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PLATE TECTONICS IN THE RED SEA REGION AS INFERRED FROM SPACE PHOTOGRAPHY

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16. Abstract

Tectonics of plate sections on land surfaces and associated geologic and morphologic phenomena have been inferred from space photography. In this report, tectonic inferences and morphologic manifestations of plate motions on two adjacent regions along the Red Sea (the Israel-Sinai plate section and the Afar region) are discussed.

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PLATE TECTONICS IN THE RED SEA REGION
AS INFERRED FROM SPACE PHOTOGRAPHY

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SUMMARY

Evidence of plate tectonics can be inferred from space photographs. North of the Israel-Sinai block, different plate sections located west of the Jordan Rift Valley are moving with respect to each other and with respect to the adjacent plate sections. The motions of these plate sections are assumed to be the cause of moderate folds between the Dead Sea and the Negev desert. At the south end of the Red Sea on the African continent, an occurrence of Pre-Tertiary basement rocks, called the Tadjura uplift, has been detected on space photographs. By the use of these space photographs, the drifting motion of the Tadjura uplift, which causes the narrowing of the Red Sea in the Strait of Bab el Mandeb, has been analyzed.

INTRODUCTION

Sea-floor spreading, together with the horizontal and vertical displacements along the Red Sea and along the Jordan Rift Valley, has been substantiated geophysically (ref. 1), proved geologically (ref. 2), and detected partially by the use of space photography (ref. 3). Geophysical evidence indicates that worldwide sea-floor spreading may occur in the axial trough of the Red Sea (ref. 4). The Israel-Sinai block is a plate margin that is separated from the Arabian plate section along the Gulf of Aqaba and the Jordan Rift Valley (ref. 5), where left-lateral strike-slip motion has occurred (ref. 6).

Estimations of the amount of horizontal displacement along the Jordan Rift Valley have been made previously. Dubertret (ref. 7) suggested that a displacement of 100 kilometers occurred in 36 million years; Quennell suggested that a 67-kilometer displacement occurred during the early Miocene period (ref. 8) and that an additional 40-kilometer displacement occurred during the late Pleistocene period (ref. 9). Freund, Zak, and Garfunkel (ref. 10) have estimated a sinistral 600-meter displacement of the Arabian Peninsula during the last 23 000 years with a calculated rate of 0.65 cm/yr.

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Girdler (ref. 11) suggested that the Arabian Peninsula has rotated. This counterclockwise rotation supposedly has occurred since the Miocene period and has now rotated 7° around a theoretical center south of Cyprus. According to this movement, the Red Sea should spread continuously toward the south. However, near the Gulf of Zula (15° north latitude), a funnellike narrowing of the Red Sea occurs. Laughton (ref. 12) suggested that the Danakil Mountains in northern Eritrea are a fragment which remained between the separating plates of Africa and Arabia and that these mountains are moving eastward toward the Arabian Peninsula.

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ISRAEL-SINAI PLATE SECTION

Quennell (ref. 6) suggested that a 100-kilometer displacement occurred along the Gulf of Aqaba and the Jordan Rift Valley (fig. 1). The displacement can be explained by internal motions in the Israel-Sinai plate section, which is west of the Jordan Rift Valley (fig. 2). As far north as Jotveta in the Israel-Sinai plate section (fig. 2), the major structural lines trend in north-south and east-west directions. However, north of Jotveta, the trend of these structural lines changes to a northeast-southwest direction, which is also the direction of the trend of the axes of the anticlines in the folded mountain ranges (Dimona, Hatira, Hatzera, and the bifurcated anticlinorium of Ramon) in northern Negev (ref. 13, fig. 3). In the northern part of these anticlines, an additional structural component that trends north-northeast to south-southwest is present (ref. 14). No tectonic explanation has been presented for these structural conditions.

From a study of Apollo and Gemini space photographs and the geologic map of Israel (ref. 15), an inference can be made that the horizontal motion of the Israel-Sinai plate section, in conjunction with the motion of the Arabian plate section, may cause the change in the trend of the major tectonic features north of Jotveta (fig. 2). Also, the evolution of the broad Tzinim depression possibly relates to the lateral drift that has occurred with the change in the plate-motion direction.

Two other plate sections that are north of the folded mountains of Negev are the northern Judaean block and the Shomron block. Both of these blocks have a motion with respect to each other and with respect to the adjacent plate sections. The relative motions of these blocks are represented by many geomorphologic manifestations. For example, the coastline along the Mediterranean Sea is aggradated along the section where no northwest trending motion occurs and degradated along the section where such motions exist. In this instance, the hypothesis is that left-lateral displacements along the Jaffa-Ramle faultline are responsible for the displacement of the axis of the northern Judaean anticline (refs. 15 and 16). Local secondary movements within or along the Jaffa-Ramle faultline could probably be the cause for the jutting of Cape Jaffa into the sea. A right-lateral motion has occurred along the Carmel faultline, which permitted the jutting of Cape Carmel into the sea.

However, the most important geomorphologic result of the motion has been the evolution of the deep northern basin of the Dead Sea (fig. 3). No horizontal or vertical displacement can explain the unique depth of this basin (800 meters below the Dead Sea water level). Only a combination of three vectors (horizontal shift, vertical displacement, and lateral separation), wherein the blocks move apart, can explain this depth in the northern basin of the Dead Sea. The movements are the results of the left-lateral displacement of the Arabian plate section along the Jordan Rift Valley.

Similar drifts that occur in the Galilee Mountains permit crisscross faulting, vertical uplifting and downdropping, horizontal and lateral separation of the blocks, and the forming of capes in the Mediterranean Sea (refs. 17 and 18). Zak and Freund (ref. 19) calculated the rate of the recent drift of the plates, but they limited the study to only a few recent horizontal shear lines along the Araba Valley. However, space photography reveals a straight geometric line that trends north to south along this valley from Eilath to the Dead Sea (figs. 4 and 5).

