ATLAS OF INTERPRETED PHOTOGRAPHY OF SOUTHERN AFRICA

FROM TIROS SATELLITES I TO VIII

By A. Morrison, J. B. Bird, and M. Lundgren

Final - Second Part

Prepared under Contract No NASr-140 by
McGILL UNIVERSITY
Montreal, Quebec

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Copies of this report may be obtained from:

Geography Department
McGill University
Montreal 2, P.Q.
Canada

FOREWORD

This report presents part of the results of work by the Planetary Surface Interpretation Project during the year 1964-65.

The National Aeronautics and Space Administration and the U. S. Weather Bureau were responsible for the photography.

The study was carried out in the Geography Department, McGill University.

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The writers acknowledge the assistance of J. A. Fellgren, National Weather Satellite Center, in procuring films, and D. B. Macgregor in making prints. The maps were drawn by G. deBelle and C. Weiss. H. Vogt prepared prints for reproduction.

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ATLAS OF INTERPRETED PHOTOGRAPHY OF SOUTHERN AFRICA FROM TIROS SATELLITES I TO VIII

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SUMMARY

This report is based on examination of the majority of wide and medium-angle Tiros pictures taken before the end of 1964 showing surface features of southern Africa (approx. south of 7°S, west of 35°E). It includes 38 interpreted Tiros pictures which provide complete coverage, and a map showing the tone which typically represents each of 93 areas of relatively uniform tone into which the sub-continent is divided.

It is usually impossible to determine uniquely the nature of an unknown terrestrial feature from Tiros pictures alone. Interpretation of pictures of other planets comparable to Tiros pictures must be even less reliable. Terrestrial features visible can be explained in general only by considering all the following: relief, plant cover and land-use, surface moisture and snow cover, soil-type, and rock-type, in addition to atmospheric and photographic conditions.

A quarter of the areal features visible is not explained by standard sources. The pictures complement rather than duplicate general-purpose atlases. Surface features larger than about 20 by 10 miles are regularly visible.

Several structural lineaments visible are not mentioned in standard works. The pictures are advantageous for finding lineaments where a thin superficial layer hides older rocks.

The quality, distribution, and frequency of coverage permit study of the permanent features, but are inadequate for following changes in surface conditions. For this purpose greater useful information content per frame, better ground resolution, more frequent coverage, a simpler relationship between surface reflectivity and photo tone, and a convenient and accurate graticule are needed. With moderate improvements, there is a reasonable prospect of detecting reliably the flooding of dry lakes and seasonally flooded swamps during seasons when they are not cloud-covered; and some possibility of following changes in savanna or steppe vegetation; but little hope of measuring variations in the level of permanently flooded swamps and permanent lakes.

INTRODUCTION

Southern Africa for the purposes of this study is limited arbitrarily in the northeast by the Western Rift Valley, and in the northwest by the southern edge of the equational belt of year-round cloudiness.

Southern Africa was chosen for study as an area where the effects of marked seasonal rainfall variation might be distinguished on Tiros pictures without undue complications introduced by mountain ranges, or variations of seasonal temperature, snow and ice-cover. In particular, visible changes in the appearance of swamps such as Okovango, dry lakes such as Makarikari, and steppe areas such as the Kalahari, were anticipated.

The average appearance was first established. This is represented by the 'tone area map' (figure 8), and is discussed in general terms in the section 'Permanent Features of the Surface of Southern Africa'. It is described area by area in 'Key to Tone Area Numbers'. Subsequently variations in the appearance of each tone area from one time to another were studied. These are discussed either under 'Variations in Appearance of the Surface of Southern Africa' or in 'Key to Tone Area Numbers'.

THE TIROS SATELLITES

The Tiros satellites were designed to obtain pictures of the cloud cover of the earth for meteorological purposes. Pictures are taken by television cameras in the satellite and transmitted to the earth by radio. Between April 1960 and the end of 1964, eight Tiros satellites were launched and for practically the whole period at least one was producing meteorologically usable pictures. The satellites travel in orbits which lie mainly between 650 and 850 km above the earth, and circle the earth about once every hundred minutes. The orbital plane is inclined to the plane of the equator at 48° in the case of Tiros I to IV, and 58° in the case of Tiros V to VIII. This means that southern Africa, which ranges in latitude from about 10°S to 35°S, is in each case well within the area which can be photographed, and that the satellites pass across the area either from roughly northwest to southeast or from southwest to northeast. Each satellite carries two television cameras pointing in the same direction. The optical axes of the cameras are practically parallel to the spin axis of the satellite. The direction of the spin axis in space changes only slightly from day to day.

Pictures are taken only when the cameras are pointing towards part of the earth that is in daylight. If the satellite is then within range of one of the two command-and-data-acquisition stations in the United States, television pictures can be relayed directly from the satellite and are recorded ('Direct' mode). Pictures taken of other parts of the world are stored on tape until the satellite is within range of one of these stations and are then relayed to earth ('Tape' mode). All pictures of southern Africa were received by tape mode and almost all on passes from northwest to southeast. A number of pictures taken consecutively is called a 'sequence'. In tape mode, a sequence consists of not more than 32 pictures, taken at intervals of 30 seconds. Frames are numbered in the order in which they are received, which in tape mode is the reverse of the order in which they were taken. Consequently frame numbers run from southeast to northwest.

Tiros VIII carries an Automatic Picture Transmission (A. P. T.) system, which permitted a relatively inexpensive installation at any point within line-of-sight of the satellite to receive up to three pictures of the surrounding area during the time the satellite took to pass from horizon to horizon.

Different types of lens have been used (table I). The 104° or wide-angle lens gives a picture 1000 km square when the camera is pointing directly downwards. The 76° or medium-angle lens gives a picture about 700 km square, and the 12.7° or narrow-angle lens gives a picture about 100 km square. The factor limiting the resolution of the system is the width of the television scan line. When the camera is pointing directly downwards, this is equivalent to 3 km at the earth's surface for wide-angle cameras, to 2 km for medium angle and 1/3 km for narrow angle. What this implies in practice is discussed later.

TABLE I - TIROS SATELLITE DATA

Tiros	Period of usable photography	Camera no.	Camera type	Heights from which photos taken, km	Orbital inclination, degrees
I	1 Apr 60 - 19 Jun 60	1 2	Narrow Wide	690 - 750	48
II	23 Nov 60 - 1 Feb 61	1 2	Narrow Wide	620 - 730	48
III	12 Jul 61 - 30 Oct 61	1 2	Wide Wide	740 - 820	48
IV	8 Feb 62 - 12 Jun 62	1 2	Wide Medium	710 - 840	48
V	19 Jun 62 - 5 May 63	1 2	Wide Medium	590 - 970	58
VI	18 Sep 62 - 11 Oct 63	1 2	Wide Medium	680 - 710	58
VII	19 Jun 63 - present	1 2	Wide Wide	620 - 650	58
VIII	21 Dec 63 - present	1 2	Wide A. P. T.	700 - 750	58

The prime depository of Tiros pictures is the U.S. National Weather Records Center, Federal Building, Asheville, N.C. 28801, where the pictures are stored chronologically on hundred-foot reels of 35 mm film, each of which contains about two dozen sequences showing many parts of the world. Copies of complete reels may be purchased either in positive or negative form from that address, with the aid of the published catalogues (ref 16).

Ref 17 lists a selection of articles on the non-meteorological interpretation of Tiros photographs written prior to that time. Since then, Fritz (ref 18) has reviewed both meteorological and non-meteorological interpretation of Tiros pictures.

CHARACTERISTICS OF TIROS PHOTOGRAPHY OF SOUTHERN AFRICA

Photography Used for this Study

This report is based on examination of most of the wide and medium-angle Tiros pictures taken before 31 Dec 1964 which show details of the surface of southern Africa. Later Tiros pictures and Nimbus pictures did not become available before the end of the study. The narrow-angle pictures taken by Tiros satellites I and II have been excluded because their resolution and coverage are of a different order of magnitude. Wide-angle pictures taken by Tiros II were out-of-focus. A. P. T. pictures taken by Tiros VIII were not archived at National Weather Records Center, and suffered from 'scalloping', a serious technical defect. Wide-angle pictures taken by Tiros I and III have been considered, but less thoroughly than later pictures because they are not of such good quality. Most of the sequences used were taken by Tiroses IV to VIII during 1962, 1963 and 1964.

Reels were selected for purchase so as to include as many sequences as possible showing surface details of southern Africa, but nevertheless, because of the need to keep the number of reels purchased within limits, it is likely that a few usable pictures have been missed, perhaps 10 to 20 per cent of the total.

Visibility of Small Features

The nominal ground resolution of the wide-angle Tiros cameras is 3 km (2 mi.) and the medium angle 2 km (1-1/2 mi.). These figures refer to the width of elongated objects which contrast strongly with their surroundings and which appear near the centre of a vertical picture. Most pictures are oblique, and most ground features are of low or medium contrast compared with the standard conditions of resolution measurement, so that features as small as this are not usually visible. Without attempting to be unduly precise, the following examples indicate the size of objects one can expect to see in practice.

Let us consider first more or less circular objects. Erongo Mt. (area 15), which is about 20 miles in diameter and contrasts fairly strongly with its background, is usually conspicuous on wide and medium-angle pictures (plates 2, 3, 5, 6). The Pilansberg (within area 76 b), which is about 15-18 mi. in diameter and of average contrast, is just visible in one or two medium-angle frames (plate 15); the Brandberg (between areas 13 b and 14), which is about 12 mi. in diameter and of low contrast, is not definitely visible on any frame.

Examples of somewhat elongated objects are the Serra da Névé (area 3) which is 6 by 40 mi., contrasts moderately with its surroundings, and is sometimes visible on wide-angle pictures (plate 1); and the Great and Little Karas Mts. (within area 26 b), which are 10 by 40 and 5 by 15 mi. in size, but of the same tone as their surroundings, and not distinguishable.

Examples of indefinitely long features are the sandy coastal strip in area 32, which is 15-20 mi. wide and of medium contrast, but is only visible on one sequence; the Cape Ranges (areas 36 b to f), which are 5-10 mi. wide, of medium contrast, and are usually just visible; the Great Dyke (within area 68), which is 3-6 mi. wide, of high contrast, and usually visible; the curving northward extension of the Kuruman Hills (area 30), which is 4 mi. wide, of medium contrast, and visible on only one frame (plate 9, wide-angle) out of many covering the area; and the lower Zambezi (in area 91), which is 2-5 mi. wide, and is just visible (plates 31, 32) during the dry season when it contrasts fairly strongly with its surroundings. Other river valleys visible on some frames may be even narrower than this, but it has not been possible to determine their width exactly.

In summary, one can expect to be able to see regularly on Tiros pictures surface features which contrast moderately with their backgrounds, only if they are over 20 miles in largest dimension and over 8-10 miles in smallest dimension.

Estimation of Position

Position of features which are not identifiable on maps cannot be determined accurately by visual estimation from Tiros pictures because of the oblique view, curvature of the earth, and lens distortion, especially in wide-angle pictures. The doubt about the true location of area 66 illustrates that there can be an uncertainty of as much as $\pm$30 miles in the position of features close to well-established landmarks. In featureless areas such as the Kalahari, even greater uncertainty can be expected. Consequently, for tracing movements of tone boundaries accurately, a graticule is needed which over the usable part of the picture is at least as accurate in position as the practical resolution, say 10-20 mi., and preferably several times better than this.

Estimation of Reflectivity

Identical surfaces do not necessarily appear in identical tones on Tiros pictures. The following are among the most important reasons for this, but the list is not complete.

A lower level of illumination, as when the sun is low in the sky, will produce darker tones on the original negative.

The ground, especially the darker areas, will seem to be represented by lighter tones when viewed through a hazy atmosphere, than when viewed through a clear atmosphere, though the additional light is actually reflected from the haze, not the ground.

If part of the surface is positioned so that it reflects light specularly (like a mirror) from the sun to the camera, then that area will appear lighter than the remainder. This effect (sunglint) is most marked on a calm water surface, but may also be noticeable on land surfaces.

The combined effect of the parts of the system in the satellite and on the ground is to distort the tone representing a uniform surface in such a way that the top and bottom edges of each picture appear darker in a positive print (ref 19). In the case of one of the Tiros IV cameras for example this effect could produce a difference in grey tone of about one-fifth of the range from white to black. It is this effect which is mainly responsible for the difficulty in plotting tonal boundaries in the Okovango area described later. It arises from a combination of non-uniformity in the light-distribution by the camera lens, movement of the focal-plane shutter, scanning of the vidicon tube, conversion of voltage to frequency for transmitting, conversion of frequency back to voltage by the receiver, display on the ground cathode ray tube, and photography of the tube by the recording camera. In addition, several of the camera systems developed a fault whereby every second frame has alternating light and dark lines across it, as in plates 20 and 34.

The direction of movement of the focal-plane shutter alternates from frame to frame, and the exposure time in each direction differs sufficiently to produce a difference of about 0.1 or 0.2 in the densities of the resulting negatives. During each sequence of 32 frames, the vidicon tube is most sensitive when first switched on, and falls to a constant sensitivity after about 10 frames. Consequently the first frames taken (numbered 32 to 22 on tape sequences) may be up to 0.4 density units darker on the negative (lighter on the positive) than the remainder. All frames are reduced to the same mean density in making the archival film, but these effects will still exert influence on the visibility of tonal differences in the very dark and very light tones. For example, it could be partly responsible for the variation in visibility of the slightly darker area within the light-toned Etosha Pan referred to later.

Three generations of film intervene between the original negative made by photographing the cathode ray tube, and the positive print or positive projected image used for interpretation by ordinary users such as the present authors. Differences in processing conditions from time to time, or from one part of the frame to another, at any of these stages will alter the resulting tones.

The result of all these sources of variation is that even a large change from one Tiros picture to the next in the tone representing an area, does not necessarily mean there has been any real change in the reflectivity of the surface. Comparisons will be valid only between immediately adjacent areas within a single frame. There it is usually correct to say that the reflectivity of the lighter area is higher than that of the darker area, and vice-versa, but how much one cannot say.

In order to use changes in tone from one frame to another as a measure of reflectivity it would be necessary to have a series of target areas of unchanging reflectivity, at least 20 mi. in diameter, scattered over the land surface, including examples ranging from low to high reflectivity. This is obviously impossible, but there may be in some areas natural surfaces which could be shown to be of sufffciently constant reflectivity to be used in this way. Some possible examples are given below (p 24).

Distribution of Coverage

Average Frequency of Coverage

The number of Tiros sequences usable for ground surface studies is surprisingly small. In the 35-month period from the launch of Tiros IV on 8 Feb 1962 until 31 Dec 1964, functioning Tiros satellites made about 25,780 passes around the earth. Southern Africa extends over about 24 degrees of longitude and is not far from the equator. Therefore about 24/360 of these, i.e. 1820 passes, must have crossed some part of the sub-continent during daylight hours. However, on most of these passes no pictures were taken because the cameras were not pointing towards the earth, or for other reasons. Consequently, only 214 sequences are catalogued as covering part of southern Africa. During more than three quarters of these picture sequences the ground was obscured by partial or complete cloud-cover or haze, or the pictures were very oblique or suffered from electronic disturbances, so that only an estimated 50 sequences included pictures usable for ground studies. 42 of these, containing 260 usable frames, were on the reels purchased by the Project and were used in this study. These are listed in table II, together with four Tiros III sequences found usable. Thus the average frequency was 50/35 or about 1.4 usable sequences per month showing some part or other of the sub-continent.

TABLE II

TIROS SEQUENCES USED

Sequence numbers shown are film legend sequence numbers

REEL	SEQUENCE	REEL	SEQUENCE	REEL	SEQUENCE
TIROS III		TIROS V		TIROS VI	
304	0158 T1	554	0130 T1	602	0034 T2
305	0173 T2	506	0145 D*1	602	0047 T2
305	0187 T2	506	0159 T1	602	0062 T2
353	0201 T2	556	0201 T1	653	0089 T2
		508	0216 T1	603	0090 T2
TIROS IV		508	0230 T1	654	0118 T2
		509	0245 T1	656	0190 T2
405	0244 T1	560	0371 T1	657	0209 T2
410	0580 T1	513	0400 T1	657	0262 T2
431	1148 T1	513	0414 T1	690	3445 T1
432	1163 T2	586	2455 T1	604A	3662 T1
432	1177 T2			610A	4699 T1
434	1205 T2				
435	1261 T1			TIROS VII	
436	1276 T1				
436	1290 T1			708	0281 T2
462	1332 T1			746	1551 T1
462	1333 T1			794	3593 T2
438	1347 T1				
462	1361 T1			TIROS VIII	
				806	0247 T1
				810A	4960 T1
				810A	4974 T1

Time Distribution of Coverage

Figure 1(a) shows the time distribution of all sequences covering southern Africa with or without cloud-cover, according to the coverage maps in the catalogues. Maxima occurred in June to September 1962 and in January 1964 but several sequences were obtained in most months.

Figures 1(b) and (c) are intended to approximate the time distribution of sequences usable for ground studies. Figure 1(b) is based on the cloud analysis maps in the catalogues and includes all sequences which have large cloud-free areas whether or not they are rendered unusable by obliqueness, haze, or electronic faults. Note that the maximum of June to September 1962, which occurred in the dry cloudless season, is still present, but that the maximum of January 1964, which occurred in the rainy season, has almost disappeared because most of these sequences would be cloud-covered.

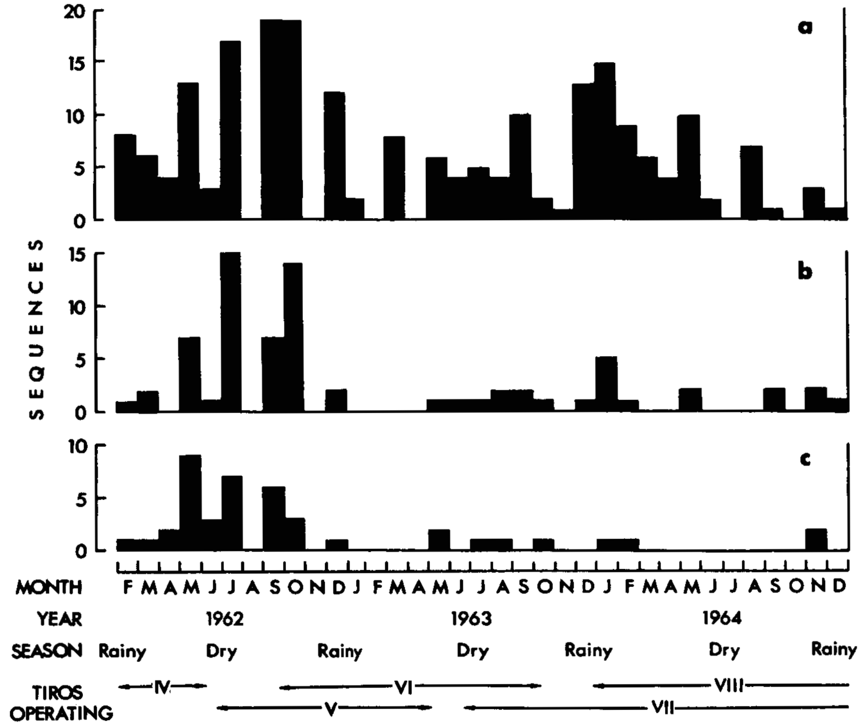

Figure 1. Time distribution of Tiros sequences covering southern Africa during 1962, 1963, and 1964. (a) All sequences, according to cloud analysis maps in catalogues (ref 16). (b) Sequences having large cloud-free areas, according to cloud analyses in catalogues. (c) Sequences used for this study.

Figure 2.
Areal distribution of Tiros coverage usable for studies of the surface of southern Africa, taken during 1962, 1963, and 1964. Numerals represent the number of usable sequences showing each area. Based only on the sequences used for this study.

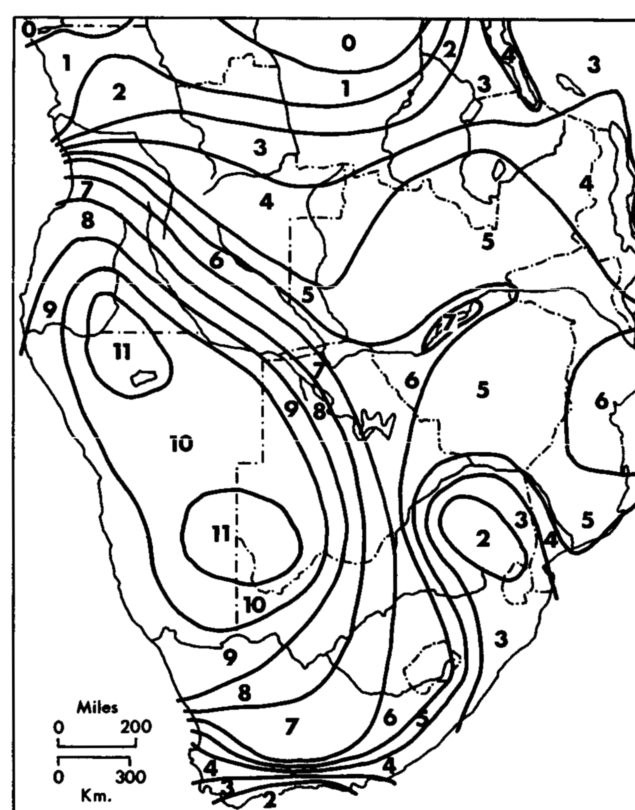

Figure 1(c) includes only the sequences used in this study. It tends to omit sequences archived on reels which do not contain other sequences of southern Africa, but to prefer medium-angle sequences, taken only by Tiros IV, V, and VI during the first half of the period. Both these effects further increase the concentration in 1962. 28 of the 42 usable sequences occur in the six months May to October 1962.

Areal Distribution of Coverage

Figure 2 shows the number of usable sequences covering each part of the sub-continent. There is at least one usable sequence showing every region, but the area studied is bounded in the north by regions which do not yet appear to have been photographed in the absence of clouds. There Tiros pictures could not be used for ground studies, except perhaps through the intermediary of cloud patterns.

One would expect the distribution in figure 2 to be positively correlated with the distribution of average sunshine duration, and negatively correlated with average cloud cover. In fact, there is a reasonable resemblance (ref 1, pp 226-229), but the variations in sunshine duration are much accentuated in the coverage map. For example, it appears that a change in annual sunshine duration from 80% to 60% of the possible duration corresponds to a change from 10 to 2 usable sequences. It is easy to see why this should be so. Conditions are not suitable for Tiros photography of the ground if the sun merely shines between the clouds occasionally. The sky must be entirely clear over an area several hundred miles in diameter. Therefore the frequency of entirely clear skies would be a better measure of the prospects for Tiros photography of ground features in a given area than would either average cloud cover or sunshine duration.

It is possible that some features of the coverage map are partly fortuitous, and would disappear if the map were based on a larger number of observations, notably the pronounced minimum in the Transvaal. However, the maxima over Lakes Tanganyika and Kariba would persist, because there is a strong tendency for tropical lakes and valleys to be free of cloud during the day even when their surroundings are obscured.

Discussion

Generalising, we can say that the Tiros system in 1962-64 produced an annual average of two sequences usable for ground studies over every part of the northeastern half of the sub-continent, and four per year in the southwestern half. Most sequences were in the dry season, and the frequency varied markedly from year to year.

For studies of the permanent features of the surface, the uneven distribution of usable coverage in time and area is not a serious disadvantage, so long as coverage of each area is obtained at some time. The most serious effect is that one sees the area only as it is in the dry season. For studies of actual changes in surface conditions throughout a given year, the frequency of sequences was everywhere too low, except in the southwest in 1962. It was everywhere too low to form a basis for a reliable system for predicting, for example, the movement of floods. However, if it were shown to be worthwhile, the frequency could no doubt be increased to some extent, even in places and at times of considerable cloud cover, and almost indefinitely in places and at times generally free of cloud, by guiding the camera axis appropriately, modifying the system, or increasing the number of satellites.

PERMANENT FEATURES OF THE SURFACE OF SOUTHERN AFRICA

Meaning of 'Tone Area'

The average appearance of each part of southern Africa in Tiros pictures was estimated by examining all usable sequences. The results are presented by means of a tone area map (figure 8). Tone is regarded as uniform throughout the 'tone area' or, in a few areas, as varying in a repeating pattern, the individual elements of which are too small to describe separately. Tone is supposed to change either abruptly along the 'tone area boundary', or gradually over a transition zone bisected by the boundary. Tone area boundaries which do not follow boundaries appearing on existing maps were plotted by visual estimation from better-established features. Each tone area has a number, which corresponds to the numbers on the plates, and in the 'Key to Tone Area Numbers'. This key not only identifies each area, but attempts to justify the identification by explaining why each area appears in the respective tone.

Interpretability of Ground Features

A rough calculation indicates that the information contained in a vertical Tiros picture is approximately equal to that in a portion 2 cm by 2 cm cut from an aerial photograph of system resolution 25 lines/mm. Interpreting the more typical oblique Tiros photograph may be more nearly equivalent to examining 1 squ. cm of air photo. This largely explains the small scope for interpretation of Tiros pictures, and makes clear why improved interpretability demands greater information content per frame as well as better ground resolution.

One interprets air photos in terms of tone, shape, texture, and pattern. On the Tiros pictures of southern Africa one has to attempt interpretation almost entirely on the basis of tone and shape.

