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Alpha track measurements for faults in northern Turkey

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Abstract : Two kinds of methods of alpha track measurement were carried out for faults including earthquake faults, active faults and non-active geological faults in northern Turkey. One is the "cup method" for detecting the fault trace and the other is the "pipe method" for evaluating the fault activity.

The results by the cup method show that the alpha track measurement is useful to detect not only active faults including earthquake ones but also non-active ones even in the region containing a little radon. They also show the good reproducibility of the alpha track measurement if they are measured in nearly the same temperature condition.

The results by the pipe method show that the seasonal change depended on the temperature mainly. But in both of two methods, the underground water supply must be taken into consideration before the evaluation of fault activity.

In Mekece region, northwestern Turkey, the seismic gap area of one branch of the North Anatolian Fault Zone, the maximum alpha track density obtained by the both methods is abnormaly high. Furthermore, the result by the pipe method shows the highest value even in winter. These facts indicate that this branch fault of the North Anatolian fault is very active.

I. Introduction

The North Anatolian Fault Zone, about 1, 200 kilometers long, is a right lateral intracontinental transform boundary between the Eurasian and the Anatolian Plates in Turkey. This fault zone trends E-W in general with a slight convex to the north in its central part. The seismic activity has been intense along this fault zone, and the well-known earthquake sequence between 1939 and 1967 produced almost continuous surface breaks, shifting from east to west with age along the main part of this fault zone.

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The authors carried out the geological investigation of some faults including earthquake faults and active faults in the North Anatolian Fault Zone in northern Turkey, employing the alpha track etching method.

In recent years, measurements of subsurface radon concentration have been used to detect faults, particularly active faults and to predict earthquake occurrence (e.g. KING, 1980).

Measurements of changes in radon concentration by the alpha track etching method were carried out in the search for the following faults.

a) surface breaks resulted from the 1939 Erzincan Earthquake at the northwestern margin of the Erzincan Basin,

b) surface breaks resulted from the 1944 Gerede-Bolu Earthquake to the west of Bolu and the active fault segment showing the creep movement at Ismetpaşa,

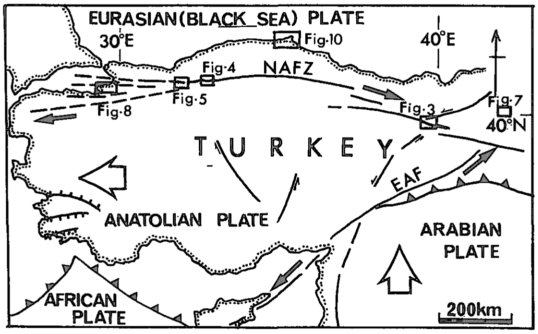

Fig. 1 Map showing investigated areas. A black arrow indicates slip sense of transform fault and a white arrow indicates that of plate motion. NAFZ : North Anatolian Fault Zone, EAF : East Anatolian Fault.

c) newest surface breaks resulted from the 1983 Horasan-Narman Earthquake to the east of Erzurum in eastern Turkey,
d) active fault segment at the one branch of the North Anatolian Fault Zone near Mekece in northwest Turkey, where an earthquake occurrence is afraid in the near future,
e) non-active reverse faults in the Sinop region facing the Black Sea, 100 kilometers north of the North Anatolian Fault Zone.

These surveyed areas are indicated by squares in Figure 1.

Most results of alpha track measurements in Turkey have been already published fragmentarily (KATO, 1984, 1986 ; KATO *et al*., 1985, 1989), however enough consideration was not made. The authors outline some faults described previously as metioned above in northern Turkey, compile those preliminary results of alpha track measurements by the cup method, and important remarks obtained by the pipe method and discuss better way for earthquake prediction.

This study is a part of the joint research projects operated by the Geological Survey of Japan (GSJ), Agency of Industrial Science and Technology (AIST), Ministry of International Trade and Industry (MITI), Japan, and Mineral Research and Exploration Institute of Turkey (MTA), Ministry of Energy and Natural Resources, Turkey, entitled in "Research on earthquake faults, active faults and earthquake prediction" (1982-1984 fiscal years) and "Research on Quaternary crustal movement and earthquake prediction" (1985-1987 fiscal years). These projects have been conducted within the framework of "the Institute for Transfer of Industrial Technology (ITIT) Project" organized by International Research and Dovelopment Cooperation Division, AIST, MITI, Japan.

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II. Principle of alpha track etching method

Radon measurements are carried out by detecting alpha particles which are emitted from radioactive decay of radon and its daughters. As the carrier fluid including those alpha particles flows up through faults and associated fractures in the basement rocks and covered sediments, the radon concentration is expected to attain a maximum value on the fault trace. Radon concentration changes in response to the vertical flow of subsurface fluid occurred in association with earthquake faulting and is expected to increase markedly just before an earthquake.

The authors tried two methods of alpha track measurements as shown in Figure 2. Both methods use small strips of cellulose nitrate film which is sensitive to alpha radiation, and explained as follows, here temporarily called the cup method and pipe method.

Cup method : This is an easy and useful way to detect the fault trace. Small plastic cups to which inside bottom film strip is attached with adhesive tape, are placed

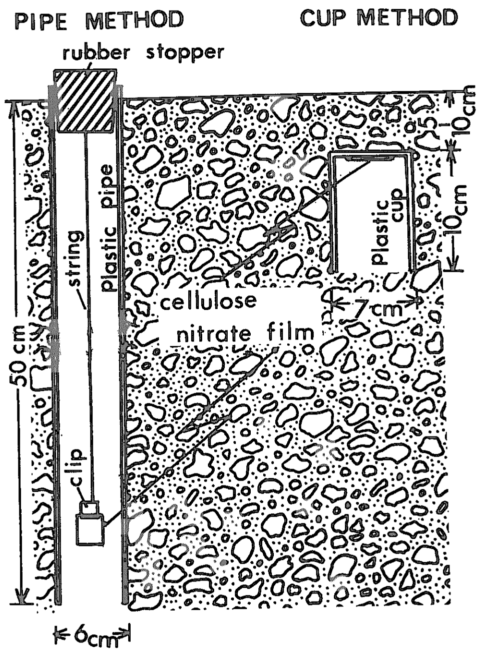


Fig. 2 Schematic illustration of two kinds of alpha track measurement (pipe method and cup method).

upside-down in shallow holes at a depth of about a few tens centimeters. They are spaced at intervals of about a few meters on a line which is normal to probable fault trace, and then are covered with soil and rock fragments whose thicknesses are about 10 centimeters, and are retrieved about one week or more later.