EASTERN AFAR REGION

Geologic investigations were made of the eastern Afar region (fig. 1) by the use of Apollo 9 photography (from 42° east longitude to the Red Sea and from north of the Gulf of Tadjura to 13° north latitude), aerial photography, and field studies (ref. 20) made north of 13° north latitude (inset map, fig. 6(a)). Two grabens have been detected in the Afar region (figs. 6(b) and 6(c)). The northernmost graben of the Afar region is the Danakil graben, which is filled with evaporite sediments and, towards the south, with extensive Aden Volcanic Series rocks of upper Tertiary and Pleistocene age (fig. 7). In the marginal horst zones of the east and west, crystalline and slightly metamorphic basement rocks of Precambrian and early Paleozoic age have been observed. These basement rocks are overlaid transgressively by clastic-calcareous Mesozic rocks. In the Danakil graben, clastic and carbonate-sulphate marginal sediments are discernible; and in the graben center, evaporites can be observed. Plateau-forming Afar Basalt of Upper Tertiary age is widely distributed in the south and can be ascribed to the marginal sediments. The volcanoes of the younger Aden Volcanic Series dominate the structure of the graben and the associated marginal areas. Three basalts of different ages and three different types of acid, alkali-rich lava and tuffs occur within the Pleistocene Aden Volcanic Series. The Danakil graben, which is the dominant structure in the north, is asymmetrical, indicating an eastward movement of the Danakil Mountains, which are on the eastern flank of this large graben (fig. 6(b)). A rift-in-rift structure, partly filled with basaltic material, is clearly perceptible. The Danakil graben, which is funnellike, opens to the southeast and may be traced as far south as 13° north latitude. A region between 13° north latitude and 12° north latitude that has cross structures and annular graben faults extends to the south. South of 12° north latitude, another graben occurs (region 3 of fig. 6(c)), with Lake Abbé located at the lowest elevation of the graben (refs. 20 and 21). No evidence, however, has been found to substantiate the existence of the northern prolongation of the Wonji fault belt (ref. 22).

Current investigations of photographs of the earth taken from the manned Apollo 9 spacecraft suggest a second uplift southeast of the Danakil Mountains. This uplift, which is north of the Gulf of Tadjura, is referred to in this report as the Tadjura uplift (fig. 8 and region 5 of fig. 6(c)). The region between the Tadjura uplift and the graben at Lake Abbé was studied on stereoscopic pairs of space photographs and on aerial photographs (inset map, fig. 6(a)). From the space photographs, the observation was made that the western part of the Tadjura uplift is tilted and downfaulted and terminates at a striking lineation that trends north-northwest to south-southeast (L in fig. 6(c)). The suggestion is made that the southeastern part of this lineation has the function of a flexure fault, because to the west, the tectonic style changes and a graben with faults that trend northwest to southeast is present (fig. 8 and region 4 in fig. 6(c)). Also, in the southeastern part of the lineament, right-lateral shear faults were observed. West of the Tadjura uplift, obvious annular graben faults were recognized on the space photography (ref. 23 and fig. 9). These faults were observed first by Mohr (ref. 22). Steep grabens enclose a region that has been affected only slightly by tectonic forces; this region must be considered an independent block. The region, which possibly is underlaid by basement rocks, appears to drift northeastward along with, but independent from, the Tadjura uplift.

A northeastward motion of the Tadjura uplift also is suggested by the shape of the northern coast of the Gulf of Tadjura, which is dissected by numerous left-lateral shear faults that can be seen on the space photographs (fig. 8). These faults extend off shore for some distance, as recorded in recent bathymetric and offshore geophysical surveys (ref. 24). However, these faults are not assumed to exist on the southern coast. If this assumption is true, the opening of the Gulf of Tadjura should be partially the result of the eastward drift of the Tadjura uplift along a right-lateral shear fault in the Gulf of Tadjura.

The drift of the Tadjura uplift made possible the development of a system of smaller grabens that extends as far west as the large graben in which Lake Abbé developed. West of the large graben, the eastern fringe of the Ethiopian Highlands produces an unfaulted plateau that consists of outcrops of basement rocks, Tertiary and Quaternary sediments, and Afar Basalt.

Between the Ethiopian Highlands and the northeastward-drifting blocks of the Danakil Mountains and the Tadjura uplift are several smaller blocks (fig. 6), which are composed of basement and Mesozoic rocks, that seem to have moved in individual drifting motions. Thus, the space between the Arabian plate section and the Ethiopian Highlands (African platform) is being filled continuously by blocks of lithosphere and by basaltic material from the oceanic crust (refs. 20, 25, and 26).

CONCLUSIONS

Plate tectonics have considerable geologic and morphologic manifestations on land surfaces, especially along the plate margins. Therefore, careful analysis and inferences from space photography should be incorporated in research on plate tectonic movement and should be used along with conventional geologic and geophysical tools.