If texture is defined as the repeated variation of tone over distances of tens of resolution elements, and pattern as a repetition over hundreds of resolution elements, then, since each Tiros picture is 500 by 500 resolution elements (lines), 'pattern' is a variation which repeats only a couple of times in one Tiros picture, and every pattern element is a separate tone area.

As each line on a Tiros picture represents about 1-1/2 mi. at best, or up to perhaps 10 mi. on the more oblique pictures, then texture represents variations over distances of about 15 to 100 mi. The few parts of the Tiros pictures which appear to have pattern (Rhodesian Plateau, Cape Ranges, Cuito-Cubango basin, plateau slopes of Damaraland) have in fact texture by this definition. Why such 'patterns' do not occur more widely in southern Africa is not clear, but it is an unusually uniform continent, and it may be that repetitive variations in the physical environment over such distances simply do not occur.

As interpretation is based solely on tone and shape, in most cases it is not possible to provide a definite interpretation of an unknown feature from the photos alone. For example area 66, an oval dark area in the Kalahari, could be an outcrop of dark bedrock, a line of hills, or a flooded area. Only in a few cases, such as the Okovango delta, is the shape sufficiently characteristic to permit a fairly confident interpretation if one does not already know the nature of the area.

Consequently interpretation of Tiros pictures, at least in southern Africa, degenerates into identification and explanation: checking whether existing knowledge of an area is enough to account for the observed tone and shape, and listing areas where it does not, with mere suggestions of possible explanations. In short, the principles outlined in the following section will often fail to yield a unique interpretation.

Principles of Interpretation

The features shown by Tiros pictures may be considered as lying within a series of layers: rock, soil, water, snow or ice, several layers of wild or cultivated plants, and the atmosphere, including clouds and haze; some of the layers may be absent. They range from completely opaque to almost completely transparent. In the general case the amount of light reaching the camera is a function of the proportion of light reflected, transmitted, and absorbed by all the layers, and it would not be correct to say that tone variations are caused by variations in any one layer. In the special case of an opaque layer such as soil, clouds, or perhaps a closed-crown forest, lower layers will have no direct effect on the amount of light reaching the camera. A lower layer may be visible indirectly, of course. For example, the distribution of a rock type may be visible through its influence on the overlying soil.

The wavelength sensitivity of Tiros cameras extends from about 0.50 to 0.80 microns, with maximum sensitivity at 0.59 (J.H. Conover, personal communication). This is intermediate between that of the panchromatic-minus blue combination usual in aerial photography (0.50 to 0.68), and that of infrared aero film with a deep red filter (0.70 to 0.88). In an infrared photograph water is perfectly black even if shallow, moist surfaces appear darker than usual, shadows are perfectly black and sharply defined, green leaves are light, and most dry surfaces are light. We should expect the tones in Tiros pictures to be intermediate between these and the tones found in ordinary aerial photographs.

Broadly speaking, in Tiros pictures water areas appear black; land areas in shades of grey; and clouds, snow, and ice white.

Though water is usually black or dark, it may appear light or white at times. This may be due to sunglint, i.e. the local direct (specular) reflection of the sun's rays, as on L. Mweru (area 83) in plate 35 (compare plates 33 and 34). Sunglint may be local and intense or widespread and less intense, depending mainly on the roughness of the water surface. Water may appear light because of suspended matter, as probably in the case of L. Rukwa (area 93) in plate 38. In shallow water a light-toned bottom may be visible if the water is clear. L. Bangweulu (area 85) is sufficiently shallow, but evidently the other conditions are not fulfilled, for it appears dark.

If adjacent land is dark in tone, the coast may be indistinguishable, as in the north of plate 18, but a zone of light-toned water often appears along the coast, as in plate 32. This may be due to partial visibility of the bottom in the shallow water; beaches, sandbanks, or reefs exposed at low tide; white foam from breakers; suspended matter stirred up by breaking waves or carried along the shore by currents from a silt-laden river; or differences in the amount of specular reflection due to differences in the roughness of the water or the orientation of wavecrests. It is not known which of these is responsible in plate 32.

Land areas not affected by snow and ice generally appear in dark to light grey. When it forms an almost complete cover, the vegetation determines the tone (compare figures 4 and 8). Thus closed-crown forests e.g. areas 35, 43, 73, and 56 appear dark, swamps e.g. areas 58, 63, 65, 86 appear dark, and denser savannas e.g. area 55 appear medium-dark, irrespective of the underlying rock or soil. In areas of moderately dense plant cover such as steppes, grasslands, cultivated areas, and the drier savannas, the average tone is medium or medium-light, but may vary from light (area 53) to dark (area 77) according to the nature of the soil (figure 5), which in turn tends to vary with parent rock and topography within a single vegetation zone. In deserts, where plant cover and developed soils are lacking, any tone may be found, according to the rock which is exposed (figure 6).

Consolidated rocks generally appear dark or medium-dark. Basic volcanic rocks are among the darkest e.g. areas 13, 25, 40, but dark sandstones, limestones, ironstones etc. may be equally dark e.g. areas 20, 30. Granite areas appear light or medium-light e.g. areas 14, 27, 70, 78. Unconsolidated superficial deposits tend to be light, but are by no means uniformly so e.g. areas 1, 17. Dry lake beds appear generally light or white e.g. area 62, but parts may be quite dark e.g. part of area 8.

The majority of tone variation in southern Africa appears to be independent of land use. This is probably because many land uses here do not greatly alter the tones, and those which do, such as afforestation or irrigation, do not usually occupy sufficiently large continuous areas. To be visible the use must affect the whole of the land in an area about 20 mi. across, or more than half the land over a much larger continuous area. Even the entirely man-modified landscape of the Rand group of cities, about 5 mi. wide and 20-40 mi. long, is not visible. Only in areas 43 b, 45, 71, and 73 is it necessary to invoke land-use as a part of the explanation of the tone. In areas 34, 42, and 44 an unresolved patchwork of different land-uses may account for the medium tone and lack of visible sub-divisions. If we believe savannas are man-induced, then land-use is part of the reason that area 55 is lighter in tone than area 56.

Surface moisture influences tone on Tiros pictures, and a map of annual rainfall is included (figure 7) as a crude measure of this, but its effect is difficult to separate from those of vegetation and soils. No doubt many of the river valleys and swamps are made visible by their moist surfaces. The Makwegana Spillway for example (x, area 65), appears dark or not at all on Tiros pictures, even though its vegetation appears light when not flooded (ref 1, facing p 417).

Relief influences tone. Areas 4, 33, 38, 41, and 72 seem to be darker than adjacent areas mainly because of greater relief. Relief reduces the percentage of light reflected because: (a) a large proportion of the surface is occupied by the shadows cast by the many small irregularities usually found on steep slopes; (b) major shadows are cast by cliffs, mountains; (c) a sloping surface reflects less light to the camera if both sun and camera are at high altitude; (d) a high percentage of the ground may be occupied by bare solid rock, which is often darker than the soil; (e) locally, there may be higher rainfall and hence a moister surface; (f) locally, there may be denser vegetation, especially in generally dry climates. These effects together are referred to in the 'Key to Tone Area Numbers' as 'relief factors'.

No map showing any element of relief is included. It would have been easy to construct a map showing the distribution of local altitude differences of thousands of feet, but it is likely that other elements of relief, such as microrelief, texture of dissection, or average slope are more relevant, and data on these are not available. It may be that microrelief contributes much to the dark tones of hard rock areas, and lack of it to the light tones of sandy areas. It may be the relief of the dunes that makes area 17 darker than one would expect.

White areas on Tiros photos may represent clouds, snow, ice, or dry lake beds, but in southern Africa they are almost always clouds. The only dry lakes large enough to be visible and white enough to be confused with clouds are Makarikari (area 62), and sometimes Etosha Pan (area 8), and these are distinctive in shape. The highveld is subject to frost for 3 to 6 months of the year (ref 1, p 224), but all lakes visible in Tiros pictures are outside this area, and never freeze; nor does the ocean adjacent to southern Africa. Widespread snowfall occurs on the highveld only sporadically, at intervals of several years, but snow falls regularly on the mountains of Basutoland and Cape Province (ref 1, p 240). Only one frame shows what is believed to be snow (III-0187 T2 frame 13* - not illustrated), in this case on the Winterberge in area 38 in July 1961, but it is possible that traces of snow may account for some of the unexplained tone variations in area 44, or for the surprisingly light tone of the part of area 42 just northeast of Basutoland in plate 30. Otherwise all white areas are believed to be clouds.

Results of Interpretation

Complementary Nature of Tiros Pictures and Atlases

Many of the features visible on Tiros photos are not shown in general purpose atlases. The photos show visible areal features e.g. the Schwartzkalk outcrop (area 20), the Knysna forests (area 35); whereas atlases show mainly linear and point features e.g. rivers, railways, towns, political boundaries, not usually visible on the photos. Atlas maps and Tiros photos are thus complementary, and combination of them between the same covers would be instructive. It would assist atlas users for example to an understanding of the true nature of the Okovango Swamp and Makarikari, which are difficult to represent informatively by existing conventional symbols.

Unexplained Tone Areas

Most of the permanent features of the tonal pattern visible on Tiros pictures of southern Africa can be explained by the principles outlined above, by reference to the standard sources (ref 1-15), and are explained in the 'Key to Tone Area Numbers' below, but about a quarter of the tone areas remain partially or completely unexplained. Probably the explanation of most of them could be found in the detailed literature on small areas, in large scale maps which may exist in some cases, or by correspondence with experts on each area. To do this for all of these areas is beyond the scope of this study. In any case, one is probably justified in saying the features are not generally known, and a few may prove to be 'discoveries'.

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* This formula designates the Tiros picture: Tiros III, received on orbital pass number 0187, by tape mode, taken by camera 2, frame number 13.

What is the sinuous light area (area 10) in Ovamboland, and the line crossing Ovamboland (area 9) just north of it? Why is part of Etosha Pan (area 8) lighter than the remainder?

Light and dark areas in the highlands of southwest Angola (area 5) do not fit the geological maps well. Why is area 11 darker than areas to east and west? Area 12 is not adequately explained.

Why is not the sandiest part of the Namib desert (area 17) lighter in tone, and what are the adjacent areas 18 and 19? The light tones of areas 21 and 24 within the generally dark tones of Namaqualand are not definitely explained.

Tonal variations within the Highveld (area 44) cannot be individually explained. Why is part of the Dwyka outcrop (area 28 a) very dark, but not the remainder? Area 36 f, within a long-settled area of the Republic, was not explained by the standard sources, only by personal knowledge.

Within the Kalahari, areas 48 and 49 may be discoveries, while areas 52 and 53 can only be tentatively explained. Why do Baikiaea forests appear in the same medium tones as dry savannas (area 57)? Areas 61, 64, and 66 are not explained with any certainty. What is the light area southwest of Makarikari (area 62)?

Maps suggest that only part, not the whole of area 69 in the Limpopo valley should be dark in tone. Why do the swamps along the exit from L. Bangweulu (area 85) appear dark, but not the main Bangweulu Swamps? The southwest boundary of area 90 does not correspond closely to any mapped feature.

Unexplained River Valleys

Almost all of the elongated features designated by letters can be satisfactorily explained as the valleys of rivers and more or less certainly identified. The exceptions are line e, which is probably not a river (area 44), and the lines at o.

The latter show the uncertainties of finding new features when working close to the limits set by picture resolution. The features appear clearly, but only on one frame (reproduced as plate 20, but probably not distinguishable on the reproduction), and their existence is not confirmed by maps. If they do exist, they are probably flood spillways carrying water from the Cuito to the Cubango.

Another unanswered question is why the Cuito (g) is more conspicuous than the main stream, the Cubango (f), on plates 19 and 20.

Structural Lineaments Noted

In many places on the Tiros pictures features of the earth's surface appear to form lines which are essentially straight for 50 mil, or more. They may be part of an abrupt tonal boundary, or a line of one tone on a background of another, which may or may not bepresent a river valley, or a line of spots of darker or lighter tone, or a combination of all these. They have been regarded as structural lineaments i.e. the surface expression of linear discontinuities in the sub-surface structure.

On the plates, lineaments which do not already appear as river valleys or tone area boundaries are marked by lines of dots. All lineaments on the sequences studied are plotted in figure 3.

It is difficult to determine which if any of these lineaments are 'discoveries'. On figure 3 are distinguished those which are specifically marked or mentioned in the standard works on the geology of the area (namely, ref 20; ref 13; ref 21, esp. p 23; ref 22, esp. p 79; ref 23, p 335) as faults, folds, warps, or tectonic trends, but not mere boundaries of rock units. However, it is not suggested that most of those lineaments shown as unmapped are necessarily previously undiscovered fractures. These sources tend to be very conservative about major fractures. In the detailed literature, probably many of the lineaments marked have already been suggested or established as tectonic lines. Others may prove not to be directly related to structure, as for instance those parts of the Great Escarpment marked as lineaments. A few, which appear on only one Tiros sequence, may prove to be illusions created by photographic peculiarities.

Over the map as a whole there is a predominance of northwest and, to a lesser extent, northeast trends which, as Furon (ref 22, p 79) has noted, are common all over Africa. These form a grid-like pattern in southern Angola and northern South West Africa. In Angola the northeast trend parallels a line of volcanic remnants (ref 24, p 300).

Among the most definite of the new lineaments is that which links areas 31, 48, and 49 across the southwest Kalahari and continues, much less definitely, to Angola in the north and the Great Karroo in the south. Lines parallel to the lineament cross the Kalahari further east in the area of the Bakalahari Rise, and one cuts the solid rock outcrop of area 51 at a point where it is offset to the north. The double curve in the lineament just north of the Doornberge is notable. It almost suggests that a block, consisting of the Transvaal and most of the area over which Karroo rocks have been deposited, moved 50 or 100 mi. to the southwest, pushing up the Cape Ranges before it, and leaving the Limpopo trough behind. The southwest coast is parallel to the lineament as a whole, with St. Helena Bay corresponding to the double bend north of the Doornberge. The Cape Ranges, like the Doornberge, terminate abruptly in the north, and do not appear to have been formed north of a line joining the two double bends.

Figure 3. Structural lineaments visible on Tiros pictures. Heavy continuous and broken lines represent respectively visible lineaments which do and do not appear in standard works on the structure of the area, namely refs 13, 20-23.

Another persistent lineament runs west-east across Ovamboland (area 9). To the west in area 5 it parallels the tectonic trend of the Oendolongo rocks as shown on ref 20, and follows the lower Cunene valley. To the east, on one frame (plate 4), it is continued in the cloud pattern. It is approximately in line with the lineament formed by parts of the Kafue and Zambezi.

It may be accidental that the dark areas 29 a & b and 28 b together form a shape suggestive of the outcrop of a plunging anticline or syncline with axis trending northwest, which has been plotted in figure 3. However, some support is given to the suggestion by the tectonic trend in the basement in this area which is northwest (ref 20), and by the shape of the Dwyka outcrop to the southeast, which indicates a syncline plunging to the southeast at that position.

Suitability of Tiros Pictures for Tracing Lineaments

The large area covered by each Tiros frame makes it possible to see the whole of long major lineaments at once, and it is possible that in some cases the separate parts of these have not been associated previously. Tiros pictures seem to be especially advantageous in areas where there is a thin cover of soft rocks which obscure the underlying structure e.g. in the Kalahari and Ovamboland, or in moist tropical areas such as Angola, where conditions are occasionally suitable for lineaments to be revealed in the cloud pattern.

Otherwise most of the lineaments visible are well-known topographic features such as the rivers Cuando and Cubango, the Luangwa Trough, or the escarpments bounding the Rhodesian Plateau. Their structural significance, if any, is just as likely to be suggested by small-scale atlas maps as by Tiros photographs. Indeed such maps reveal many lineaments, especially in the river pattern in moist savanna and forest areas, which are not visible on Tiros pictures. On the other hand, the rectilinear nature of the Cuito-Cuanevale valley (plate 19) is not apparent on some atlas maps, which show these rivers on scales of 1:5,000,000 to 1:20,000,000, perhaps because of losses of accuracy in compilation, though it is obvious at the 1:1,000,000 scale.

Some lineaments apparent on Tiros pictures may be illusory. Distortion, especially in wide-angle pictures, bends straight lineaments on the ground into curves, which would therefore be missed and, worse still, bends curves into straight lines, which might be erroneously plotted as lineaments, as perhaps the line running northwest through area 55 in plate 19. Because of the poor ground resolution and limited ability of Tiros pictures to bring out grey tone differences, those lineaments which appear on only one frame may be due to a combination of photographic peculiarities with the tendency of the eye to link irregular blotches to form lines, e.g. the line which runs east-northeast across area 47 in plate 9.

In conclusion, Tiros pictures can be valuable for picking out lineaments in the circumstances mentioned, but more impressive results could be expected from pictures with a resolution about 3 to 10 times better, even at the expense of a corresponding reduction in the area covered per frame, especially if the pictures were vertical and lens distortion were less.

Surface Features Made Visible by Cloud Pattern

On the pictures studied there are many examples of ground features influencing cloud formation to such an extent that the ground feature is practically 'visible' in the cloud cover. Examples are quoted below. Because cloud-free sequences were selected for study, these situations may be typical only of periods of little cloud cover over land.

The west coast forms the most persistent cloud boundary. Because of the upwelling of cold ocean water along the coast, the sea is often covered by a layer of stratiform cloud though the land is clear, as in plates 1, 3, 5, 6, 7, 9, 19, 20. The edge of the cloud usually follows the coastline closely but locally deviates 10 mi. or so seawards or landwards. The significance of these small deviations is beyond the scope of this study, but may reveal local variations in direction of surface winds or inshore horizontal or vertical water movements.

Topography influences cloud formation, but southern Africa has few major isolated mountain ranges, so that examples of cloud areas following mountains are hard to find. The classic example of orographic cloud, the 'table cloth' on Table Mountain, is visible in plates 10 and 11 in the southwest of area 34 b. The cloud area in the northeast of plate 3 lies over the highest parts of the Angolan Plateau, and its northwestern edge roughly follows the Great Escarpment. In plates 14-16 the horseshoe of cloud around area 76 b follows the low ridges of the western Bankeveld.

Because of the great size and height of the African Plateau and the abruptness and continuity of its edge (the Great Escarpment), orographic cloud does not tend to form over the Plateau as a whole. Rather, it forms in the zone of ascent along the Great Escarpment, as perhaps along the Natal Drakensbergs in plate 14, or remains confined below the Escarpment. This may be the case in plates 13 and 17, but it is shown more clearly in IV-1347 T1 frame 24 (ref 17, p 94) for the Natal Drakensbergs, and in V-0201 T1 frame 17 and VI-0262 T2 frame 29 (neither of which is illustrated) where the rectilinear edges of the Rhodesian Plateau rise above a sea of cloud.

Surface roughness may influence cloud formation. This may be the reason that dense clouds cover the Knysna forests (area 35) in VIII-0247 T1 frame 4 (not illustrated), but are absent over adjacent non-forested areas of similar relief. The same effect has been noted over the forests of Les Landes in southwestern France in IV-1020 T2 (ref 17, pp 28 & 27).

Lakes, swamps, and large rivers often appear as cloud-free areas within a cumuliform cloud cover, because water remains cool compared with adjacent dry land during the day, and so inhibits convection. Good examples are the Kafue Flats (area 86) in plate 22, and the floodplains of the Cuando and Zambezi in IV-1177 T2 frame 7 (ref 17, p 92). This effect may indicate whether these areas are flooded or not. Poorer examples are the upper Zambezi (z) in plate 22, the R. Cubango (f) in plate 24, the R. Congo (not lettered) in the northwest of plate 18, the R. Lualaba (zz) in plate 33, and the lagoons and creeks behind the Moçambique coast in III-0158 T1 frame 9 (ref 17, p 95).

The grid-like pattern of lines visible in the clouds in the northeast corner of plate 4 is no doubt of similar origin. The line or lines running northwest-southeast must be the valley of the Cuito and/or tributaries of the Cubango. The southwest-northeast lines do not represent valleys of major rivers, but one of them lines up with the lineament across Ovamboland which can be seen in plate 2. It is suspected that the lines of the grid follow structural weaknesses, probably in the rocks beneath the surface cover of Kalahari Sands. The soft surface rocks might tend to subside slightly along these lines to form depressions occupied by small swamps or streams, which would appear as a cloudless line even if not followed by a through-going surface river. The surface relief responsible cannot be more than a few hundred feet. A similar effect has been noticed in the Amazon Basin (ref 17, p 129).

The combination of topography with the moderating effect of water on surface temperatures accounts for the frequent lack of cloud over Lakes Tanganyika and Nyasa, the Luangwa trough, and the Zambezi valley near L. Kariba, as shown in plates 22, 34, and 38, and in sequences III-0158 T1 and III-0173 T2 (ref 17, pp 91 & 95).

The local area of cumulus cloud over the Taokhe distributary (p) of the Okovango in plate 23 calls for an explanation in terms of local differences in the underlying surface. At that time, July 1962, the floods would be at their peak. The cool water would prevent convection over the swamps, while supplying water vapour to the air above them. If the wind was from the northeast, this moist air would be carried southwest and convected to form clouds over the first non-flooded area encountered. Confirmation is provided by the similar small patch of cloud southwest of the Shesheke Plain (area 65 b). The implication is that the Taokhe was not thoroughly flooded at the time. This effect could perhaps be useful in tracing flooding.

The clear area northwest of Lake Upemba (area 82) in plate 33 is unidentified, but it must be located approximately along the Lomami valley. The lack of cloud, and indeed of haze, which apparently is widespread over the southern part of this picture, suggests the area is a swamp, but none is mapped here. It may be a mapped area of grass steppe (ref 7), though exactly why this surface should discourage cloud formation is not obvious.

VARIATIONS IN APPEARANCE OF THE SURFACE OF SOUTHERN AFRICA

Lakes

Variations in lake level could be detected on Tiros pictures only where shores slope so gently that small changes in lake level produce large changes in the position of the water's edge. From what has been said about practical resolution, a movement of the edge, or a combined movement of opposite edges, of about 20 mi would be necessary. On steeply-sloping shores like those of L. Nyasa the horizontal movements of the water's edge do not approach this value, even when the water level changes through its long-period variation of 20 ft (ref 25, p 14).

In L. Rukwa (area 93) the movement of the water's edge may be as great as 40 mi., and there is a good prospect of tracing this change. The main difficulty is that the milky water is of almost the same tone as the surrounding dry portion of the lakebed, and it is not possible to be entirely certain where the edge of the water is in any of the four sequences showing the lake.

The filling of L. Kariba (area 67) over a period of three years involved a movement of the upper end of the lake progressively up the valley for more than 150 mi. One can tell from the size of the lake in July 1961, when the first usable pictures of the area were obtained, that most of the up-valley movement had already taken place. It is not possible to ascertain from the pictures whether there have been subsequent changes, without the use of grids. Future changes in the reservoir level should not be large enough to be noticeable in any case.

Swamps

There is no prospect of detecting changes in water level in perennially flooded swamps, such as the 'wrist' of the Okovango Swamp, the southern margin of the Chobe Swamp and Shesheke Plain, the Bangueulu Swamp, and the central part of the Kafue Flats. These areas will appear dark whatever the water level.

Prospects are better in swamps which are flooded only seasonally. In the Kafue Flats (area 86) the surrounding denser types of savanna provide a reference surface of fairly constant tone. When flooded, the Flats appear darker than their surroundings. When dry, they are indistinguishable or even slightly lighter than their surroundings. In the Chobe Swamp and Shesheke Plain (area 65) there is some indication that flooding produces both a detectable darkening in tone and an increase in extent. In Barotseland (area 63 a), in addition to changes in the intensity of the dark tone, there are changes in the shape of the dark area, which may be related to the flood stage. In all these areas the possibility should be investigated that the appearance of the area in outline, as a gap in the cloud cover, is an indication of flooding of a certain intensity.

In the Okovango Swamp (area 58) definite changes in appearance were not found, perhaps because the area would be more or less flooded during all the months when usable pictures were obtained. However, a means of deducing the flood stage may perhaps be provided by the Makwegana Spillway (x) which, at times of highest flood, carries the overflow from the Okovango Swamp to the Chobe Swamp. Visibility of the spillway was as follows:

Plate	Date	Angle of view	Visible
-	26 Jul 61	Wide	No
-	1 May 62	Medium	No
21	9 May 62	Wide	No
-	14 May 62	Wide	No
-	30 Jun 62	Wide	No
20, 23	6 Jul 62	Wide	Faintly
26	20 Sep 62	Medium	Yes - dark
24	22 Sep 62	Medium	Yes - dark

One explanation of the visibility only in the latter months is that the spillway was only flooded at that time. If this is true, then we can conclude that, when the spillway is visible, the floods at the upper end of the Okovango Swamp have reached a certain stage. Visibility of the Botletle (y), clearly visible only on plate 26, could have a similar significance for the lower end of the Swamp. However, it is quite likely that these channels are visible only in September sequences because these were the only good medium-angle pictures of the area, or because the surroundings were drier at that time.

Dry Lakes

The two major dry lakes, Makarikari (area 62) and Etosha Pan (area 8) are usually flooded during the wet season. All usable pictures of Makarikari were obtained during the dry season, and it appears equally light on all of them. The area is sufficiently large that even if only a fraction of it were flooded this would be detectable on a good Tiros picture.

