DEFORMATION OF HAKONE VOLCANO, SOUTH-WEST OF TOKYO, JAPAN

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(Received January 6, 1970)

INTRODUCTION

Of those around the north-western margin of the Pacific Ocean about 196 well-known volcanoes of Quaternary age are in Japan, including 16 calderas** (KUNO, 1953), and eruptions of about 46 have been recorded since the eighth century.

The investigation of these volcanoes has been approached from various disciplines, particularly by way of volcano-stratigraphical, petrological, and geophysical studies, in which recently considerable advances have been made, as may be judged from the 286 papers listed in the "Selected Bibliography of Japanese Volcanoes" at the end of this paper (ISSIKI *et al.*, 1968).

The study of deformed volcanoes has long been neglected, however, as TSUJIMURA (1952) has remarked. In general Japanese volcanoes, especially those of Pleistocene age, exhibit evidence of considerable deformation both on a regional and a local scale. In this paper the deformation of the Hakone volcano is described as an example—though it has already been studied exhaustively by KUNO (1937, 1950, 1953, 1962, 1966). This volcano consists of two somma mountains (older*** and younger somma) together with seven central cones with NNW alignment.

TECTONIC SETTING

Immediately south of the Hakone volcano there is a rugged range with north-south alignment which consists of much dissected and deformed Pleistocene volcanoes—Yugawara and Taga. Farther south-west, Daruma is similar, but the Holocene volcanoes Fuji (MACHIDA, 1967, 1968; TSUYA, 1968) and Oshima (NAKAMURA, 1961) are not deformed (Fig. 1). Non-Volcanic mountains surrounding the Hakone volcano are also apparently much deformed, for example, Tanzawa mountain to the north (KANEKO, 1964) and the Oiso Hills to the east, beyond the Sakawa graben (Fig. 2).

The Hakone district has been very unstable, especially in the late Pleistocene or these abouts; thus study

of the deformations of Hakone is not only interesting on its own account but is also of importance in the assessment of crustal instability in the southern part of the Fossa Magna (MATSUDA, 1962).

GEOMORPHIC MAPPING OF THE DEFORMATION OF THE LAND SURFACE

Interpretation of aerial photographs is of importance in the study of surface deformation, especially in volcanic regions, in which the conventional geological method can be applied only in a few restricted localities. As a result of this few faults have been mapped on the geological sheet.

Mapping of faults geomorphically has been attempted on topographic maps to the south of Hakone (TSUJIMURA and AWAJI, 1934), but photo-interpretation has greatly improved the accuracy of this procedure.

The writer has used aerial photographs on the scale of 1:20,000, and the results of photo-interpretations were tested in the field. Criteria applied to surface deformation are dislocations of ridges and spurs in both the vertical and horizontal sense (and more rarely such dislocations of the original surface); offset and bent streams are sometimes found also.

As noted by TSUJIMURA (1952), the present-day geomorphology of the Hakone volcano affords evidence of complex deformation. Though some strike-slip faults are traced, dip-slip faulting (including monoclinical flexure) predominates. Tentatively these faults are divisible, as follows, into five classes: (1) graben faults (including sector grabens); (2) strike-slip faults; (3) collapse faults; (4) transecting (east-west trending) faults; (5) surface gravity faults.*

The graben and collapse types of faulting have been noteworthy. The somma mountains have reached the residual-mountain stage of dissection, and so if the direction of faulting is parallel or nearly parallel to the radial ridges surface dislocation will not be detectable unless geomorphology is taken into account (COTTON,

* In this paper details of faults of this kind will not be recorded, as they are curved, short, and somewhat irregular traces crossing or parallel to the ridges, so that they are apparently unimportant in relief-making. In the south-east part of the older somma, however, surface gravity faulting may have accelerated the rock fracturing and weathering which have supplied a vast amount of debris to Nebukawa earth flows a million cubic metres during the Kanto earthquakes in 1923 (IMAMURA, 1937, p. 70).