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National Aeronautics and Space Administration
Houston, Texas, September 30, 1970
914-50-16-12-72

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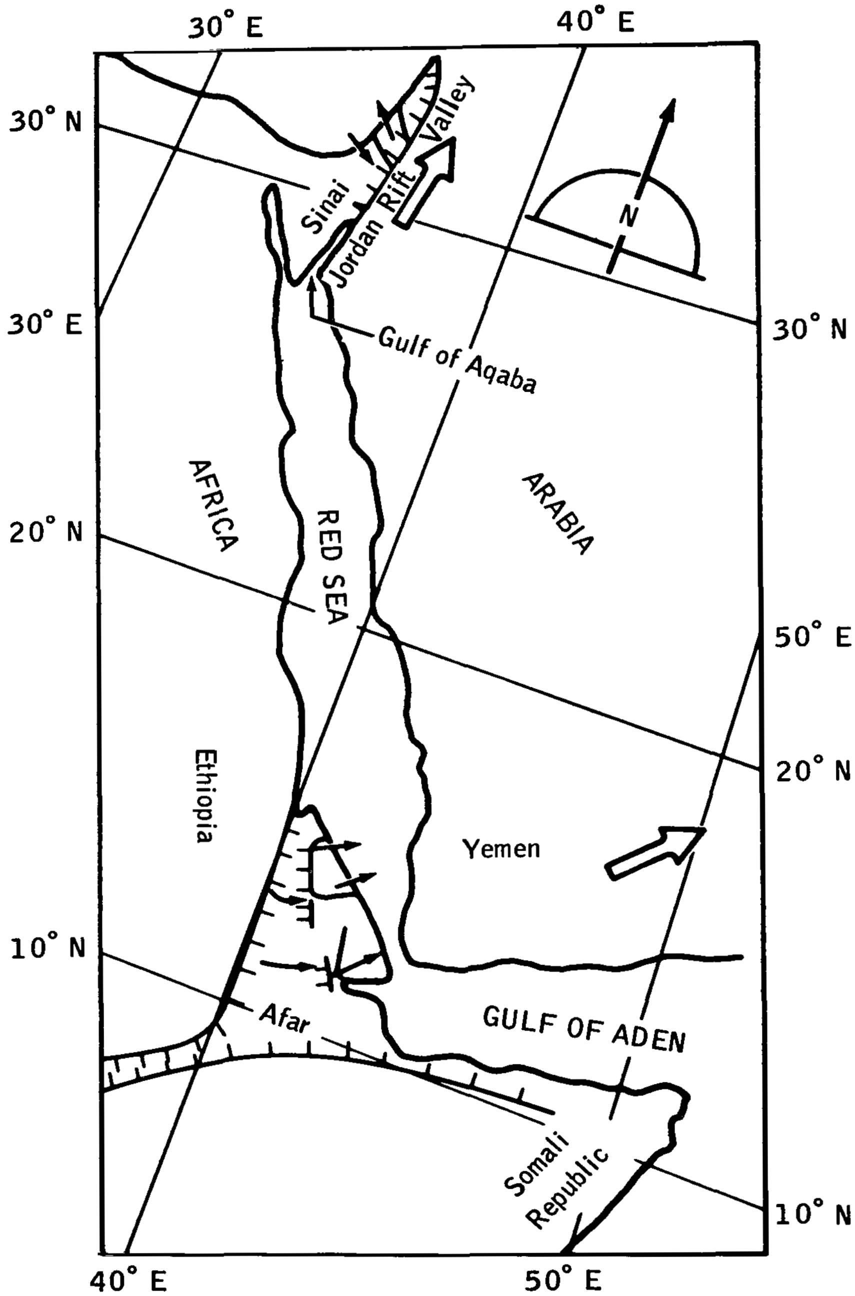
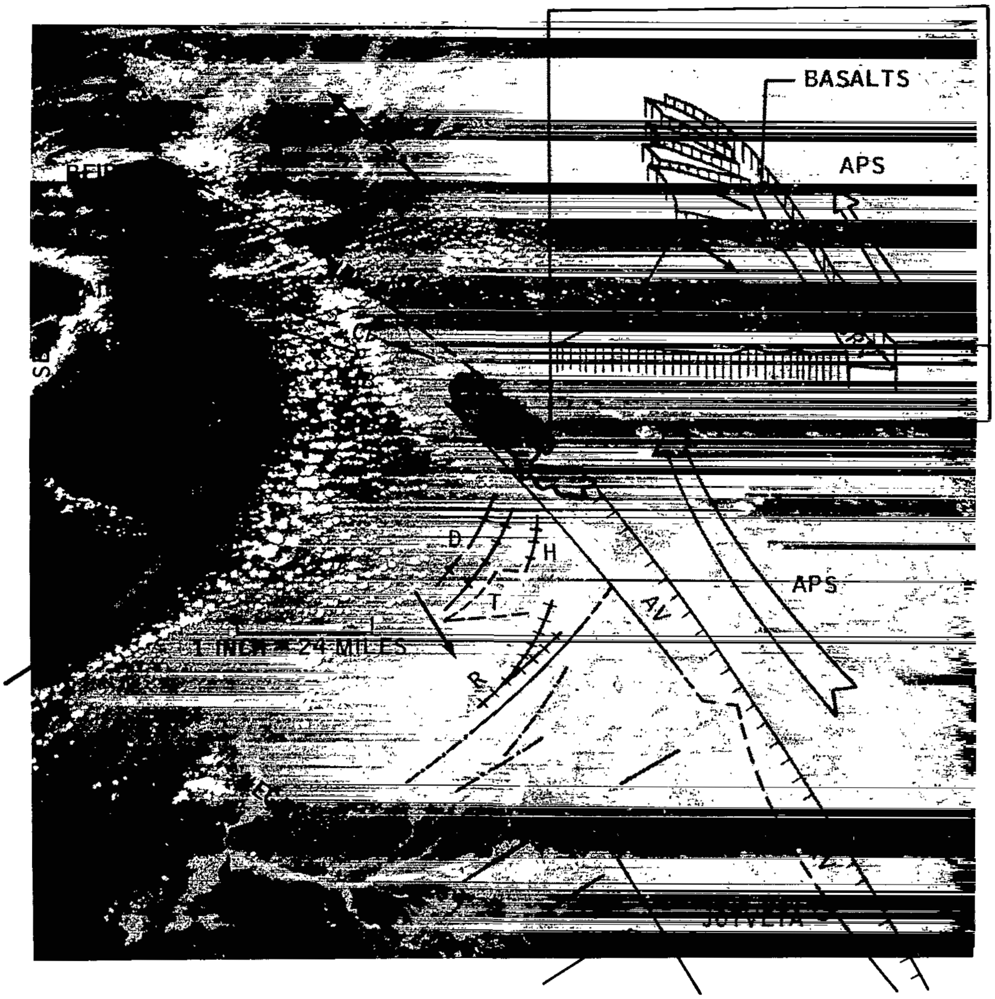