Pictures of Etosha Pan are also mainly in the dry season, but there is one sequence in November and one in February. In the latter sequences, and in more than half those in the dry season, the centre and east of the pan are of medium tone, the remainder light. Though it is possible that the surface in the dark area may be damper than the remainder, it is not believed that it represents a continuous area of standing water because this would appear darker. Nor can the apparent variation represent real changes in the area because the darker areas are visible on 30 Apr, 9 May, and 12 May 1962, but not on 1 May and 13 May 1962; and are visible on 30 Jun and 6 Jul 1962, but not on 4 Jul and 5 Jul 1962. It is believed that the apparent variations are due to chance differences in the conditions of illumination, photography, or electronic or photographic processing, and not to a real difference in reflectivity. However, it has not been possible to prove that the variations are consistently related to sun direction or altitude, camera direction or nadir angle, or the angle of view of the camera used.

Savannas and Steppes

One would expect that the growth of grass in steppe areas after a rainstorm, or the gradual drying out of savannas during the dry season, would be accompanied by changes in reflectivity which would appear in Tiros pictures as changes in tone. An area of unchanged reflectivity is needed for comparison, and may be provided by bedrock areas which owe their reflectivity characteristics mainly to the rock, e.g. the Aha Hills (area 60).

These hills are faintly visible in six sequences in May and June (including plate 21), all wide-angle except one; they are visible in three wide-angle sequences in July (including plates 6, 20 and 23); and clearly visible in two medium-angle passes in September (including plates 24, 25). This may be a measure of the progressive drying of the area around the hills, or it may be because the September pictures are better.

Areas 49 and 25 provide a more convincing example. 49 is probably an area of steppe on Kalahari sand adjacent to 25, an area of dark basalt on the west, and to medium-dark bedrock areas (22) on north and east. These are the tones found during the dry season when, on eleven sequences in April, May, June, July and September (including plates 6, 23, 24, 25), the areas are separately distinguishable. However, in the wet season, area 49 is problematical in a sequence in November (VIII-4974 T1 - not illustrated), and in February (VII-3593 T2 - not illustrated) areas 49, 25 and 22 are a uniform medium-dark tone. This suggests that a thicker grass cover was present, which not only darkened area 49, but may have lightened area 25.

In Ovamboland (area 9) the bedrock areas to the west (areas 5 & 6) provide a standard for comparison on the dark side, while Etosha Pan (area 8) seems to maintain a reasonably constant tone on the light side, though whether this represents a constant reflectivity is not known. In sequences in the dry season (including plates 3, 5, 6, 19, 20) Ovamboland is intermediate in tone between Etosha Pan and the highlands, but in sequences in February and November (plates 2 and 4) Ovamboland, especially the west, is indistinguishable in tone from the highlands, suggesting the surface is moister, or the vegetation denser, or both.

Similar changes in vegetation may be responsible for the apparent fluctuations of the boundaries between areas 47, 50 a, 57 and 55, but it is difficult to separate these changes from chance photographic effects (see 'Estimation of Reflectivity'). An attempt was made to map these boundaries in the neighborhood of Okovango Swamps. On some sequences no boundary could be placed. On most, the apparent positions of tonal boundaries alternated from frame to frame, suggesting that the alternating direction of shutter movement, or regular rotation of the camera, may be responsible, but an average position could be mapped. When all boundaries which were obtained had been plotted, it appeared that two zones were preferred, and these were adopted for the northern and southern boundaries of area 57.

Relief Effects

If areas of large relief appear dark on Tiros pictures because of the combined effect of numerous shadows, then one might expect the apparent darkness of the area to vary with the direction and altitude of the sun and camera.

For example, one might expect that area 4, which is an escarpment facing west, would be most conspicuous when the sun was low in the sky to the east, and the camera was pointing vertically or towards the east. In fact, area 4 is distinguishable in all cloud-free pictures of the region, except those which were very oblique or subject to electronic faults, irrespective of the direction of sun and camera. Pictures showing the area were taken with the sun in various directions from northwest to northeast, and at various solar altitudes, with the camera pointing between west and south, at various nadir angles.

More support is perhaps given to the theory by area 41, with its huge escarpments facing southeast and northeast. This area is not visible in three wide-angle almost vertical sequences with the sun in the northeast (not illustrated), but it is visible in the southeast in a wide-angle almost vertical sequence with the sun in the northwest (plates 12, 13), and is perhaps visible in the northeast in a medium-angle picture pointing southeast with the sun in the northwest (plate 30).

CONCLUSIONS

'Tiros pictures' here means wide and medium-angle pictures received by tape mode from Tiros satellites before the end of 1964, and especially during 1962, 1963, and 1964.

The appearance of the surface of southern Africa in Tiros pictures is sufficiently constant to be generalised into a map showing the tone typically representing each area.

About a quarter of the areal features visible cannot be adequately explained by reference to standard sources i.e. they are not well known: some may not have been recognised previously.

Features visible tend to complement rather than duplicate those marked in general-purpose atlases.

It is usually impossible to determine uniquely the nature of an unknown ground feature from a Tiros picture. This is because of the small content of useful information per frame, the poor ground resolution, and the indefinite relationship between photo tone and surface reflectivity. If pictures at several seasons exist, the choice of possible explanations may be reduced.

Interpretation of pictures of other planets comparable to Tiros pictures must be of very low reliability, considering how uncertain is interpretation of Tiros pictures of the surface features of our own planet.

Areas of darker or lighter tone visible in Tiros pictures may be explained in the general case only by considering all the following factors: relief, plant cover and land-use, surface moisture and snow cover, soil-type, and rock-type, in addition to atmospheric and photographic conditions. Over a limited area, where the values of all other factors are constant, or where lower layers are entirely hidden, tone variations may correspond to variations in only one or two of these factors. In southern Africa snow cover and cultivated plants (other than forest plantations) are relatively unimportant factors.

Cloud patterns occasionally reveal surface features not visible in their absence, or provide evidence of the nature of the surface beneath.

Many structural lineaments are visible which are not mentioned in standard works, two of them quite definite and major features. Tiros pictures are able to reveal lineaments where a thin cover of superficial deposits hides older rocks, but in areas of uniform, dense vegetation they may fail to show lineaments which are evident even on general-purpose maps.

One can expect to see regularly on Tiros pictures ground surface features which contrast moderately with their backgrounds, only if they are over 20 mi. in largest dimension, and over 8-10 mi. in smallest dimension.

For the greatest accuracy in plotting the position of surface features, a graticule ('grid') is needed which is correct in position within 10-20 mi. at worst, and preferably several times better than this.

During 1962-64 the Tiros system produced an annual average of two sequences usable for ground studies over every part of the northeastern half of the sub-continent, and four per year in the southwestern half. Most sequences were in the dry season, and the frequency varied markedly from year to year. This frequency permits study of the permanent surface features, especially as they appear in the dry season, but it is generally inadequate for following changes in surface conditions in a given year, even for academic studies carried out retrospectively.

Deducing changes in an area of the ground surface from changes in the tone representing it on Tiros pictures is extremely unreliable because of the many factors other than surface reflectivity which affect tone.

Only in a few areas can one expect to detect changes in savanna or steppe vegetation without the ability to derive quantitative reflectivity values readily from the pictures.

There is no prospect of detecting variations in the level of permanent lakes and permanently flooded swamps, except in rare cases.

There is a better prospect of detecting the flooding of areas which are seasonally flooded during the local dry season, but the Tiros system of 1962-64 cannot do this reliably.

There is a good prospect of detecting flooding of dry lakes during seasons when they are not cloud-covered, though no such instances were found.

Changes in the Tiros system which would increase its potentiality for ground surface studies include greater useful information content per frame, better ground resolution, more frequent coverage, a simpler relationship between surface reflectivity and photo tone, and a convenient and accurate graticule. The order of priority of these varies according to the exact application, but a system which took only vertical pictures with medium-angle or somewhat narrower lenses, using an increased number of satellites, would lead to some improvement in all of them.

KEY TO TONE AREA NUMBERS

Unless stated otherwise, information for this section is derived from the standard sources listed in refs 1 to 15, maps of the various 1:1,000,000 series, and general-purpose atlases, gazetteers, encyclopedias, and from personal observation. The photographs in refs 26 and 27 were also found very valuable.

1 (white) Sandy areas of the northern Namib desert (plates 1, 2, 3, 5). The sandy surface accounts for the light tone, in the practically complete absence of rain, vegetation and organic soil.

2 (medium-light) Plateau slopes of southwest Angola (plates 1, 2, 3), below the Great Escarpment, ranging from sea level up to 4000 ft. in altitude. Rocks are mainly Basement granite-gneisses. Topography is irregular, with many remnants of the Plateau standing out, capped by Proterozoic quartzites and ironstones. Rainfall is between 10 and 30 in. in most parts, and vegetation drier types of savanna, but some areas of sub-desert steppe with lower rainfall are included along the southwest coast. These factors might be expected to combine to produce a medium-light tone.

3 (dark) Serra da Névé (plate 2), a mountain range 40 mi. long, 6 mi. wide, rising abruptly to about 5700 ft. from surroundings at about 3000 ft. It is an unusually large 'plateau remnant' of the type mentioned under area 2. Relief factors (see p 14) would be sufficient to account for the dark tone, but if the range is formed of dark rocks, as is likely, they would also contribute.

4 (dark) Great Escarpment behind Lobito Bay (plates 17, 18, 1), where it rises abruptly from near sea level to 4000-8000 ft. Within and on both sides of this long, narrow area the rock is Basement granite (ref 13), the rainfall 20-40 in., and the vegetation moister types of savanna, though ref 7 shows a few patches of moist forest here, which may lie along the Escarpment. Relief factors must be almost entirely responsible for the dark tone, though variation of the appearance of the area on the photos does not confirm this (see p 25).

5 (dark) Serra da Chela (plates 1, 2, 3), the high edge of the African Plateau immediately behind the Great Escarpment, at heights between 4000 and 7500 ft. It is underlain by Basement granite-gneisses, but these are capped in most places by darker Proterozoic sediments: quartzites and ironstones in the north; quartzites, sandstones, and conglomerates in the south (ref 1, pp 66, 67). In the south there are also basic intrusives (ref 13). The area corresponds closely to an area of rock and rock debris on the soil map (ref 10). Rainfall increases from 20 in. in the south to over 40 in. in the north, while vegetation changes from drier to moister types of savanna. There is a small area of montane evergreen forest on the highest part. The dark tone, compared with areas 2 and 9, is due to the widespread exposure of dark rocks. The lighter areas, which can be distinguished within area 5, must be areas of granite-gneiss, though they cannot be identified from the maps. In the northeast the tone boundary, which would no

doubt otherwise follow the geological boundary, is obscured by the denser savanna vegetation, and its location is indefinite.

6 (medium-dark) Ovashimba Highlands (plates 2-6) are similar to area 5, but have a lower rainfall (10-20 in.), some areas of sub-desert steppe, and perhaps a higher proportion of granite-gneiss outcrops, all of which would tend to produce a lighter tone than in area 5.

7 (dark) Otavi Highlands (plates 6, 3). Here rainfall increases again to 20-30 in., and vegetation is drier types of savanna, or wooded steppe, so that the tone is again as dark as in area 5. Rocks are mainly Proterozoic dolomites in east-trending folds. There are brown arid and semi-arid soils as well as lithosols.

8 (light) Etosha Pan (plates 2-6, 19, 20). According to Wellington (ref 1, pp 61-62, 297), this is a lake bed, dry in winter (May - September), but filled in summer (November - March) by flood waters from a network of channels to the northwest. The pan itself is free of vegetation, but there is pure grassland, as opposed to savanna, in adjacent swampy areas. The pan is floored with "sandy clay, grey-green and slightly salt in most parts, but very saline near the southern margin". According to ref 10, the pan itself is surfaced with juvenile soils on recent lacustrine alluvium, but a narrow marginal area of uniform width includes also halomorphic soils. On most Tiros pictures the central and east-central areas of the Pan are of medium tone while the edges and western part are white. If the white areas are the very saline parts, then their distribution must be a little different from those given by refs 1 and 10. The tone contrast could be produced in a number of other ways (ref 28), but the central area is unlikely to be water brought by surface floods, as it does not show a consistent seasonal variation (see p 23), and is only of medium tone. Vowinckel states (personal communication) that there are scattered 'islands' of vegetation within the pan which, with areas of damper surface and occasional pools of water, may cause the dark area.

9 (medium-light) Ovamboland (plates 2-6, 19, 20) is a featureless plain. Its light tone compared with areas 5, 6 and 7 to the west can be attributed to the smooth surface and light-toned soils derived from the sandy rocks of the Tertiary and Quaternary Kalahari System. The lighter rainfall (20-30 in.), the drier types of savanna vegetation, and the brown semi-arid soils distinguish this area from darker areas to the north. Maps provide no adequate explanation of the boundary in the east, but see area 11. As might be expected, on sequences taken in the wet season (plates 2 and 4) area 9 is darker than in the dry season, if we assume areas 5 and 8 are unchanged in tone. The north-central part of the area is seamed by innumerable channels which carry flood waters to Etosha Pan in summer, but are practically dry in the winter, when they have a surface of mud or grasses (ref 1, p 62). If maps are correct, the channelled area is not distinguishable on the Tiros pictures. It makes up only a part of tone area 9, but is more extensive than tone area 10. The area is crossed by the political boundary between Angola and South West Africa, and Wellington (ref 1, p 63) states that the relationship between the flood channels in Angola and those in South West Africa is consequently not exactly known. However, Tiros pictures cannot solve this problem because individual channels are not

resolved. On several frames (notably plate 2) a line is visible crossing area 9 in roughly the position of the political boundary. This may be the surface expression of a geological weakness, but if movement across the frontier is strictly controlled, then differences in grazing or burning practices could make the boundary visible.

10 (light) Unidentified area north of Etosha Pan (plates 2-6, 19, 20). This area is located within Ovamboland, and is shaped like a tadpole with a rounded head in the southeast tapering through a sinuous tail to a point in the northwest. It always appears light, but varies in distinctness according to the tone of Ovamboland which surrounds it. It is visible on all passes which show the area, which were mainly between April and September 1962, the dry season, but also include sequences in February (plate 2) and November 1964 (plate 4), which normally would be the wet season. In the latter sequence it is more extensive, almost reaches Etosha Pan, and could be equated with the area of flood channels, though one would expect these to be darker, not lighter, in the wet season. On all other sequences it extends east of the area mapped as occupied by flood channels. The winding shape suggests a broad valley. It may be what Wellington refers to as "an extensive area of pure grassland occupying what appears to be a formerly flooded depression bordering Etosha Pan" (ref 1, p 297). It could also be a series of tribal areas, which appear lighter because of more frequent burning or more intensive grazing. (See ref 1, p 63.)

11 (medium-dark) Unidentified area east of Etosha Pan (plates 3, 6, 19). On about half of the sequences which cover it, area 11 appears darker than Ovamboland to the west, though lighter than the highlands to the south. In most respects the area is entirely similar to the adjacent areas to west and east - a plain underlain by Kalahari Sands, covered by drier types of savanna, with a rainfall of 20-30 in. Ref 10 shows area 11 as having ferruginuous tropical soils, which might be slightly darker than the brown semi-arid soils of area 9. Area 11 is probably the swelling in the sandveld 600 ft. above the Pan, which bounds the Etosha basin in the east (ref 1, p 61). Vowinckel suggests (personal communication) that this area and area 12, as watersheds, may have an appreciably smaller proportion occupied by pans (dry lakes), and may therefore appear darker. In one sequence (plate 3) area 11 appears to be darker at the edges than in the centre. This could be explained if the area was underlain by the centre of a syncline of solid sediments, i.e. if the centre of the Etosha structural basin (ref 1, p 297) lay east of the Etosha Pan.

12 (medium-dark) Unidentified area east of Ovamboland (plates 19, 3). On many sequences this area is not distinguishable from area 9 nor from area 55, but on some the north of area 12 appears darker than the adjacent parts of area 55. This could be accounted for by the outcrop of several different types of rock, all of them darker than the Basement granite-gneiss of area 55, as shown by geological maps. The southern part of the boundary of area 12 has been inserted as it appears on sequence VI-0090 T2 frame 16 (similar to plate 3), where it has an irregular but abrupt boundary. The abrupt outline suggests that it is the edge of an area of dark rock or of forest vegetation, but there is no evidence for either on maps.

13 a & b (dark) Lavas of the Kaokoveld (plates 2, 3, 5, 6). The dark tone is that of the Mesozoic Karroo lavas. There is almost no rain, and most of the surface is bare rock, though there are a few scattered patches of desert soil with desert plants.

14 (medium-light with dark lines) Plateau slopes west of Damaraland (plates 5, 6). According to ref 1, map I, this area is underlain mainly by metasediments of the Primitive systems, but according to ref 13, about half of these are granitised, and this would account for the generally light tone. On the coastal plain bare rock is exposed. The Great Escarpment is absent, and the plateau slopes are much dissected by river valleys. The interfluves are grass-covered but the valleys are bush-filled. The darkening towards the east is accounted for by higher rainfall, more vegetation, a higher proportion of dark rocks, and better-developed soils of brown arid and semi-arid type.

The dark lines crossing the area represent the valleys, and also probably, in some cases, strips of the darker non-granitised rocks. From north to south one can distinguish on plate 6 the valleys of the Omaruru (a) just to the north of the Erongo Mountains (area 15), the Khan (b), and the Swakop (c). The largest river of the area, the Ugab, is not clearly visible because of a background of dark rocks, but roughly forms the northern boundary of the area. The Kuiseb valley (d) is just visible beyond the southern boundary of the area on plate 7.

15 (dark) Erongo Mountains (plates 5, 6, 2), a circular mass about 20 mi. in diameter, which rises 2000 ft. above the Damaraland Plateau. The west slope forms part of the Great Escarpment. They are composed of Karroo lavas and post-Karroo granite. Most likely, the exposed dark rock and relief effects account for the dark tone. The Brandberg, an even higher though similar mountain mass a little farther northwest, is not distinguishable on Tiros pictures, no doubt because of its smaller diameter (12 mi.) and because it is closer to other areas of dark rock.

16 (medium) Eastern Damaraland plain (plates 6, 2) is underlain by medium to dark rocks, including metasediments of the Primitive systems, and Karroo sediments. The medium tone is produced by the combination of these rocks with a rainfall of 12-20 in. and a vegetation of wooded steppe, both of which would otherwise tend to a lighter-than-average tone. Soils are lithosols or brown semi-arid soils.

17 (light) The middle Namib desert (plates 6, 7) is practically devoid of rain, soil and vegetation. Wellington (ref 1, p 121) states that it is almost entirely dune sand. One would expect dune sand to appear even lighter than this, more like area 18, but perhaps the relief of the dunes darkens the tone. Otherwise one would have to suggest that there are numerous scattered rock outcrops, or other unconfirmed explanations.

18 (white) Namib desert near Aus (plates 7, 8, 9). No satisfactory explanation has been found of why this area should be lighter than area 17. It differs from area 17 in having a predominance of Basement granite outcrops, and some weakly developed sub-desert soils,

rather than pure sand, but this should make it appear darker, not lighter.

19 (medium-dark) Unidentified areas within middle Namib (plate 7), comprising two or three separate dark spots within the middle Namib, close to the edge of area 20. No mapped distribution has been found which closely corresponds to them, but some outcrops of solid rock are marked in this general area, and the most likely explanation seems to be that they are detached areas of the Plateau (area 20) left behind by recession of the Great Escarpment, and appearing dark because of relief factors and/or darker rock. There are also within this area two oases, the Sossus Vlei and the Tsondab Vlei, which would appear dark when flooded by the periodic floods from the interior, but the dark spots appear to be too large and in the wrong places to represent these oases.

20 (dark) Namaqualand Highlands (plates 6-9) ranging in altitude from 3000 to 6000 ft. The tonal boundaries in the east and north are sharply defined, and closely follow the Fish River. The dark tone is due to the dark rocks of the Nama System, probably of Cambrian age (ref 1, p 21). These dip gently eastwards forming two main cuestas and dip slopes. The western cuesta, which is part of the Great Escarpment, is formed by the Schwartzkalk Series, composed of dark limestones and green shales, with reddish sandstones and shales at the base. The eastern cuesta is the Schwartzrand, composed of greenish-grey quartzite. Rainfall is less than 10 in. Vegetation is a sub-desert steppe of Karroo shrub and grass. Soils are lithosols or weakly developed sub-desert soils. In short, the tones seen are those of the dark rock.

21 (medium-light) Basin east of Zarisberg (plates 6, 7). This area, within the otherwise dark area 20, appears to correspond to a basin, occupied by grass-covered sand dunes according to the World Aeronautical Chart. These might account for the light tone. The area lies at the western foot of the Schwartzrand, just southwest of Maltahöhe. The dark band west of this area is the Zarisberg.

22 (medium-dark) Northern Namaqualand Highlands (plates 6, 23, 24) are a rugged area above 4000 ft. in height, rising in the northwest to the exceptionally rugged Khomas Highland which exceeds 8000 ft. The rainfall of about 12 in. is slightly higher than in area 20, and produces a somewhat denser vegetation of wooded steppe, and a better-developed brown semi-arid type of soil where the surface is not bare rock. But since the rainfall, vegetation and zonal soil are essentially similar to those in lighter-toned areas to the east and north, rock and relief must account for the dark tone. Rocks range from very dark Karroo lavas, Nama beds, and diabase dykes; through medium or dark Karroo sandstones and shales, and Primitive metasediments; to light-toned Basement granite and Kalahari sands. The mixture of these light and dark rocks would account for a medium tone, while the general ruggedness would darken the tone. Tone variations are often distinguishable within the area, and represent areas of darker or lighter rock, some of which can be identified from maps, but the variations are not sufficiently persistent to justify subdivision of the

tone area. On some pictures the area seems to extend much further east and northeast than on others. This can be accounted for by the very gradual increase in completeness of cover by Kalahari sands (ref 1, p 72).

23 (light) Weissrand (plates 9, 23). This area lies just east of the Fish River, south of Mariental. The rainfall and vegetation do not differ sharply from those in adjacent areas 20 and 47 so that the light tone, which is lighter than in areas either to east or west, must be accounted for by a light-toned rock or the soil derived from it. According to geological maps (Wellington, ref 1 - Map 1; and ref 13) this is an area of Karroo rocks, which are usually dark or medium-toned, but according to Wellington's text (p 72) and section (p 41), the surface is formed of Kalahari conglomerates and sand, dipping eastward. Their abrupt western edge is the Weissrand. On many frames (plates 7, 8, 9) this area is not distinguishable from area 47.

24 (light) Unidentified (plates 23, 24, 6, 7). This area lies along the Fish River valley northwest of Mariental. It is indistinguishable in tone from area 23, but has been separated because it does not necessarily owe its light tone to the same cause. It is a broad, flat-floored valley, so that lack of relief may be the main cause of light tone (Vowinckel, personal communication). Otherwise, the causes must be geological. Geological maps (ref 1, Map I; and ref 13) show the area as on the boundaries of the Nama System, the Karroo sediments and the Karroo lavas, all of which usually appear dark or medium in tone. One can only speculate as to which particular light rocks are in fact present - the rocks of area 23, a local deposit of sandy alluvium, or a calcareous crust, which ref 10 shows is present only a short distance to the east.

25 (dark) Karroo lavas of northern Namaqualand (plates 6, 7, 23, 24, 25). This area, lying just to the northeast of Mariental, owes its dark tone to the outcrop of Karroo lavas. In other respects it is similar to area 22.

26 a & b (medium-dark) Nama outcrops of eastern Namaqualand, etc. (plates 7, 8, 9). These areas resemble area 20 in their scanty rainfall and vegetation, and weakly-developed soils. They are largely underlain by the same dark Nama System sandstones but include also areas of Karroo sediments, and Metasediments of the Primitive systems. The less-dark tone may be due to a partial cover of calcareous crust and Kalahari sands (ref 10), and to outcrops of Basement granite in the extreme southeast, south of the Orange River, all of [illegible] which would be light-toned. Included within these areas are the Great and Little Karas Mountains which rise several thousand feet above the surrounding plain and are respectively 40 by 10 mi. and 15 by 5 mi. in size. They are not apparent on the photographs despite their large size, probably because the background rocks are so dark that the relief of the mountains cannot produce any further darkening.

27 a, b, c, d (light) Granite areas of Bushmanland (plates 7-10). These areas have a rainfall of about 5 in. and are either desert or occupied by sub-desert steppe consisting of a desert shrub with a higher

proportion of grass than usual (ref 1, p 284). The light tone is due to the underlying Basement granite which weathers to provide abundant sand. Where the soil is not simply aeolian sand, it is a brilliant white pavement of quartz pebbles and gravel (ref 1, p 323). The light area does not include the eastern extremity of the granite outcrop northeast of Marydale, nor the western part, which have been included in areas 26 and 32 respectively. On the pictures area 27 d extends much further northeast than granite areas shown on maps, and almost separates area 26a from 26b. Vowinckel states (personal communication) that the grass cover in this area appears exceptionally white, which may be the explanation.