Pipe method : At one site radon concentration is to be measured repeatedly in such a long term as half year to about a year by this method because retriving and changing films is much easier than the cup method. Plastic pipes with a diameter of about 6 centimeters and a length of about 50 centimeters are placed on and around a fault line. The film strip is suspended from the rubber cap put on the top of the pipe and is replaced to new one for each measurement.

Retrieved films are processed in 20% NaOH solution for 100 minutes at 60°C to produce visible track-like images of alpha particles generated by radon isotopes. The alpha tracks are counted under the microscope and calculated by T. D.=N/(S×T) where T. D. is alpha track density, N is the number of tracks, S(cm^2) is area of the film and T is the exposure time (day). Obtained track density represents the average concentration of radon isotopes at the measuring point.

III. Erzincan Region

III-1 Geological and seismological settings

The Erzincan Basin is one of the Neogene-Quaternary intramountain basins along the North Anatolian Fault Zone. The Erzincan Basin measures about 50 km in length and 10 km in width. The basin is situated at 1,150 m-1,130 m high above sea level.

Miocene marine sedimentary rocks unconformably overlies the basement rocks of pre-Neogene age.

Volcanoes of Pliocene-Pleistocene age with well preserved conical shapes are arranged sporadically on the subsidiary faults which run nearly parallel to the North Anatolian Fault Zone. These volcanoes are composed of a wide variety of rocks facies such as rhyolite, dacite and andesite.

The basin is filled with Holocene gravels in which minor faults develop associated with the active movement of the North Anatolian Fault Zone. The Erzincan Earthquake whose magnitude was 7.9 on a Richter scale occurred on 26 December, 1939 around the Erzincan Basin in eastern Turkey, although its precise epicentral situation may not be reliable. This earthquake produced a 350 km long fault break between Erzincan and Amasya. The maximum horizontal displacement of right lateral sense is about 350 cm and the maximum vertical displacement of south side up is about 200 cm (KETIN, 1948).

The Erzincan Basin is situated along or

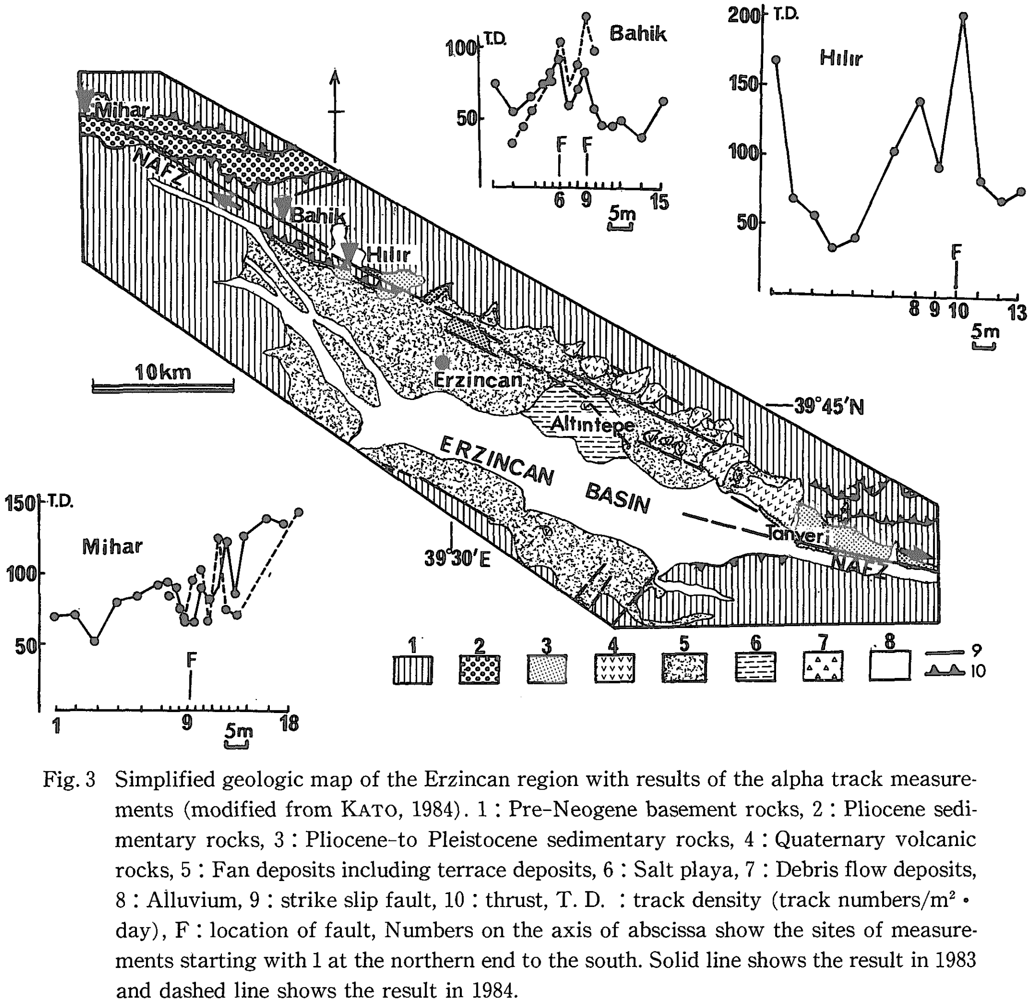


Fig. 3 Simplified geologic map of the Erzincan region with results of the alpha track measurements (modified from KATO, 1984). 1 : Pre-Neogene basement rocks, 2 : Pliocene sedimentary rocks, 3 : Pliocene-to Pleistocene sedimentary rocks, 4 : Quaternary volcanic rocks, 5 : Fan deposits including terrace deposits, 6 : Salt playa, 7 : Debris flow deposits, 8 : Alluvium, 9 : strike slip fault, 10 : thrust, T. D. : track density (track numbers/m^2 • day), F : location of fault, Numbers on the axis of abscissa show the sites of measurements starting with 1 at the northern end to the south. Solid line shows the result in 1983 and dashed line shows the result in 1984.

around the eastern terminal of this fault break. In detail the earthquake fault is divided into several segments such as the Mihar, Bahik, Hılır, Altintepe and Tanyeri segments from northwest to southeast in and around the basin as shown in Figure 3. The Mihar (A), Bahik (B) and Hılır (C) segments gave markable results.