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** More than 20 if those of doubtful origin are included (KUNO, 1953).

*** The date of the older somma eruption may be $20-30 \times 10^4$ B. P. (NAGATA *et al.*, 1957).

Fig. 1 Quaternary volcanoes in South Fossa Magna.
Shaded, Neogene Tertiary volcanic rocks (green tuff); ticks,
Quaternary volcanics. D, Daruma; Y, Yugawara; T, Taga volcano.

1950, p. 743—4). The direction in which the scarplet of a normal fault dislocating a ridge faces is commonly down-slope (or along the slope inclination), but in rare cases the scarplet faces the mountain owing to down-throw on the up-slope side. If such faulting is due to collapse of the summit the scarplets formed could be called (infacing) collapse scarplets (COTTON, 1968, pers. com.).

GRABEN-FORMING FAULTS

The most commonly observed landform is a lenticular hollow or graben, the subsided strip is bounded by variously inclined normal faults, and its pattern somewhat resembling the radial arrangement shown on Fig. 2.

A description of major examples follows: A large-

scale down-warping, of some 100 m or more, is recognisable in the south-western part of the older somma (Pl. 1; Fig. 1, Fig. 4) by the following features: (1) down-warped original surface; (2) fault-controlled drainage pattern; (3) dislocated ridges or spurs; (4) small faults and joints in pyroclastic shower deposits near the fault traces.

In the Hakone-toge (pass) area the fault pattern is complex owing to development of strike-slip faults. Geological evidence of the graben faults is not clear, as it is in the Nagao-toge area to the north (Fig. 2), where details of the somma topography are perhaps determined by east-west (or WNW)-striking normal faults astride the somma mountain (caldera rim). The subsided part (though on a small scale) makes a relatively low pass, and embayments (a drowned shoreline) are

Fig. 2 Surface deformations of Hakone volcano and its surrounding district.

1, contour line of summit level; 2, original surface (includes erosion surface on Neogene Tertiary); 3, alluviated Sakawa graben floor; 4, marsh; 5, Kamiyama mud flow (Holocene); 6, mud flow and other ejecta (Ko-Fuji) (Pleistocene); 7, pumice flow deposits (Pleistocene); 8, gravel deposits (Suruga gravels, Pleistocene), arrow indicates tilted surface; 9, younger somma lavas; 10, andesite lava of Yagawara volcano; 11, basement rock (Neogene Tertiary); 12, monoclinical flexures; 13, Kannawa up-thrust fault; 14, fault (fault-scarp height below 20 m); 15, fault (fault-scarp height ranging 20—50 m); 16, fault (fault-scarp height over 50 m). Crosses, horizontal depositional surface; K, Kintoki-san; H, Hakone-toge; N, Nagao-toge; M, Myozinga-take.

formed along the base of the caldera.

The most complex example of a down-faulted area is found in the north-eastern somma. The younger somma, in the south-eastern part of the floor of the caldera, is similarly down-faulted with the graben system (Pl. 1, Fig. 2).

Some ENE- and NW-striking graben faults are apparently traceable beneath and to the north of Futago-yama* lava dome (Pl. 1, Fig. 2).

Fissure traces on the top of Futago-yama suggest

rejuvenation of the graben system beneath the dome. Geological evidence of similar down-faulting to the north at Futago-yama have been observed at several places at Loc. *a* (Fig. 3), where the minimum (extension) stress axis, trending NE-SW, is inferred from analysis of the conjugate sets of small fault.

East of Ashinoyu pyroclastic shower deposits up to 10 m or more thick have been observed to be tilted and faulted, particularly in Locs. *c*, *d*, but also in others. Farther southeast, at Loc. *e*, a collapse-like scarplet on

Fig. 3 Fault map in Central cones area.

