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TECTONIC LANDFORMS AND ACTIVE FAULTING IN THE AREA SURROUNDING SUMBURU HILLS, NORTHERN GREGORY RIFT VALLEY, KENYA.

Yoshihiro UEMURA

ABSTRACT

Tectonic landforms and active faults in Sumburu Hills and Suguta Valley have been examined by means of aerial photographic interpretation and field work. The purpose of this paper is to discuss the characteristics of tectonic landforms, and the nature and cause of active faulting during the Quaternary.

The main results are summarized as follows,

(1) Active faults are almost all dip-slip normal, and are widely distributed trending NNE in parallel with Rift Valley. They are classified into I, II, III and IV, based on the degree of certainty of activity during the Quaternary. Landform of the eastern shoulder and median graben are largely controlled by active faulting and flexuring.

(2) Active faults are classified into A, B, C, D and E types, based on their nature and cause. A type: distributes in the hills consisting of Miocene rocks as antithetic faults with downthrown to east side, and derived from reactivity of preexisted faults. B type: distributes in Tirr Tirr plateau, and forms horst-graben topography as a results of extension caused by updoming. C type: distributes along the boundary between west-end escarpment and median graben, and derived from boundary fault and flexure with large displacement downthrow to west side. D type: linearly distributes as Kangirinyang fault swarm cut many pyroclastic cones in Suguta Valley. Linear graben structures indicates the extensional axis along deep fracture associated with intrusion of basaltic magma. E type: distributes in the eastern part of median graben, and are short in length but tectonically young and active.

(3) The intense faulting that largely determined a deep graben, has occurred since

around 3 Ma. Based on Yairi's method, the direction of horizontal extension in Suguta Valley is estimated to be N 67°W. This direction is at a right angle to the general trend of median graben.

(4) Since the Miocene, the main area of faulting and flexuring have migrated with the time from east to west, and its horizontal migration amounts about 20km. The mean rate of migration reaches 2 mm per year and nearly equals to the spreading rate of East African Rift.

Key ward:
(Kenya, Gregory Rift Valley, Sumburu Hills, Suguta Valley, tectonic landform, active fault, median graben)

I. INTRODUCTION

East African Rift Valley is characterized by the great topographic depression that breaks across the East African Plateau. The Rift Valley makes down-faulted graben that bounded on both flanks by fault scarps, and extends about 4000 km in length from Ethiopia to Mozambique meridionally. This Valley is subdivided into Ethiopia Rift, Gregory Rift (also known as Kenya Rift), West Rift and Malawi Rift (Fig 1). It is generally believed that the Rift Valley is the result of crustal extension and associated normal faulting, and represents the earliest stage of continental breakup. It is noticeable that seismicity and volcanism in Africa are concentrated within the narrow rift zone. Gregory Rift is characterised by a deep median graben crossing Kenya dome which is elliptical uplift with maximum height of about 2000m. Also, one of the best known spectacular landscapes in the world.

Sumburu Hills area is situated in the northern part of Gregory Rift, northern Kenya, and its western end is faced with a graben floor called Suguta Valley (Fig. 2). Tectonic landforms which resulted from active faulting are widely distributed in and around Sumburu Hills.

The purposes of this study are to clarify the distribution and characteristics of tectonic landforms resulted from active faults, and to discuss the nature and causes of active faulting during the Quaternary.

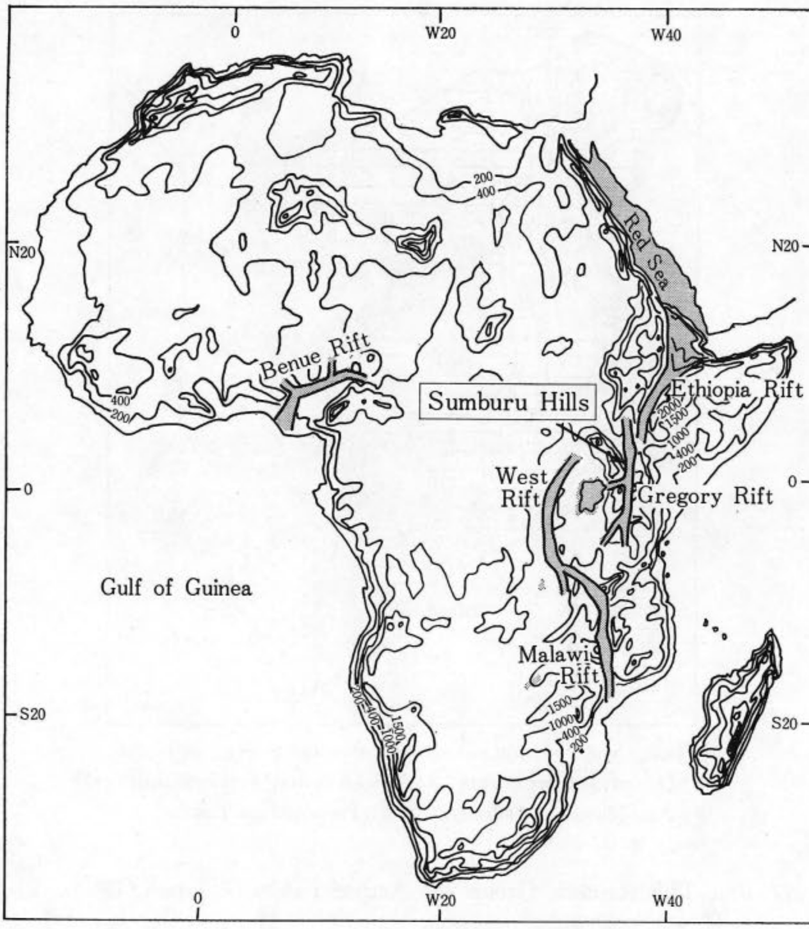

Fig. 1 Rift system and topographic feature of Africa.

II. METHOD OF INVESTIGATION

Tectonic landforms which mainly resulted from active faulting have been identified by means of interpretation of vertical aerial photographs on a scale of 1:35, 000 or 1: 60, 000. Fault traces were plotted on topographic maps on a scale of 1:50, 000 published by Survey of Kenya. Displaced landforms such as scarplet, fresh fault scarp and horst-graben topography which are reconized on flat surfaces, are clear signs of active faults. It is believed that these landforms were created by the cumulative displacement of faulting during the Quaternary. Therefore, the amount of displacement of faulting could be deduced by topographic features.

In this paper, active fault means that has repeatedly moved since the Quaternary. The method of recognition of active faults applied in this study, was followed Matsuda

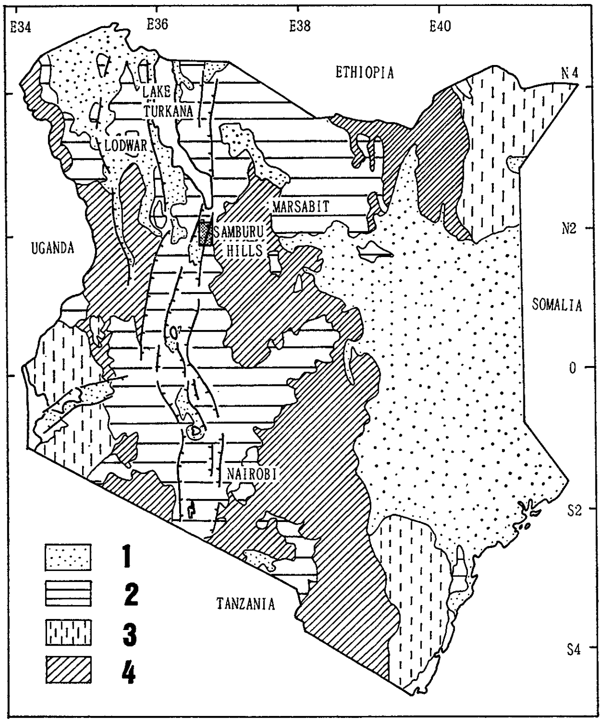

Fig. 2 Map showing of the study area and geology of Kenya.
1 : Quaternary Sediments 2 : Volcanics and Tertiary Sediments
3 : Pleo-Mesozoic Sediments 4 : Precambrian Rocks

et al. (1977) and The Reseach Group for Active Faults of Japan (1980). Field survey was carried out in August, 1990 and 1993.

III. OUTLINE OF LANDFORMS AND GEOLOGY

The study area is situated to the western part of Baragoi in Sumburu district, northern Kenya. Climatologically, this area is regarded as semi-desert and tropical, because mean annual rainfall is 250～500 mm and mean temperature is about 25°C (Fig. 3).