The Mihar segment, about 17 km long, strikes N80° W and has a nearly vertical dip. This segment displaces numerous ridges and valleys dextrally. Therefore, this segment shows the right lateral sense as a whole, but it seems to be a high angle strike-slip fault with a remarkable reverse displacement in the west of Mihar Village. Small hills line up intermittently just on the south of this segment. These hills were resulted from the cumulation of vertical displacements along this segment.

The Bahik segment, about 16 km long, strikes N55° W and dips 84° NE. This segment and subsidiary faults can be observed in a small dried-up valley where fractured serpentine and colluvial deposits are exposed to the east of Bahik Village. Horizontal striations indicating the right lateral sense of this segment develop on the fault plane accompanied by fault clay.

The Hılır segment strikes N65-80° W and has a nearly vertical dip. To the southwest of Hılır, it can be observed that serpentinite on the northern side of the segment is much crashed but the gravel bed of Pliocene-Quaternary age is little fractured.

The alingment of these segments does not always show a right lateral echelon pattern although each segment and the North Anatolian Fault Zone show the right lateral movement at present time as a whole.

III-2 Alpha track measurements in the Erzincan Region

Measurement was carried out twice to examine the reproducibility of measured data by the cup method for the Mihar and Bahik segments in July, 1983 and July, 1984, and also for the Hılır segment in July, 1983.

At the Mihar segment, measuring cups were buried at the intervals of a few meters from north to south crossing the E-W trending fault scarp to the west of Mihar Village. At and around this segment loose gravel bed of presumably Pliocene to Pleistocene age is distributed.

At the Bahik segment, the measuring cups were mostly also buried with a space of a few meters from north to south crossing the fault trace on the banks about 5 meters high where the fault plane is observable. Furthermore, at the first measurement two measuring cups were placed just on the fault plane and another one measuring cup was placed on the subsidiary fault at the bottom of the ravine. Around these measuring points, weathered soil of colluvial origin and serpentinite fragments are distributed.

At the Hılır segment, the cups were placed with a space of 5 meters from north to the south crossing the fault trace on the gentle slope covered with weathered soil and serpentinite fragments.

Results in Erzincan region are shown in Figure 3.

At the Mihar segment, although the earthquake fault is believed to run near the measuring point No. 11 of the first measurement in 1983, the remarkable peak of alpha track density was not recognized at the point. It seems that the track density rather unevenly, increases from north to south especially from the point No. 11 to the point No. 18. These points are located on the fault scarp. The result of the second measurement in 1984 is similar to that in 1983 in general.

At the Bahik segment, two peaks of track density are at points No. 6 and No. 9 in both of two measurements. Therefore the first result is in a general agreement with the second one.

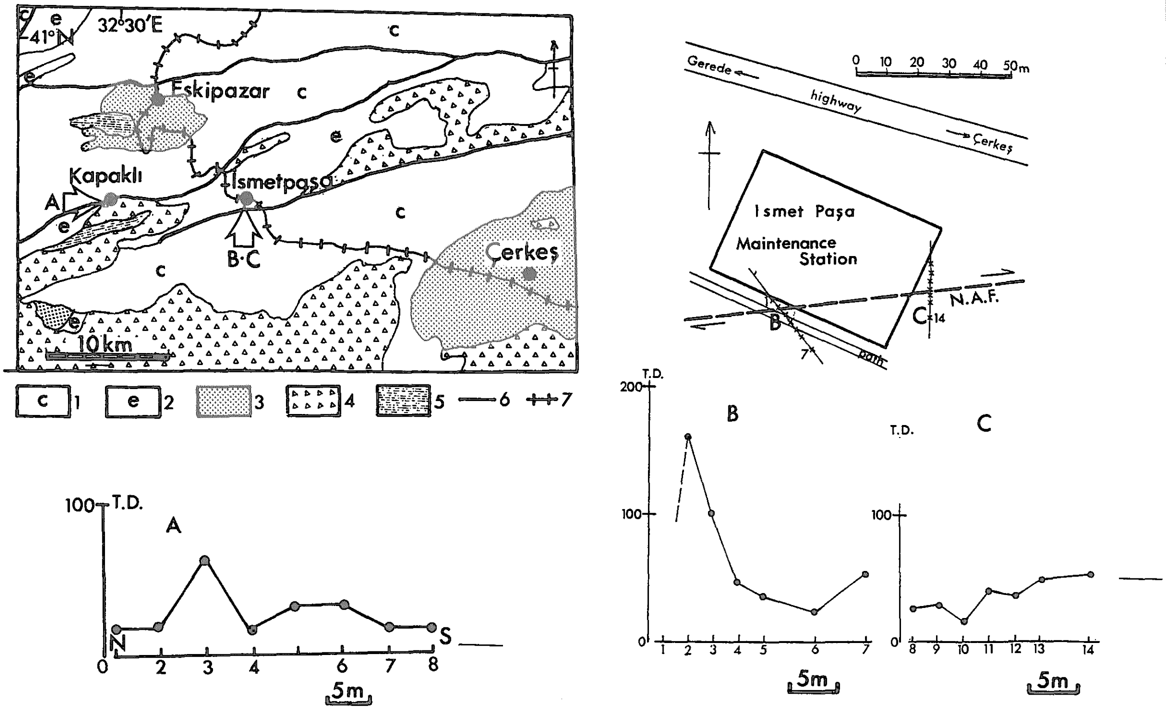
At the Hılır segment, the track density shows the maximum value at point No. 10 where the fault is considered to pass through. Another high value of track density at point No. 1 where a subsidiary fault may pass through. The track density at point No. 9 shows a relatively low value because the film surface was covered with drops of water.

IV. Kapaklı-Ismetpaşa-Yenice Region

IV-1 Geological and seismological settings

In this region the surface break of Bolu-Gerede (Gerede-Çerkeş) Earthquake occurred along the North Anatolian Fault Zone. This earthquake with magnitude about 7.4 on a Richter scale occurred on 1 February, 1944 in northwestern Turkey. The total length of the earthquake fault is about 160-190 km. The right lateral strike-slip displacement is 350-360 cm and the dip-slip displacement (north side down) is 100 cm (KETIN, 1948 ; AMBRASSEYS, 1970 ; DEWEY, 1976 ; TOKSÖZ *et al.*, 1979).