28 a & b (medium-dark) and 28 c (medium) Dwyka areas of Bushmanland and eastern Namaqualand (plates 7-10). These areas are similar to areas 27 except in their underlying rock. This is the Dwyka tillite which is blue-green and weathers to a clay, with little sand accumulation. Often the soil has a surface of black desert-varnished pebbles, which would account for the dark tone. There are also numerous dry lakes which, when not flooded, are covered with drab silty clay (ref 1, p 323). A light area, just distinguishable within area 28 a on plate 10, probably represents the two largest of these, the Groot Vloer and Verneuk Pan. Area 28 c does not appear so dark as the other areas, probably because it includes some scattered areas of Kalahari sand or limestone. Area 28 comprises only about one third of the area of the Dwyka outcrop within the Republic of South Africa. It is not clear why the remainder of the outcrop does not also appear darker than the adjacent higher formations of the Karroo System. However, it does seem from the pictures that the darkest areas of Dwyka outcrop are also the driest. Probably it is only in the driest areas that weathering produces the dark desert varnish. Possibly also in more humid areas the plant cover may be lighter in tone than the soil it hides. Moreover, ref 10 shows the eastern part of the Dwyka outcrop as covered by Kalahari sand or limestone crust, which would lighten the tone.

29 a & b (medium-dark) Valley of the lower Orange River (plates 7-10). This area is true desert devoid of vegetation except for a narrow line of bush along the river banks. The river flows in a gorge several hundred feet deep. The fairly dark tone is due mainly to the densely dissected relief of the main and tributary valleys, and partly to the fairly dark tone of the Primitive metasediments exposed by the downcutting of the river (ref 1, p 74). At the extreme eastern end of the area there is some irrigated land on both banks of the river, which could also produce darker tones.

30 (dark) Asbestos Mountains, Kaap Plateau, etc. (plates 9, 10, 13). In this area the rainfall is 10-15 in., and vegetation is Karroo shrub, but there are no sharp changes in moisture or vegetation compared with adjacent areas which could account for the tone differences observed, so these must be due to differences of relief or rock type. The eastern part of the area is the Kaap Plateau, formed of Proterozoic dolomitic limestone, its surface exceeding 4000 ft. in altitude, bounded on the east by an abrupt escarpment. In the centre

are the Asbestos Mountains and Kuruman Hills, formed of Proterozoic ironstones, slates, phyllites and lavas trending roughly north-south. In the west the Langeberg and Korannaberg ranges are formed of Proterozoic quartzites. The mountain surfaces are rock-strewn. Elsewhere there are brown semi-arid soils developed on a surface deposit of Kalahari sand, and calcareous crusts (ref 10) but, judging from the photos, these are not sufficiently extensive to lighten the average tone.

31 (black) Doornberge (plates 9, 10, 13), an anticlinal range of resistant Proterozoic ironstones and slates, which trends northwest and parallels the course of the middle Orange River. It is similar to the ranges within area 30. Maps show that it is bounded on the southwest by a major fault trending northwest.

32 (medium-light) Southern Namib and part of Little Namaqualand (plates 7-10). This area is somewhat darker than both the middle Namib further north (area 17) and the granite areas of Bushmanland inland (area 27). It includes the sandy coastal strip about 15-20 mi. wide, which is similar to area 17, but it is distinguishable on only one frame (V-0245 T1 frame 9 - not illustrated). Inland, area 32 includes the fringe of the Plateau, at a height of over 4000 ft., where the rainfall may exceed 10 in. and the succulent shrubs may be up to 12 ft. high, but soils are absent or skeletal (ref 10). The rock here is the same Basement granite found in area 27 a to the east. The dark tone compared with area 27 a must be due to relief factors, the greater rainfall, and denser vegetation. Another relevant point may be that in this area the rainfall maximum is in winter (March - September) -- the first area met where this is so. Therefore, in pictures taken towards the end of this period, area 32 might be expected to have received more rainfall than areas further inland which have rainfall at a different season, and therefore to appear darker.

33 (medium-dark) Great Escarpment in northwestern Cape Province. On a few sequences (e.g. plates 8, 9) a dark strip can be distinguished within area 32, corresponding in position to the Great Escarpment. The northern part of this area corresponds to a local outlier of dark Nama rocks (ref 14). The dark tone must be due to the various relief factors and the dark rock, in the absence of abrupt changes in any other factors.

34 a & b (medium) Lowlands of south and southwest Cape Province (plates 10-12). Considered together, areas 34, 35, and 36 are composed of anticlinal mountain ranges, intervening lowlands, and coastal plains, trending east-west in area 34a and north-south in 34b. Rocks are Paleozoic sediments of the Cape System. Sandstones and whiteish quartzites outcrop in the mountains, and shales in the valleys. In this area, rainfall is sufficiently high for factors other than rocks and relief to be considered as causes of well-defined tone-variations. A rainfall of 25 in. is typical, but it may be over 60 in. in the mountains, or under 10 in. in rain shadows. Unlike most parts of southern Africa, the west of this area experiences a winter rainfall (April - October), while the

eastern part has rain at all seasons. Zonal soils include ferruginous tropical as well as brown mediterranean soils (ref 10). Vegetation is Mediterranean sclerophyllous bush, consisting mainly of evergreen shrubs with leathery leaves, with fewer trees than is usual in Mediterranean areas, and very little grass. However, the natural vegetation has been partly replaced by grain fields, orchards, or vineyards, with more or less irrigation, in the valleys, or by forest plantations on the lower mountain slopes. Some regions within area 34 appear darker, and are described separately as areas 35 and 36 a - f. The remainder consists of lowlands and minor hill ranges below the resolution of Tiros pictures. In these areas the medium tone results from the juxtaposition of dark patches, for example forest plantations or irrigated farms, and light patches, such as dry soil visible between the shrubs.

The sand dunes along the shore of Algoa Bay form a prominent light zone in the east of the region.

35 (dark) Knysna forests (plates 10-12). This is the largest area of true forest in the Republic of South Africa, and the largest covered by this report apart from the tropical moist forests. The dark tone is due almost entirely to the fairly complete cover of temperate evergreen forest, which masks whatever effects the rocks or soils might otherwise have on the appearance. The area extends from the coast up the slopes of the Langebergen (area 36 b), so that relief effects may also contribute slightly to the dark tone. Rocks include red granite and Primitive metasediments which are not found in adjacent areas (ref 14), but their limit does not correspond to the limit of the area, which includes also areas of the widespread Table Mountain sandstone, so they cannot be directly responsible for the dark tone. On ref 10, area 35 corresponds closely to a soil association of lithosols, ferruginous tropical soils, and highveld pseudopodsolic soils, of which the latter does not occur in adjacent areas. The rainfall of 30-40 in. comes at all seasons. Consequently, the area is usually cloud-covered on Tiros pictures.

36 a - f (medium-dark) Cape Ranges (plates 10-12). These are narrow, rugged mountain ranges rising from lowlands below 2000 ft. to heights which may be as great as 6000 or 7000 ft. in some cases. The direct and indirect effects of relief account for the dark tone. There are large areas of bare rock, either Table Mountain sandstone or Witteberg quartzite, both rather light in tone. Where soil is present, it is a dark brown sand. Rainfall is much higher on the ranges than between them. Probably 30-40 in. is common. The plant cover is grass and low sclerophyllous bush, with patches of forest in ravines. Forests of pine have often been planted on the lower slopes, which would tend to accentuate the tonal contrast with the adjacent lowlands.

36 a (plate 10) includes most of the ranges which lie between the Swartland (in area 34 b) and the western Karroo (37 b), for example the Sederberge and Swartruggens.

36 b is the Langeberge (plate 11).

36 c (plates 10, 11) probably includes the Groot Winterhoekberge, the Baviaanskloofberge, and the Elandsberge.

36 d is the Swartberge (plates 11, 12).

36 e (plates 11, 12) probably includes the Klein Winterberge, Suurberge, and Swartwaterberge.

36 f (plates 11, 12) corresponds in position to the Fish River Rand (ref 14), a low escarpment which rises immediately north of the Fish River. This is a smaller feature than several of the Cape Ranges which are not visible, so that relief alone cannot explain its visibility.

37 a & b (medium-light) Great Karroo (plates 10-12). This is an elongated basin lying between the Cape Ranges to the south and the Great Escarpment to the north. The light tone is due to dryness and the lack of a continuous vegetation cover. Rainfall is under 10 in. or, in area 37 b, under 5 in. Vegetation is the variety of sub-desert steppe known as Karroo shrub, which consists of woody and succulent shrubs spaced several feet apart. Annuals including grasses spring up after rain. The typical soil consists of the slightly decomposed shales and sandstones of the Lower Mesozoic Beaufort Series.

37 b (plate 10) is the detached western part of the Great Karroo, the driest part of all. Here wind-blown sand occurs in places.

38 (medium-dark) Mountain ranges north of Great Karroo (plates 8-13). These include the Roggeveldberge, the Nieuwveldberge and the Sneeuwberge, which form part of the Great Escarpment, and the Bankberg and Winterberge, which continue the line to the east. They rise abruptly 2000 ft. or more above the Great Karroo. The dark tone must be due directly or indirectly to the relief since no other factor varies sufficiently to account for the difference. Heavy forests are found only on the south slopes of the Winterberge. Elsewhere the vegetation is merely a taller variety of Karroo shrubs. Rainfall is a little heavier than in surrounding areas. The physical prominence of these ranges is due to resistant dolerite sills. Near these outcrops the slopes are strewn with rock fragments. Elsewhere the soils are lithosols. In the west, the northern limit of the tone area is not often distinguishable, because of the lack of a sharp relief boundary.

39 (medium-dark) Stormberg, etc. (plates 11, 12). This is that part of the Great Escarpment which extends from west of Middelburg in the west to Basutoland in the east. It rises abruptly from about 4000 ft. to 6000 or even 8000 ft. The Escarpment is not well marked in the west, nor is the tone area distinct there. The area is similar in most respects to the western part of area 38, except that in area 39 the vegetation is scrubby grassland, which might be a little denser and darker than the Karroo shrub of area 38, and the rock is in part Stormberg sandstone, which would be lighter.

40 (dark) Basuto Highlands (plates 12, 13). This is a maturely dissected plateau between 5000 and 10,000 ft. in altitude, composed of Mesozoic Stormberg basalts, exceeding 4500 ft. in thickness, the highest

member of the Karroo System. The dark tone is due mainly to the clay soil derived from the basalt, which is black on the moister south-facing slopes, brownish-black on the drier north-facing slopes. The soil is extensively exposed in arable fields in the lower areas, and elsewhere is covered only in short grass. The dark tone must also be partly due to relief, and to the moist surface produced by the fairly heavy rainfall of 25 to over 60 in., which is sufficient to produce bogs in the highest areas.

41 (black) Natal Drakensberg (plates 12, 13). This is that part of the Great Escarpment which forms the edge of the Basuto Highlands (area 40). It is often precipitous, between 2500 and 7000 ft. high, with a top between 8000 and 11,500 ft. in elevation. The darker tone of this marginal strip is due to relief factors and it is even possible that it may be simply the shadow cast by the huge precipice (see p 25). The width of the strip is exaggerated on figure 8.

42 (medium) Eastern plateau slopes of Natal and Cape Province (plates 10-14). This extensive area includes quite diverse landscapes but nevertheless it has not been possible to distinguish any persistent sub-divisions, apart from the two small areas marked 43. Moreover, it is not separated from areas 37 and 34 to the southwest and area 92 to the northeast by any sharp physical changes, so these boundaries are also ill-defined. It consists of the country below the Great Escarpment, descending from about 6000 ft. to sea level. The degree of dissection and local relief vary widely. The underlying rocks are mainly Karroo System with numerous dolerite sills and dykes but there are also inliers of Basement granite and Cape System sediments. Soils at high levels are high veld pseudo-podsolic soils with a brownish grey friable sandy loam surface. At medium elevations they are humic ferrallitic soils with dark brown clay surface. At low levels they are ferruginous tropical soils with grey sandy loam surface. Plant cover is grassland at higher, savanna at lower elevations. This is a densely populated area, and either European or native agriculture is scattered throughout. Probably agricultural patterns confuse whatever natural tone boundaries might otherwise be present, but do not form sufficiently large blocks to create tone areas of their own. Rainfall is about 30-40 in. The medium tone must be the result of the moderate values of all the variables of the physical environment, and of the averaging of many small dark and light areas too small to be individually resolved.

43 a & b (dark) Forests at medium elevations on the Eastern plateau slopes (plates 12, 13), including both natural and planted forests. On the hills and spurs rising slightly above their surroundings in the belt at about 4000 ft. elevation, scattered remnants of a formerly more extensive cover of temperate evergreen forest remain. Plantations of pine and wattle have also been made in this belt, especially within a few miles of railways. There are frequent mists and a rainfall of 30-40 in. Soils are humic ferrallitic. Area 43 a corresponds to a local rainfall maximum of over 40 in., and to an area of natural forest shown by Acocks (ref 9, map 2). Area 43 b corresponds less closely to the areas shown by Acocks, and may possibly be planted, as it seems to follow the railway north of Kokstad, and is near the main wattle area as shown by Cole (ref 3, p 260).

44 (medium) The Highveld (plates 9-14, 30) is a plateau of generally low relief from which rise isolated flat-topped hills. Altitudes range from 3000 to 6000 ft. The area is everywhere underlain by the Stormberg, Beaufort, Ecca and Dwyka sediments of the Karroo System. The first of these has been separated as area 45. The Beaufort Series includes sandstones, shales, mudstones, and some limestones; grits, sandstones, carbonaceous shales and coals form the Ecca Series; and tillite and shale occur in the Dwyka. There are also frequent dolerite dykes and sills. Rainfall varies from 5 in. in the west to 30 in. in the east. There is a corresponding transition from Karroo shrub with practically no agriculture in the southwest, to temperate grassland in the northeast, where there is considerable mixed farming with about one third of the farmed land cultivated. From west to east sub-desert soils with a light brown sandy loam surface give place to highveld pseudo-podsolic soils with a brownish-grey sandy loam surface. Black clay soils form on dolerite outcrops. In the east the moderate tones are what one would expect in an area of low but continuous plant cover, medium-toned soil, and moderate rainfall. In the west one would expect tones to be lighter owing to sparser vegetation and low rainfall, but in general they are the same. Vowinckel states (personal communication) that from the ground the Karroo shrub appears darker than the grassland because of the greater height of the plants. This effect might be reduced in the vertical view, but might be enough to maintain the same tone. On some sequences one can distinguish differences in tone within area 44, some of which seem to be related to permanent differences in the surfaces, though they do not appear consistently enough to justify their separation as tone areas. Dark areas may be the solonetz or black alkali soils which occur within the outcrop of the Beaufort Series, or areas of dark clay developed from dolerite intrusions or from Dwyka tillite. Light areas may be dry lake beds surfaced with drab silty clay, which are common on the Dwyka and Ecca outcrops, or the Orange Free State sandveld, an area of aeolean sandy soil with numerous dry lakes, overlying the Ecca shales.

Line e (plate 12) resembles the valley of a river draining northwest from the Basuto Highlands (area 40), but in fact it cannot be because it crosses the Caledon River (in area 45) at right angles. It could be a line of alluvium rich in dark minerals deposited by a former river, or a series of dolerite dykes.

On a few sequences, e.g. IV-0580 D*1 (not illustrated), fragments of what is believed to be the Orange River are visible.

45 (medium-light) Caledon River lands (plates 12, 13), the part of the Highveld (area 44) which is underlain by the Stormberg Series, lie at the foot of the Basuto Highlands at an altitude of 5000-6000 ft. The highveld pseudo-podsolic soils are here modified by sand weathered from the almost white Cave Sandstone, to produce a soil surface which is light brownish grey loamy sand. Rainfall is 25-30 in. The natural vegetation is temperate grassland, but this is the most populated part of Basutoland, and most of the land is in mixed farms in which much of the land is cultivated, with wheat and maize the main crops. The light tone is explained by the light soil, especially as it is exposed to view by cultivation over an appreciable part of the area.

46 (medium) Lichtenburg and Ventersdorp Plains. Like the adjacent parts of area 44 this area owes its medium tone to a continuous but not dense plant cover (grassland and pasture, with some cultivation), medium-toned soils, and a moderate rainfall (20-25 in.). On some sequences (e.g. plates 13, 14) the area appears darker than area 44. This must be due to the different rock type, which is here a dolomite of the Transvaal System in the north and Ventersdorp lava in the south (both Proterozoic), and to the different soils derived from them (brown or reddish brown ferruginous tropical soils, and lithosols). Usually lava areas appear very dark, but in this case the lava is partly obscured by wind-blown Kalahari sand, water-borne gravel, and frequent dry lakes. Moreover, the lava is andesitic, that is it contains fewer dark minerals than the basaltic lavas which are usual in southern Africa.

47 (light) Southern Kalahari (plates 7-10, 15, 16, 23-25) is a featureless plain. In the southwest, fixed dune ridges trend north or northwest. Often there are dry lakes between the dunes. Rocks are of the Kalahari System, mainly sands, sandstones and calcareous sandstones. The southwestern part is capped by a sheet of calcareous sandstones and grits. Rainfall is from 8-12 in., but does not remain long to moisten the surface, as it is either quickly evaporated or sinks into the sands. The plant cover is a form of wooded steppe, but trees are few, and grass is plentiful only in the rainy season, so it consists mainly of sparse shrubs. There are brown soils of semi-arid tropical type. The generally light tone is due to the dry, sandy surface, exposed by the thin soil and vegetation cover. The area never appears uniformly light. Areas which consistently appear lighter have been numbered separately as 23, 48 and 49. In the northeast this area interdigitates with the somewhat darker tones of area 50 a. The tonal boundary is visible on most pictures of the area, but appears to fluctuate from one to the other over a distance of a hundred miles or so. It is possible that this is due to changes in the surface moisture or the grass cover in the area.

48 (light) Unidentified area in southwest Kalahari (plates 7-9, 15, 16, 23, 25). This is an elongated area trending north-northwest. In location it corresponds roughly to the Nossob and/or Auob river valleys. One would not expect the rivers themselves to be visible on the photos, as they are usually dry, though ground water is plentiful beneath their beds. No doubt the light area represents the outcrop of a light-toned rock, either consolidated or unconsolidated, but exactly what rock is unknown. Van der Merwe (ref 11, p 59) states that limestone is exposed in the bed and on either side of these fossilised rivers, varying in width from 500 yards to more than a mile, but the visible strip is much wider than this.

49 (light) Unidentified area in northeast Namaqualand (plates 6, 23-25). On geological maps this area appears as Karroo sediments or older rocks which are usually medium or dark in tone, but the soil map (ref 10) suggests that the light tone must be due to a cover of Kalahari sands and calcareous crusts. The World Aeronautical Chart shows dunes in this location. This area is not visible in pictures (not illustrated) taken in February and November 1964, during the rainy season, but is visible in all other pictures, which were taken between April and September.

50 a & b (medium-light) The south-central Kalahari (plates 23-26, 15, 16) is generally similar to the southern Kalahari (area 47). The light tone compared with surrounding areas which are similar in other respects is again due to the dry, sandy surface. The darkness of the tone, compared with the southern Kalahari, is due in part to higher rainfall, which is here 15-20 in., and is probably visible mainly through its effect on vegetation, in that the thorn trees are here more closely spaced. However, there is considerable variation in the rock type within the Kalahari System, and in the way the sand has weathered (ref 1, p 29), and either of these could produce the same effect.

50 b (plates 6, 24) is lighter than the areas to the east and west, presumably because of the lack of any hard rock outcrops.

51 (dark) Mabele-a-Pudi and other hills (plates 23-25, 16). This area is a line of low hills known by a variety of names in different places but all developed on the outcrops of the dark sandstones of the late Proterozoic or early Paleozoic Waterberg and Dominion Reef Systems. These outcrop on either side of a major fault, which may be a continuation of those which form the Luangwa trough and Kariba gorge further to the northeast (ref 1, pp 52, 20, 13). In some cases the outcrops do not form hills. The hills may cause some difference in the thorn savanna vegetation (ref 1, facing p 48), and may cause shadowing, but the dark tone is due mainly to the darkness of the rock compared with the surrounding sands. It is possible that part of the dark tone of area 51 (e.g. on plate 16) represents the Ngami depression, if it happened to contain appreciable moisture at the time of the pictures, but this is unlikely because since 1925 only the extreme northeast end has been flooded each year, the floor is becoming overgrown with thorn bush, and the true margin of the depression is hard to determine (ref 1, p 413 and facing page). Therefore, one would not expect the depression to appear different from its surroundings.

52 (medium) Bakalahari Rise (northwest part) (plates 23-25, 6). Though the appearance of this area varies from sequence to sequence, and the edges are indistinct, it is usually present as a dark southeasterly extension from the highlands of northern Namaqualand (area 22). In position it seems to correspond to the northwest part of the low swelling known as the Bakalahari Rise, which separates the Nossob-Molopo drainage to the south from the Epukiro to the north. No definite reason for the darker tone can be found, though one could suggest several possibilities. It is believed that the sand swelling follows a rise in the bedrock surface. In this case the most likely explanation seems to be that the bedrock brings the water table closer to the surface along this line, with a consequent moister surface or denser vegetation.

53 a & b (light) Unnamed (plates 23-25, 6). These areas appear to represent depressions adjacent to areas 51 and 52, crossed by a number of usually dry river beds from west to east. They are similar to area 50 but appear slightly lighter. One may surmise that this is due to a predominance of sandy alluvium, and small dry lake beds.

54 (medium) West-central Kalahari (plates 23, 24, 6). This is a detached part of area 50, but its average tone is darkened by several

darker bands and blotches. The Tiros pictures strongly suggest that they are scattered outcrops or near-outcrops of dark rock, such as the Waterberg or Karroo sandstones which outcrop in the adjacent areas 51 and 22. One persistent dark band approximately follows the boundary between this area and area 53 b. The new geological map (ref 13) confirms that there is an outcrop of the Stormberg Series in approximately this position.

55 (medium-dark) Moist savannas (plates 17-21, 1, 33-36). The greater part of Angola, Zambia (formerly Northern Rhodesia), and those parts of the Congo which are covered by this report are combined in this huge tone area. Though tone variations are just distinguishable within the area on some sequences, they are not sufficiently definite or consistent to justify its sub-division. However, it contains a few landmarks of small extent which are numbered as separate areas 82-86. Area 55 corresponds quite closely to the area mapped (ref 7) as moister types of savanna. The uniform fairly dark tone must be due to the continuous dense plant cover which masks all but the most extreme variations in the underlying soil and rock type. In the definition of savanna used in ref 7 the characteristic feature is the presence of perennial grasses from 3 ft. to 10 or 15 ft. high. They are associated with trees, the density of which varies from virtually complete absence to an almost complete canopy. The amount of shrubby undergrowth varies greatly. Swamps, large and small, occupy considerable areas - as much as 20 per cent of the plateau areas of Zambia (ref 25, p 15). In most places annual rainfall exceeds 40 in. Ferrallitic soils are characteristic, mainly the yellowish-brown type, but the exact nature varies with the underlying rock and the presence or absence of a ferruginous crust. Rocks in the centre of the area are of the Kalahari System, whereas in the west and the east various older rocks, mainly Precambrian, are exposed. In the desert and semi-desert areas of southern Africa, already described, these rocks give rise to tones ranging from light to medium-dark, but here, because of the thick covering layers of soil and vegetation, these differences are scarcely distinguishable.

56 (dark) Moist forests of northwest Angola (plates 17, 18); the southern-most extensions of the moist forests of equatorial regions which have no prolonged dry season. Most areas of this type have numerous clearings in various stages of re-growth, or may have been converted into a mosaic of forest and savanna, but this is evidently not sufficient to reduce their dark tone. The areas shown here are mainly on the Plateau at about 3000 ft. altitude, and have a rainfall exceeding 40 in. There are red and yellowish-brown ferrallitic soils and some ferrisols. The area is underlain by various Precambrian rocks which are covered in some places by Cretaceous and Tertiary continental deposits, but these variations are completely hidden by the forest. Plate 17 shows in the northeast dark fingers of moist forest following the rivers Kwango, Wamba, etc., separated by light areas, probably the grass steppe which here occupies the interfluves.

57 (medium) Dry savannas of northern Kalahari (plates 19-22, 26, 27). Unlike the moist savanna zone (area 55) further north, where the ground cover is sufficiently dense to mask variations of rock, within the dry savannas areas of darker rock or moist surface are distinctly visible, and have been separately described. Therefore area 57 includes only those areas of dry savannas which occur on the Kalahari Sands formation. The sands are usually flat, featureless and fixed by vegetation. Mopane savanna is especially widespread. This may range from almost pure forest on clay soils to almost pure grassland on the widespread sandy soils. Annual rainfall is between 20 and 30 in. The western part of area 57 corresponds closely to the belt of ferruginous tropical soils which separates the brown semi-arid soils of area 50 from the ferrallitic soils of area 55, but in the east area 57 includes also brown soils.

The southern boundary of area 57, separating it from areas 50 a and b, represents a real difference in tone, but one which takes place gradually over a long distance, and which is confused by the distinct areas 58, 60, 61, 62, and the dark outcrops within area 54, and cannot be precisely defined.

The northern boundary of area 57, separating it from area 55, is different. In the west, it is abrupt but interdigitating, as fingers of forest penetrate down the valleys of the upper Cuito and its tributaries. Further east the boundary is gradual and also varies in position over a distance of at least a hundred miles, but nevertheless is real in the sense that northern areas usually appear darker than southern areas. In two passes, both in May 1962, the boundary appears to swing north so that area 57 includes the Cuando and upper Zambezi valleys, where the plant cover is classified in ref 7 as "grass steppe on Kalahari sand" and "dry deciduous forest with abundant Baikiaea". One would expect the former to appear lighter than the moist savannas to the north, but the latter should appear darker, except perhaps during the few weeks when the leaves are shed. If this occurs in May it explains why the boundary swings north only in May.