Figure 1. - The Red Sea, the Gulf of Aden, and the adjacent parts of Africa and Arabia. Small black arrows indicate local tectonic movements. Large white arrows indicate rotation of the Arabian Peninsula. Lines with short tick marks indicate major faults, with tick marks pointing to downfaulted side.



Fault and lineation
Fault suggested
Fault inferred from ref. 15
Shear fault
Axis of anticlines
Local motions of small plate sections
Local motions along shear fault
Rotation of the APS
T Tzinim
NJB Northern Judaean block

JRV Jordan Rift Valley
AV Araba Valley
DS Dead Sea
CF Carmel faultline
JRF Jaffa-Ramle faultline
SB Shomron block
APS Arabian plate section
D Dimona
H Hatzera
R Ramon

Figure 2. - Apollo 7 photograph AS7-11-2010, showing the region along the Dead Sea and the Jordan Rift Valley. This photograph was taken October 12, 1968, from an altitude of 235.2 kilometers (127 nautical miles). The inset map is a generalized block diagram showing the displacement along the Arabian plate section shear faultline.

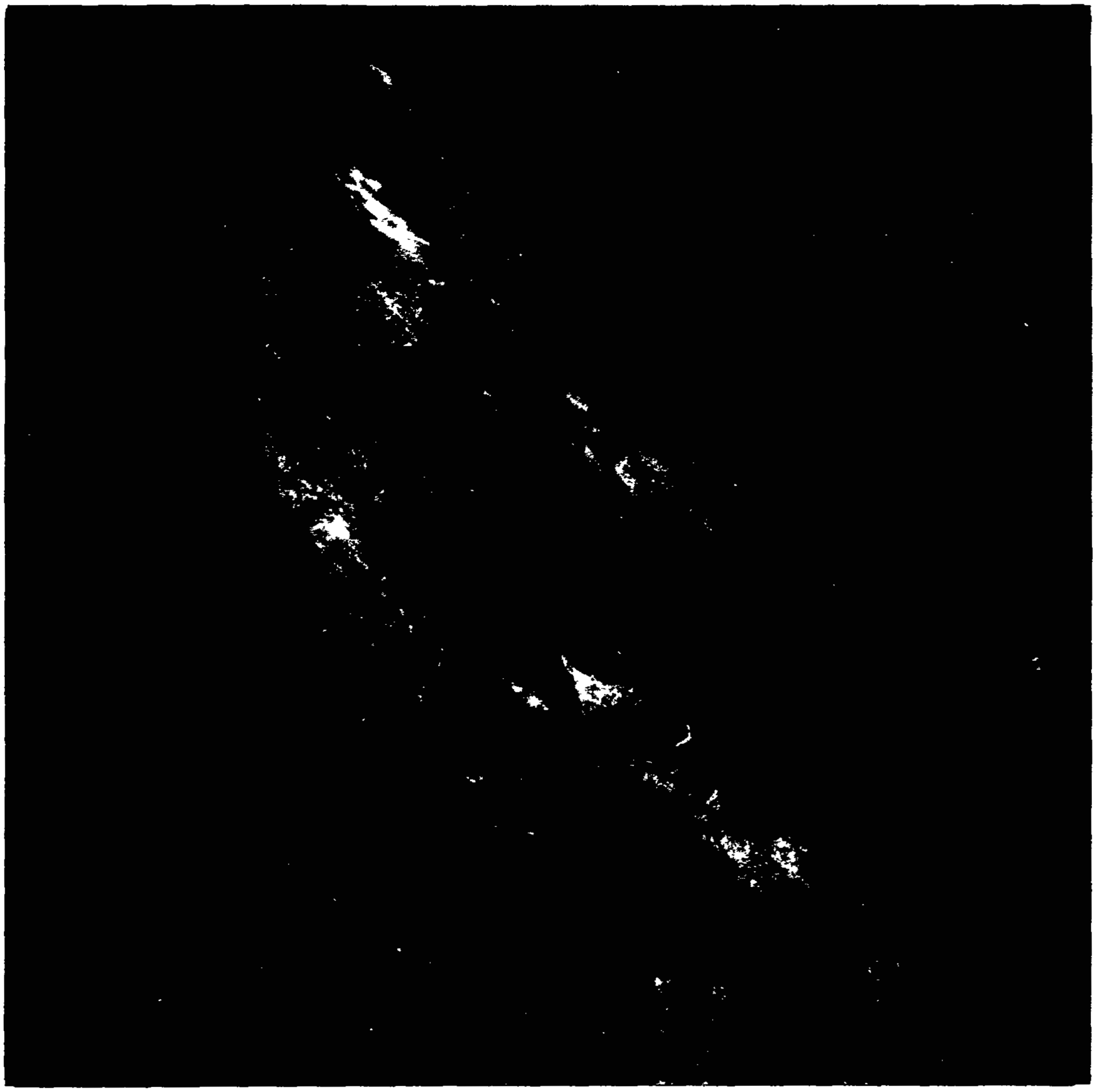


Figure 3. - The Dead Sea and the Jordan Rift Valley as seen from Apollo 7 (AS7-6-1698). The Dead Sea resulted from complicated plate motions.