In the Kapaklı Region, the Black Sea Plate (a part of the Eurasian Plate) on the northern side of this fault, is underlain by Pre-Eocene ophiolitic melange containing blocks of Per-



Fg. 4 Simplified geologic map of the Kapaklı-Ismetpaşa region with results of the alpha track measurements. 1 : (Jurassic-) Gretaceous rocks (c), 2 : Eocene rocks (e), 3 : late Miocene sedimentary rocks, 4 : late Miocene volcanic rocks, 5 : Quaternary sediments, 6 : faults, 7 : railway. Dashed line indicates the expected tendency though the alpha track density value of that measuring point is lacked.

mian to Jurassic limestone, which are overlain by Eocene turbidite and Miocene conglomerate, and Miocene volcanic rocks. In the Anatolian Plate on the southern side of the fault, there occur Cretaceous turbidite, Jurassic to early Cretaceous massive limestone and late Miocene volcanic rocks.

In the Ismetpaşa Region 10 km east of Kapaklı, the creep movement by the North Anatolian Fault Zone is well known (AMBRASSEYS, 1970). The average slip rate of right lateral sense is estimated at about 1 cm/year based on the instrumental data since 1969 (AYTUN, 1980). On the northern side of the fault zone Eocene turbidite rests on the late Cretaceous ophiolitic melange. At a few kilometers north of the fault zone, this Eocene sedimentary rocks are covered with Miocene volcanic rocks. As Holocene deposits are extensively distributed around Ismetpaşa, physiographic features of the fault are not clear. On the southern side Jurassic to early Cretaceous massive limestone is distributed.

Yenice to the southwest of Bolu is situated near the western end of the 1944 Bolu-Gerede Earthquake Fault. The Bolu Basin, one of the intramountain basins along the North Anatolian Fault Zone, measures 25 km in length, 8 km in width, and is 700 m to 800 m high above sea level. The North Anatolian Fault Zone extends along the western margin of the basin. At Loc. 1 (Fig. 5), an isolated small hill trending E-W, which is related to the active faulting of the North Anatolian Fault Zone rises 790 m above sea level in the

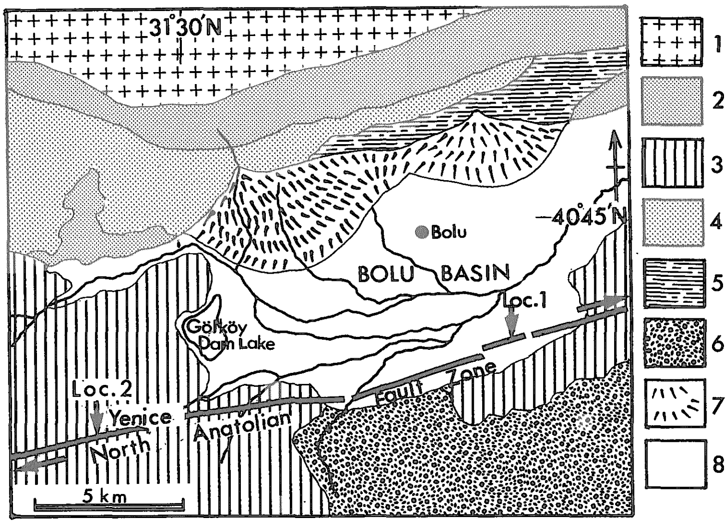


Fig. 5 Simplified geologic map of the Bolu Basin and its adjoining areas. 1 : Gneiss, mica schist and amphibolite of unknown age, 2 : Devonian rocks, 3 : Jurassic to Upper Cretaceous sedimentary rocks, 4 : Upper Cretaceous flysh, 5 : Eocene flysh, 6 : Quaternary tuff, agglomerate and andesite lava, 7 : Holocene fan deposits, 8 : Holocene deposits except fan deposits.

basin. The northern slope of this hill dips 40-50° N and the southern slope dips 10-20° S. This hill is composed of andesite lava and andesitic tuff breccia of presumably Pliocene to Pleistocene age, which are unconformably covered with Quaternary fluvial conglomerate. The earthquake fault in 1944 extends along the northern foot in the western part of the hill, but it extends along the trough-like landform between two peaks of the hill in the eastern part. A villager told that the vertical displacement of the earthquake fault is about 50 cm though the horizontal one is unknown. Near Loc. 2 (Fig. 5) the fault displaced the Quaternary travertine right laterally. At Loc. 2 near Yenice, a shallow trough caused by the earthquake fault in 1944 extends about E-W. The groundwater springs out and is stagnant in some places of the trough. On the southern side of the trough, long and slender mounts composed of Cretaceous limestone trending E-W are aligned, and their height is about a few meters. This suggests the accumulated displacement of vertical components of the active faulting related to the North Anatolian Fault Zone including that of the earthquake fault in 1944.

IV-2 Alpha track measurements in the Kapaklı-Ismetpaşa-Yenice Region

In the Kapaklı Region a small ridge is displaced right laterally by the active faulting of the North Anatolian Fault Zone. The measuring line crossed this fault trace near the creepmeter settled by MTA, and the measurement was carried out in August, 1983. The track density is maximum at measuring point No. 3 where the fault passes through, though the value is less than 100 as shown in Figure 4 A.

At Ismetpaşa the alpha track measurement was carried out on two measuring lines along the masonry walls of the railway station displaced by the creep movement of the fault. The values of the track density were rather

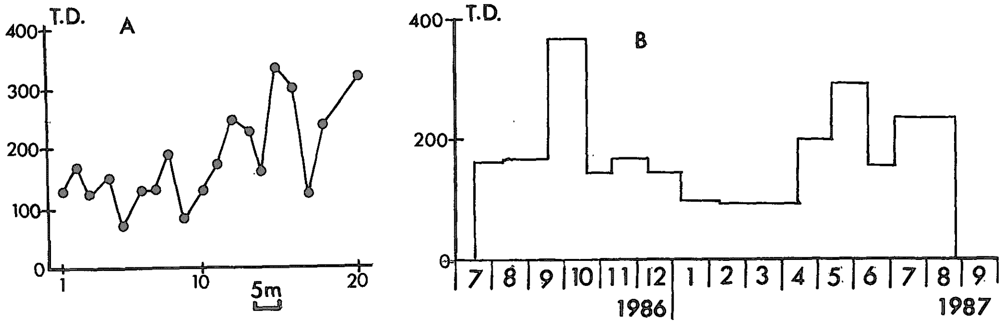


Fig. 6 Results of the alpha track measurements in Yenice (Loc. 2 in Figure 5). A : cup method for the 1944 earthquake fault (KATO, 1986), B : pipe method for the 1944 earthquake fault (Locality is just on the fault trace).

lower than expected, and a clear peak of the track density was not observed.