Coloured geological maps of this area were produced by Baker (1963) and Key (1987) with excellen explanations. Makinouchi et al. (1984) and Ishida (1989) reported on the stratigraphy,

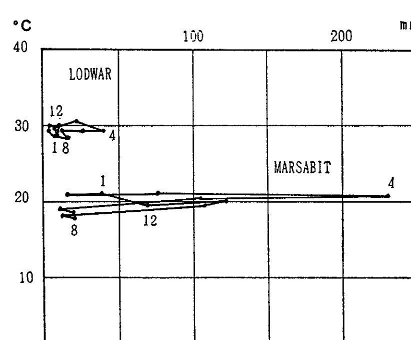

Fig. 3 Climograph of Lodwar and Marsabit which are the nearest towns to the study area.

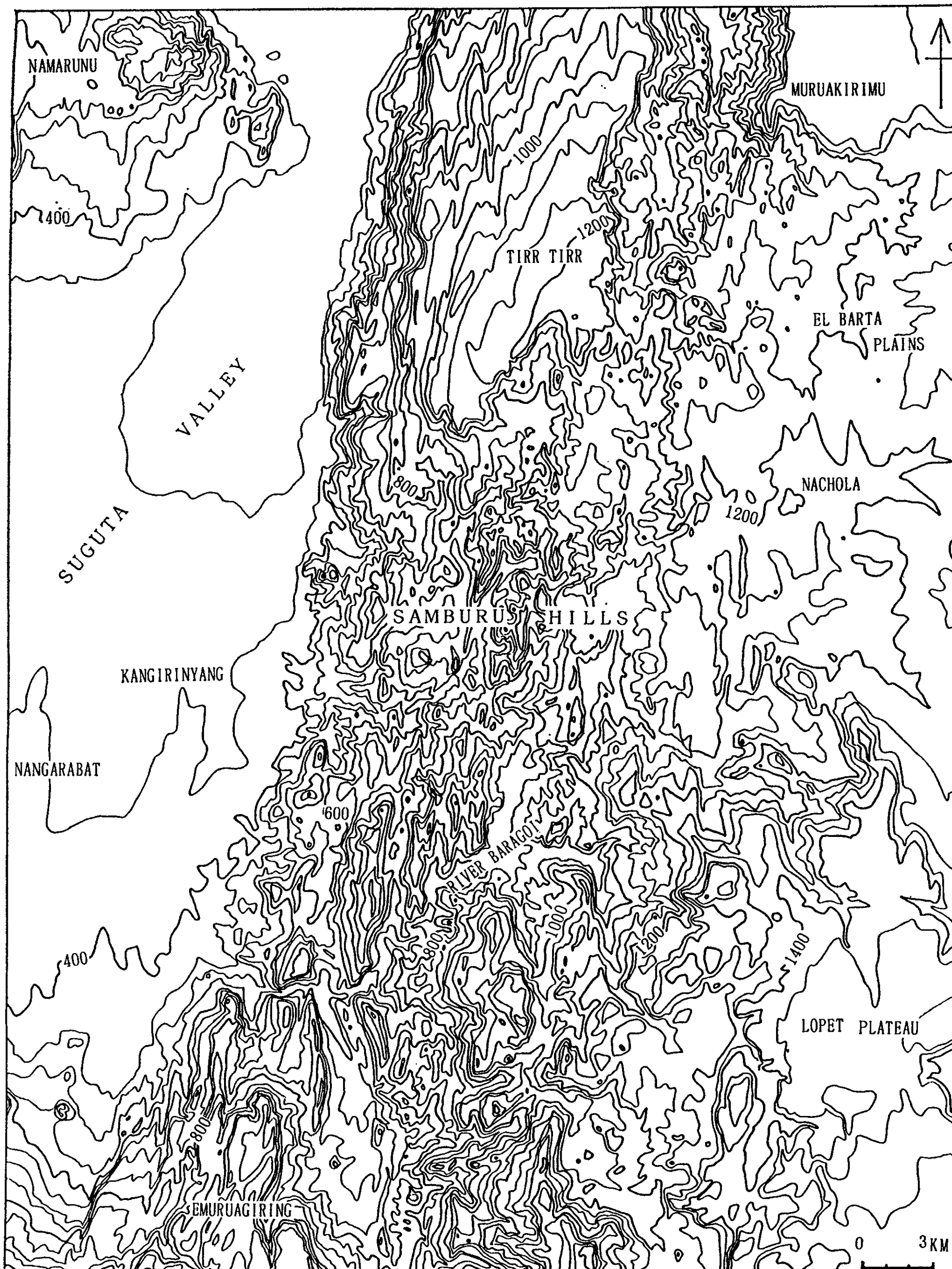

Fig. 4 Generalized contour map in and around Sumburu Hills.
Eliminating valley less than 1 km across. Contour interval is 50 m.

structure and absolute ages of Cenozoic strata of Sumburu Hills. However, the landform and active fault have not yet been studied in detail.

The geomorphologic and geologic structure of Sumburu Hills are parallel to the direction of Rift Valley. Topographically, this area is subdivided into four topographic provinces: low relief plainland, lava plateaus, hilly land and median graben from east to west (Fig. 4). Based on the interpretation of aerial photographs and topographic maps, a geomorphological map has been worked out (Fig. 5).

(1) Low relief plainland

This plainland is broadly distributed in the upper course of Baragoi River, and is called as El Barta Plain. The altitude in this area range from 1100 to 1300m, and relief energy is usually less than 100m. Many inserbergs underlain by Precambrian basement rocks are recognized as protrudings on this surface. Low relief erosional surface cut on basements, and is believed to be correlated with the sub-Miocene surface. On the other side, flat-top surface of inserbergs might correspond to end-Cretaceous erosion surface (Saggerson & Baker, 1965).

(2) Lava plateaus

The plateaus are classified into two groups. One is the Lopet plataeu extending throughout the southeastern part of this area. This flat surface has 1350～1700m hight and dips to NNE direction with 1% gradient. The plateau consists of Lopet phonolite dated as 11 and 13.5 Ma, and northwardly phonolite is intercalated into Miocene strata underlying Sumburu Hills. It is believed that a large part of this surface correlates to the end-Tertiary erosion surface because of the existence of some inserbergs protruding from it. The other group includes Emuru Akirimu in northeast, Tirr Tirr in north and Emuruagiring in south of Sumburu Hills. The first has flat surface 1200～1300m high, but the surface of the second has northwest-tilted surface with 5% gradient and 700～1260m high. The western end of the plateau is cut by tectonic escarpment and is bordered on the east margin by Suguta Valley. The last is 1000～1200m high and downthrows step by step to the Valley. They all consist of basaltic and trachytic lavas in 3.5～3.9 Ma, and rest uncomformably on the west-ward dipping Miocene formation which underlays hilly land.

The flat surfaces of plateaus preseve the original surfaces of lava flows erupted in the Pliocene, so can help us to identify active fault.

(3) Hilly land

Sumburu Hills ranges from 1000m in the east to 600m high in the west. The landforms of this hills are characterized by ridges and V-shaped valleys resulting from severe erosion. The ridges have different gradients on the west and east sides asyme-