1, contour line of summit level; 2, Kami-yama mud flow; 3, steep slope fringing central cones; 4, lava flows of Kami-yama; 5, lava flows of Komaga-take and other; 6, original surface remnant; 7, younger somma lavas; 8, lava dome; 9, Kami-yama strato-volcano; 10, 1930 earthquake fault; 11, major fault (fault-scarp height over 50 m); 12, fault (fault-scarp height ranging 20—50 m); 13, fault (fault-scarp height below 20 m); 14, monoclinical flexure; X, boring site; G, Gora; S, Sengen-zan; A, Ashino-yu; KM, Komaga-take; KA, Kami-yama; F, Futago-yama.

* The Futago-yama lava dome has recently been dated at about 5,000 B.P. (MACHIDA, 1964).

the younger somma slope has been clearly observed on an aerial photograph and in the field, while at many places—e.g. at Locs. *a-d*, *g*, *i*, and *j*—actual fault planes dislocating the central cone lava are recognisable; the vertical displacement at Locs. *g* and *i* is 30–40 m. It is possible, on the other hand, that the north-facing steep slope* of the central cone (strato-volcano of Kami-yama (KUNO, 1950)) has been originated rather large-scale down-faulting. In this regard, a recent boring operation (OKI, *et al.*, 1968) at Loc. **Q** is suggestive.**

Photo interpretation leads to the assumption that the so-called Kami-yama mud flows, consists of avalanche debris (KUNO, 1950), are composed of materials derived from at least three separate source*** areas.

Another topographic form observed is the triangular area of subsidence, or sector graben (WILLIAMS, 1941; COTTON, 1952), of which there are examples in the north-west and south-east parts of the flanks of the older somma, where the radial ridges are obliquely downthrown along several faults and monoclinical flexures.

STRIKE-SLIP FAULTING

There are lateral-slip faults in two separate area; Hakone-toge and east of Myozinga-take area. At the Hakone-toge (pass) locality several dominant left-slip faults cross the mountain of the older somma; such faults seems to be traceable on aerial photographs (as some of the faults were actual during the North Izu earthquake, in 1930) (cf. Fig. 4), but no convincing geological evidence of it has yet been found.

As recorded by TAYAMA (1931), fault **A**, which has been traced also on air photographs by the writer, developed displacements during the 1930 earthquakes, the eastern side being downthrown, without any lateral slip. Scarplet **B**, however, to the west, showed 0.5 m of left-slip in 1930 (IHARA and ISHII, 1932). This scarplet appears to continue farther south-eastward, judging by the similar scarplet near Kurakake-yama, where NW-trending cracks opened in 1930.

Horizontal movement along the fault **C**† in 1930 has not been mentioned, but left-slip topography and crushed rock have been observed along the fault trace in the south-eastern part of the Hakone-toge.

The most clearly traceable faults on aerial photographs, **D** and **E**, are probably active (Pl. (2)). Along the fault **D** a diverted stream, spur offsets (at three

places), cracks trending 330° which opened in 1930, and seismic sliding (at Loc. **D'**) have been recognised, but the writer has been unable to determine whether the fault movement was horizontal or vertical.

Along the fault **E** two shutter-ridge horizontal displacements in the left-lateral sense of up to several tens of metres are assumed. This active fault may extend farther to the south towards fault **F**. Left-slip topography appears to be traceable again (KUNO, 1966; MATSUDA and OKADA, 1968). Many earlier investigators, however, with the exception of TAYAMA (1931), though they have observed trenches, scarplets, and other cracks, have failed to report unequivocal evidence of strike-slip displacement.

The NNW-trending faults mentioned above seem to be all left-slip faults, and some of them are apparently active. Faults of the graben system are not, however, offset by this system. This may be the result of lateness of development of the strike-slip faults; or possibly the displacement diminishes as the Hakone-toge area is approached.

Recently MATSUDA and OKADA (1968) have mapped active faults trending east-west to west-northwest in the Hakone-toge area, one of which is scarplet **K** (Pl. 2) (the scarp is 15–25 m high). The upstream part of a stream that crosses the last-mentioned scarplet has been downthrown to the north, with the formation of a windgap. Such dislocation is suggested also by minor step faults in pyroclastic shower deposits near the trace at its eastern end.