In the Yenice Region (Loc. 2 in Figure 5) two kinds of alpha track measurement were carried out. The result by the cup method in July, 1985 is shown by the average of neighbouring three values in Figure 6 A. The track density shows relatively higher than those of the Kapaklı and Ismetpaşa Regions. Though the maximum value of the track density is 346 at the measuring point No. 15 where the fault trace runs, original measured data show broad range of high values near the fault trace and therefore, unique peak of the track density cannot be distinguished. The measurement by the pipe method was carried out from July, 1986 to August, 1987. The pipe was set just on the fault trace at Loc. 2 in Figure 5. Any change indicative of the earthquake was not observed. It is noted that two peaks of alpha track density are observed as shown in Figure 6 B.

V. Horasan-Narman Region

V-1 Geological and seismological settings

A destructive earthquake named the Horasan-Narman (or Erzurum-Kars) Earthquake occurred on 30 October, 1983 in the Erzurum Province, northeastern Turkey. The magnitude is estimated at about 6.42 based on the strong motion record (YILMAZ, 1984). Eastern Turkey including the epicenter area of this earthquake is defined as the triple junction of plates by the North Anatolian and East Anatolian Faults. This area is under the N-S trending compression regime due to the northward movement of the Arabian Plate. The main characteristics of the deformation resulted from the N-S trending compression are as follows.

(1) E-W striking reverse or thrust faults, (2) NNE-SSW or NE-SW striking left lateral strike-slip faults, (3) NW-SE striking right lateral strike-slip faults, and (4) N-S trending extension fractures or normal faults.

In the Horasan-Narman Region discontinuous surface break zone of approximately 12 km in length and 4 km in width was detected after the earthquake.

The assembly of surface breaks occurred mostly within the ophiolitic melange produced a wide shear zone, not a continuous single fault. Most of surface breaks are dominant in the left lateral motion with the vertical component of east side down. At just north of Cimenli the left lateral displacement of 25 cm was measured. Less developed right lateral segments of the fault produced a conjugate pair with the left lateral ones. N-S striking tension cracks develop to the north

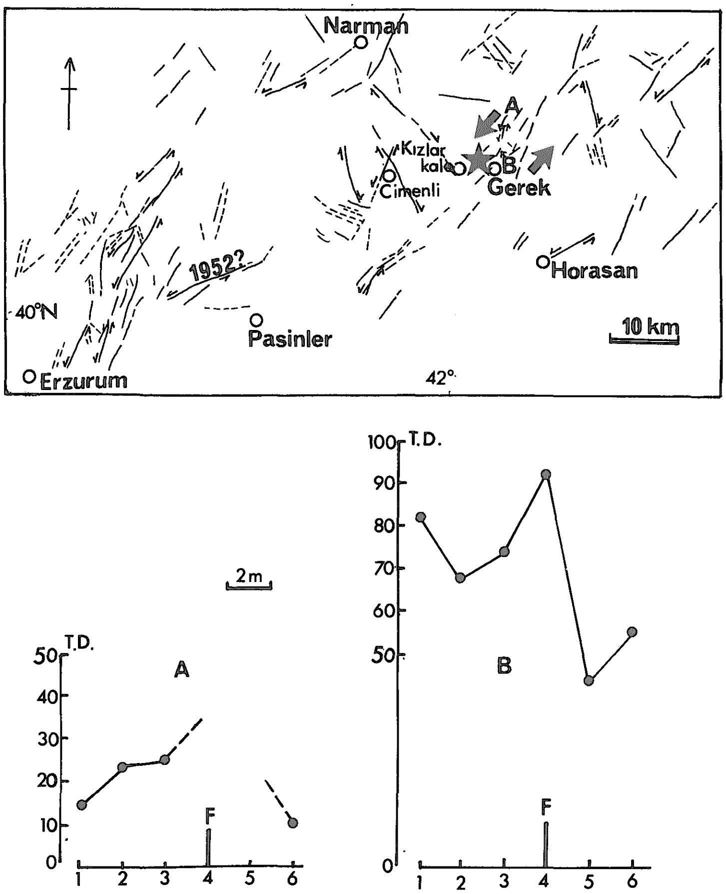


Fig. 7 Map showing active faults and localities of measuring points by the cup method in the Horasan-Narman Region (modified from Barka *et al.*, 1983), and results of the alpha track measurements. Dashed line indicates the expected tendency though the alpha track density value of that measuring point is lacked.

of Kızlarkale.

The pattern of these various surface breaks indicates the N-S trending compression corresponding to the compression axis estimated from the focal mechanism of this earthquake (Barka *et al.*, 1983).

V-2 Alpha track measurements in the Horasan-Narman Region

The measurement was carried out from July to August, 1984 at following two localities.

At Loc. A (Fig. 7) the clear surface break of 1,500 m in length occurred and displaced a small road. The left lateral displacement is 100 cm and the vertical displacement of east side down is 60 cm. On the fault plane 20-30° NE pitch of slickenside lineation was observed. The measuring line for the cup method crossed this break. The film at point No. 4 just on the fault plane was lost and that of point No. 5 was dug out to exposed by someone.

At Loc. B (Fig. 7) the fault shows the en echelon pattern composed of tension cracks