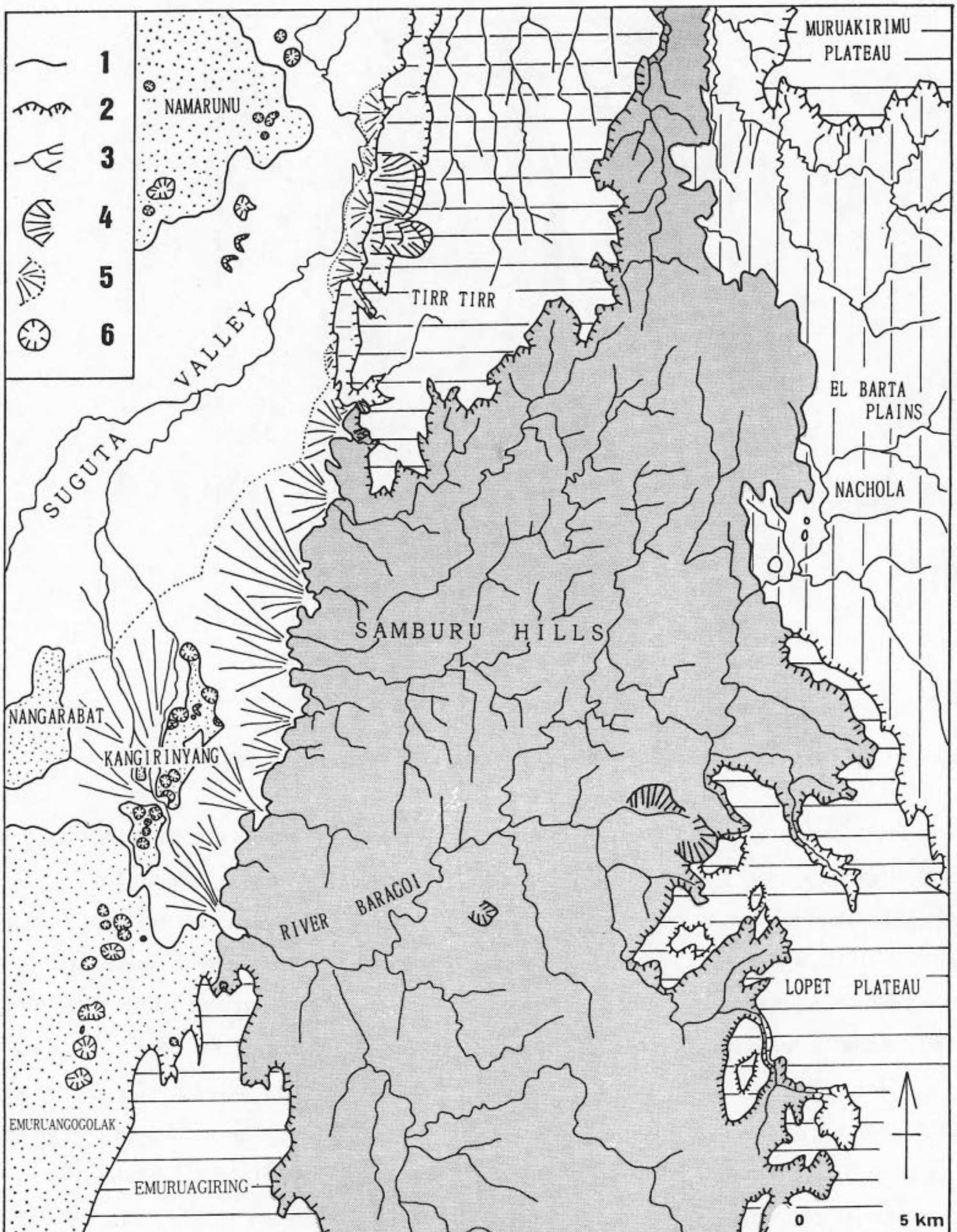

Fig. 5 Geomorphological map of Sumburu Hills and Suguta Valley.
1 : Boundary of geomorphic province 2 : Escarpment 3 : Drainage system
4 : Landslide 5 : Alluvial fan 6 : Pyroclastic cone
Vertical line: Plainland, Horizontal line: Lava plateau, Dotted area: Quaternary volcanic fields.

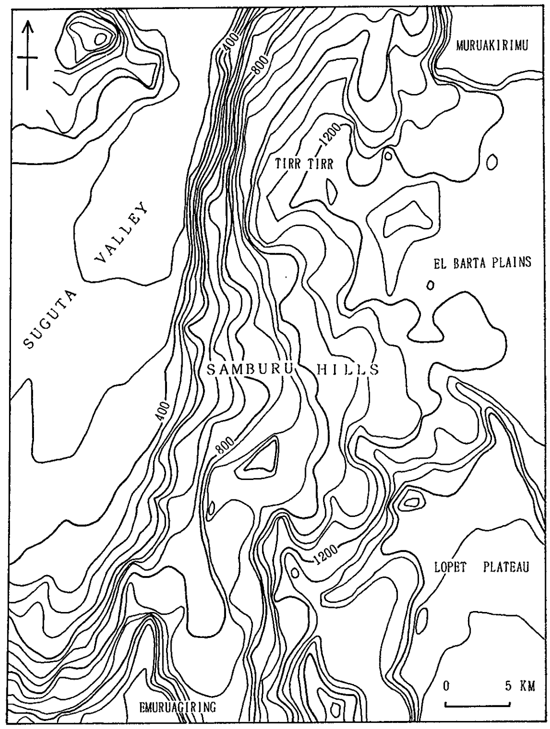

Fig. 6 Summit level of Sumburu Hills and adjacent area.
Eliminating valley less than 3 km across. Contour interval: 50 m.

trically, what is called homoclinal ridge. The summit plane of the hills is dissected into stage of maturity and their heights gradually lower from east to west (Fig. 6).

The Baragoi River, only one which transverses the hills from east to west, entrenches itself deep into hills. Insised meander course probably originated in the ancientfree meander on a low-lying plain. Hence, this course could be recognized as an antecedent and means to have been uplifted during recent time.

Many N-S trending valleys form steep gorges along fault traces. The hills are underlain by Miocene sedimentary and volcanic rocks about 700m thick that range in age from 20 to 8 Ma (Table 1). The geologic structure is controlled by Sumburu Flexure downwarping toward the median graben (Baker, 1963; William & Chapman, 1986).

(4) Median Graben

Suguta Valley, a floor of graben, is about 20 km in width trending to NNE-SSW direction. The floor gently slopes toward the north with 0.23% gradient from 280 to 380m in height. This flatness originated from the bottom of ancient Lake Suguta which have existed during the latest Pleistocene (Truckle, 1976).

Table. 1 Geologic succession in Sumburu Hills and Suguta Valley.
Absolute ages adopted from Pers. comm. of Y. Sawada

Geologic age	Geologic unit	Rock Type	Absolute age (Ma)
Holocene	Alluvium	gravel, sand, silt	
Pleistocene	Suguta Bed Suguta Volcanic Complex	silt, sand, gravel, diatomite basalt	0.12, 0.45
Pliocene	Tirr Tirr Formation	basalt, rhyolite, tuff breccia	3.6, 3.8, 3.9
Miocene	Nagbarat Formation	basalt	5.34, 5.38
	Kongia Formation	basalt	5.67, 6.03
	Namurungule Formation	sandstone, conglomerate, mudflow deposit	
	Aka Aiteputh Formation	basalt, trachyte, pyroclastics	10.8~15.0
	Nachola Formation	sandstone, trachyte, basalt, pyroclastics	15.0~19.2
Precambrian	Precambrian Basement Complex	gneiss, quartzite, marble	580~830

Suguta Valley is bounded on both sides by fault-controlled escarpments up to 300 ~500m high. The graben floor has been rapidly depressed, and is underlain by thick Quaternary sediments. Many alluvial fans are built by intermittent rivers which flow down from the foot of marginal escarpments to the center of the Valley. These rivers flow together, and drained by Suguta River which finally flows into Lake Logipi in the north.

Small volcanic body called Kangirinyang and Nangarabat are distributed in the central part of the graben. In paticular, Kangirinyang consists of basaltic lava and ten more scoria cones. This shows extreme linearity in NNE-SSW direction. Although lavas have been dated as 0.1~0.45 Ma, geomorphologically some cones are believed to have erupted in the Holocene.

In the north, volcanic body called Namarunu is located in west and center of the floor. At this place, the width of Suguta Valley is narrowed to only 2.5~3km. Further, on the southern plain near here, three small protrusions can be seen. These crescents most likely originated in tuff rings.

IV. TECTONIC LANDFORMS AND ACTIVE FAULTS IN AND AROUND SUMBURU HILLS

Active fault can be recognized as lineament accompanied by characteristic feature created by cumulative displacements of faulting. The author tried to identify active faults on the basis of interpretation of fault topography by aerial photographs, and by field checking.