Within area 57 and the south of 55 several lines are visible on plates 19 and 20 which represent river valleys, but are not wide enough to be described as tone areas. They have been lettered as follows:

f	Cubango (Okovango)	k	Longa and/or Oiriri
g	Cuito (Kwito)	m	Cueio
h	Cuanevale	n	Cuatir
j	Luassinga	o	Unidentified channels

These rivers are all tributary to the Okovango, which feeds the Okovango Swamps. They are conspicuous on plates 19 and 20 probably because these were taken in July, which is during the local dry season, though the rivers would still be fairly high with flood waters from rains further north.

It is curious that the Cuito is more conspicuous than the main stream the Cubango (f). There is no evidence that the Cuito carries more water. The Cuito-Cuanevale valley appears straight and continuous as if fracturecontrolled, whereas the Cubango's does not. The World Aeronautical Chart shows that the Cuito-Cuanevale is followed by a narrow band of swamp, whereas the Cubango is not. On the other hand, the soils map (ref 10) depicts the Cubango followed by a band of mineral hydromorphic soils, whereas the Cuito is not.

58 (dark) Okovango Swamp (plates 20-26), the inland delta of the Okovango River, is shaped like a hand. The narrow upper tract or 'wrist' is a perennially-flooded swamp, with dense growth of reeds and papyrus, dotted with mounds carrying trees, and traversed by small channels, though none of these details appear on the pictures. The dark 'fingers' can be identified as the areas fed by the following distributaries:

p	Taokhe	u	Santantadibe
q	Jiao	v	Gomoti
r	Kkhwapa	w	Mochaba
s	Boro	x	Bonga, leading to Makwegana Spillway
t	Ngokha		

In these areas the flood waters seasonally fill depressions. Near the main distributaries are perennial or seasonal channels and lagoons, which are liable to be overgrown with reeds and papyrus, but the area as a whole is without these swamp plants. Soils have a thick surface humus layer.

Rainfall over this area is only about 15-20 in., with a maximum in summer (January), but the swamps are fed by the much heavier rains (over 40 in.) of the Angola highlands, which also have a summer maximum. The flood reaches a peak at the upper end of the swamp about February - March, but the water is so retarded by the swamps that the maximum at the lower end is not until July - August, in the dry season. The minimum is about October at the upper end and presumably about March at the lower end. These dates are very variable however, and may be upset by heavy local rains. Usable pictures of the area are in May, June, July and September. No definite seasonal changes are distinguishable. One must conclude that the darkness of the area does not vary with the level of the floods. The distal part of the Taokhe (p), which is not so dark in tone, is described by Wellington (ref 1, p 409) as "formerly flooded (before 1888)". The soil must have been altered sufficiently, prior to that time, for it to remain dark.

59 (medium-light) Chief's Island (plates 22-26) rises 10-20 ft. above high flood level, and presumably appears light because of the sandy soil and dry savanna vegetation.

60 (dark) Aha Hills (plates 23-25, 6), developed on an outcrop of Proterozoic sediments. As in area 51, the dark rock accounts for the dark tone, together with relief and perhaps denser vegetation.

61 (medium-dark) Area north of the Aha Hills (plate 24). On geological maps this area is shown to contain only one small outcrop of Proterozoic sediments, but the pictures show the whole of the area as darker than its surroundings, though not as dark as the Aha Hills. Perhaps there are numerous small bedrock outcrops, or the bedrock may merely be closer to the surface in this area. This might raise the water table or in some other way affect the soil or vegetation.

62 (white) Makarikari (plates 25-28, 16), is a pair of dry lakes, barely linked. They are dry in winter, but often partly flooded in summer, usually only by local streams, but occasionally by the Botletle (y, on plate 26) which carries the overflow from the Okovango Swamps. No doubt the dry salt or clay surface accounts for the very light appearance, which can easily be confused with cloud. Makarikari appears white on all pictures in which the area is cloud-free, but these are all during the dry season. It would no doubt appear darker when flooded. On V-0245 T1 frame 10 (not illustrated), the two main pans appear whiter than the area between, unlike Etosha Pan where the centre appears darker than the edges. The light area southwest of Makarikari on plate 26 is unexplained.

63 a, b & c (dark) Floodplains of rivers Zambezi, Cuando and Luiana (plates 19-22, 24), known as the Barotseland Plain in the case of the Zambezi. In general, these areas are surfaced by swampy grassland growing on mineral hydromorphic soils and river alluvium, though these soils are more extensive than areas 63 (ref 10). They are seasonally flooded at the end of the rainy season of their headwaters, which is the beginning of the local dry season. Specifically this means February to June in Barotseland, and several months later in the Cuando valley. All cloud-free pictures of Barotseland and the Cuando flood plain are in months when they would be flooded, so no doubt the dark tone is due mainly to the water surface, though damp soil left after the floods have receded would also cause this. In addition, all major rivers in the savannas are followed by belts of forest, which could darken the tone. This may be the cause in the valley of the Luiana, since maps do not specifically mark swamps or floodplain soils along this valley. On the only two sequences, IV-1205 T2 (ref 12, p 91) and IV-1290 T1 (plate 21), which show Barotseland and the Cuando floodplain clearly on the same pictures, Barotseland appears darker, but both sequences are in May, when the Zambezi floods would be higher than the Cuando's. The relationship could be reversed later in the year. In plate 21, Barotseland appears to have two distinct branches, but in sequence IV-1205 T2, taken six days previously, the branches are combined. This may be because the flood had reached a different level, or it may be because Barotseland is less clearly shown in IV-1205 T2 and the two branches, though present, are not resolved.

64 (dark) Shelangu Forest Reserve (probably) (plates 20-22). Two explanations of this elongated dark area are worth considering. The less probable is that it is the Matabele Plain, which appears to be a broad, flat-bottomed, abandoned channel which formerly linked the Cuando to the Zambezi. According to ref 7, it is covered by grassland but not swamp. Therefore one would not expect it to appear especially dark, unless it was temporarily flooded at the time of the pictures, which is possible.

Immediately south of the Matabele Plain, occupying the edge of a low plateau within the Kalahari Sands area, and therefore probably localised by the good drainage of the site, is the Shelangu Forest Reserve. Ref 7 shows this as an area of dry deciduous forest with abundant Baikiaea, as opposed to savanna. The dense forest would explain the dark tone, but the same map shows several other areas of this forest a little further south, which are not conspicuous on the photos. This cannot be adequately explained, unless it be due to the more continuous cover and elongated shape of the Forest Reserve.

65 a & b (dark) Chobe Swamp and Shesheke Plain (plates 26, 20-24). These areas are swamps, with a surface of grasses and reeds, and some open water in places. They are sharply bounded on the south by a low rise in the ground, but not on the north. The southern edge is always flooded, but the remainder is flooded only annually, beginning during May or June. On plate 21, taken in May, the Shesheke Plain (65 b) is more conspicuous than the Chobe Swamp (65 a). This is to be expected because the former draws its floods mainly from the Zambezi, which floods before the river Cuando (Linyanti) which feeds the Chobe Swamp.

Letter x marks the Makwegana Spillway, a shallow channel, usually dry, which occasionally carries flood waters from the Okovango Swamp to the Chobe Swamp. It is not occupied by trees but by grassland, which would normally make it appear lighter. Of eight usable sequences covering the area, it is visible in three only, namely V-0245 T1 (not illustrated), VI-0034 T2 (plate 26), and VI-0062 T2 (plate 24), taken in July and September, and then as a dark line, suggesting it was flooded, or at least damp at that time.

66 (dark) Unidentified (plates 26, 27). From visual estimation this area is located at 25°E, 18-1/4°S, and is elongated southwest to northeast. At this location maps show the Shinamba Hills and the Ngwezumba water course, which flows occasionally into the Mababe Depression to the southwest (ref 1, p 415). The former appears the more likely explanation, in which case the area is merely a detached continuation of area 51. Distortion is considerable and it is just possible that it is a part of the Zambezi valley.

67 (black) Kariba Lake (plates 22, 25, 27, 31, 35) is the reservoir formed behind the Kariba dam. The dam was completed in 1960, but the reservoir was not entirely full until 1963. Tiros pictures showing it range from July 1961 to July 1963, and slight differences in size and shape over this period are apparent, but it is not possible, without the aid of grids, to distinguish the effects of picture variability from those of rising water level.

68 (light with dark lines and patches) Southern Rhodesian Plateau (plates 31, 32, 27, 28). Though situated at more than 4000 ft. above sea level this is generally an area of small relief, dissected by rivers only around the edges, and especially in the west. The generally light tone must be due to the light-toned sandy soils, developed from the light-toned Basement granite rocks which cover most of the plateau. These include ferruginous tropical soils, yellowish-brown ferrallitic soils, and ferrisols (ref 10). Moreover, rock outcrops are generally in the form of smooth-surfaced exfoliation domes (Buiss, personal communication). Although the rainfall is 20-40 in., and more than half the area is occupied by damper savanna types, these are evidently not sufficiently dense to hide the light soils. The darker patches no doubt represent areas of brown and reddish-brown clay loam and clay soils which are produced by the action of the same soil-forming processes in areas of metasediments and basic and ultra-basic intrusives. One of the dark lines can be definitely identified as the Great Dyke, which extends for 350 mi. from north-northeast to south-southwest (plate 31).

69 (medium-dark) Non-granite area of the Sabie-Lundi and Limpopo valleys (plates 29, 28, 31, 32). The boundaries of this area follow geological boundaries and therefore must be due to differences in rock type and derived soils. In the north the rock is mainly paragneiss, on which has developed brown soil of semi-arid tropical type. In the south are rhyolite and a little basalt, on which are found lithosols and vertisols rich in dark minerals (refs 15, 10). Paragneisses are not usually especially dark rocks, so that the dark tone is directly explained by the nature of the rock only in the south. In both parts, rainfall is 10-20 in., the plant cover is savanna, relief is small, and the altitude around 2000 ft. Buiss states (personal communication) that although the local relief on the paragneiss is about the same as on the granite of area 68 to the north, the paragneiss area is more closely dissected and therefore darker.

70 a & b (medium-light) Transvaal Lowveld (plates 27-30). The boundaries of this area correspond to the limits of the outcrop of Basement granite, which must account for its light tone. However, the tone is not as light as that of granite areas of sparser vegetation and rainfall, such as Bushmanland (area 27). This is because the rainfall of 10-20 in. here permits the development of a greyish-brown sandy loam soil belonging to the brown semi-arid group, rather than a pure sand, and a dry type of savanna vegetation. In area 70a there are scattered areas of dark volcanic rocks and metasediments of the Primitive System (ref 14).

71 (dark) Soutpansberg (plates 27-29). This is a mountain range rising as much as 3000 ft. above its surroundings, abruptly in the south, gently in the north, with maximum elevation almost 6000 ft. In the east it is deeply dissected and split into several ranges. Rocks are of the Proterozoic Waterberg and Dominion Reef Systems: red and purple quartzitic sandstones and conglomerates, and andesitic and acid lavas (ref 14). The summits are rocky, there are thin sandy soils on the slopes, or sometimes deeper soils with a brownish sandy surface, and in the valleys often waterlogged sandy soils. The plant cover is in general montane grassland, but the summits are bare rock, and the valleys may be densely bushed, while evergreen forests occur on the southeast slopes. The valleys in the east are cultivated, and forest plantations and spots of intensive cultivation occur on and below the southern slopes. Rainfall ranges from 20-76 in., being highest in the southeast. Nevertheless some of the cultivation is by irrigation. The overall dark tone must be due mainly to relief effects and perhaps to the frequent exposure of a fairly dark rock. However, the especially dark area in the southeast is mainly due to areas of forest, and greater surface moisture, and partly to areas of cultivation, and to the more broken topography.

72 (medium) Great Escarpment south of Soutpansberg (plates 27-30) does not differ from the Transvaal Lowveld to the east nor the Pietersburg Plain to the west in any respect other than relief, which must therefore account for the darker tone. It consists of a series of valleys and spurs descending from 3500-6000 ft. to 2000 ft. This part of the Great Escarpment is lighter in tone than the areas to the south and the Soutpansberg to the north because it lacks forest cover.

73 (dark) Forests of Transvaal Drakensberg (plates 28-30). This is part of the Great Escarpment, facing east. The top may be at almost 6000 ft., the base as low as 2000 ft., though in places the descent is in two steps. The scarp is formed in most places by the Black Reef quartzite, which despite its name is generally light in tone. Elsewhere it is formed of other quartzites, or in the extreme north Basement granite. There are brownish humic ferrallitic soils. Rainfall ranges from 30 to over 60 in., with frequent mists. Above 4500 ft., except for a small gap, the Escarpment is covered in montane evergreen forest, often 70-100 ft. high, with epiphytes and shrub, fern and herb layers. Elsewhere there is scrub or grass. In the north and south of this area the natural forests have been replaced or supplemented by plantations of pine and eucalypts (ref 3, p 260). This area is the darkest-toned in the Transvaal, and among the darkest in the Republic of South Africa. The feature which is unusual for South Africa is the forest cover. This must be by far the most important cause of the dark tone. The generally moist surface may be the next most important. Large relief and humic ferrallitic soils characterise areas 71 to 74, but are not peculiar to area 73. Geology cannot be important as the same rocks are found in adjacent areas, and are not dark in tone.

74 (medium-dark) Great Escarpment between the Natal and Transvaal Drakensberge (plates 29, 30, 14) is up to 3000 ft. high, with a top between 5000 and 6000 ft. It is abrupt in places, but elsewhere divided into several steps or cut across by river valleys. There are a few plantations of black wattle, pine and eucalyptus (ref 3, p 260), but the dark tone must be due mainly to relief, and perhaps also to the humic ferrallitic soils, because in other respects the area is similar to adjacent areas. Rainfall is increased by the Escarpment, and reaches 50 in. in places.

75 (medium-dark) Barberton Mountains (plates 30, 29) could be regarded as a protruding part of area 74, and the explanation of the dark tone is similar. It is mainly due to the rugged relief, with altitudes ranging from 1000 to over 6000 ft., and to the dark quartzites, ironstones and shales of the Archean Swaziland System. Rainfall may be as high as 60 in. Cole (ref 3, p 261) mentions the presence of eucalypt plantations near the town of Barberton but not necessarily on the Barberton Mountains. If plantations cover a large area they also may contribute to the darker tone, so that the dark area visible may not correspond exactly to the mountains.

76 a & b (medium-dark) Eastern and western Bankeveld, etc. (plates 27-30, 15, 16). These two areas are lighter than area 73 to the east because they lack a continuous forest cover, but they are darker than most other adjacent areas because of dark soils and rocks and to some extent relief and cultivation. They are scarplands, made up of cuestas curving round the eastern and western rims of the Transvaal Bushveld Basin (area 78). In the west there are four cuestas rising about 300-1,500 ft. above the Bushveld Basin, which lies at about 3500 ft. In the east there are numerous cuestas with a relative relief of up to 2000 ft., and reaching an altitude of 7000 ft. in places. Area 76b probably also includes in the southeast the similar Witwatersrand ridges. Rocks of the scarplands include Proterozoic ferruginous quartzites, shales, dolomites and lavas; and Recent alluvium. Parts of the basin floor included within these areas are underlain by norite (gabbro), which weathers to a

black clay soil. Some of the quartzites produce shallow talus soils with innumerable angular rock fragments, which would also appear very dark. However, most of the rocks weather to brownish ferruginous tropical soils of medium or medium-dark tone. Plant cover is mainly grassland in 76a and drier types of savanna in 76b. The vales between the scarps are intensively cultivated, often with irrigation, but agriculture in the basin floor is limited to irrigated areas along one river. Africa's largest urban area, the Rand, occurs in the southeast of 76b, but it is not distinguishable. Rainfall varies from 20 in. up to 60 in. in parts of the eastern Bankeveld.

The Pilansberg is just distinguishable in two frames as a lighter circular area in the middle of area 76b, but probably not in the reproduction of one of them as plate 15. It is in fact a circular ridge rising 2000 ft. above its surroundings and 15-18 mi. in diameter, which is the remnant of a volcanic plug.

77 (dark) Springbok flats (plates 27-30), are dark because of the exceptionally dark soil, which has a surface of brownish black clay and is developed on the dark-toned Stormberg basalts. Within the area there are also Karroo shales and sandstones which give rise to brown or reddish-brown ferruginous tropical soils, of medium tone. The rainfall is relatively low, about 22 in., so that despite the very fertile soil about 70% of the area is grassy flats, used for pasture, and only about 30% is devoted to an extensive type of cultivation, with peanuts and maize the main crops (ref 3, p 646).

78 (medium-light) Transvaal Basin floor (central and eastern parts) (plates 27-30). Compared with the Bankeveld areas (76a & b) the light tone of this area could be due to its lesser relief, because apart from some local buttes and ridges it is a relatively flat plain at 2000-3500 ft. above the sea. However, since it is lighter than area 77, an even flatter area, the light tone must be due to the grey, sandy surface of the ferruginous tropical soils which develop here on the Bushveld red granite (Proterozoic). The plant cover is drier types of savanna, with a high proportion of trees, and rainfall is 20-30 in.

79 (medium-light) Pietersburg Plain (plates 27-30), a gently undulating plain sloping from 6000 ft. in the south to 3000 ft. in the north. The light tone is mainly that of the sandy surface of the ferruginous tropical and brown semi-arid soils which here develop on the Basement granite, and partly that of outcrops of the bare granite itself. There are also east-west ridges formed by ironstones of the Archean Swaziland System which are of medium tone.

80 (medium) Waterberg Plateau (plates 26-29). This is an undulating plateau with a surface between 3500 and 6900 ft., which in places rises abruptly above its surroundings. Rocks are red or purple quartzitic sandstones and conglomerates of the Waterberg and Loskop Systems (late Proterozoic). Soils are generally thin, immature and sandy, with numerous rocky outcrops. Valley soils are very sandy but often waterlogged. On the flatter uplands a more mature brownish sandy ferruginous tropical soil develops. The plant cover is grass and scattered trees, with tree growth in ravines. Rainfall is mainly under 20 in., but there are some

irrigated areas along rivers. The medium tone probably results from a balance between outcrops of dark rock and appreciable numbers of trees, which tend to dark tones, and a light-toned soil and rather dry climate, which tend to light tones.

81 (medium) Southeast margin of Kalahari (plates 26-29, 15, 16, 23). Approaching the southeast edge of the Kalahari from the centre of that area the thickness of the Kalahari System rocks becomes less, and outcrops of older rocks become gradually more extensive. These rocks include Waterberg sandstone, Karroo sandstones and lavas, and younger and older granites, and are correspondingly varied in tone. Because the individual outcrops are not clearly distinguishable, this heterogeneous area has been designated a single tone area. These rocks form a series of plateaus at heights of about 3000 ft., in places separated from each other by escarpments. Rainfall is 10-20 in. There is a transition from wooded steppe within the Kalahari to the drier types of savanna further east. Brown semi-arid tropical soils are typical. In the southwest of the area one finger of dark rock extends far into the Kalahari (plates 16, 23). It probably underlies the Bakalahari Rise, and appears again in area 52.

82 (dark) Lake Upemba, and adjacent permanent lakes and swamps which, like those in areas 83-85 and 88, owe their dark tone to the water surface. Of four cloud-free sequences covering this area, only one (plate 33) shows Lake Upemba. This area can be confused with area 85, because of its similar shape.

Line zz is the R. Lualaba (plate 33).

83 (black) Lake Mweru (plates 34, 33) is also indistinct, presumably because of the dark tone of its surrounding forests and savannas, except when brought out by sun-glint as on plate 35.

85 (black) Lake Tanganyika (plates 34, 38).

85 (dark) Lake Bangweulu and adjacent swamps (plates 36, 34, 37). Lake Bangweulu is permanent but shallow, with a depth not exceeding 30 ft. (ref 29), but appears dark, unlike L. Rukwa (area 93). The dark area seems to include also the adjacent small Lake Kampolombo and the swamps along Bangweulu's outlet, the Luapula River, but not the main Bangweulu Swamps east of the lake. There is no information that the main swamps differ in any way from those along the river. Both are papyrus swamps through which only a small part of the water flow takes place in open channels (ref 29). The apparent shape of the area does not change, though it tends to be more clearly visible at the end of the dry season in October than it is in May, perhaps because the surroundings are drier.

86 (dark) Kafue flats (plates 35-37, 31). A small central part of this area is a perennially flooded swamp, but most of the flats are a grassy plain flooded only seasonally. Soils are vertisols, rather than the hydromorphic soils usual in perennial swamps (ref 10). Usually the main flooding begins in mid-January or later, and the flats are fully flooded by April or May. The floods then begin to recede (ref 25, p 52). This is one area where seasonal variations in surface moisture seem to be distinguishable.

In sequences in May 1962 (IV-1205 T2 - not illustrated, and plate 37) and July 1962 (plate 35) the flats are distinctly visible, whereas in sequences in July 1963 (VII-0281 T2 - not illustrated) and October 1962 (plates 36, 31) they are invisible or lighter than their surroundings. This would seem to indicate that the floods had receded considerably when the latter three sequences were taken.

87 (medium-light) Luangwa trough (plates 35, 37, 38) is a rift valley, its flat floor lying at about 2000 ft., within the Plateau of about 4000 ft. altitude. Rocks are Karroo sandstones, shales, etc. Soils are a complex of brown medium-textured ferrallitic soils, alkaline soils, and extensive sandy ferruginous tropical soils. Rainfall is given as 20-40 in. (ref 1, map III). Plant cover is drier types of savanna. The lighter-coloured soils and less dense type of savanna vegetation only partly explain why the area appears lighter than its surroundings. Perhaps the rainfall is in fact lower than maps suggest. Certainly the trough appears cloud-free on a number of sequences where the surroundings are clouded e.g. III-0158 T1 and III-0173 T2 (ref 17, pp 91, 95). On some sequences but not all, the tone area appears to extend into the Zambezi valley, which agrees with mapped distributions.

88 (dark) Lake Nyasa (plates 38, 37) is renowned for its variations in surface level, which may be as great as 20 ft. over a long period (ref 25, p 14), but its shores are too steep for this to cause any noticeable change in shape on the Tiros pictures.

89 (medium-dark) West of Lake Nyasa (plates 38, 37) are plateaus standing above the level of the main African Plateau. They are at elevations of 4000-8000 ft., and more or less dissected. The area includes their eastern slopes, which may also be much dissected, descending to the lake at 1500 ft. Rocks are mainly gneisses and schists of the Basement Complex, but there is a variety of other rocks including intrusive granite in the north, and some metasediments. Soils are humic or other ferrisols on the highlands, lithosols on the slopes, and vertisols along the lake (ref 10), most of which are fairly dark in colour. The plateaus are covered by grassland, with patches of forest and some peat bogs. Lower areas have savanna cover. Rainfall is from 30-60 in. The boundary of the tone area corresponds more closely with the 40 in. rainfall line than with any other boundary. Probably relief and dark soils are just as important in causing dark tones.

90 (medium) Plateau east of Luangwa trough (plates 37, 38) is an area of small relief, mainly at 3000-5000 ft. elevation. The comparatively light tone may be due to the sandy ferrallitic and ferruginous tropical soils developed from the gneisses, granites and metasediments of the Basement Complex, which underlie the area. However, the vegetation is classified as moister types of savanna (ref 7), which usually are dense enough to hide the effects of underlying rock. Rainfall is moderate, 30-40 in.

91 (medium-dark) Northern Moçambique plain and lower Zambezi valley (plates 31, 32). This is an area of plains and plateaus mainly below 3000 ft. The largest areas are occupied by moister types of savanna,

but there are also areas of drier types of savanna, forest-savanna mosaic, and cultivation. Rainfall is 30-50 in., except in the Zambezi valley where it is below 20 in. The fairly dense vegetation apparently masks variations in the soils and rocks. These are mainly ferruginous tropical soils or, in the Zambezi valley, brown semi-arid soils, developed on Cretaceous and Tertiary limestones and sandstones, Basement granites, volcanics and, in the Zambezi delta, Recent alluvium. The area could be regarded as an extension of area 55 on to lower ground: there is no clear boundary between them. With better pictures it is likely that this area would need subdivision. For example, on plate 32 the interior of the coastal plain northwest of Beira appears lighter. This corresponds roughly to the area of drier savannas shown by ref 7. There are other sequences where the Manica Plateau inland appears either darker or lighter than the coastal plain.

Letter z marks the R. Zambezi (plates 32 & 31). The upstream part is darker than its surroundings, like most rivers, but the lower part is lighter. This is because the river here spreads out over a braided bed 2-5 mi. wide which, in the dry season, August to November, is a huge expanse of sand (ref 1, p 402). Plates 31 and 32 were taken in October and November.

92 (medium) Southern Moçambique plain (plates 29-32), lies mainly below 1000 ft. The medium tone is due to the lack of marked relief and to the medium values of all factors. Rainfall is mainly 20-40 in., but is below 10 in. in the lower Limpopo valley. This gives rise to a plant cover mainly of drier types of savanna, but denser types occur near the coast. There is some cultivation. The lower rainfall and less dense vegetation account for the lighter tone than area 91. Soils and rocks are similar to those in area 91.