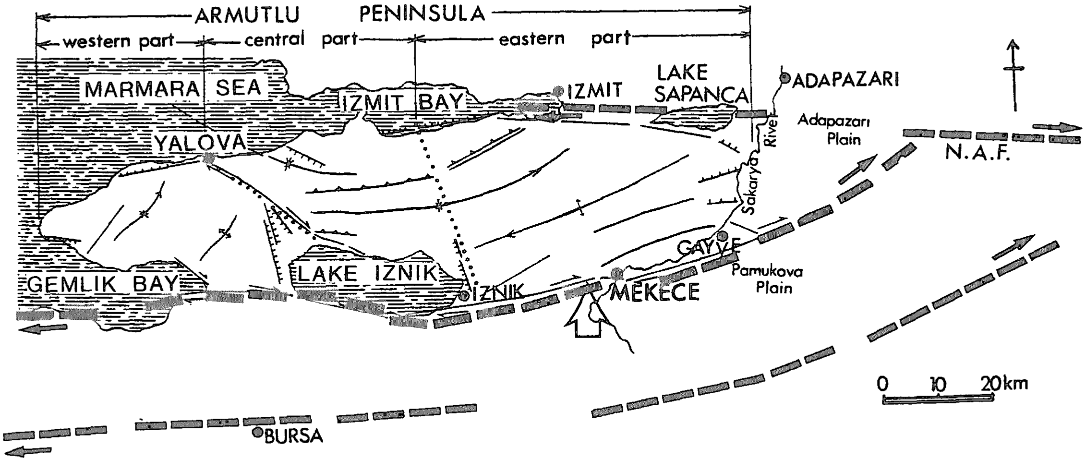


Fig. 8 Simplified structural map of the Armutlu Peninsula Region (modified from Erendil *et al.*, 1989). Thick dashed lines show the North Anatolian Fault and its branches. A white arrow shows the measuring locality of alpha track measurements at Mekece.

and pressure ridges. The total left lateral displacement is about 100 cm. The measuring line for the cup method crossed one of these cracks. The apparent peak of the alpha track density is situated on the fault segment.

VI. Mekece Region

VI-1 Geological and seismological settings

The North Anatolian Fault Zone seems to branch away into a few strands indicated by a series of depressions around Marmara Sea in northwestern Turkey. The direct extension of the North Anatolian Fault Zone is geomorphologically defined by a linear depression passing through Izmit Bay and Sapanca Lake at the northern margin of the Armutlu Peninsula. But the most active branch is considered to be a pronounced linear depression passing through Gemlik Bay, Iznik Lake and the Pamukova Plain at the southern margin of the Armutlu Peninsula. This branch shows right lateral strike-slip sense with some vertical component. The area around this branch is known to have been a seismic gap since 1967.

In the Armutlu Peninsula, Miocene Limestone and Pliocene to Pleistocene formations consisting of conglomerate and sandstone of continental origin overlie unconformably pre-Tertiary rocks. Holocene deposits such as fan deposits, riverbed deposits and lake deposits cover extensively this area and veil the active faulting of the branch (Kato, 1989).

VI-2 Alpha track measurements in the Mekece Region

Measurement by the cup method was carried out from July to August, 1985 between Iznik and Geyve as shown in Figure 8. Cups were buried along a narrow unpaved path striking about N-S across the most active branch of the North Anatolian Fault Zone mentioned above. This measuring spot is situated a few hundreds meters east of a pond. Measurement by the pipe method was carried out from July in 1986 to August in 1987. Films were replaced and retrieved about every month to detect alpha track density. The result by the cup method is shown by the average of neighbouring three values in Figure 9 (A). It is noted that two peaks of alpha

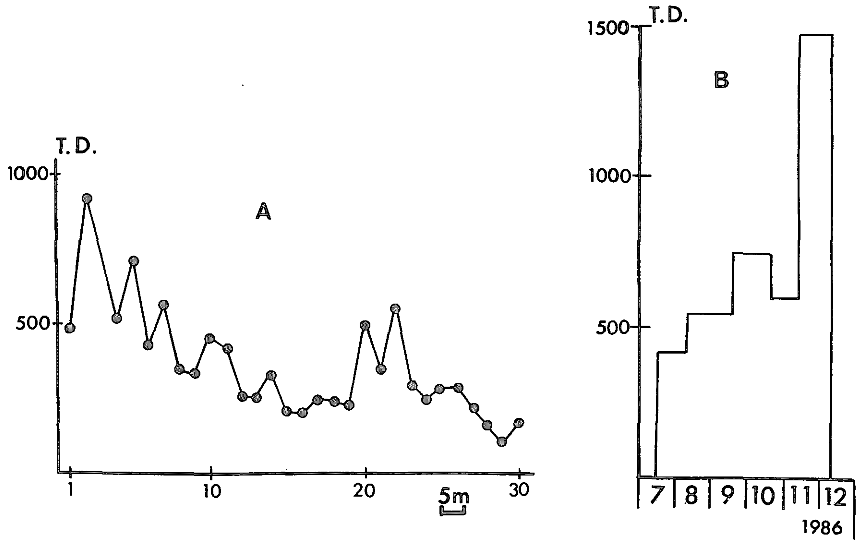


Fig. 9 Results of the alpha track measurements at Mekece. A : cup method for one branch of the North Anatolian Fault (KATO, 1986), B : pipe method for one branch of the North Anatolian Fault (Locality is near the measuring point No. 2 by the cup method).

track density, at which two small fault segments of the active branch of the North Anatolian Fault Zone, are considered to pass through, are found, and that all the values of track density are extremely high, especially at point No. 2 (Fig. 9A). The result by the pipe method is shown in Figure 9 (B). Any change related to the earthquake was not observed. It is noted that values of alpha track density are generally higher than those at other points, and that the maximum value ammounts to about 1,500 (T. D).

Ⅶ. Sinop Region

Ⅶ-1 Geological and seismological settings

Approximately E-W trending reverse faults develop in the Sinop Region and show an clear pattern of the northward migration (Fig. 10). The Erikli Reverse Fault accompanied with an overturned anticline, which extends over 100 km in the Sinop Region, borders the southern margin of Eocene basin. The Ayancik Reverse Fault appeared during the Eocene. The Balifakı Reverse Fault making the southern margin of Neogene-Quaternary basin, came to existence at the end of Eocene to Oligocene time. This fault is covered by (late) Miocene sediments in the eastern part of the Sinop Peninsula. Therefore, the activity of this fault ceased during the early to middle Miocene or earlier. This northward migration of reverse faults probably continued throughout the Miocene and created the Pontic Escarpment all along the southern Black Sea Coast. The Kurtkuyusu Fault is an alleged fault or only a lineament depicted from aerial photographs. The Sinop II Fault is a reverse fault striking WNW-ESE, dipping to the north, which appeared in late Miocene. After the erosion of the hanging wall of this fault in Pliocene to early Pleistocene time, marine terrace deposit and sand eolian deposits covered the basement rocks in late Quaternary. The Balifakı, Kurtkuyusu and Sinop II Faults distributed within or adjacent to the agglomerate and