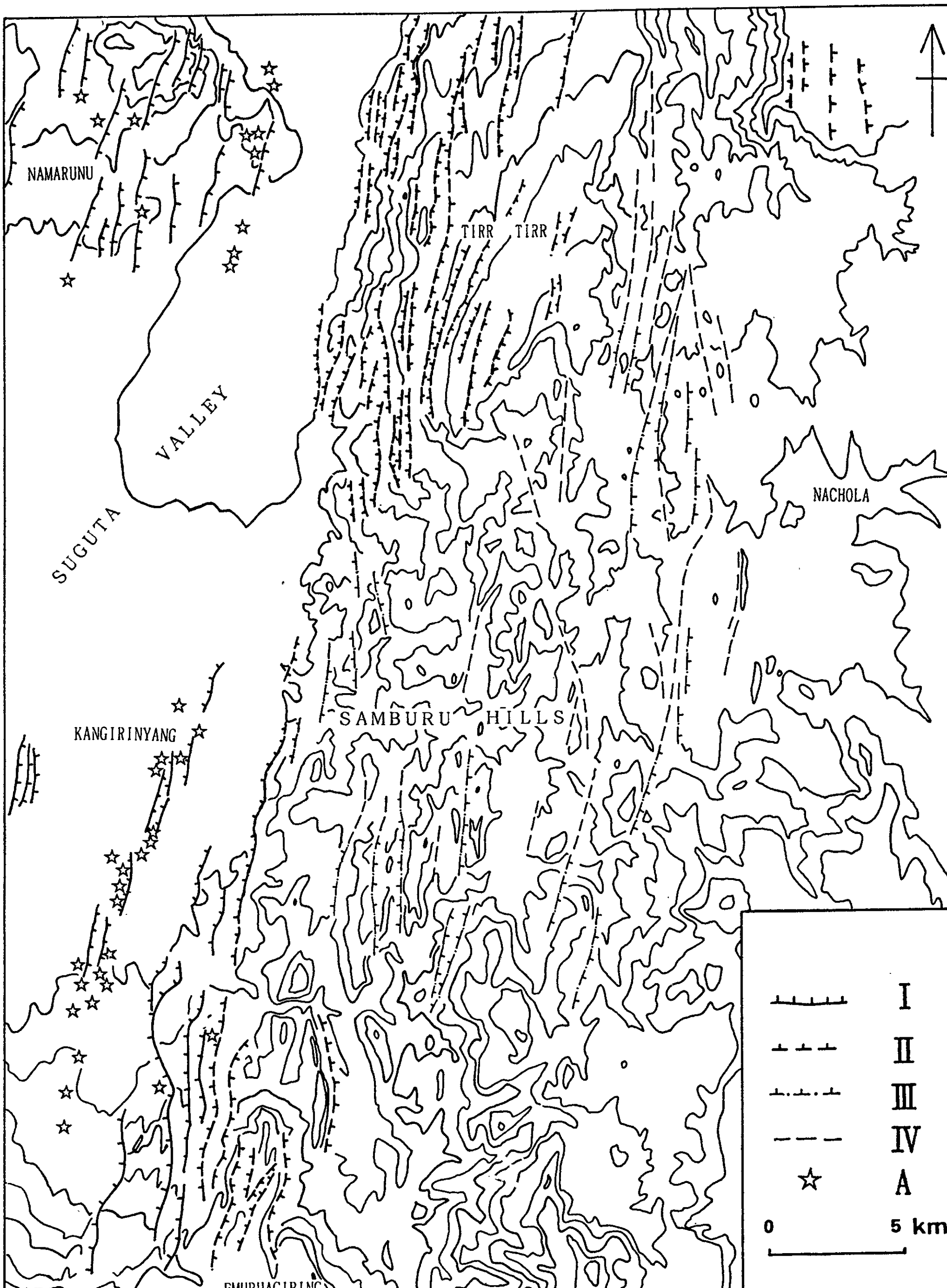

Fig. 7 Distribution map showing active faults in and around Sumburu Hills.
I : fault which have moved during the late Quaternary. II : fault which have probably acted during the Quaternary. III : fault which is expected to have been active during the Quaternary. IV : fault which have little been acted during the Quaternary. A : Pyroclastic cone.

In the investigated area, active faults could be classified into four types based on the degree of certainty of activity in the Quaternary. Active faults of certainty I mean those that have certainly moved during the late Quaternary. Certainty II faults are those whose mode and activity during the Quaternary, can be inferred from topographic and tectonic features. Certainty III faults are distinct lineaments with dislocation of hill surfaces. They are believed to might have been active during the Quaternary. Certainty IV faults are recognized as lineaments with no dislocation of landforms. It is unlikely that they experienced any activity during the Quaternary. A distribution map of active faults has been worked out by the way above mentioned (Fig. 7).

Here is the discription of the tectonic features and active faults of each topographic provinces.

(1) Low relief plainland

No tectonic landforms and active faults are distributed in this area.

(2) Lopet Plateau

No tectonic landforms and active faults are recognized. But some extent of the southern area has not yet been checked because of the absence of aerial photographs.

(3) Emuru Akirim Plateau

Small scarplets which run parallel trending to N-S are observed. These faults were usually uplifted on the west side less than a few meters, but topographic expressions are not so clear.

(4) Tirr Tirr Plateau

Many active faults are distributed in this plateau accompanying clear tectonic features. They are subdivided into east and west groups. The former has fresh scarplets in the NNE-SSW direction. The trace of faults generally tend to become more dense and distinct toward the westside. And, the direction changes to N-S with parallel trending. Splendid horst-graben topography is observable (Fig. 8). The pattern resembles the one recognized in the up-dome or anticlinal structure. The NNE-SSW strike of faults makes a right angle with the northwestward tilting of surface. Dissected valleys are followed along the fault trace flowing down to NNE direction.

In the west, faults with N-S trending are densely distributed with running parallel. Active faults are distributed in a zone within 2～3 km width, and form boundary escarpments bordered by median graben. Here, faults with uplifting east sides are dominant and each vertical displacement attains 50 to 200m. But there are only a few faults uplifting west side and their displacement only reaches 10 to 40m. Largescale

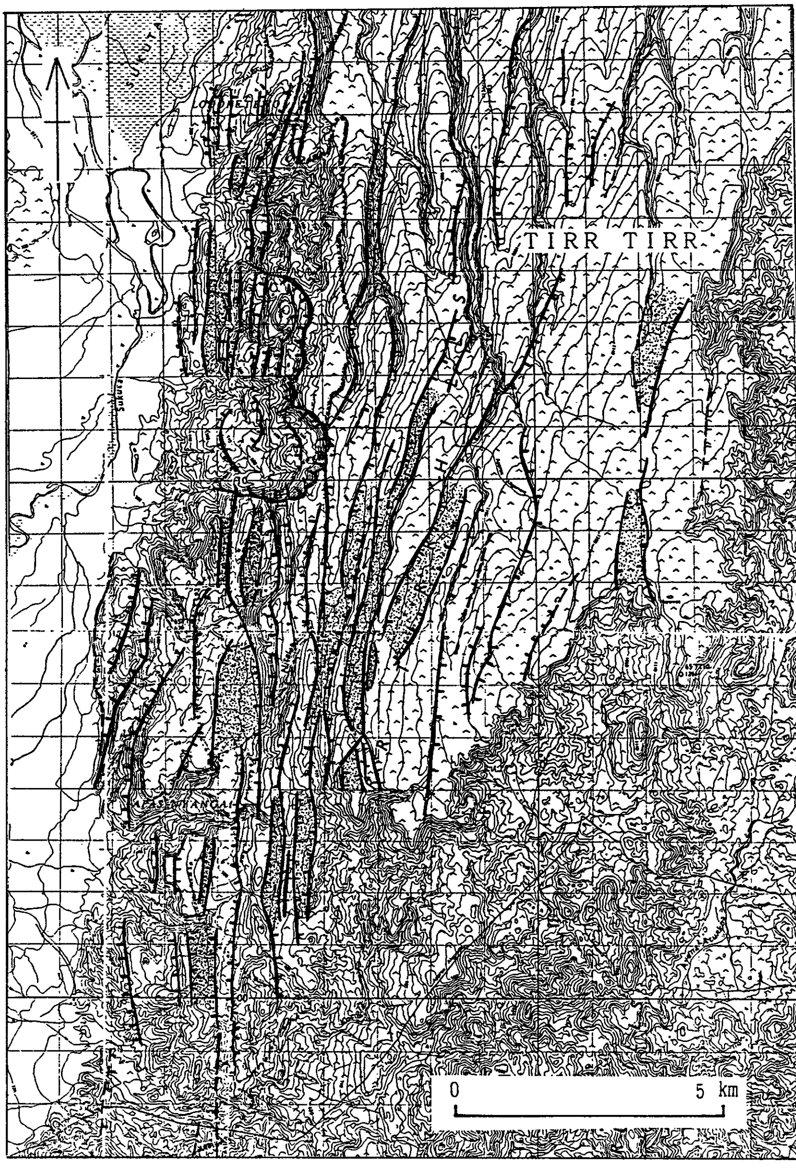

Fig. 8 Fault traces in Tirr Tirr Plateau
Combs indicate the down-thrown sides of dip-slip fault. Dotted area shows graben.
Topographic map is Lobar sheet on a scale of 1 : 50, 000.

landslides or gliding scars are found along this escarpment, and some faults downthrowing westward probably caused by gravity sliding.

(5) Emuruagiring Plateau

Many faults are recognized as fresh fault scraps. They are 4 to 10 km in length and trendinng N-S direction. The flat lava surface is suddenly interrupted by faults steps like stairs. Block structures bounded by step faults predominate.

(6) Sumburu Hills

In this hills, sharp lineaments are presumed to be faults stretch along the valley, and are distributed within the eastern and western zones. They are 10 to 20km in length with trending NNE direction. Some of them are recognized as certanity III, but others are IV with no displacement. As a whole, they have almost all low certainty. The western side is usually upthrown 10 to 100m, but some downthrow to the west. Their distribution is nearly identical with faults showing on geologic maps.

Along the foot of west-end escarpment, NNE trending fault with west-side down-thrown is clearly recognaized about 15km in length, and cut terrace surfaces with fresh fault scarplets.