93 (light) Lake Rukwa (plate 38) is shown on most maps as an ordinary lake, but its light tone on Tiros pictures shows that it is not. Maps show the lake about 70 mi. long, but in fact only the southern 30 mi. is permanent water. The maximum depth is about 10 ft. The water is very brackish, and of a milky colour from the mud stirred up by the wind. The remainder is an expanse of bare mud in the dry season, but may be flooded to a depth of about 4 ft. in the wet season. All Tiros pictures of the 'lake' are in the dry season, so the light area must be at least partly dry mud. The lightest area, near the southern end of area 93 in plate 38, must be the milky permanent water, providing the lake has not now entirely dried up.

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KEY TO RIVER VALLEY LETTERS

These letters appear on the plates and the tone areas map (fig 8)

a	Omaruru	See area 14 (p 31)
b	Khan	
c	Swakop	
d	Kuiseb	
e	? former river - See area 44 (p39)	
f	Cubango (Okovango)	See area 57 (p 43)
g	Cuito (Kwito)	
h	Cuanevale	
j	Luassinga	
k	Longa and/or Ciriri	
m	Cueio	
n	Cuatir	
o	Unidentified channels - see p 16	
p	Taokhe	See area 58 (p 44)
q	Jiao	
r	Kkhwapa	
s	Boro	
t	Ngokha	
u	Santantadibe	
v	Gomoti	
w	Mochaba	
x	Bonga, leading to Makwegana Spillway - see area 65a (p 46)	
y	Botletle - see area 62 (p 45)	
z	Zambezi - see areas 65b, and 91 (pp 46, 52)	
zz	Lualaba - see area 82 (p 50)	

PLATES

Legend

———————	Edge of cloud - covered area.
━━━━━━━	Tone area boundary, visible on this plate, abrupt or gradual, including coastlines.
— — — — —	Tone area boundary, not visible on this plate
— · — · — · —	River valley, visible on this plate on the ground or in the cloud pattern.
· · · · · · · · · · · · · ·	Lineament, possibly structural, visible on this plate on the ground or in the cloud pattern.

Capital letters have the following meanings:

C	Cloud-covered
PC	Partly cloud-covered
W	Water area, not otherwise specified
L	Land area, not otherwise specified

Lower-case letters alone such as a, c, w, designate river valleys which are not wide enough to be regarded as tone areas. The key to the letters is given on the opposite page. They also appear on the tone area map (fig. 8).

Numbers designate tone areas. The key to tone area numbers appears on pages 28-52. These numbers also appear on the tone area map (fig. 8). Numbers followed by lower-case letters designate parts of tone areas which are split by other areas. Thus areas 27a, 27b 27c, and 27d are essentially similar, and together constitute area 27.

The Greenwich Mean Time (GMT) given for each plate is the time when the middle frame of the sequence was taken. It may differ by up to 8 minutes from the time the frame reproduced was taken. Local time in the areas photographed is one to two hours later than GMT.