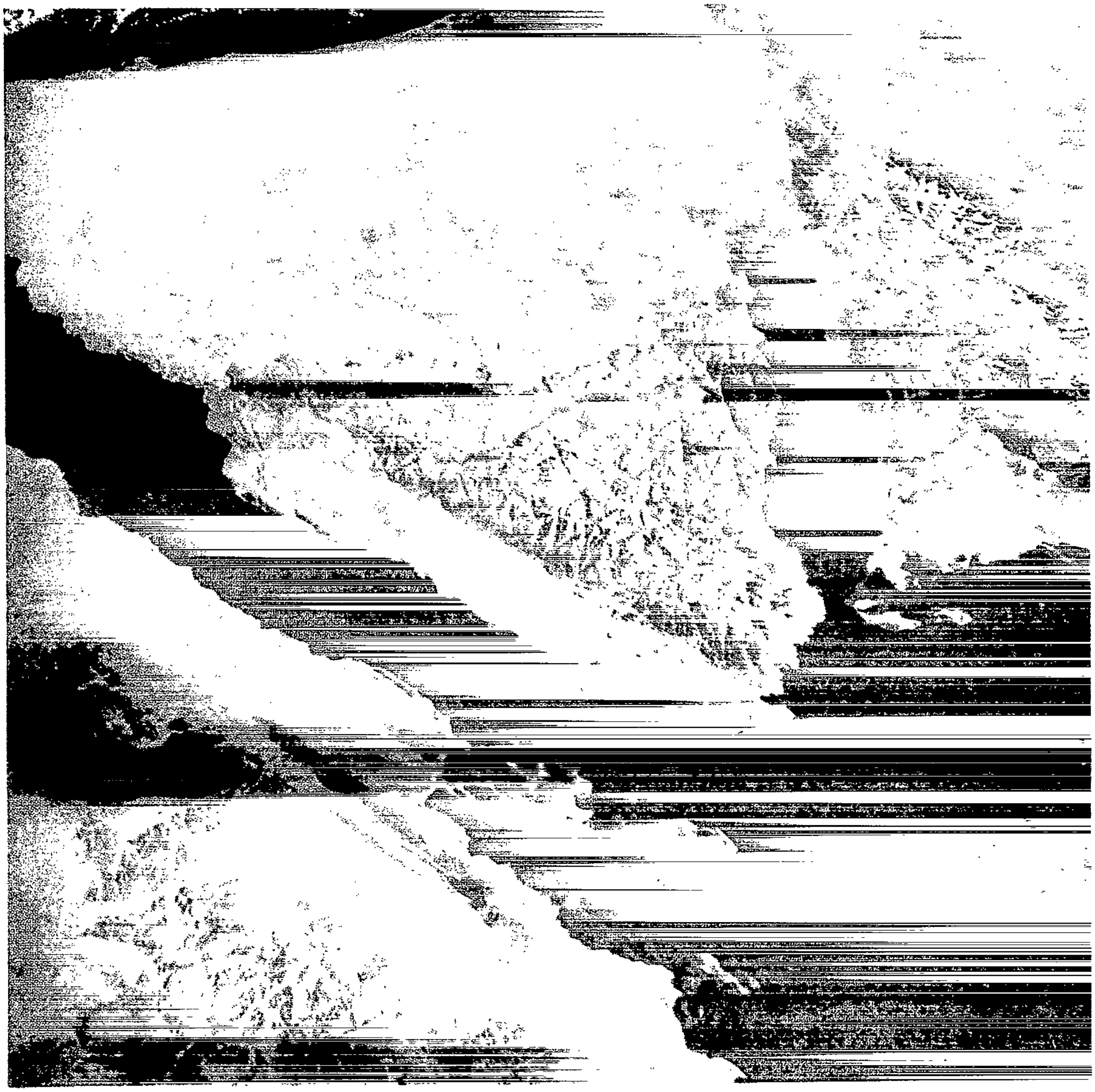
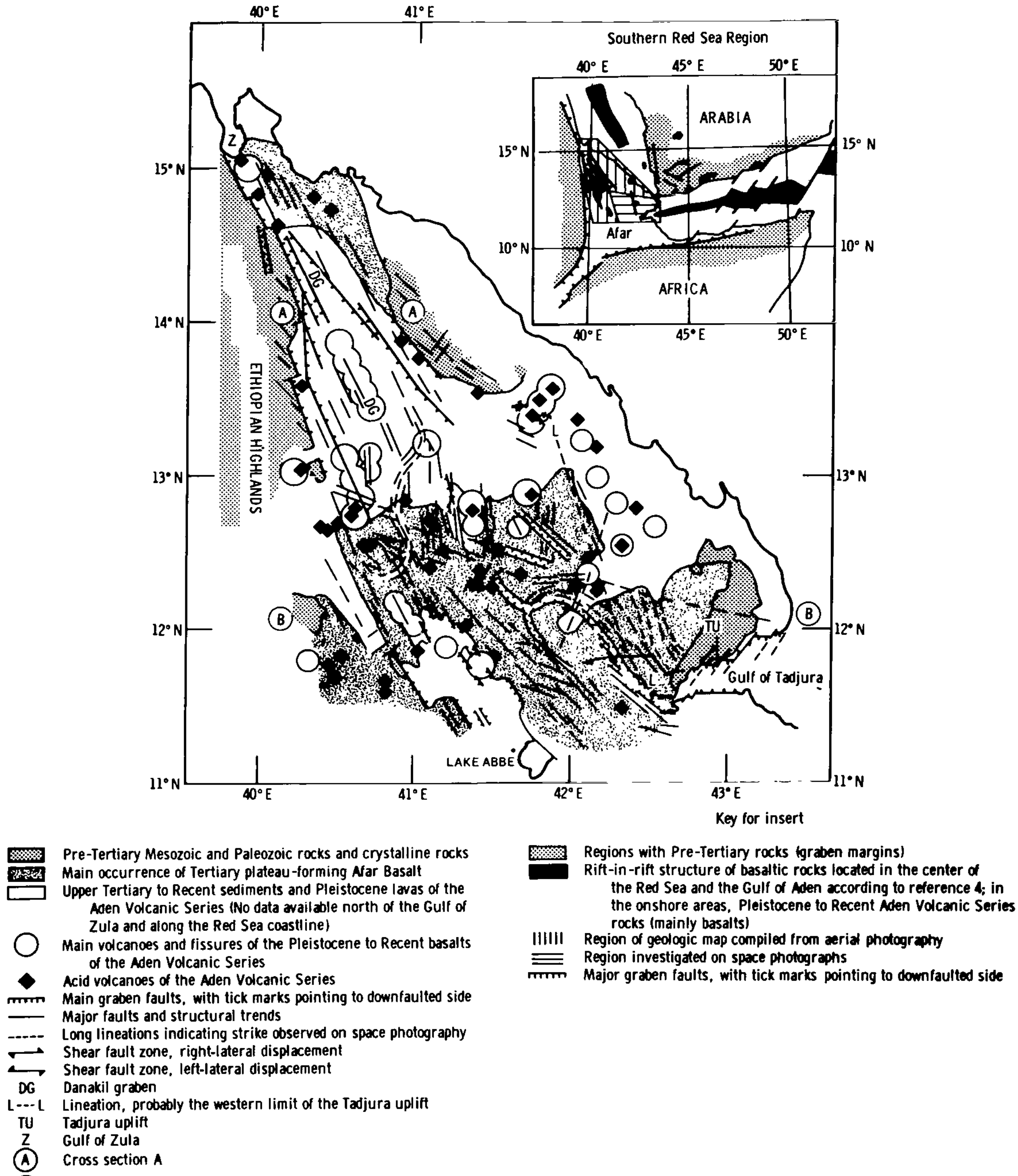