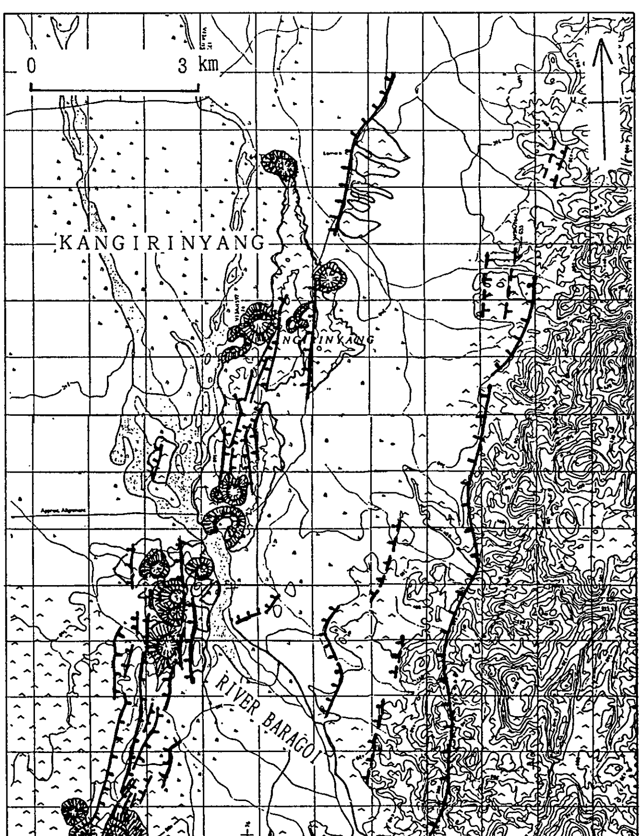

Fig. 9 Fault traces and Pyroclastic cones around the Kangirinyang.
Topographic map is Lomaro sheet on a scale of 1: 50,000

(7) Suguta Valley

The faults are grouped into two areas in this graben. In one, faults are densely distributed in Kangirinyang rising, where NNE trending scarplets and fissures cut volcanic body. Many faults make a swarm 10km in length and 2km in width. The swarm is characterized by dextral en échelon arrangement and is associated with many pyroclastic cones (Fig. 9). A graben structure is recognized along the axis of swarm. Uniformly, westside of the axis is down on the east, on the contrary eastside is down to west. At this northern extension, the west-facing scarplet on the alluvial fan surfaces of Nakaporatelado River records recent faulting. Vertical displacement is about a few meters upthrown on the east side.

The other is recognized in the zone about 2 km wide between Kangirinyang rising and the foot. The faults are running in NNE direction, but are discontinuous and short in length. Alluvial fans and terrace surfaces built by Baragoi, Keemo ngror and Kaeteli cjaragan Rivers are interrupted by fresh scarplets resulted from recent faulting. Vertical displacements are a few to ten meters up to the east side.

In the Namarunu volcanic area on the western side of Suguta River, fresh fault scarps run parallel in NNE direction. Each scarp is 3 to 4 km in length arranged with intermittent continuation and uniformly up to the west.

V. DISCUSSION

(1) Distribution of active fault

The situation of active fault has been written down on projected profiles in E–W direction (Fig. 10). The distribution and characteristics of active faults is in harmony with the nature of each topographic provinces. Active fault are rarely distributed in El Barta plain where Precambrian rocks are exposed, and besides in Lopet and Emuru Akirim plateaus where basement rock is buried near the surface. This means that the eastern part of this area has been free from tectonic movement.

In Sumburu Hills, faults run side by side in parallel with trending in NNE direction. Usually, westward upthrowing is dominant. Faults are distributed in two zones. The eastern zone is located along the axis of flexure reported by Baker (1963), and the western one is distributed along the west-end flexure zone. In fact, distribution and nature of faults in the hills are effected by two flexure zones.

Tirr Tirr plateau is characterized by the great number of active faults. Faults are subdivided into two types. One is distributed in the eastern part. These faults form

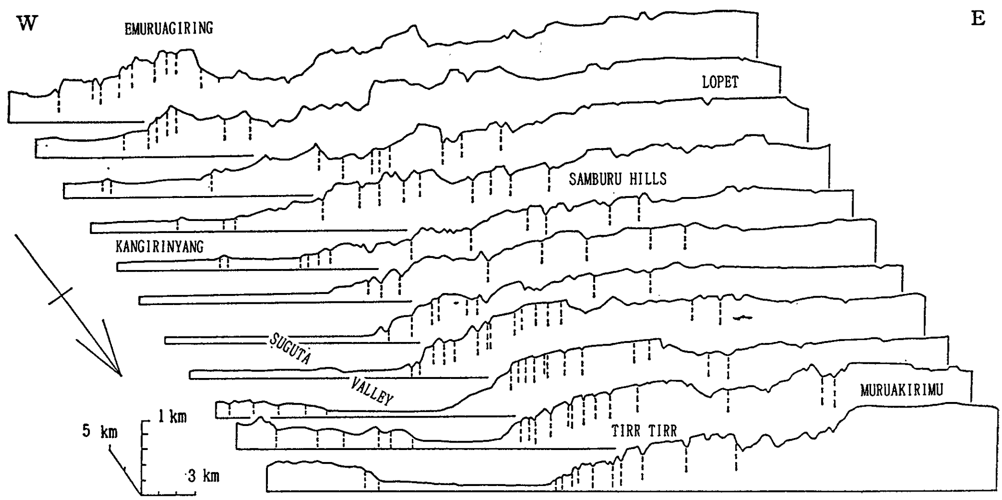

Fig. 10 Projected profiles of the study area in E–W direction. Long-dashed lines show situation of active faults.

distinct horst-graben topography related with up-doming of the plateau, but don't extend into the hills. The other is mostly located in 2〜3km width of the western margin. They are trending in NS direction and have large displacements downthrown to the west. The faulting is probably related to east-upthrown boundary fault formed west-facing escarpments.

In Emuruagiring, active faults have long continuation in N–S direction. The step-like fault blocks are dominant and almost all downthrow to the west.

In the Suguta Valley, active faults are divided into two groups. In one, the faults are recognized in the zone between east-end escarpment and Kangirinyang rising, and have NNE trending parallel to the topographic boundary. They have westward downthrown sense and cut alluvial fans and terrace surfaces at some places.

The other is distributed in linear Kangirinyang swarm and its extension. This swarm is accompanied with violent volcanism. It has to stressed that a graben structure is formed along the axis of it, and that uniformly the west side of the axis down-faulted to the east and the east side to the west. So, faults in the Nangarabat and Namarunu volcanic area which are situated in the west side of the axis, are dominated by downthrow to the east. As a whole, this area is controlled by a graben structure along the intruding axis of magma.

(2) Characteristics and cause of active faulting

Based on the characteristics and cause of active faults, they could be classified into A, B, C, D and E types.

A type is distributed in Sumburu Hills, and almost all faults have been upthrown to the west side. They could be inferred to be normal and antithetic faults, and to be backward tilted. This faulting is considered to have reacted of the preexisted faults in Miocene rocks, and caused by interstratal shearing in flexural slip folding (Mandl, 1988). But their activity since the Quaternary was not so high.

B type is distributed in Tirr Tirr plateau. The strike changes from NNE direction in the east, to N–S direction in the west. In the bending area, horst-graben structure is conspicuously evolved. They are presumed to be gravity faults formed by the tensional stress due to updoming of the plateau. Lava plateaus are underlain by thick lava which unconformably overlies Miocene rock, but the hills consist of west-dipping Miocene rock. Therefore, faults in the plateaus is likely caused by fracturing brittle lava layer.

C type is recognized in the border zone between the escarpment and valley floor. The dip slip faults with west side downthrow are dominant and synthetic ones. They are accordant with the direction and dislocation of west-end escarpment. Recent fans and terrace surfaces are cut by fault running along west margin of hills. Displacement of west-facing fresh scarplets have accumlated during the late Quaternary. This means that active faults have repeatedly moved with destructive earthquakes in recent time. The faulting probably resulted from tensional stress by rift extension, and might be controlled by deep seated boundary fault.

D type is recognized in median graben, and is accompanied with volcanism. In Kangirinyang swarm, numerous faults are densely distributed within 2km width, and strike about N10°E. Graben structure bounded on both sides by faults is recognized along the axis. Along the southern extension, many pyroclastic cones and crater of Emuruangogolak volcanics are lineally arranged. It should be stressed that the swarm is accompanied with many fresh scoria cones. It appears that this is located along the deep fissure zone parallel median graben, and marks the axis of extension caused by upwelling of magma.

By Yairi's method (1974) based on en échelon arrangement of faults, maximum direction of extension of this zone could be estimated to be N67° W. Forcal mechanism solution of earthquake in the Rift indicates extension of the same direction.

E type is recognized in a zone within 2～3km width between the foot of west-end escarpment and Kangirinyang swarm. They are short but young downthrown to west side. Fresh fault scarps cut alluvial fan and terrace surfaces formed during the latest Quternary. That they might be subordinate normal fault caused by adjustment of stress between boundary fault and Kangirinyang fissure zone.