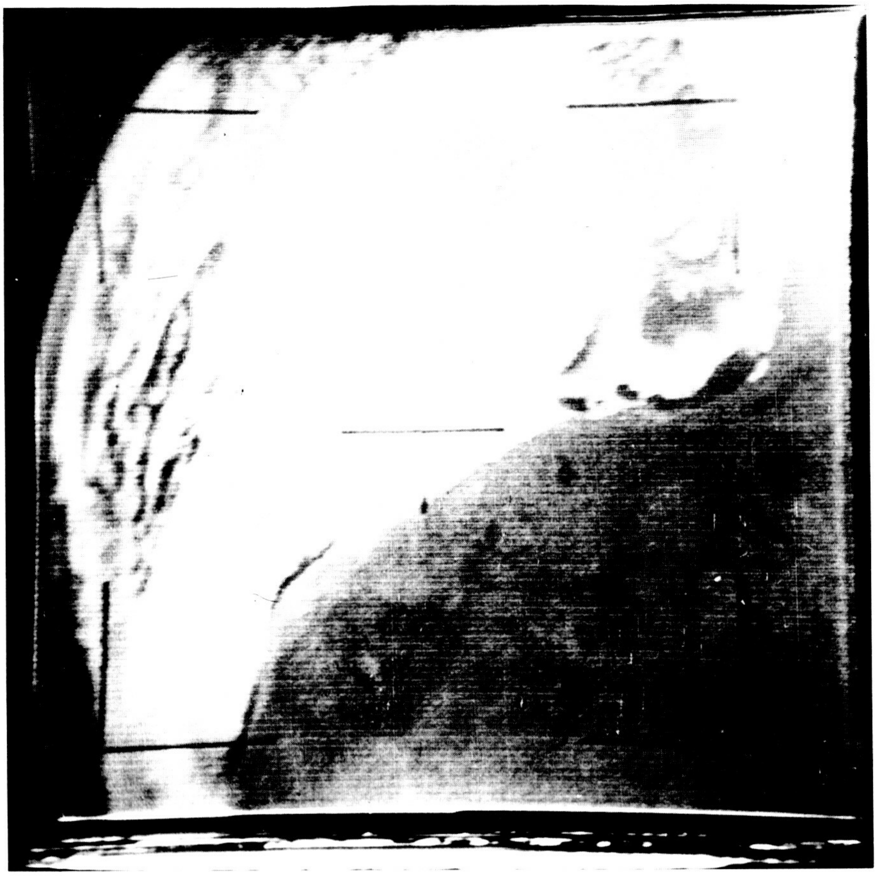


PLATE 1

Tiros V

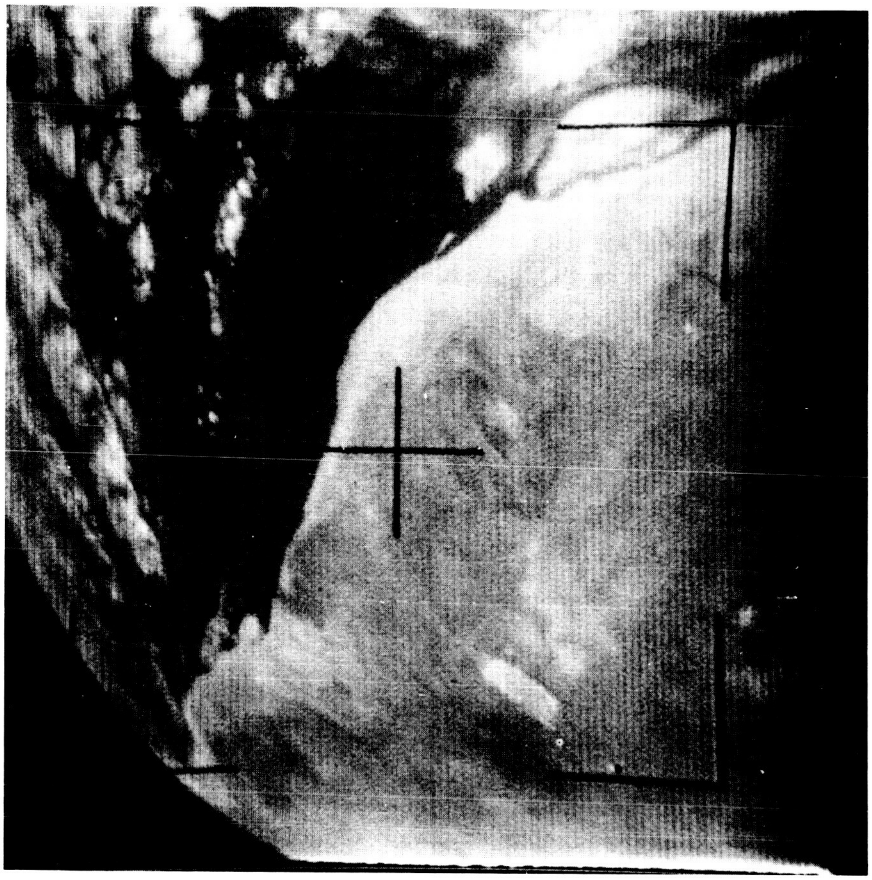
Sequence
0230 T1

Frame 19

Wide-angle

1232 GMT

5 July 1962



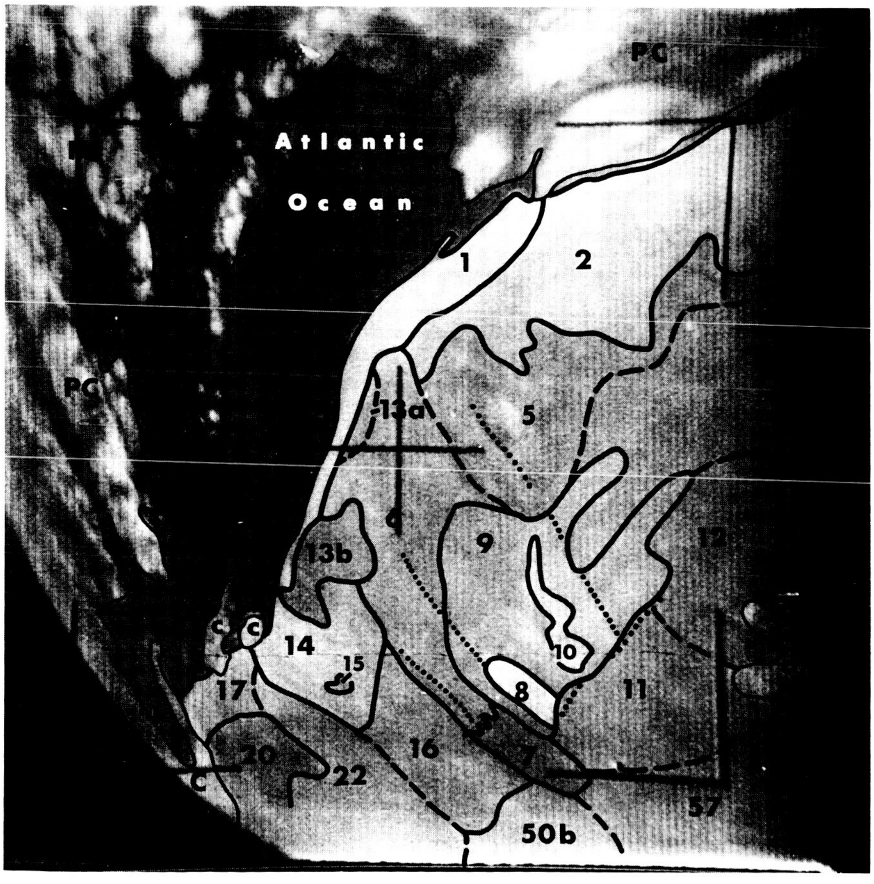


PLATE **2**

Tiros VII

Sequence
3593 T2

Frame 31

Wide-angle

1017 GMT

17 Feb 1964

PLATE **3**

Tiros VI

Sequence
0090 T2

Frame 17

Medium-angle

1208 GMT

24 Sept 1962

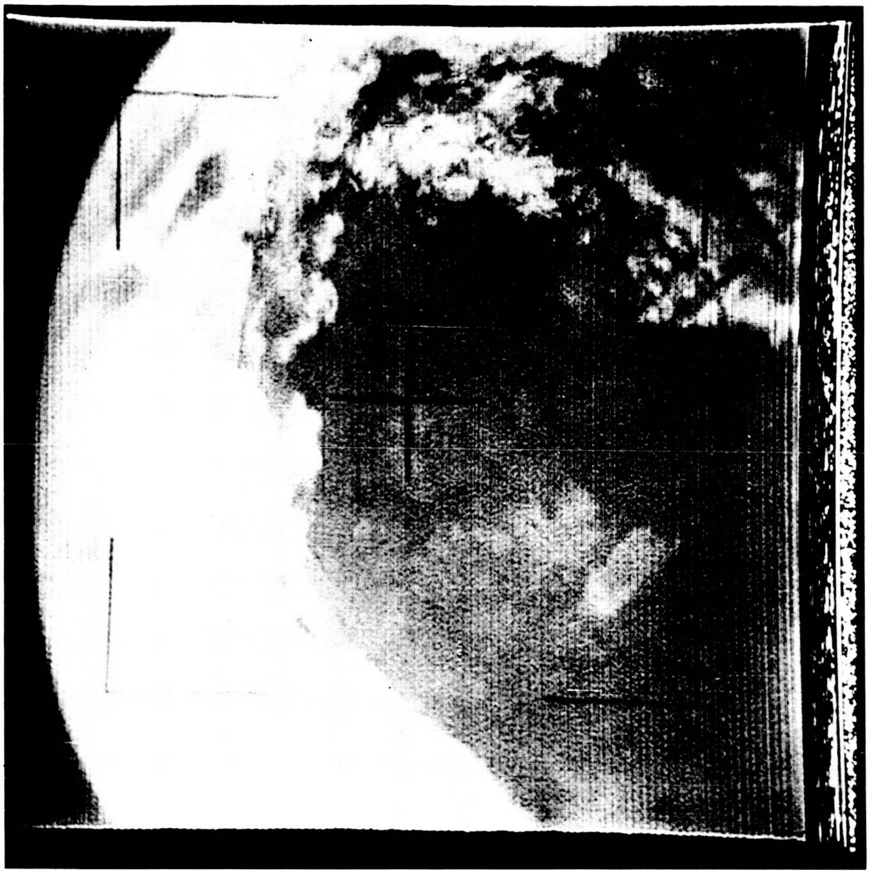


PLATE **4**

Tiros VIII

Sequence
4974 T1

Frame 23

Wide-angle

0636 GMT

28 Nov 1964

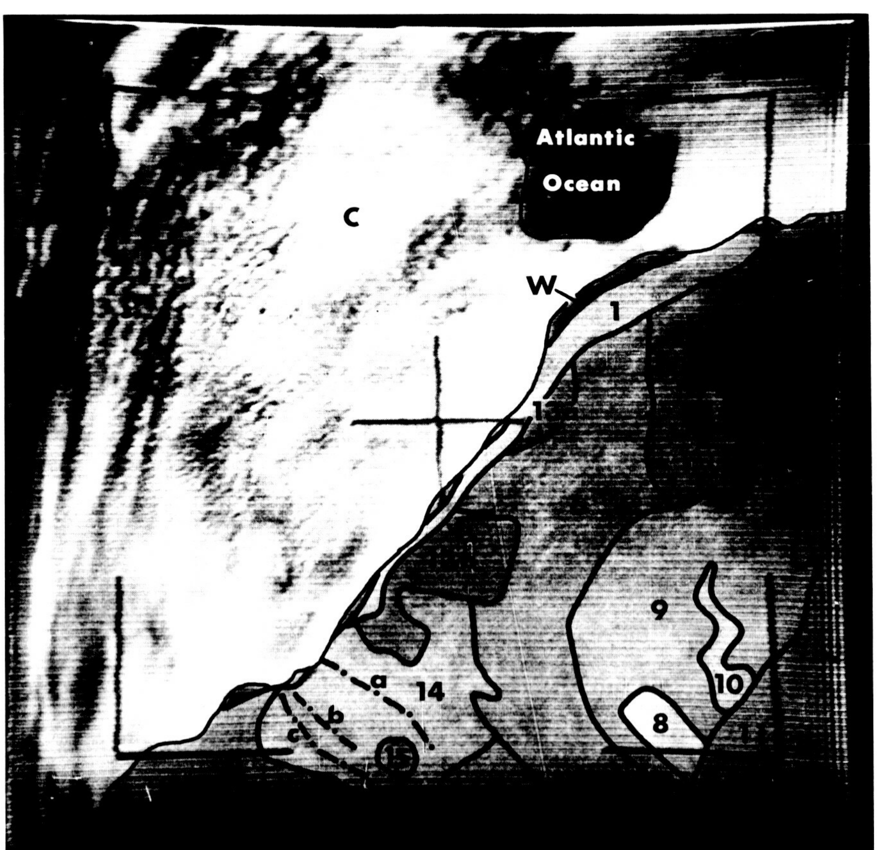


PLATE **5**

Tiros V

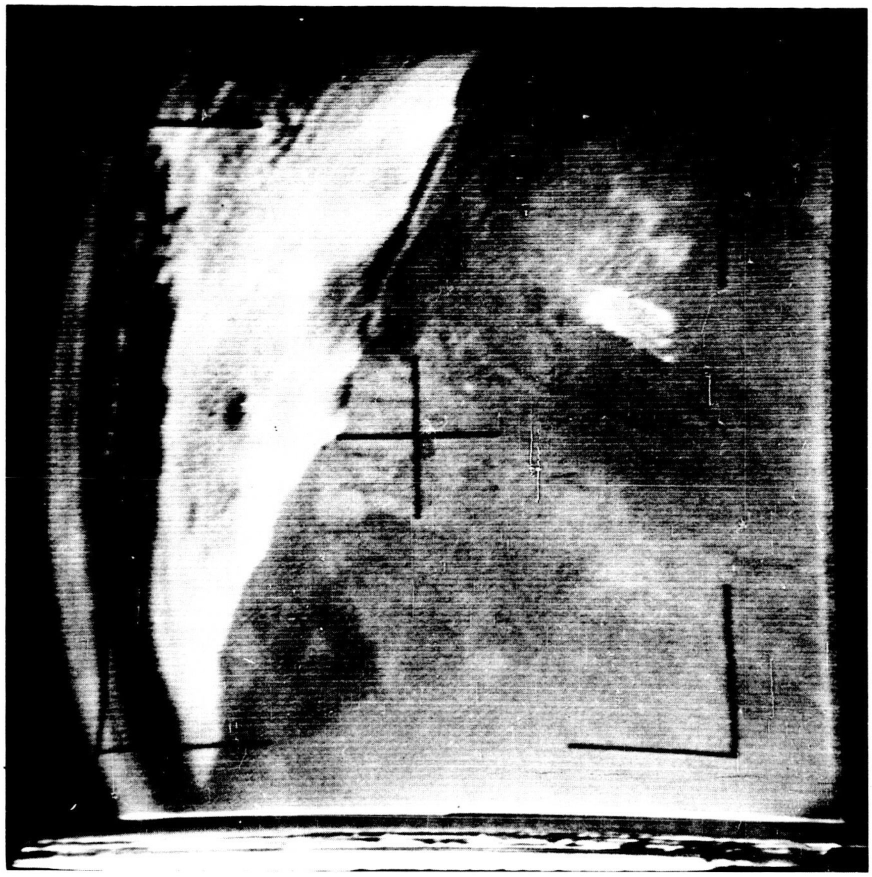
Sequence
0216 T1

Frame 16

Wide-angle

1307 GMT

4 July 1962



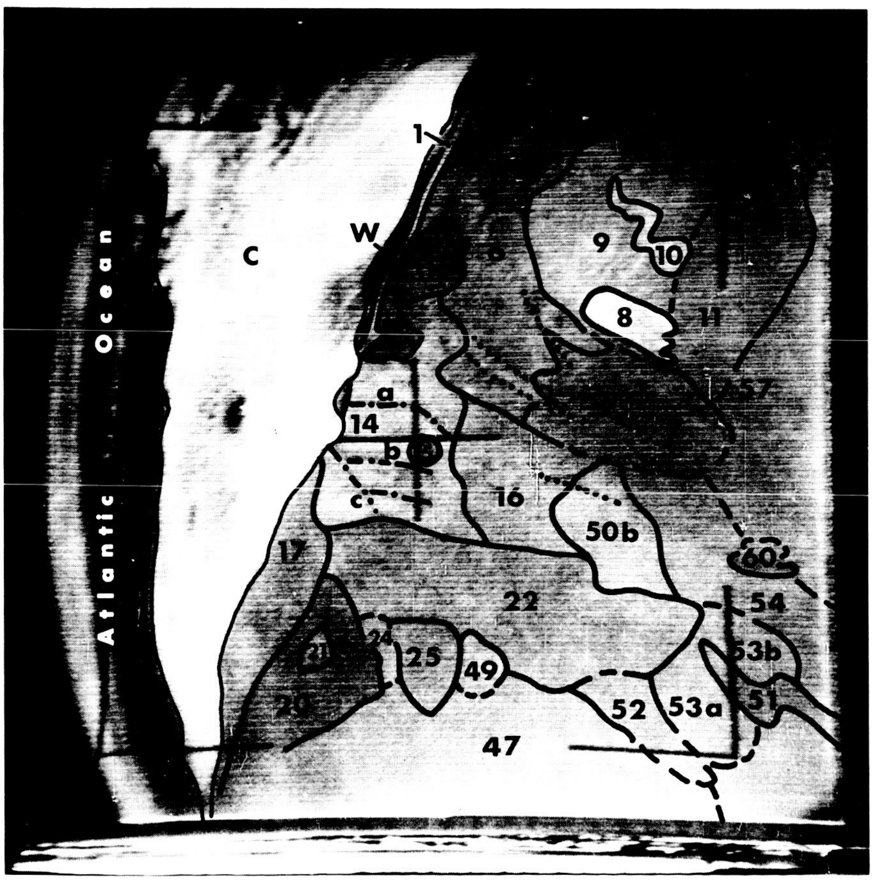


PLATE **6**

Tiros V

Sequence
0230 T1

Frame 15

Wide-angle

1232 GMT

5 July 1962

PLATE **7**

Tiros V

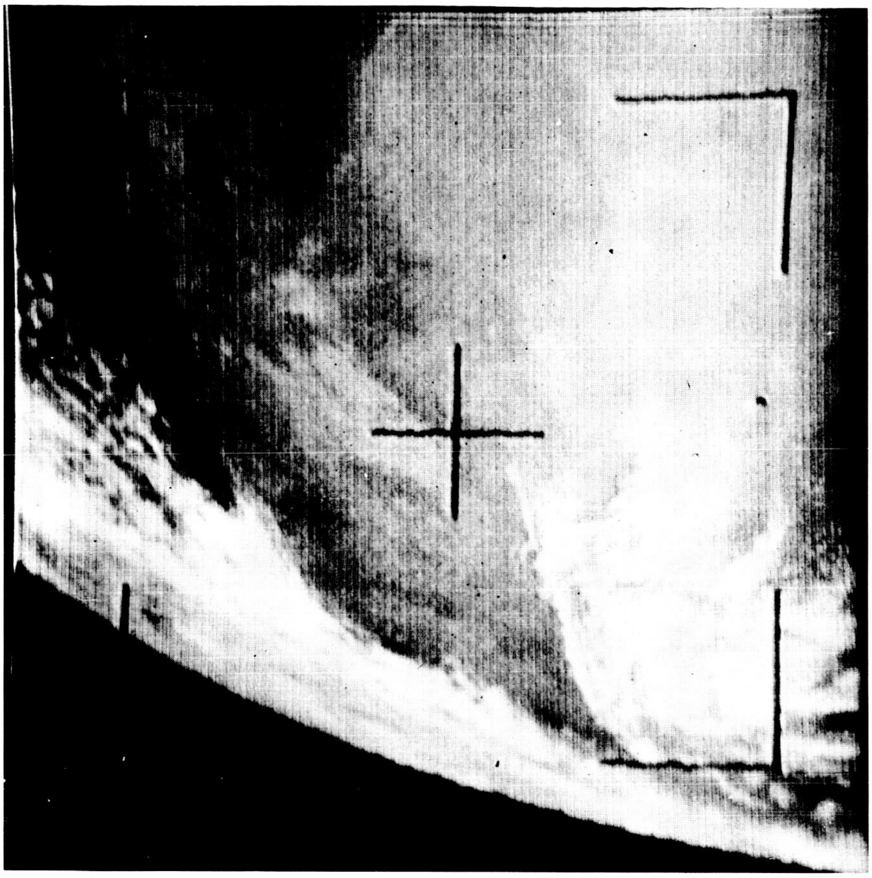
Sequence
0216 T1

Frame 12

Wide-angle

1307 GMT

4 July 1962



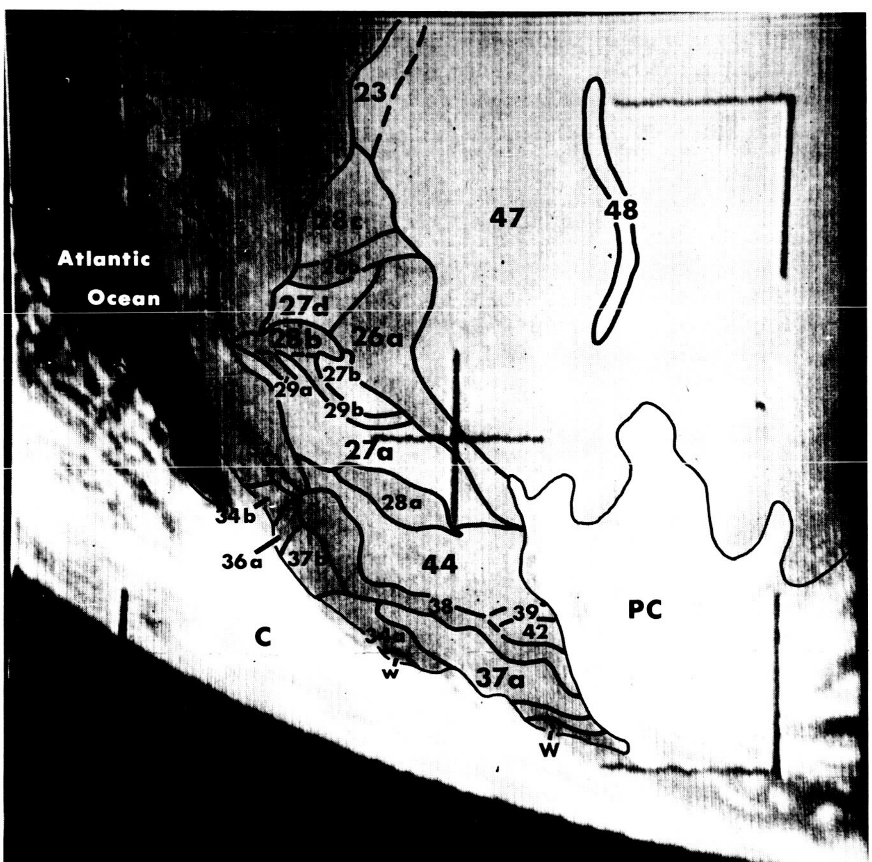


PLATE **8**

Tiros VI

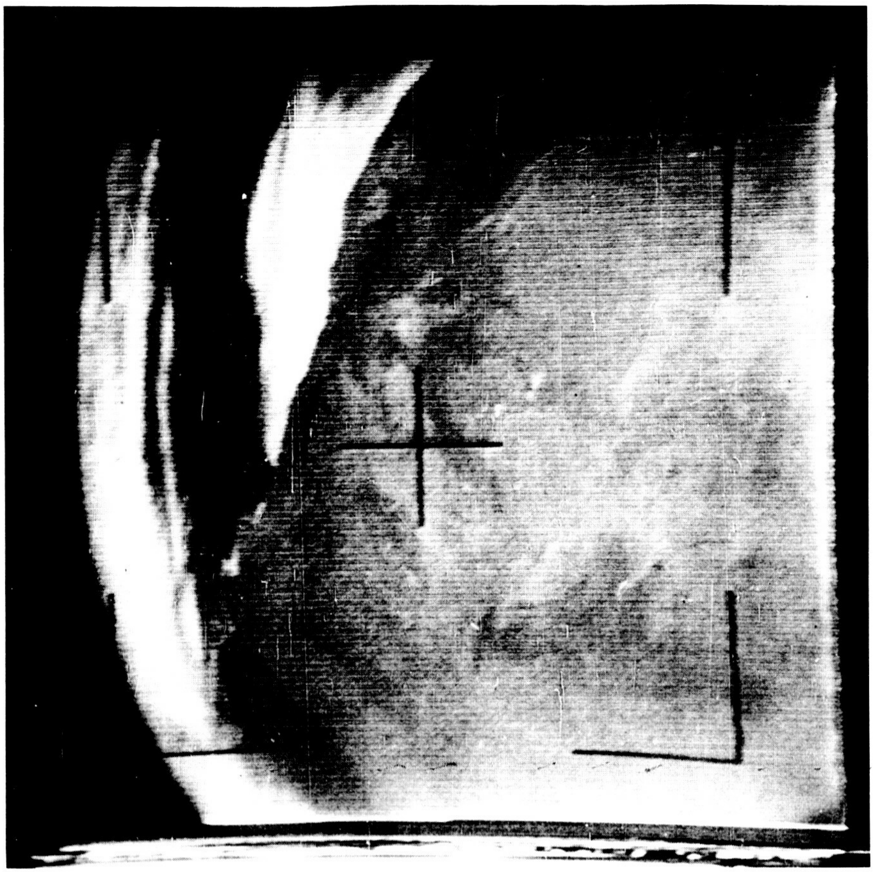
Sequence
0090 T2

Frame 11

Medium-angle

1208 GMT

24 Sept 1962



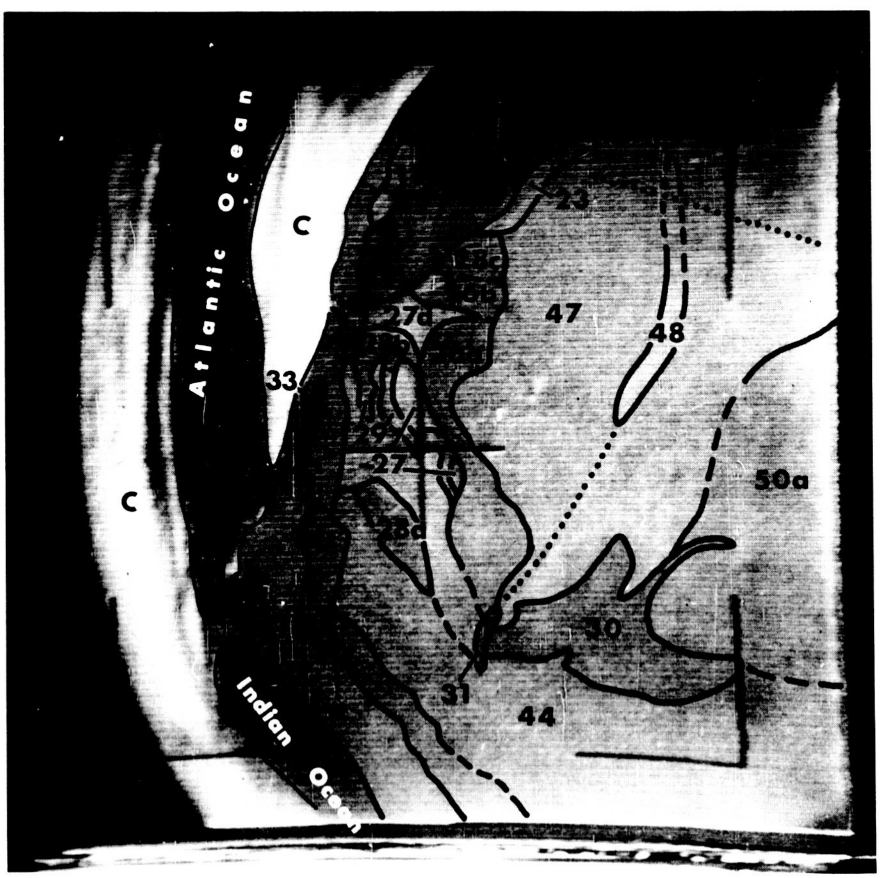


PLATE **9**

Tiros V

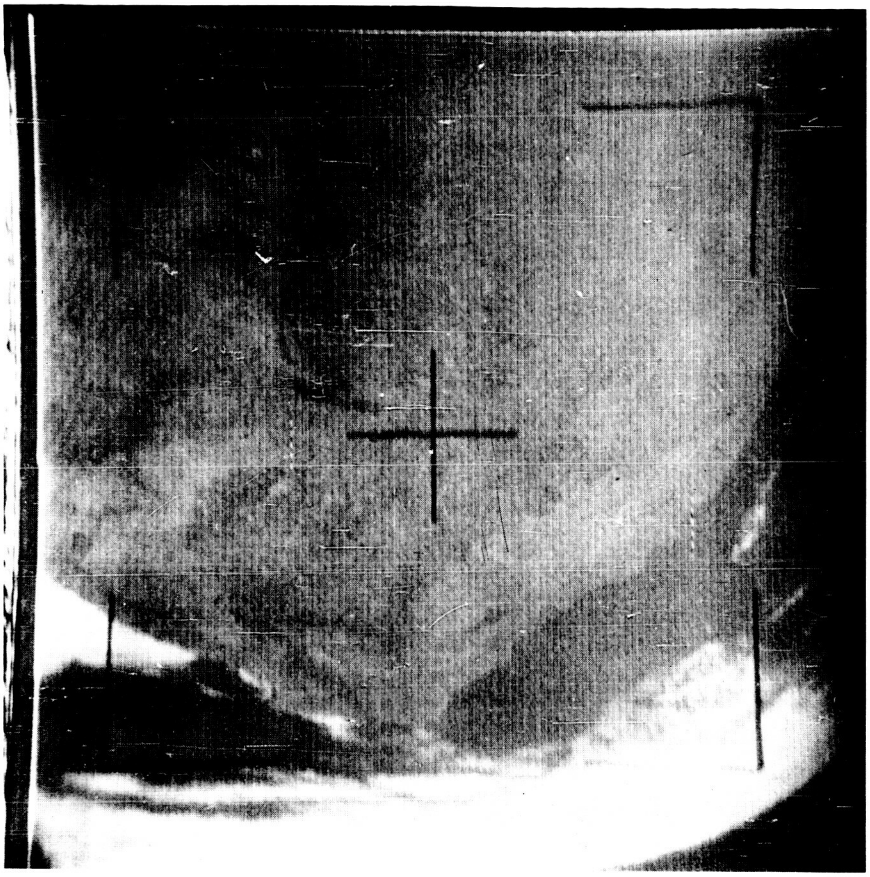
Sequence 0230 T1

Frame 11

Wide-angle

1232 GMT

5 July 1962



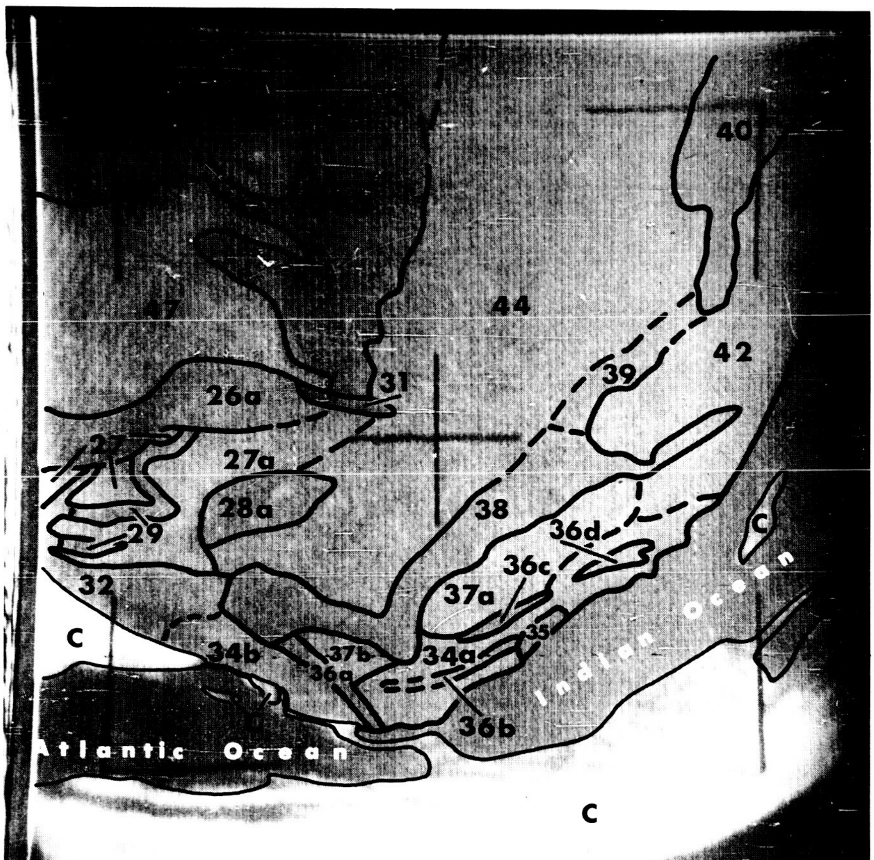


PLATE **10**

Tiros V

Sequence
0230 T1

Frame 9

Wide-angle

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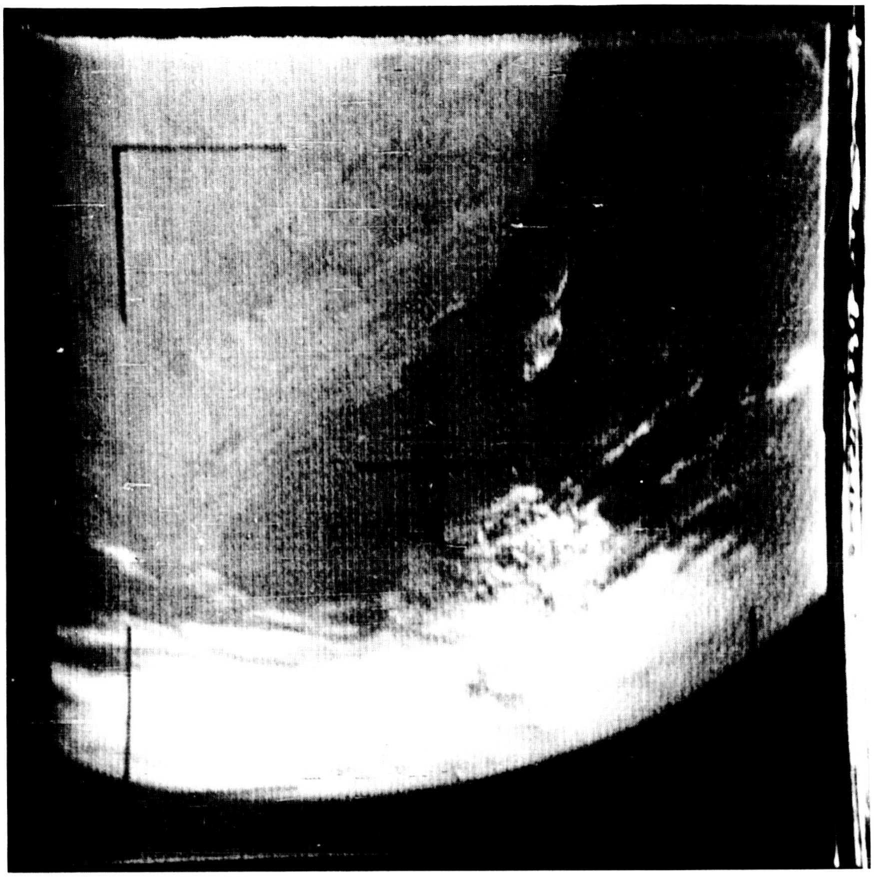

PLATE **11**

Tiros V

Sequence
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Frame 7

Wide-angle

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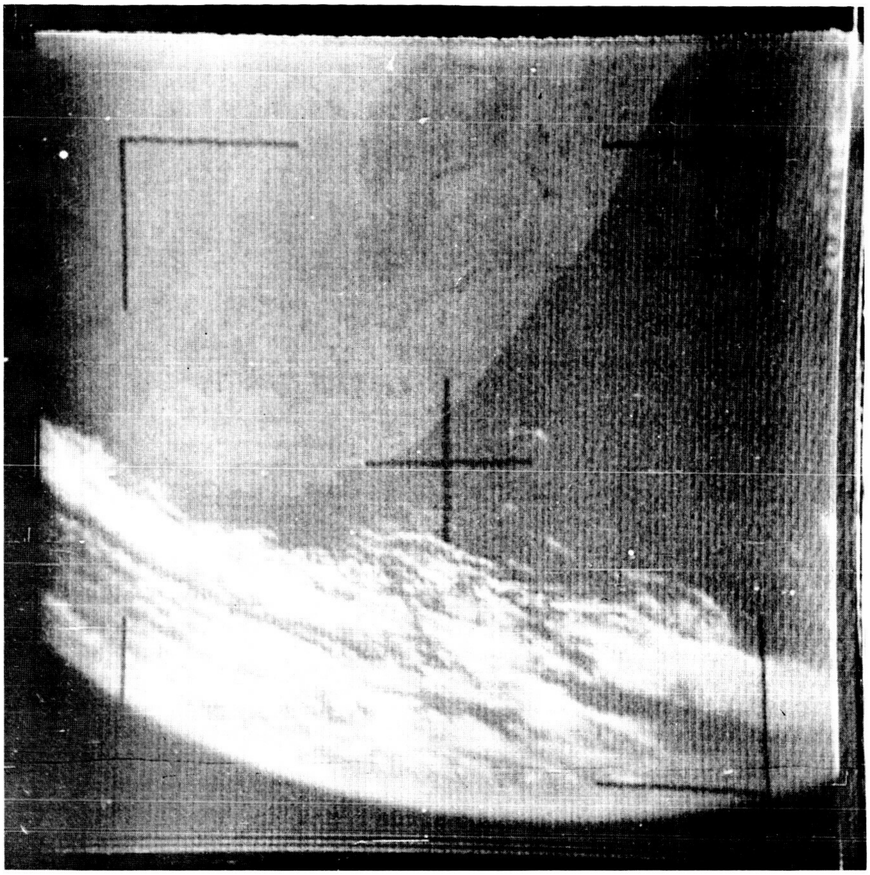
5 July 1962