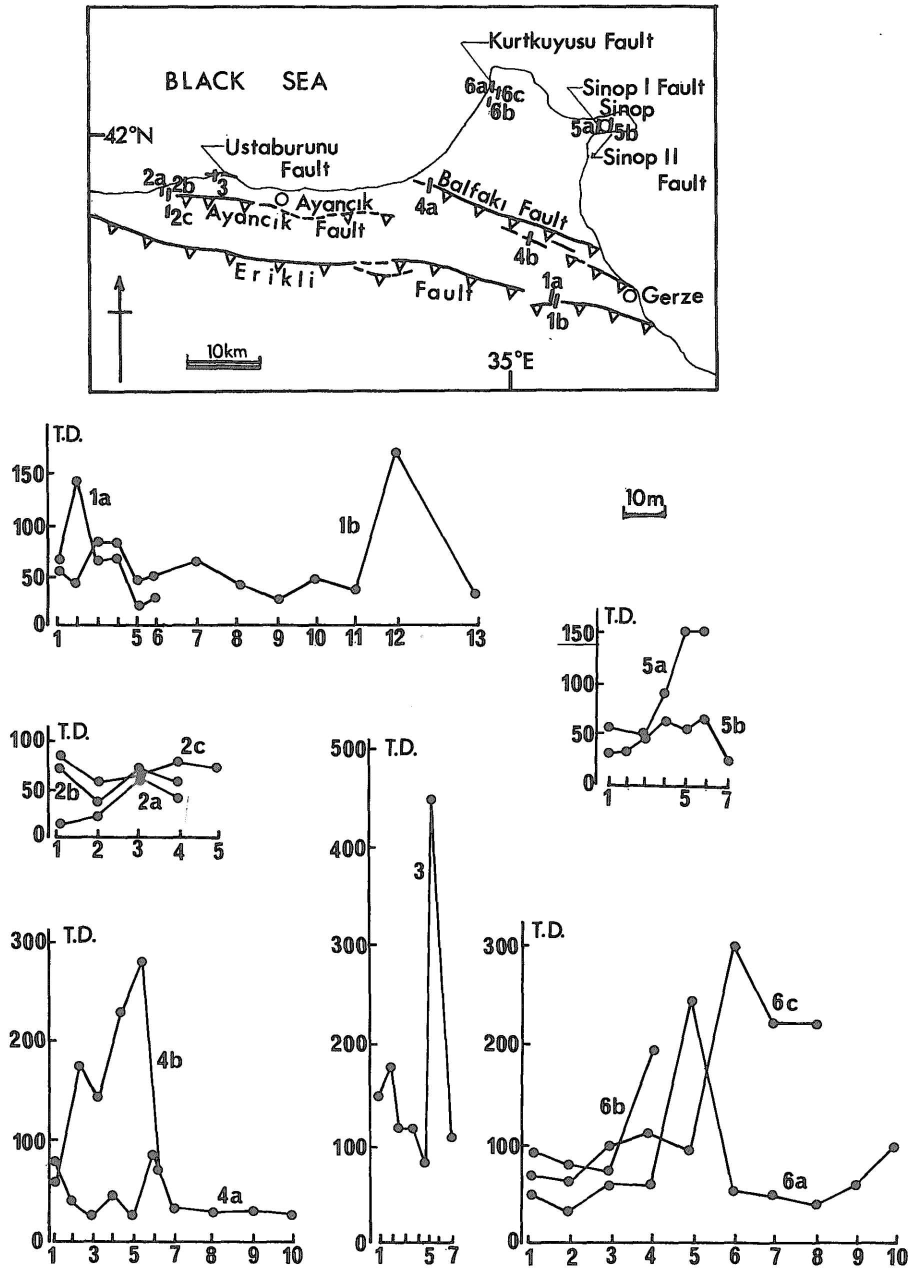


Fig. 10 Simplified structural map of the Sinop Region, showing localities (1a, 1b, 2a, 2b, 2c, 3, 4a, 4b, 5a, 5b, 6a, 6b, and 6c) of alpha track measurements and results by the cup method.

basaltic dikes of late Cretaceous age. All faults mentioned above have no geological and physiographic evidence that they are active at present.

In the Sinop Region there is no record of historical or instrumental large earthquakes although small and moderate earthquakes occurred occasionally in the Pontide Escarpment.

VII-2 Alpha track measurements in the Sinop Region

Measurements by the cup method were done at the localities 1a, 1b, 2a, 2b, 2c, 3, 4a, 4b, 5a, 5b, 6a, 6b and 6c in summer to autumn, 1983 (Figure 10).

The results of the Erikli (1a and 1b), the Ayancik (2a, 2b and 2c), one profile on the Balifakı (4a), Sinop I (5a) and Sinop II Fault (5b) are rather lower than expected. The Ustaburnu Fault which is the western continuity of the Balifakı Fault showed the highest track density during the present survey. On the southern side of this fault alternating sandstone and mudstone are distributed and on the northern side limestone is distributed. Both of them are of late Eocene age. The Balifakı Fault at locality 4b also shows high track density.

VIII. Discussion

At the Mihar segment, one of the 1939 earthquake fault segments, the reason why the track density of the measuring points No. 9 and 10 near the fault trace was fairly low in the first measurement in 1983, may be explained that cups were placed in the small artificial troughs for irrigation. Because the diffusion of radon to the ground surface is often disturbed if the surface soil were cultivated within a few years before the measurement. In general, it seems that the track density increases from the north to the south unevenly, especially from point No. 11 to No. 18. These measuring points were located on a gentle slope resulting from active faulting. The southern side of the fault moved upward several meters for a few earthquake events. The Mihar segment seems to be a high angle reverse fault, though its main displacement is right lateral. It is well known that the buldge of the hanging wall of the reverse fault is much fractured. Therefore it can be recognized that the track density increased generally from the fault line which passes through the margin of the hill to the top of the hanging wall, that is, the buldge. The second result in 1984 is similar to the first one.

At the Bahik segment, one of the 1939 earthquake fault segments, the result of the first measurement in 1983 shows two peaks of alpha track density, that is at points No. 6 where the main fault trace passes through and at point No. 9 where a subsidiary fault is situated. In another measuring just on the main fault trace in the dried-up stream where is a few meters east, the track density is nearly the same as that at No. 6. The result of the second measurement in 1984 is also similar to the first one as well as at the Mihar segment. These results strongly support the good reproducibility of the alpha track measurement.