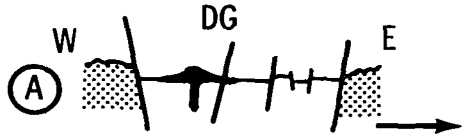
Figure 4. - Apollo 7 photograph AS7-5-1623. Sinai Peninsula with the Gulf of Suez on the left and the Gulf of Aqaba on the right. Note the striking shear fault between the Gulf of Aqaba and the Dead Sea in the north. This shear fault enables the northeastward rotation of the Arabian plate section.

Figure 5. - Gemini photograph S-66-54893. The northern end of the Red Sea. The landmass in the lower portion of the photograph is Africa. In the center is the Israel-Sinai block. East of this block is the Jordan Rift Valley and the Dead Sea, along which the Arabian plate section is drifting northeastward.



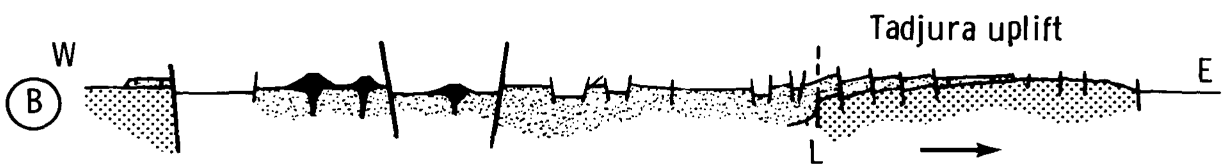
(a) Schematic sketch map.

Figure 6. - The northern part of the Afar region in eastern Ethiopia.



Basalts of the Aden Volcanic Series
Pre-Tertiary rocks
DG Danakil graben
Faults
Direction of motion

(b) Cross section A, along 14° north latitude.



Basalts of the Aden Volcanic Series
Pre-Tertiary rocks
Afar Basalt
Faults
Direction of motion
L Lineation, probably the western limit of the Tadjura uplift

(c) Cross section B, along 12° north latitude.

Figure 6.- Concluded.