(3) Evolution and areal migration of faulting

In Sumburu Hills, deposition and tectonism during the Miocene were controlled by the west downthrowing Sumburu Flexure. Intense faulting took place in late Miocene (around 7～10 Ma). After the enormous eruption of Tir Tir and Emuruagiring lavas updoming of the plateaus caused numerous nomal faults. The faulting in the plateaus started around 3 Ma (late Pliocene) after the eruption of lava. But boundary fault along the west-margin of the hills has started to act in early Quaternary (after updoming of the Tirr Tirr plateau). Therefore, formation of median graben and large west-end escarpment has started in early Quaternary. The Kangirinyang swarm in the graben has evolved since about 0. 5Ma.

These facts indicate that the main area of faulting has migrated with the times from east to west. That is, the horizontal distance of migration since Miocene amounts about 20km. The mean rate of migration attains 2mm per year. This rate almost equals extensional rate of 3 mm per year across the grabens as the East African Rift, Gulf of Suez and Red Sea Rift, estimated by Lepichon and Francheteau (1978).

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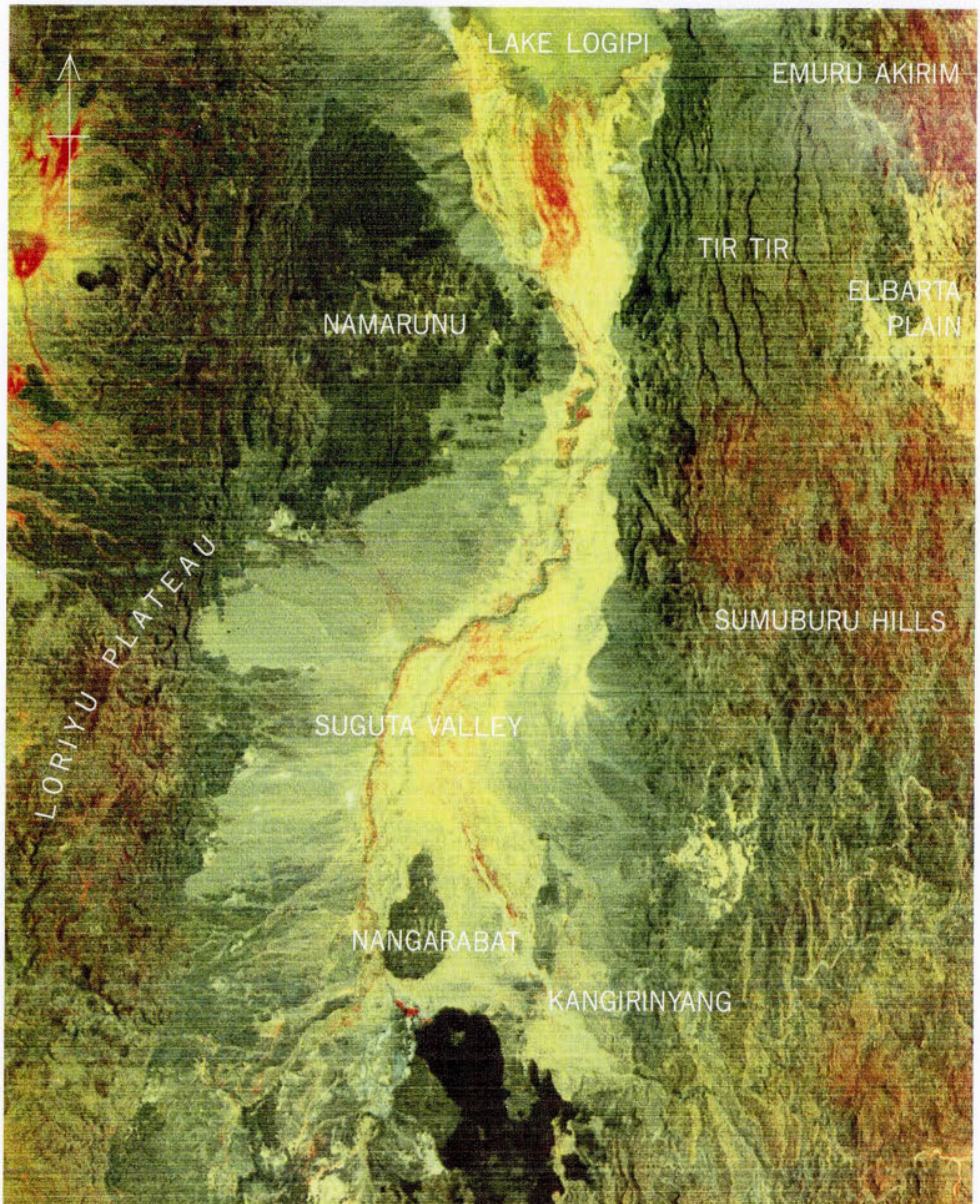

Fig. 1 Landsat image of the Sumburu Hills and Suguta Valley, Northern Gregory Rift.

Plate 2

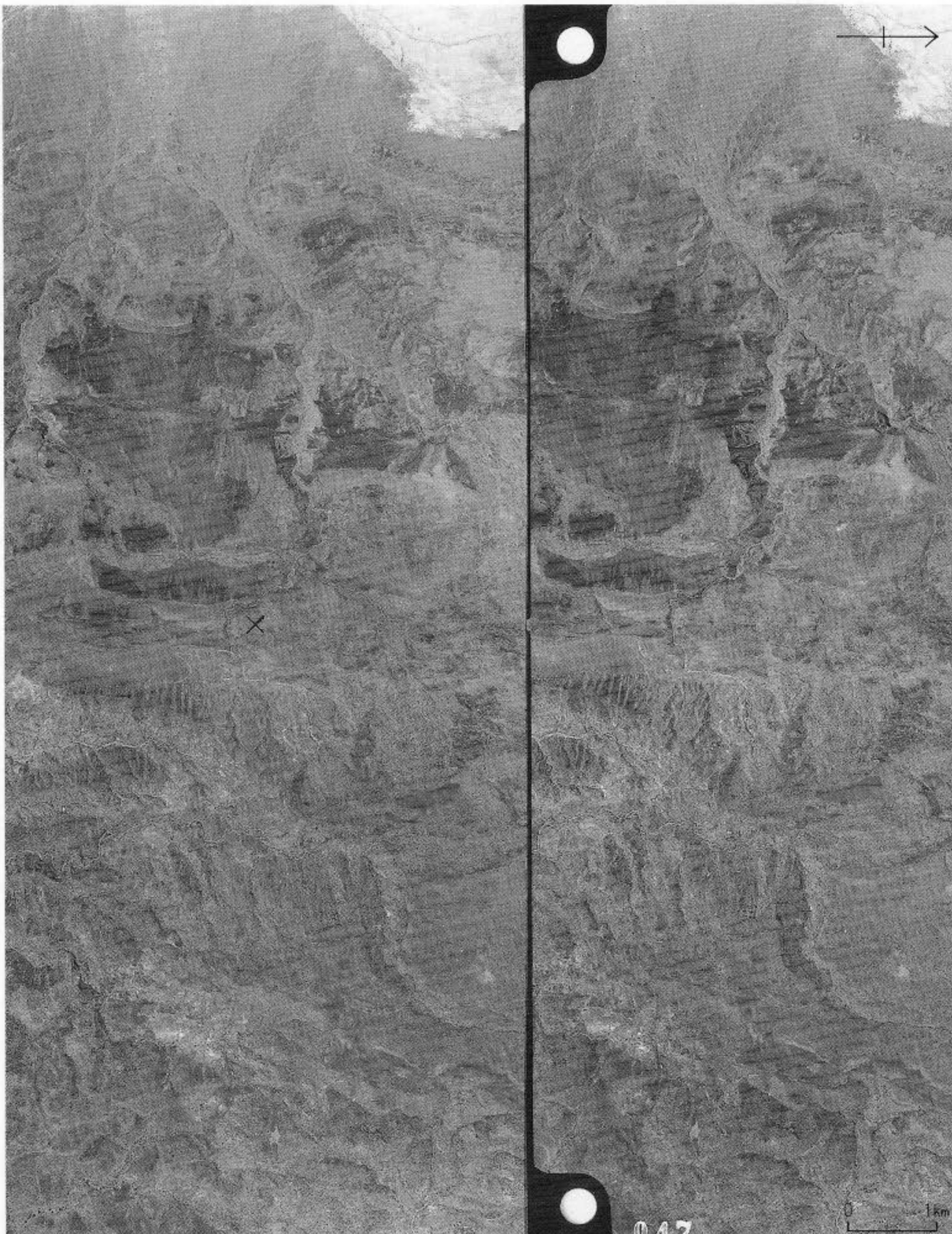

Fig. 2 Stereo pair of aerial photographs showing southwest Tir Tir plateau. Note grabens and west-upthrown faults on lava surface, and gravity faults distributed along west-end escarpment.