To the north scarplets **I** and **K** have been recognised, right-slip displacement of up to several tens of metres being estimated from offset spurs and valleys and from a bent stream (Fig. 4). Some transcurrent-buckling features have been observed, as shown in Fig. 4.

To the south, E-W or more north-westerly-trending fault traces have been clearly recognised on aerial photographs, most of them showing right-slip.

If the left-slip and right-slip faults mentioned above have originated as a conjugate set in the same stress field during the late Pleistocene and the Holocene (MATSUDA and OKADA, 1968), then the horizontal compressive stress seems to have acted in the direction 310° (330° farther south). An earthquake fault that occurred along the Ashino-Ko (Fig. 4) during the earthquake of 1930 is particularly noteworthy in this connection. The writer also has found left-slip fault (6 km long, with a west-facing scarplet 10 m high) east of Myozinga-take (Mt. Myozin) (Fig. 2); its fault trace crosses the major radial ridges and displaces them from 35 to 180 m.

COLLAPSE FAULTS

Strange to say concentric fault patterns are scarcely observable, except for caldera-formed faults. Major

* Owing to the high viscosity of the magma central cone are steep-sloped, but traces of fault-controlled slopes (facet-like scarps) are recognisable also, as shown in Figs. 2 and 3.

** The test bore hole, 400m deep, in the graben floor passed through 50m of mud-flow deposits, 200m of andesitic lava (lave flows of Kami-yama), and 150m of pumice flow, and reached to the andesitic younger somma lava at 410m below the surface.

*** The southernmost mud flows blocked the Hayakawa River valley thereby forming, Ashino-ko (Lake Ashi).

† A Photograph in IHARA and ISHII's report (1932, pl. 10, Fig. 5) shows left-slip displacement.

fault traces, striking E-W or more northerly, are identifiable dislocating the somma mountain, its eastern flank in particular. These cross the radial ridges obliquely and downthrow then consistently towards the north, the total displacement being about 300 m. A conclusion that the east-west-trending fault system has been established only recently is based on the following facts: (1) the faults are almost absent or are discontinuous in the area dominated by the graben system; (2) the fault cross the north-south-trending left-slip faults; (3) there is down-warping or tilting of pyroclastic (pumice) flow deposits adjoining the fault traces.

DEFORMATION AROUND THE HAKONE VOLCANO

Deformed landform in considerable variety encircle the volcano. To the north of it, as has been known since 1910 (KUNO, 1950), there is the Kannawa reverse fault, between the Tanzawa (early Miocene) and Ashigara (early Pliocene) formations, with east-west trend. MATSUSHIMA and IMANAGA (1968) have pointed out that up-thrusting in this fault was renewed in the middle Pleistocene; the western third of it shows upthrusting towards the south-east, to judge by striated surfaces, though the physiographic trace is less conspicuous. Near the eastern end of the up-thrust, where other linear faults are present, its displacement will perhaps be strike-slip.

While to the west the Tanzawa mountain is characterised by recent vertical movements and south-facing fault scarps are associated apparently with 10–20 m of downwarping of middle Pleistocene deposits, similar, though younger, downwarping, in this case on north-south lines (Fig. 2) is recognised in the north-eastern part of Gotenba by deformation of mud flows* of late-Pleistocene age (MACHIDA, 1964; 1968).

This suggests upheaval of the basement of the volcano—

—Ashigara mountain, on its eastern side—or else relative subsidence of the whole volcanic mass against the basement.