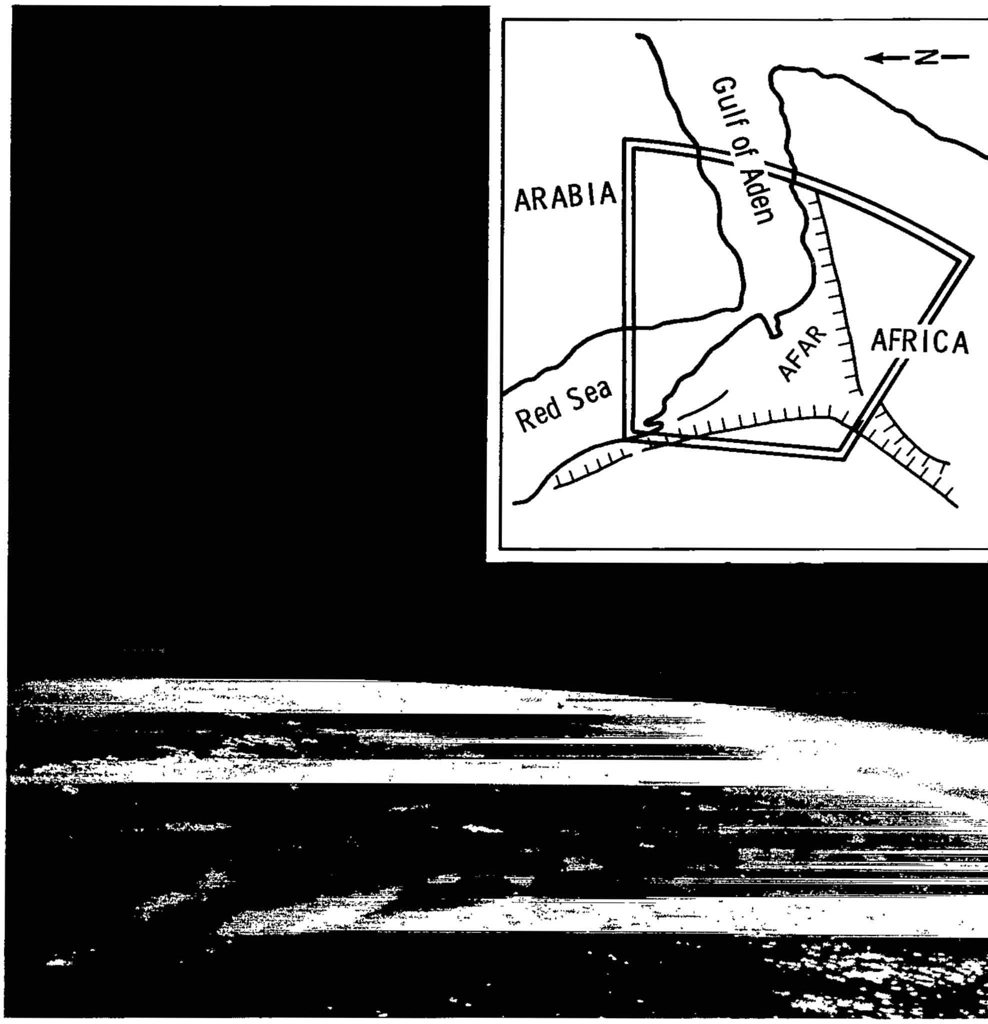


Figure 7. - Gemini photograph S-66-38423, eastward-looking view. In the foreground are the Ethiopian Highlands. The width of the Red Sea (left) decreases toward the Strait of Bab el Mandeb; then, the sea joins the Gulf of Aden. The eastern coast of the Red Sea is built by the northeastward-drifting Arabian Peninsula. Between the Ethiopian Highlands and the Red Sea is the northern part of the Afar region. The light-colored salt plain of the Danakil graben is interrupted by an outpouring of black basalt. Bordering the Red Sea are the Danakil Mountains and the Tadjura uplift, which are drifting away from the escarpment of the Ethiopian Highlands and are causing the funnellike narrowing of the Red Sea. The insert shows the region covered by the photograph; lines with short tick marks indicate major faults, with tick marks pointing to downfaulted side.