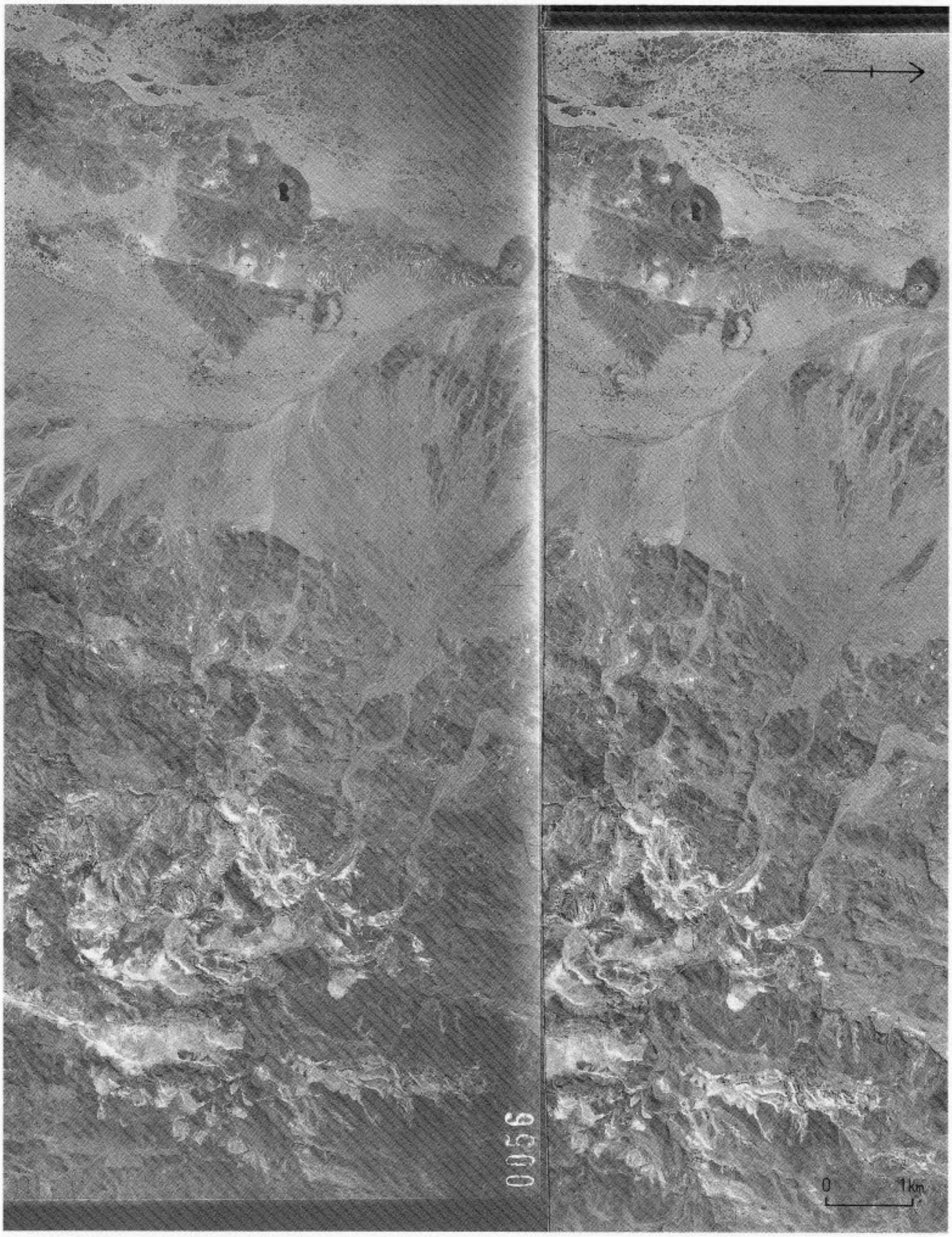

Fig. 3 Stereo pair of aerial photographs showing west-end escarpment of Sumburu Hills and Kangirinyang volcanic body. Note N-S trending faults in border between foot of escarpment and median graben, and Kangirinyang fault swarm.

Fig. 4 Physiographic feature of erosional surface in El Barta Plain, north of Baragoi. Inserbergs are visible in the distance.

Fig. 5 North-east end of Lopet plateau, showing a mesa capped by phonolite lava.

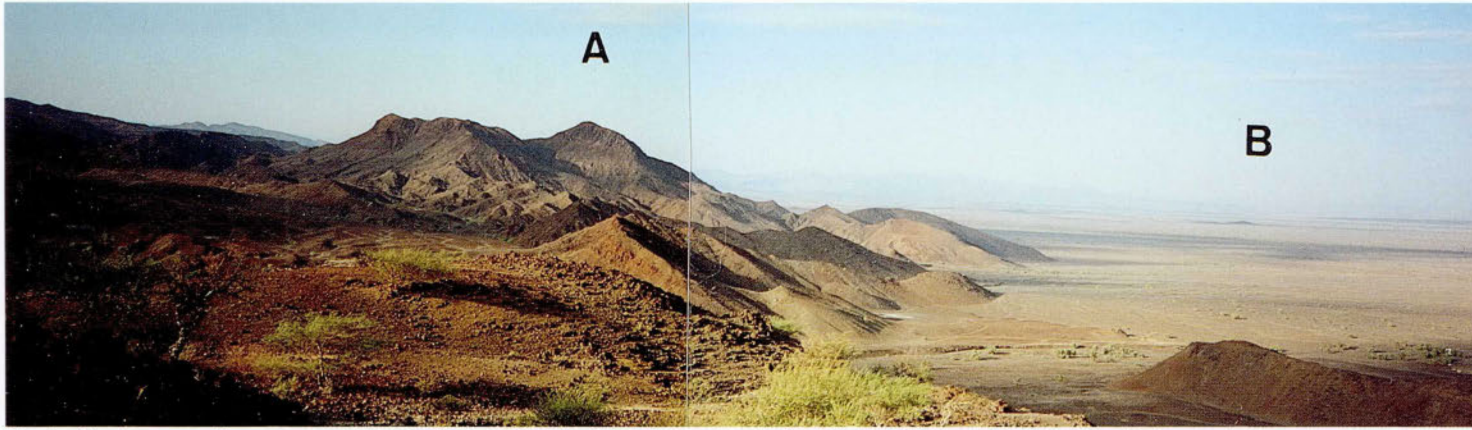

Fig. 6 Escarpment of western end of Sumburu Hills, and median graben called Suguta Valley, looking toward the south.
The area covered from Gate of Sumburu (A) in the foreground to Kangirinyang (B) in the far background.

Fig. 7 Topographic feature of Sumburu Hills, showing asymmetrical ridges by differential erosion of west dipping Miocene rocks.

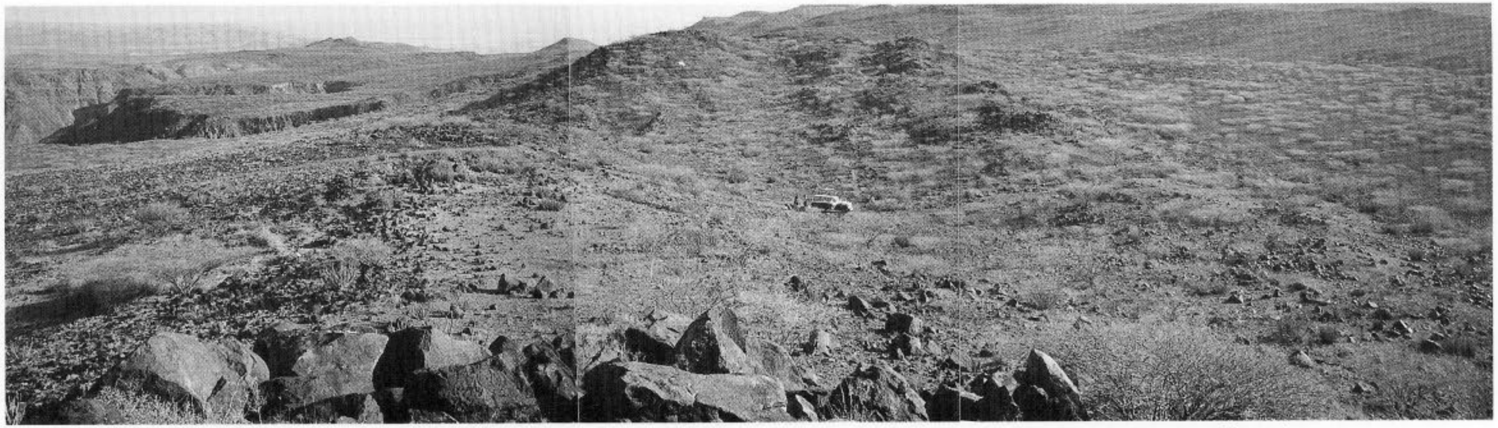

Fig. 8 Horst-graben topography in the southern Tirr Tirr plateau, looking toward the north. A jeep stops in a small graben.

