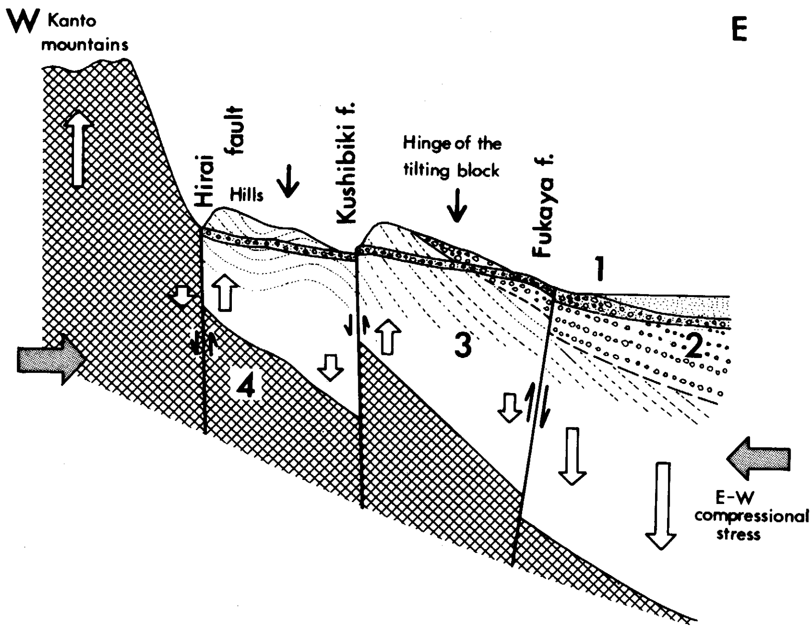

Fig. 6 Schematic geological cross section traversing the northwestern part of the Kanto Plain in E-W direction. Open arrow shows the movement direction of the each block.
1: late Pleistocene; 2: early to middle Pleistocene; 3: Tertiary; 4: basement rocks.

are composite result of the downwarping of the basin and the NE-SW trending compressional stress. The active fault movements, however, are not related to the downwarping of the basin directly. They are the expression of the relative movement at the boundary of the tilting blocks. Some of the preexistent basement faults which have the strike at the right angle to the tectonic stress field beneath the plain rejuvenate as the active faults at the edges of the blocks. In consequence, the edge of the blocks are defined by the location of the basement fault. This is the reason why all of the active faults in the Kanto Plain have large displacement in the underground structure.

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