In contrast with this, at the foot of the volcano on the east side is the alluviated Sakawa graben (Fig. 2), up to 4 km wide, with east-west asymmetry. A west-facing conspicuously developed fault scarp turns WNW at its northern end and turns south-eastward towards the head of Sagami Bay; the scarp may continue farther south-eastward (SHEPARD *et al.*, 1964). The height of this fault scarp after deposition of pumice flows at its base during the middle-Pleistocene is estimated at 100 m or more (MACHIDA and MORIYAMA, 1968). The fault plane has not been observed, but indirect evidence for major faulting is afforded by the following: (1) Lava blocks that occur in the scarp (imbedded in a Pleistocene formation) are derived from the older somma volcano (KUNO, 1950); (2) there are gaps of 100 m or more (in the vertical sense) between outcrops of the pumice-flow deposits on the two sides of the fault scarp (MACHIDA and MORIYAMA, 1968)**; (3) there are down-faulted terraces of Holocene age (20–25 m) near Kozu (YONEKURA *et al.*, 1968); (4) there are minor normal faults and tilted deposits bordering the major fault scarp; (5) there is a tilted fault block*** standing above the graben floor. It is noteworthy that during the Kanto earthquake (1923) some subsidence or shaking down has occurred along the several-metres-high scarplet that bounds the western edge of this tilted block. (Fig. 5).

The last-mentioned scarplet may extend northward across the basin floor and across the major north-west-trending fault scarp, which is associated with step faults dislocating the Oiso Hills (Fig. 2).

If this is the case, the northerly-trending curved fault (with fault scarp and step faults) was probably in existence before the formation of the north-west-trending major fault scarp.

Fig. 5 Low-standing tilted fault block in alluviated Sakawa graben (see Fig. 2).

* These are largely volcanic mud flows, with also ejecta, from Ko-Fuji (TSUYA, 1968), which cover, or partly rest upon, the somma flank (Fig. 2).

** The writer has reached nearly the same conclusion north of the graben, where the thick pumice deposits of the graben floor do not occur, but only gravel deposits up to 50m thick.

*** This block is covered by thick pyroclastic shower deposits and seems to be older than the Holocene terraces fringing the Oiso Hills which have been mentioned above.

In the Hakone-toge area some faults are hybrid in nature, combining strike-slip and collapse faults; similar dislocations have been observed in the area of Yugawara volcano, especially adjoining the part of the Yugawara where the down-warped zone elongated from west to east or north-east is recognised (Fig. 2).

As already mentioned, many features suggest subsidence to form a moat-like deformation (though less symmetrical) that encircles the Hakone volcano. On the western somma flank and elsewhere, there are minor faults and monoclinical flexures, hitherto undescribed, that seem to demonstrate such sympathetic movement.

SOME DISCUSSION OF THE DEVELOPMENT OF THE HAKONE VOLCANO

As the result of repeated eruptions (see foot note p. 247) of basaltic and andesitic lavas a strato-volcano estimated to be 2,700 m high (KUNO, 1953) had been built up over a low relief surface of the Neogene basement (KUNO, 1950). After that collapse of a summit area (10×6 km) occurred; this collapsed caldera is thought, from petrological study, to be of the Glencoe type (KUNO, 1953).

After some considerable erosion, acidic (but relatively fluid) eruptions opened within the older somma and built a shield volcano. From this summit nearly 5×10^4 years ago a vast amount of dacitic or andesitic pumice flows were emitted (MACHIDA and MORIYAMA 1968). Such rapid exhaustion of magma beneath the volcano has been considered to be the main cause of collapse of Krakatau type and the western half of the shield volcano was down faulted and disappeared, leaving nearly triangular and less symmetrical collapse calderas* equalling or exceeding the former Glencoe-type caldera in dimensions. During this last activity emission of viscous lava took place, building six lava domes and a strato-volcano (Kami-yama) aligned in a north-westerly direction within the younger somma (KUNO, 1950).

Assuming that each bed of tephra generally represents one event of explosive activity, MACHIDA and MORIYAMA (1968) point out, as a result of tephrochronological study of the Oiso Hills, that the magnitudes of the eruptions of Hakone have clearly diminished progressively from the somma stage to that of the central cone eruptions.