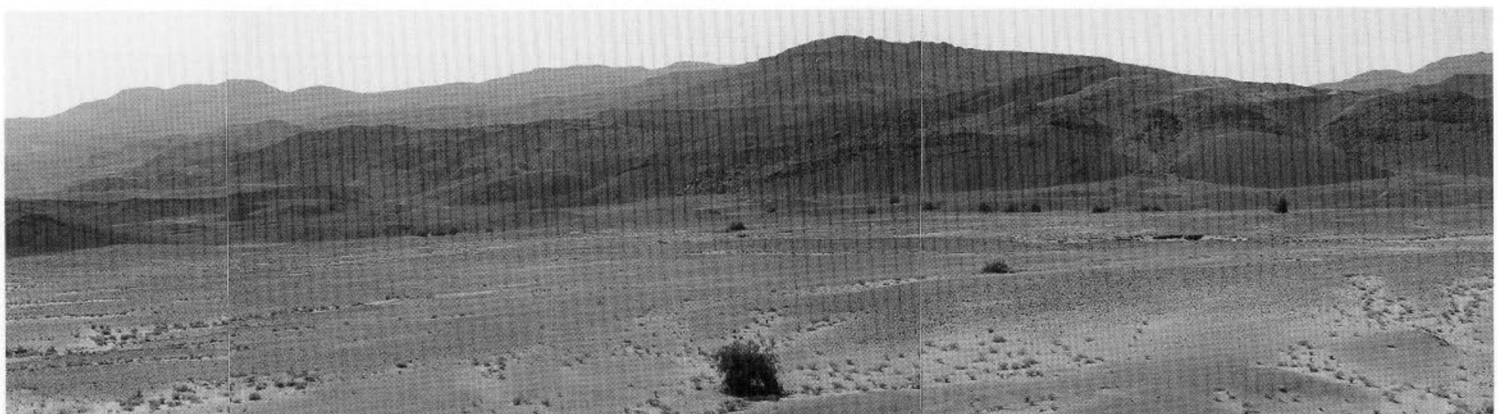

Fig. 9 View of west-end escarpment of Sumburu Hills and graben floor of Suguta Valley.
Looking toward the east from hill located in southern lower reach of Keemongor River.

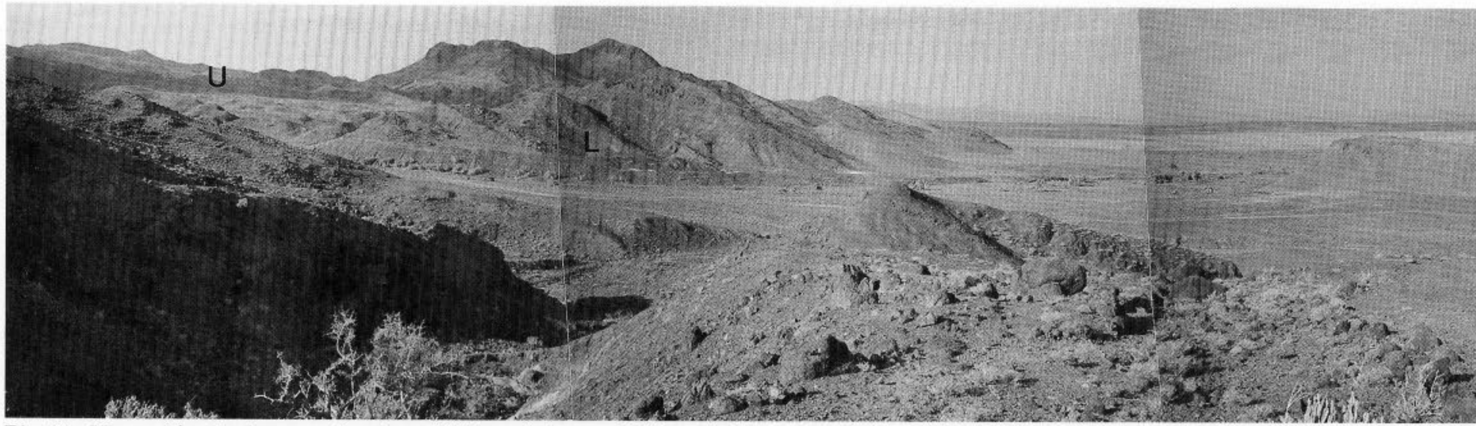

Fig. 10 View of border between Sumburu Hills and Suguta Valley, looking toward the south. Showing two terrace surfaces (U and L) distributing along Kongia River.

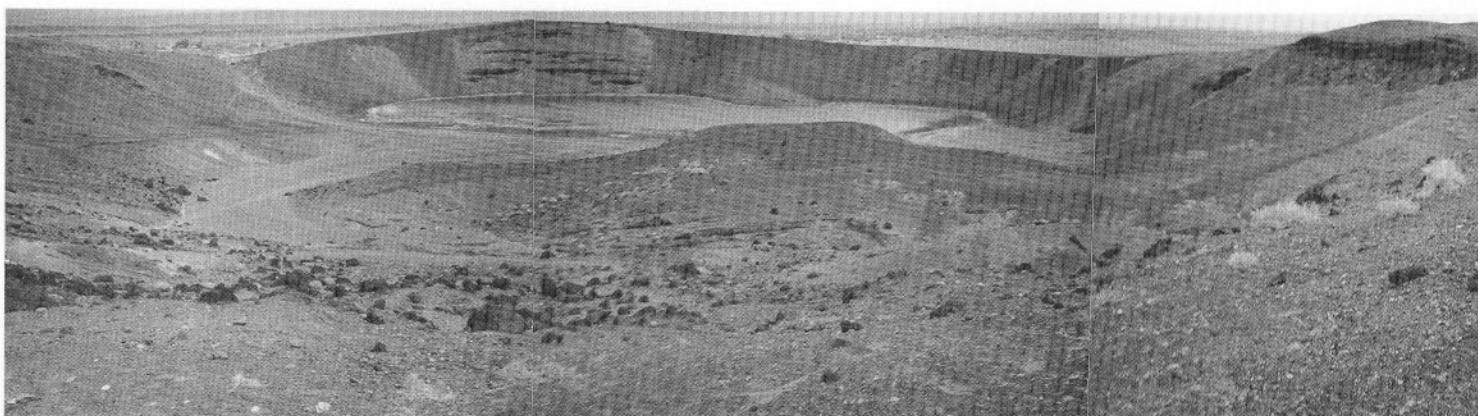

Fig. 11 One of the largest scoria cone in Kangirinyang. A crater lake is visible in the center.

Fig. 12 Fresh fault scarp with small depression cutting two terrace surfaces, situated in north bank of Baragoi River.
Note displacement of older surface (far background) is larger than younger's one (foreground).

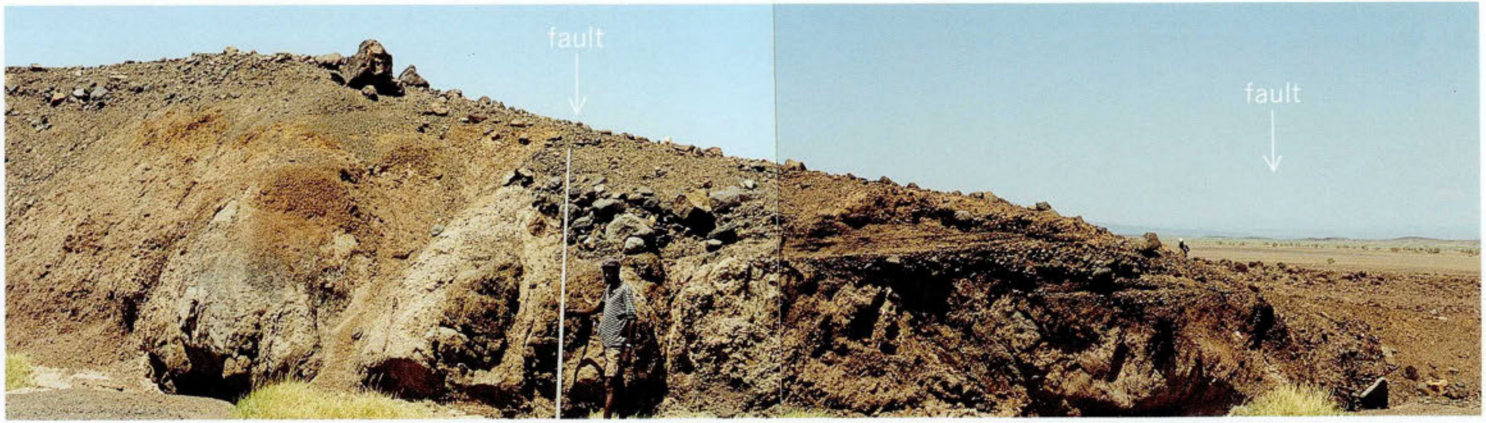

Fig. 13 Outcrop of the latest Quaternary terrace deposits cut by step faults, in south bank of southern small tributary river of Kaeteli cjaragan River.