At the Hılır segment, the track density shows the maximum value at point No. 10 where the fault may pass through. The track density at the point No. 9 is relatively low because the film surface was completely covered with drops of water when the film was retrieved. Although the high value of track density at point No. 1 could not be well interpreted, a subsidiary fault probably passes through at that point.

At Ismetpaşa where the North Anatolian Fault Zone has a creep movement, the result did not show meaningful values. This is because measuring conditions were wrong. That is, the water gushed and settled in the depression of the ground surface near masonry wall when films were retrieved, therefore puddles might interrupt the difussion of the soil gas including radon, and the ground surface was hardended artificially.

Also at Kapaklı showing a creep movement of the North Anatolian Fault Zone, the result did not show meaningful values. MTA settled a creepmeter at this point, but no creep mevement of the fault has been recorded.

At Yenice the peak of track density by the cup method is rather broad but the maximum value in 346 at point No. 15 and is higher than those at other places mentioned above. It is because the fractured zone of this segment might be broad here. Limestone around here is crushed along the fault segment by brittle deformation. The underground water through this crushed zone can supply soil gas and enough to make possible the higher concentration of radon. The result by the pipe method show the clear relation between track density and temperature, as the track density is lower in winter and higher in summer.

In the Horasan-Narman region, the measuring at Loc. A was unfortunately disturbed. Therefore we can not say anything about it. At Loc. B, the apparant peak of track density is situated just on the fault segment. The peak value is not so high as expected although these measurements were carried out within a year after the earthquake occurrence.

In the Mekece Region, it is noted by the cup method that two peaks of track density, where fault segments are considered to pass through are found, and that all values are so high, especially at the measuring point No. 2. Even though the underground water caused by the neighboring pond supplied excessive soil gas, this value seems to be anomalously high radon concentration. The result by the pipe method in this region also shows very high concentration of radon as a whole. Furthermore, it shows that the maximum track density was attained in winter. This region has no record of historical earthquake, but can be considered to show one of the most active features of the North Anatolian Fault Zone geomorphologically. Therefore, these results may indicate the earthquake occurrence in the near future.

In Sinop Region, the high amount of radon of the Ustaburnu Fault (3 in Figure 10) resulted from that agglomerates in the depth may well be the source of high radon as well as rock type and that the water supply through the fault may be excessive. Note this measuring place is very close to the sea coast facing Black Sea. Also the high track density of the Balifakı Fault (4b in Figure 10) was taken place near a soda spring. Although the Kurtkuyusu Fault was recognized by the expression of a lineament and a relative bench, no geological evidence has been found. The basement rock is agglomerates which occurs only within a few tens of meters below the ground. However this profile gives high track density, it should be noted that there is a small pond near the measuring place.

IX. Conclusion

The alpha track measurement by the cup method is capable of detecting not only the active fault including the earthquake fault but the geological fault even in the region where rocks containing a little radon are distributed in Turkey. The results of the alpha track measurements have good reproducibility if the weather condition, especially the temperature is nearly the same.

In the seismic gap area of one branch of the North Anatolian Fault Zone, that is Mekece region, the maximum alpha track density obtained by the cup method is abnormally high although the basement rocks contain little radon. Furthermore, the results by the pipe method also show the high values of the alpha track density even in winter. The branch fault of this region is physiographically active and there is no historical record of earthquakes in this area. These facts indicate that this branch fault of the North Anatolian Fault is most active now and in near future. Therefore it is necessary to carry on the alpha track measurement by the pipe method in some places in this region. But the underground water supply must be taken into consideration before the evaluation of fault activity, eapecially earthquake occurrence. Because not only active faults but also non-active faults sometimes show high track densities if measuring points are near the sea, the pond or spring.

So as to compare the absolute values of the track density between different faults, it is required that the basement and cover rocks should be similar to provide a comparable amount of radon and its diffusion along faults through the surface. Then it would be possible to assess whether high track density indicates fault activity or not.

The results by the pipe method show the seasonal change depended on the temperature. It is better to detect the fault by the cup method of the alpha track measurement in summer generally because the diffusion of the gas containing radon through the fault plane is sprightly. But for evaluating the fault activity, it is necessary to keep measuring radon by the pipe method in a few years.

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トルコ北部におけるアルファ・トラック測定

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要　旨

トルコ北部を北に緩く弧を描いてほぼ東西に約 1200 km にわたって発達する北アナトリア断層は右横ずれのトランスフォーム断層で，1939 年本断層東部のエルジンジャンで発生した地震以降，本断層沿いにＭ７クラスの地震が相次いで発生しその震源が西方移動していることが知られている．

筆者らは，それらの代表的な地震断層である 1939 年エルジンジャン地震断層，1944 年ゲレデ•ボルー地震断層，クリープ運動を示すイスメット・パシャ付近の活断層，近い将来の地震発生が懸念される同断層西部のメケジェ付近の地質学的調査と断層トレースの追跡及びその活動性調査のためのアルファ・トラック法による地中のラドンの相対濃度測定を実施してきた．また，比較のため，北アナトリア断層と関連しないが，最も近年トルコ東部で発生した 1983 年ホラサン-ナルマン地震断層及び黒海沿岸部のシノップ地域に発達する地質断層である東西性の逆断層群においても同様な調査を行った．

アルファ・トラック法は断層トレースに簡便なカップ法と継続測定に有効なパイプ法の二通りを使い分けた．前者は，上底部にアルファ線に鋭敏な硝酸セルロースフィルムを添付したプラスチックカップを想定される断層線に直交する測線上に数mおきに地下浅く埋設し，1 週間から 10 日程度経過した後取り出したフィルムを化学処理して単位面積・単位時間あたりのトラック数を測定しその地点のラドンの相対濃度とするものである.. 後者は，径 6 cm，長さ 60 cm 程度のプラスチックパイプを断層トレース上に埋め込み，上端を塞いだゴム栓にとめた糸でフィルムを吊るして，前者と同様に測定し，長期にわたって繰り返すものである．

その結果，調査地域のようなラドン含有濃度の低い岩石の分布地域においても，断層の精密トレースに，カップ法が有効であり，しかも測定結果の再現性も良いこと，ラドンの相対濃度値は，測定点付近の地下水などの賦存状況に影響され，非活動性の地質断層でも高い値を示す事，パイプ法によって地震空白域であるメケジェ付近では地下水などの賦存状況や地温変化などを考慮しても異常に高いラドンの相対濃度値が連続してえられ，このことは，同地域の活断層の活動度が極めて高いことを示唆していることが明らかとなった．

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