The somma mountains have been dislocated predominantly by the graben-forming faults, this type of faulting being a fundamental deformational unit. It is not yet known whether the radial arrangement of these faults is the result of rifting by expansive force

exerted by up-doming, or whether the graben system is merely a subordinate phenomenon that accompanied collapse, or indeed, whether the so-called collapse-caldera was formed really as a result of combined effects of the graben system.

Considering the distribution of pumice-flow deposits (KUNO, 1962, Fig. 17), the graben system that localised the overflow of the pumice flows seems to have been in existence during these eruptions. The graben system has, however, been developed progressively with successive eruptions, especially those associated with the collapse of the shield volcano. The system of grabens leading away from the volcanic centre diminishes in scale during later stages.

Some authors have recently discussed the geological and structural background of the establishment of the collapse calderas of Japan. After study of the relation between their diameters and the original heights of the volcanoes SUZUKI (1968) has discredited the belief that the diameter is proportional to the height. He has also pointed out that the settlement of the volcanic mass—that of Hakone as a whole—has occurred relatively to the Ashigara mountain.

It is noticeable, moreover, that the collapsed volume, 12 km^3 according to KUNO (1953), is much larger than the volume of pumice-flow deposits erupted, 8.4 km^3 (KAIZUKA *et al.*, 1963), but such discrepancy of volume will disappear when new discoveries of pumice-flow localities (MACHIDA and MORIYAMA, 1968) are taken into account, together with the volume of water that has escaped as volcanic gas (KAIZUKA *et al.*, 1963). But such discussion is, as pointed out by YOKOYAMA (1969), of highly difficult matter, for the estimated volume is not accurately obtained.

From another angle, ORIDE (1968) has pointed out general characteristics of Japanese calderas of the Krakatau type—namely, their rectangular form; the fact that they are relatively low-lying (-50 m to 500 m); the basement consists of younger Neogene and early Pleistocene rocks; and there is some tectonic control of the establishment of calderas during the late Pleistocene. He came to the conclusion that the location of Hakone is just upon the large-scale crustal down-buckling that connects the Suruga-Sagami trench encircling the Izu resurgent craton (MATSUDA, 1962; KANEKO, 1964). This suggestion of down-buckling is not supported, however, by the writer's observations on the Hakone volcano, no evidence being found of required east-west-trending zone of dislocations, though large magnetic anomalies (HAGIWARA, 1965) suggest surface disturbances with a more northerly strike. Complex deformation in the north-eastern flank of the somma (especially at northwest part of Myozinga-take) a south-westward extension of this along the rim of the younger somma are also very noticeable features. It must be

* Recently YOKOYAMA (1969) has pointed out, with his gravity measurements and other informations of drilling, that the Neogene basement is rather upheaved in the Hakone area, so the origin of collapse caldera is debatable. He suggested that the caldera has probably been enlarged by the combined effects of explosion and erosion.

pointed out here that this (NNE-striking) direction is fairly accord with the trend of regional gravity anomalies (YOKOYAMA, 1969).

At one time KUNO (1937) postulated from parasitic cone arrangement during the first stage of activity that a line of dislocation (a hinge fault) had formed across the stratovolcano from north-west to south-east. If such a feature was really formed, however, it is not now identifiable in the landforms. Flank eruptions of Hawaiian type along the rift has been suggested to explain this mechanism (NAKAMURA, 1969).

Another conclusion of NAKAMURA is that the channel facilitated the intrusion of a dike swarm and recurrent eruptions on a NW-trending line has been opened as extensional fracturing caused by a NW-trending field of compressive stress. The writer's observation, however, do not allow him to interpret what has been going on under the Hakone volcano, though he might suggest that the cause of complex surface dislocation as well as down-warping around the volcano may have been due partly to large-scale evacuation of magma from beneath it and partly to the effect of the load of a huge volcanic accumulation on the flexible Neogene crust.