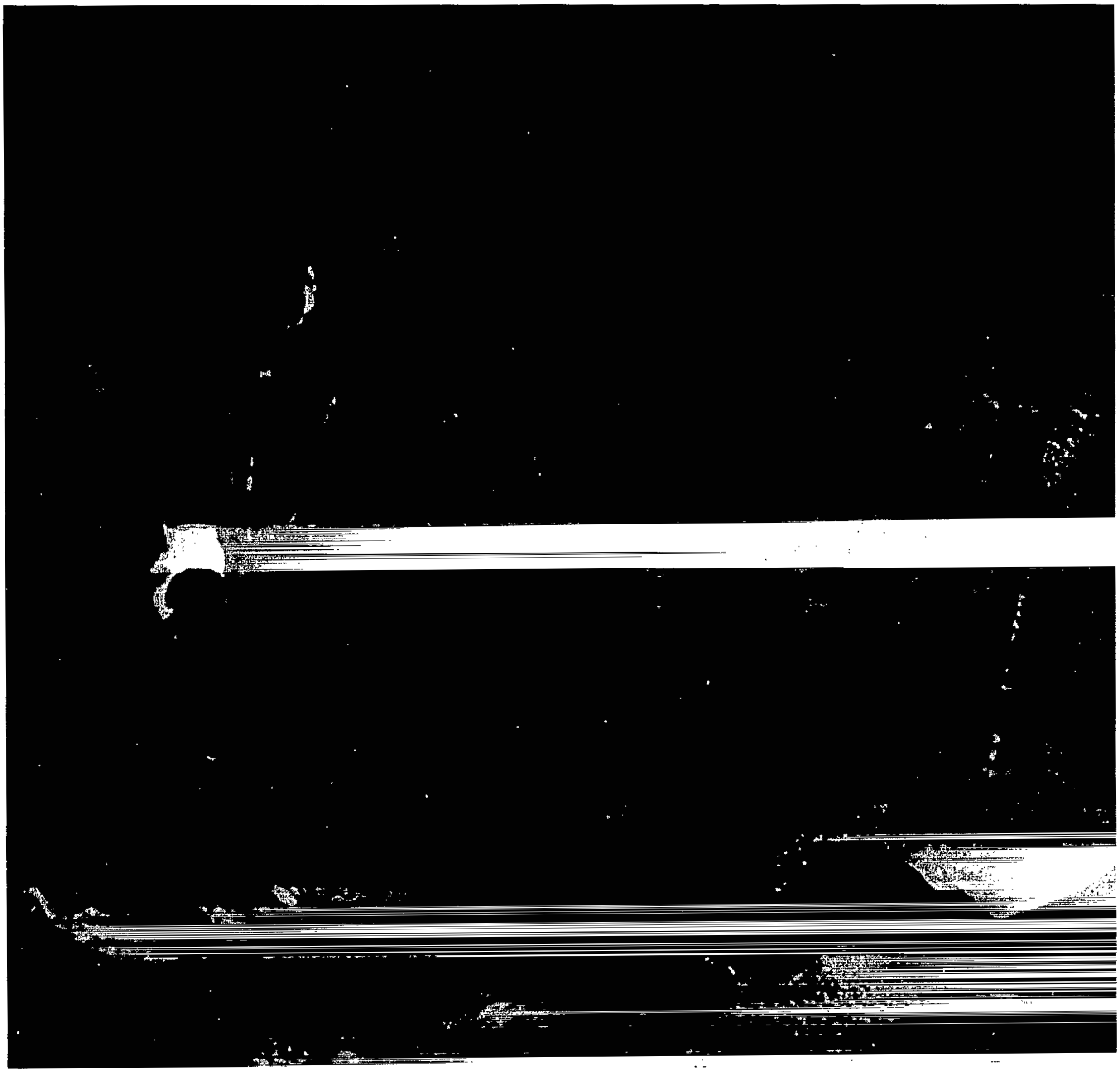


Figure 8. - Apollo 9 photograph AS9-23-3539. Gulf of Tadjura and the Tadjura uplift (right) overlain by black Afar Basalt. The intensity of tectonic movement increases to the southwest (left).

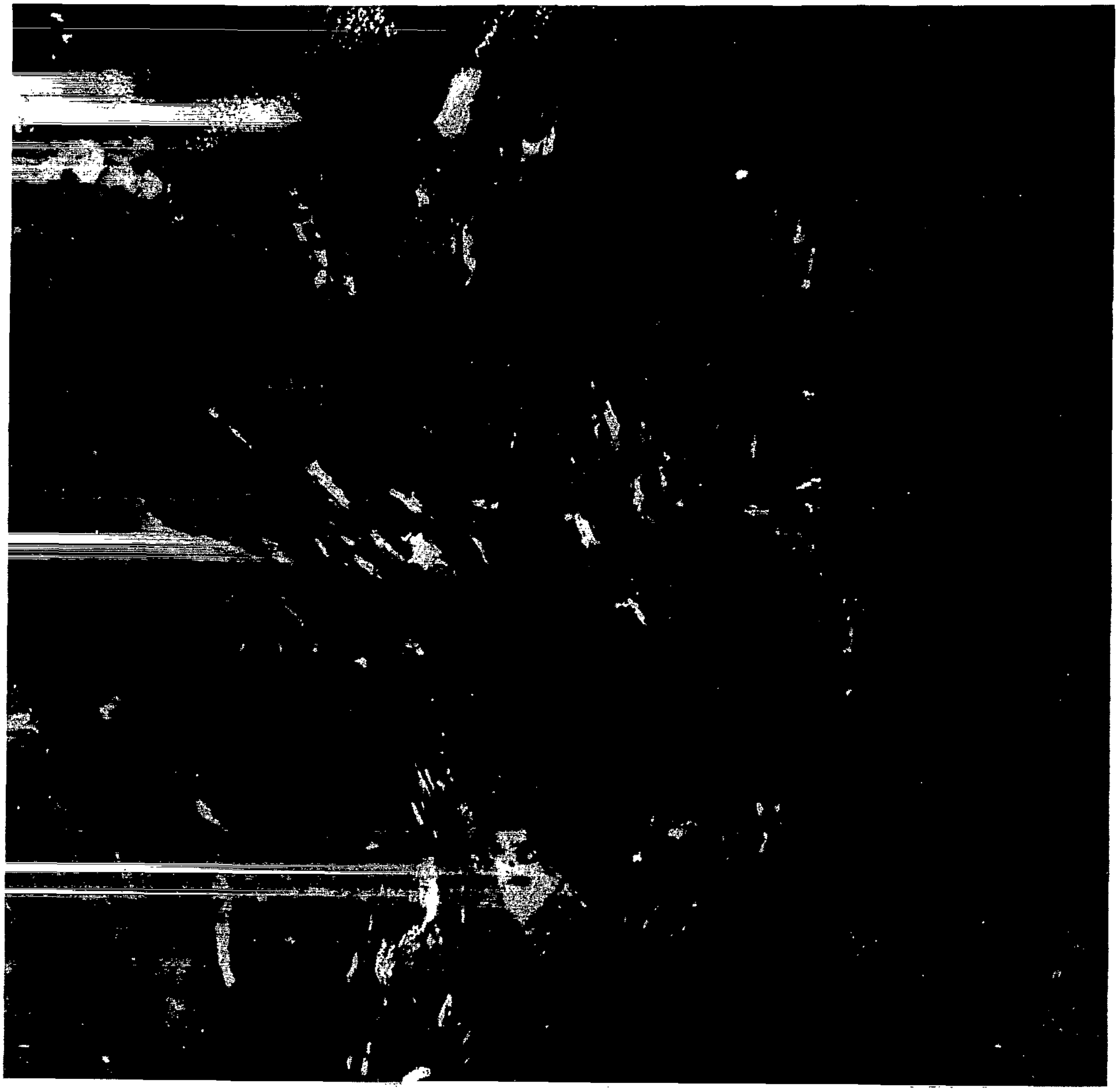


Figure 9. - Apollo 9 photograph AS9-23-3538. (Overlaps region shown in AS9-23-3539. Investigation could be done in stereoscopic view for the entire region.) This photograph shows the complex of annular grabens. In the center of the photograph are the youngest basalts of the Aden Volcanic Series (black). The acid extrusive rocks of the Aden Volcanic Series have a rougher surface and a lighter color than the basalts of the Aden Volcanic Series.

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