Phenomena of local isostatic settlement associated with the formation of the central cone has been discussed by HORIE (1956) in connection with the deformation of lacustrine terraces developed along the Ashinoko. The occurrence recently of much local settlement, for example, adjoining the Hutago-yama is suggested by the following: a tilted lava flow at Loc. t (Fig. 3); a collapse-fault scarp at the southern foot; dislocations or fractures on the dome; and slight tilting of the two domes towards each other. Besides this, adjoining parts of the Hakone are characterised by much differential block movement, as noted earlier. It is apparent, therefore, that the present-day forms of the Hakone and of its surrounding are the results of a combination of isostatic with regional deformation.

CONCLUSION

It has become apparent from investigation of deformations of the surface, that the Hakone volcano has been disturbed by complicated interplay of various kinds of faulting (including monoclinical flexuring) both regionally and locally.

The graben-faults with a generally radial arrangement are of considerable importance. The major faulting has been probably taken place during the formation of the younger somma, but perhaps continued in a later period. It is impossible, however, to draw a definite conclusion regarding the mechanism and the geological implications of the deformation associated with the system of graben faults.

This parts of the crust around the Hakone at a dis-

tance of 10 to 16 km from the volcanic center are also deformed to form a moat-like down-warped zone.

While active strike-slip faults are dominant in the southern part of the Hakone, some of them have clearly moved during the North Izu earthquake of 1930. These faults indicate regional horizontal compression in a NW-SE direction (a similar direction has been inferred also from the trends of dike swarms and parasitic and central cones).

To the north and east of Hakone tectonic deformations are now actually in progress apparently, isostatic deformation has been superposed on such crustal deformation on a regional scale.

ACKNOWLEDGEMENTS

I must thank Sir CHARLES A. COTTON, for the generous and obliging spirit in which he have read this paper throughout. I could have never compiled of this paper if he had not generously afforded me assistance. And I also must thank Prof. Ryohei MORIMOTO, of Tokyo University, for his warmest encouragement of this study.

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箱 根 火 山 の 変 形

金 子 史 朗

(要 旨)

箱根火山の地表の変形を、空中写真判読と野外で検討した。その結果、この火山体は、種々な型式と規模の複雑な断層運動および撓曲的変形をうけていると考えられる。断層は、およそ、グラーベン型、横ずれ断層型、山頂部の陥没に関与した型式のもの、山体を横切るもの、および、ごく地表付近の重力型断層など、五種に区分ができた。幾分か放射状配列を示すグラーベン型の断層で断層の基本型とみられ、新期カルデラ成立時に、おおよそ現在の pattern が完成したらしい。その形成のメカニズムは明らかでないが、陥没カルデラの成立に重要な役割を演じたらしい。火山体の南部、箱根峠付近には、外輪山をきる北西～北北西の左横ずれ断層、および東西方向の右横ずれ断層があって、とくに前者は、1930 年の北

伊豆地震時に再動したので、第一級の活断層であろう。

火山山頂部の陥没を示唆する同心円状の断層は、カルデラ壁の断層をのぞいて、予期に反してほとんど認められない。なお、火山体東斜面には、南北方向の左横ずれ断層および山体を斜断する正断層系がみられる。とくに注目される点は火山中心部から 10～16 km 付近に、いくらか非対称的な配置をもった moat 状のへこみが見いだされることである。

つまり、箱根火山の地表変形は、地域的な応力場で生じた変形と、可塑的な第三紀層の上につみ重なった巨大な火山体の荷重に対するアイソスタシー的な調整運動との両者の Superposition としてとらえることができる。

Explanation of plates

Pl. 1, Fig. 1 Large-scale down-warping astride the older somma in Hakone-toge area, viewed
(Upper) from the northeast. (after IWANAMI Photo Library)

Pl. 1, Fig. 2 Futago-yama (1090, 8 m) viewed from the north—Komaga-take. Background;
(Lower) older somma, middle right; down-faulted younger somma Byobu-yama block
standing about 950 m.

Pl. 2 Left-slip fault crossing the older somma in Hakone-toge area, viewed from the
south. Arrow indicate the fault **D**, **E** and **K**; **H**, Hakone-toge. (after IWANAMI
Photo Library)