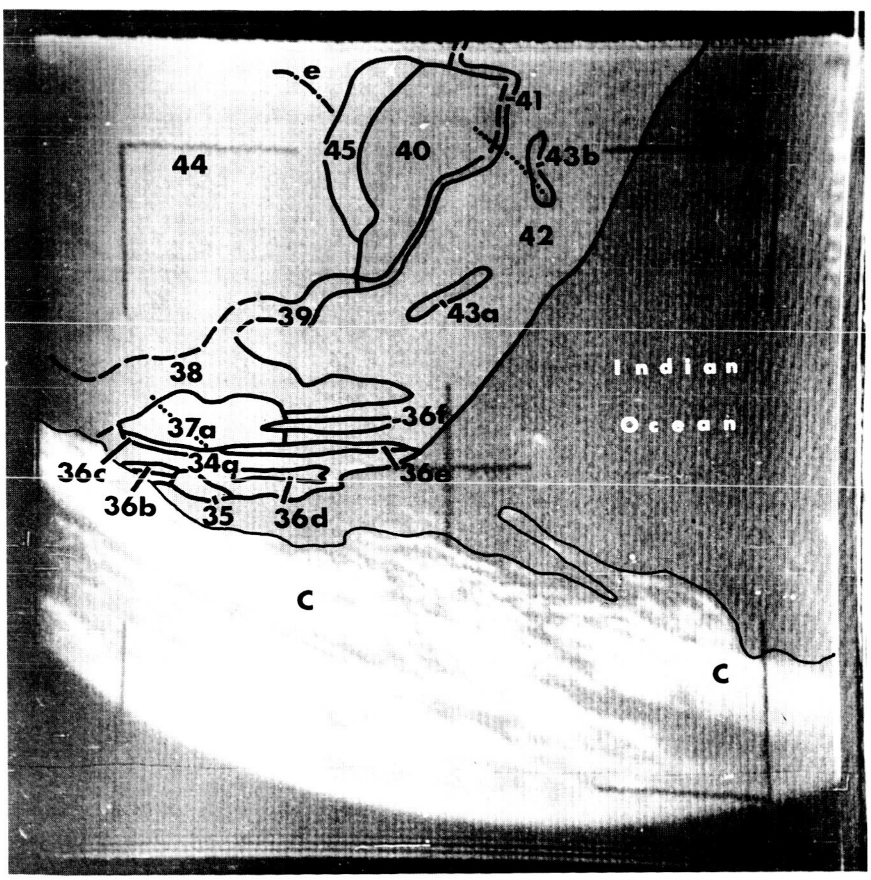


PLATE **12**

Tiros V

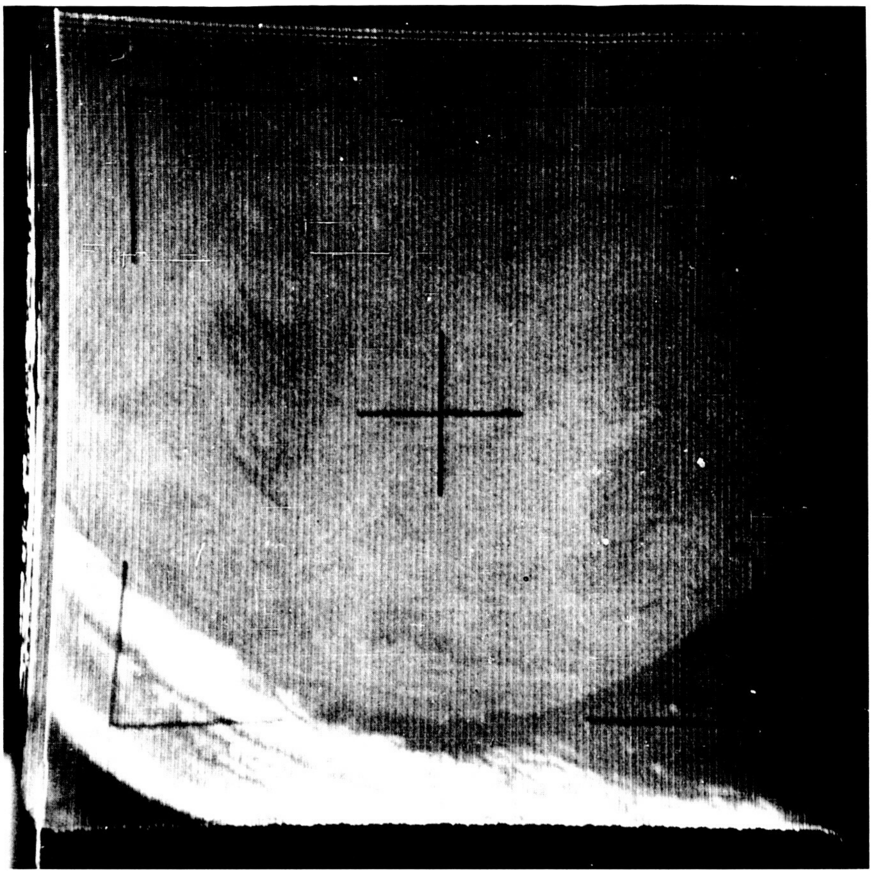
Sequence 0245 T1

Frame 5

Wide-angle

1200 GMT

6 July 1962



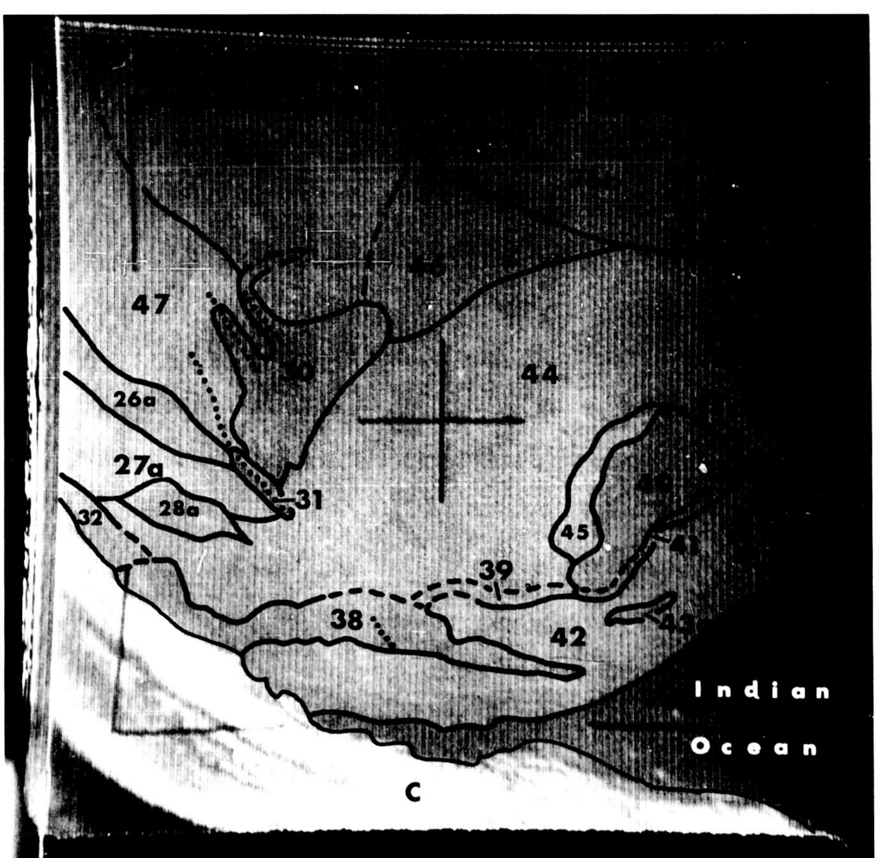


PLATE **13**

Tiros V

Sequence
0245 T1

Frame 7

Wide-angle

1200 GMT

6 July 1962

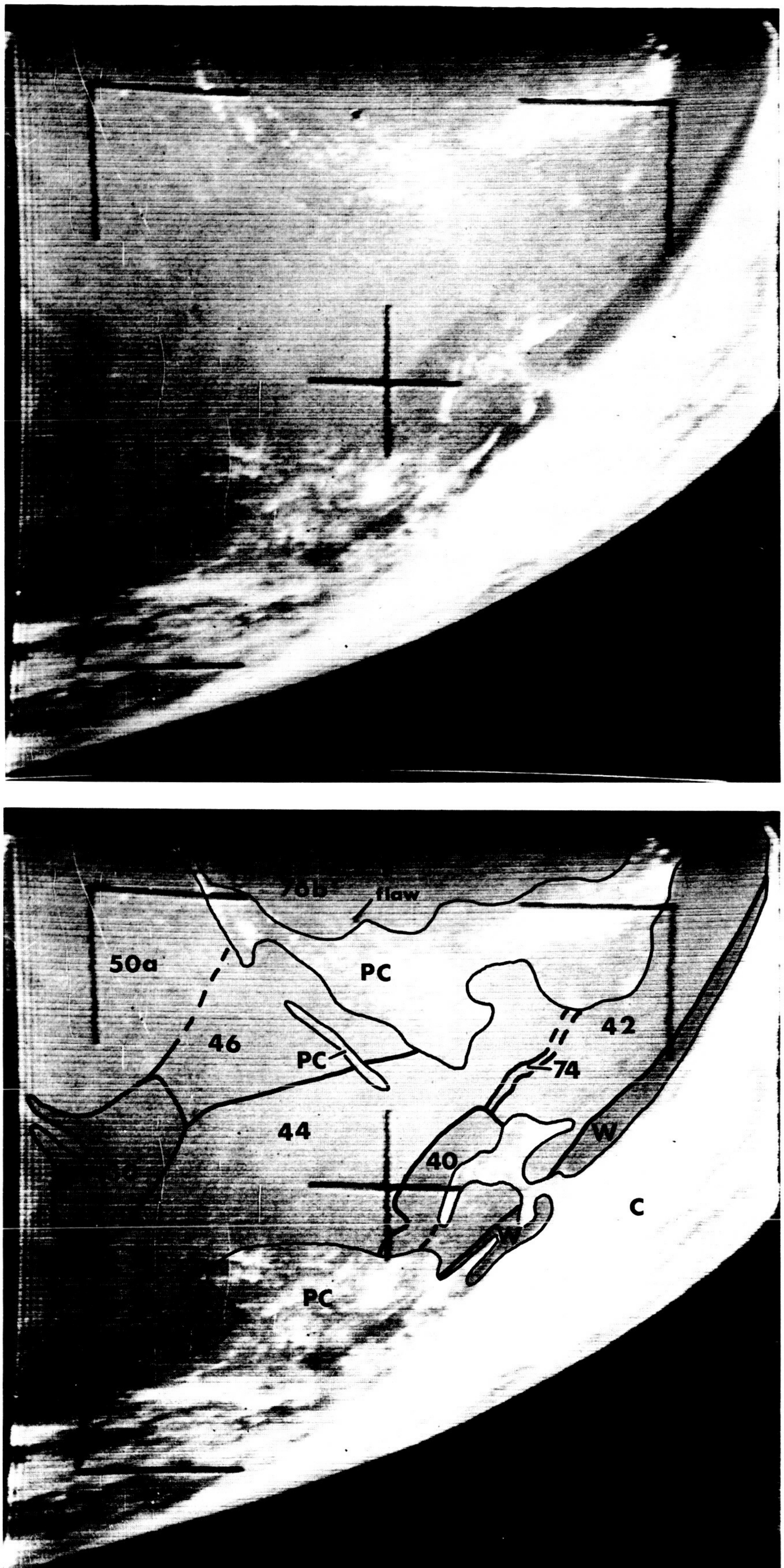


PLATE **14**

Tiros VI

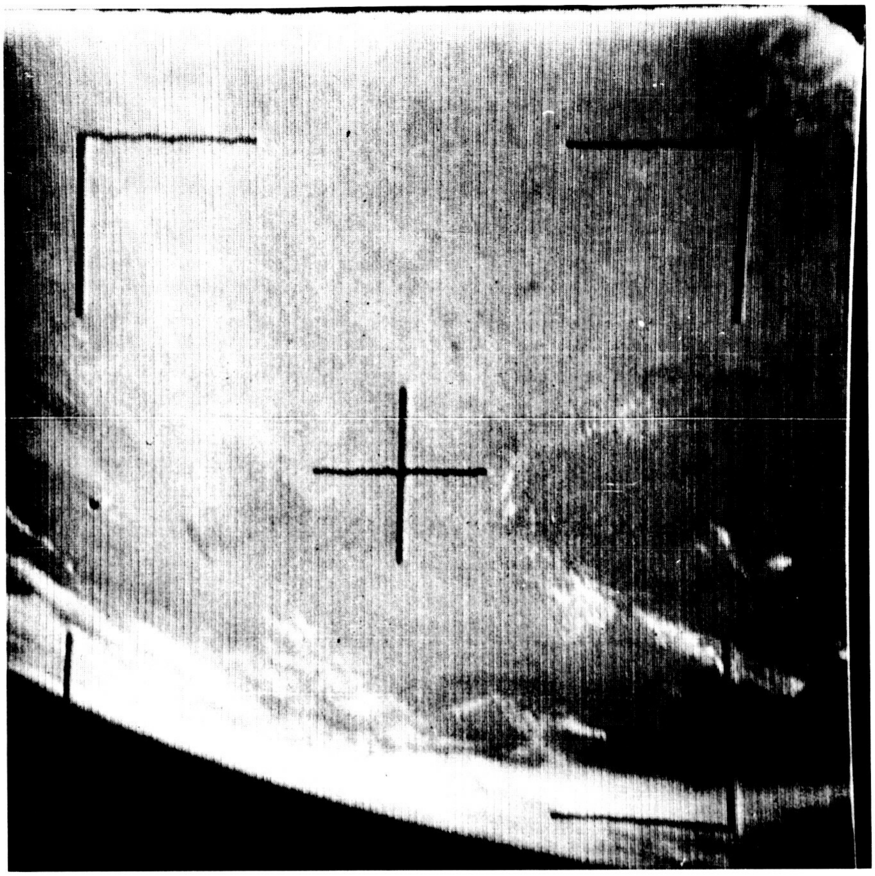
Sequence
0062 T2

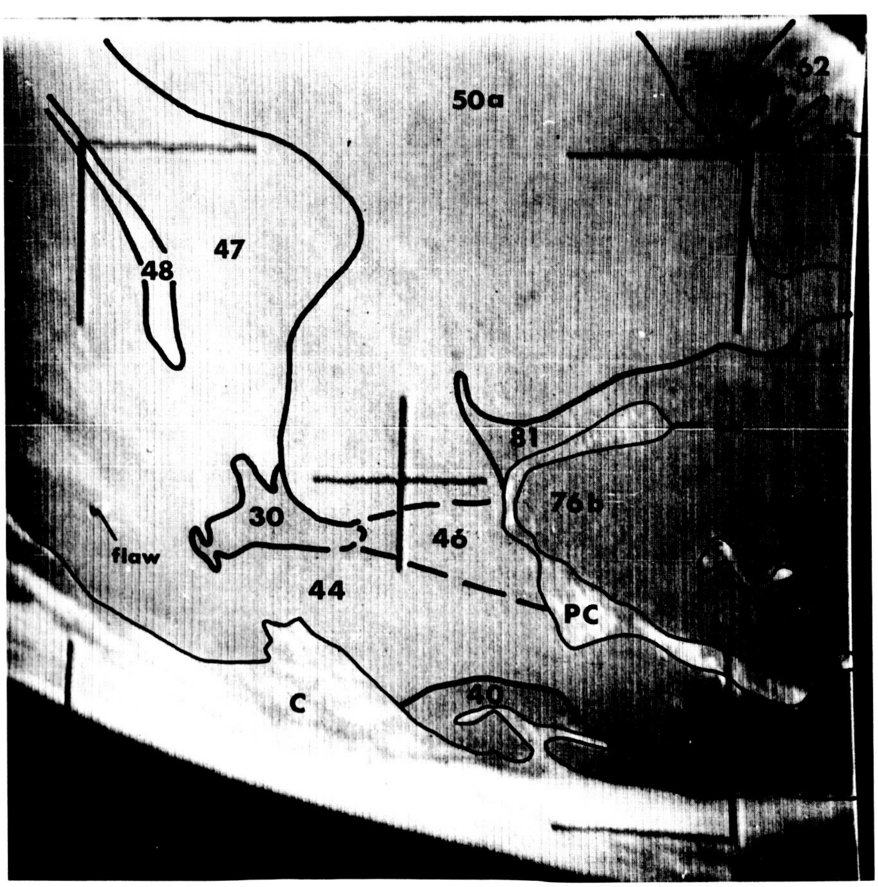
Frame 9

Medium-angle

1225 GMT

22 Sept 1962





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Tiros VI

Sequence
0062 T2

Frame 11

Medium-angle

1225 GMT

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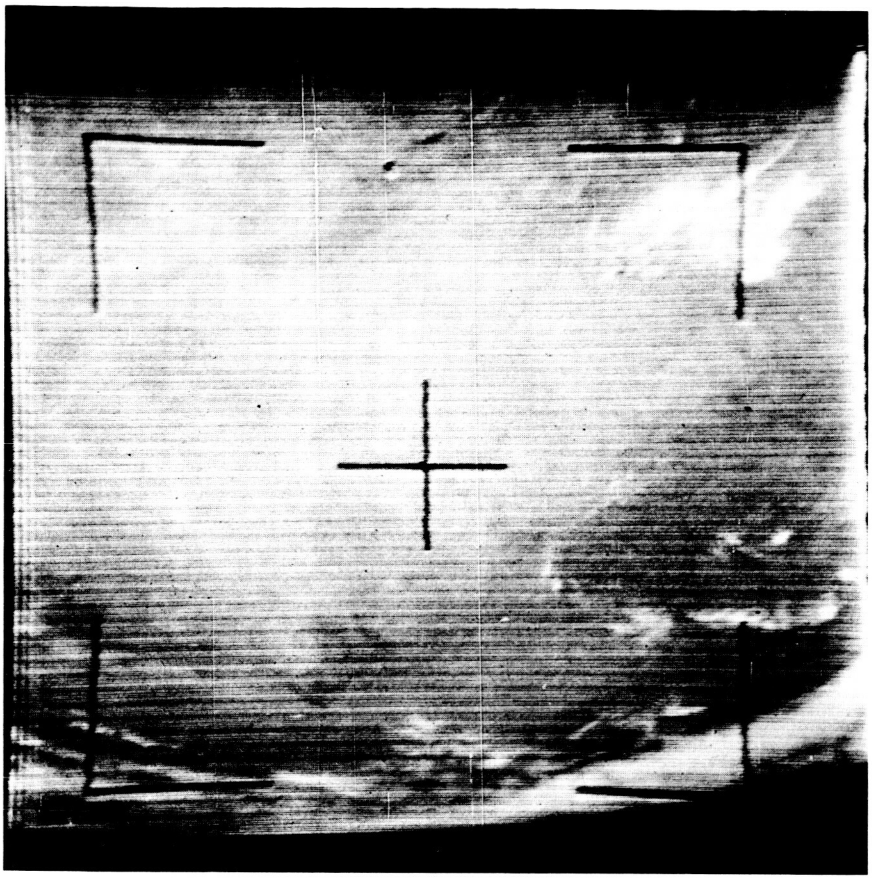


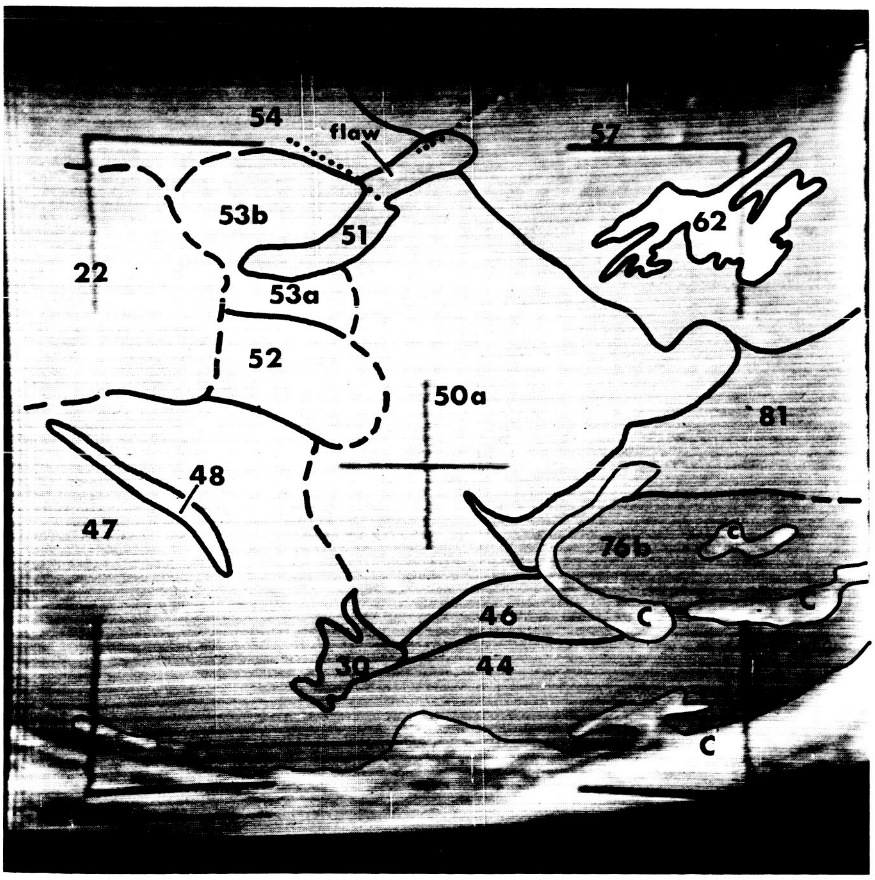


PLATE **16**

Tiros VI

Sequence
0062 T2

Frame 12

Medium-angle

1225 GMT

22 Sept 1962

PLATE **17**

Tiros IV

Sequence
1290 T1

Frame 7

Wide-angle

0810 GMT

9 May 1962

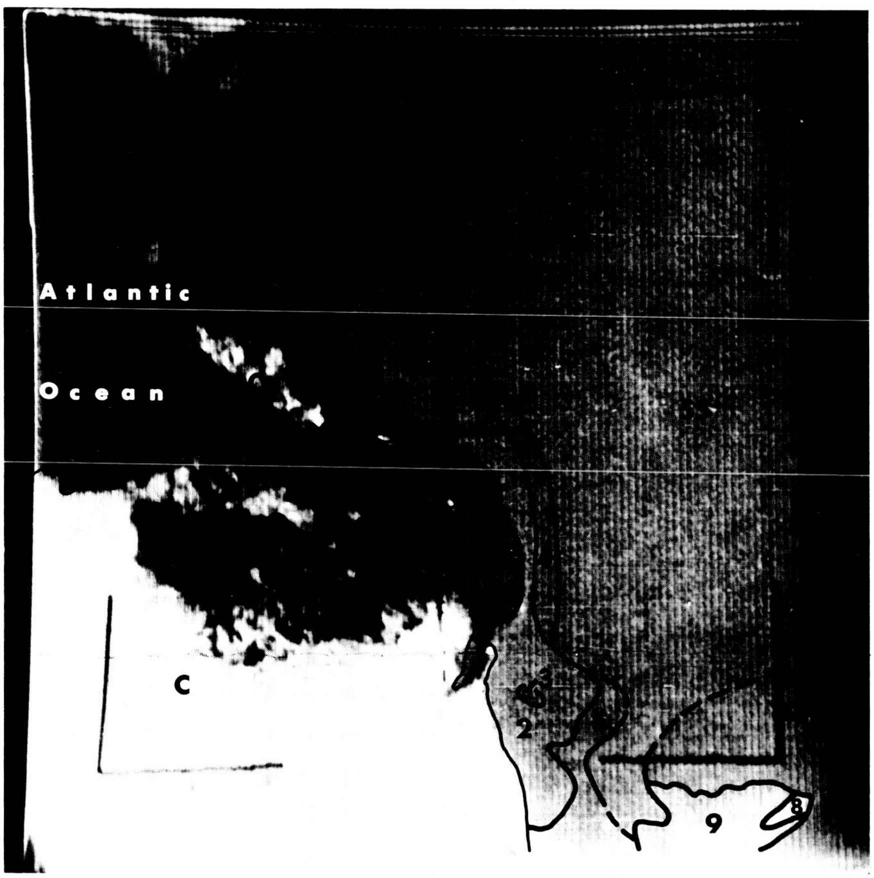


PLATE **18**

Tiros V

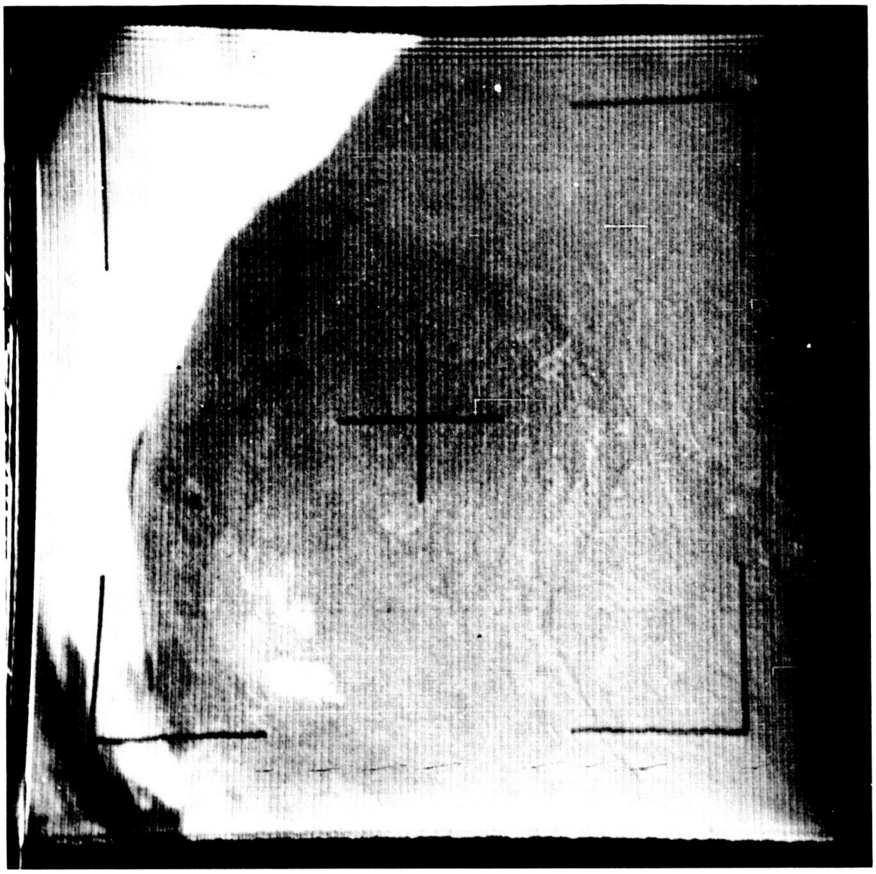
Sequence
0145 D*1

Frame 13

Wide-angle

1409 GMT

29 June 1962



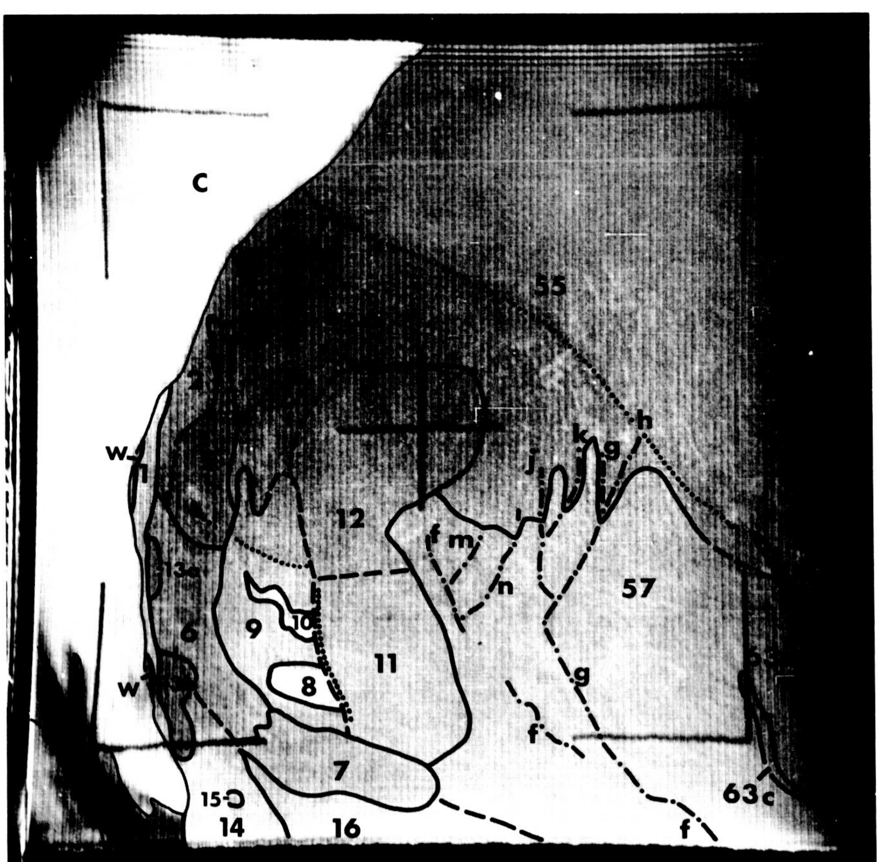


PLATE **19**

Tiros V

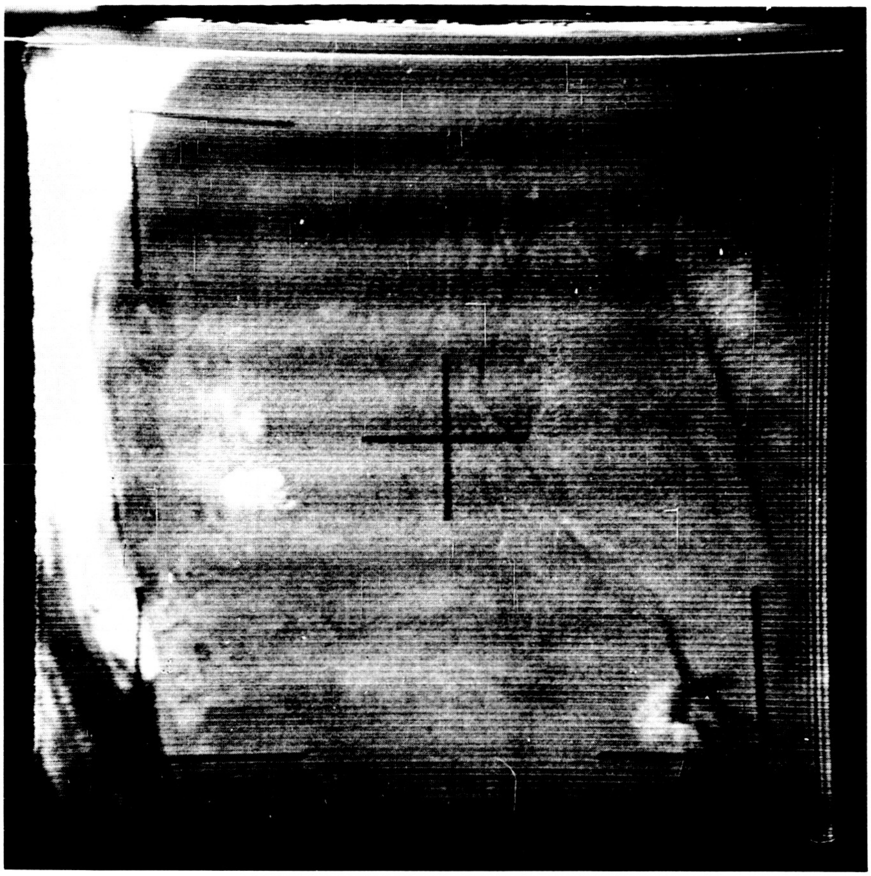
Sequence
0245 T1

Frame 15

Wide-angle

1200 GMT

6 July 1962



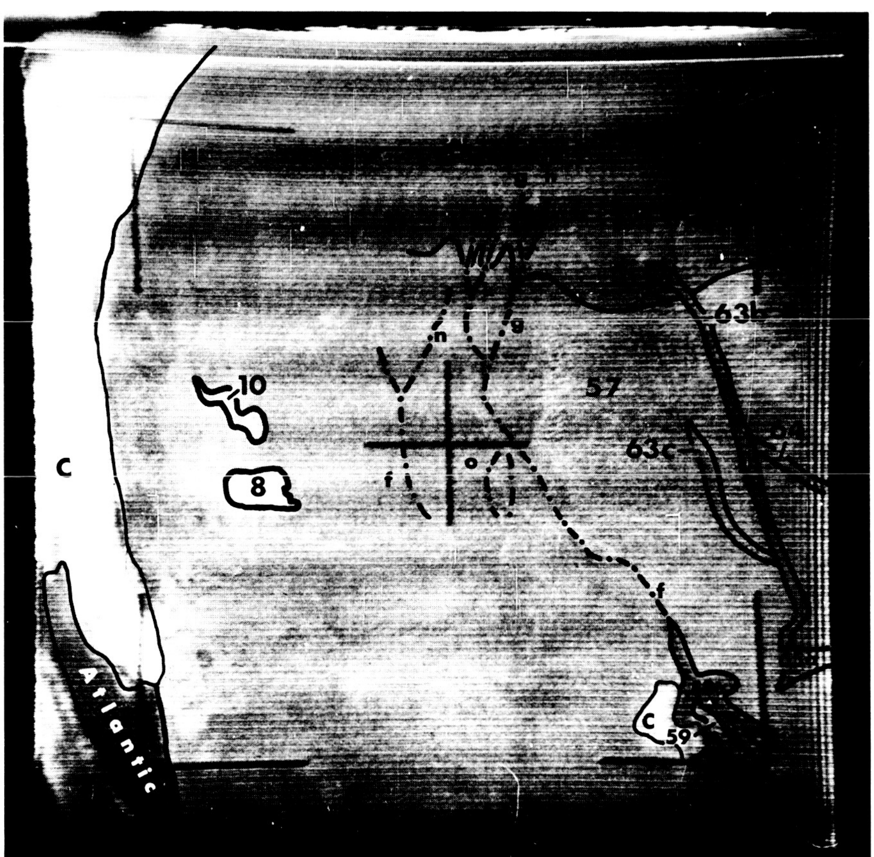


PLATE **20**

Tiros V

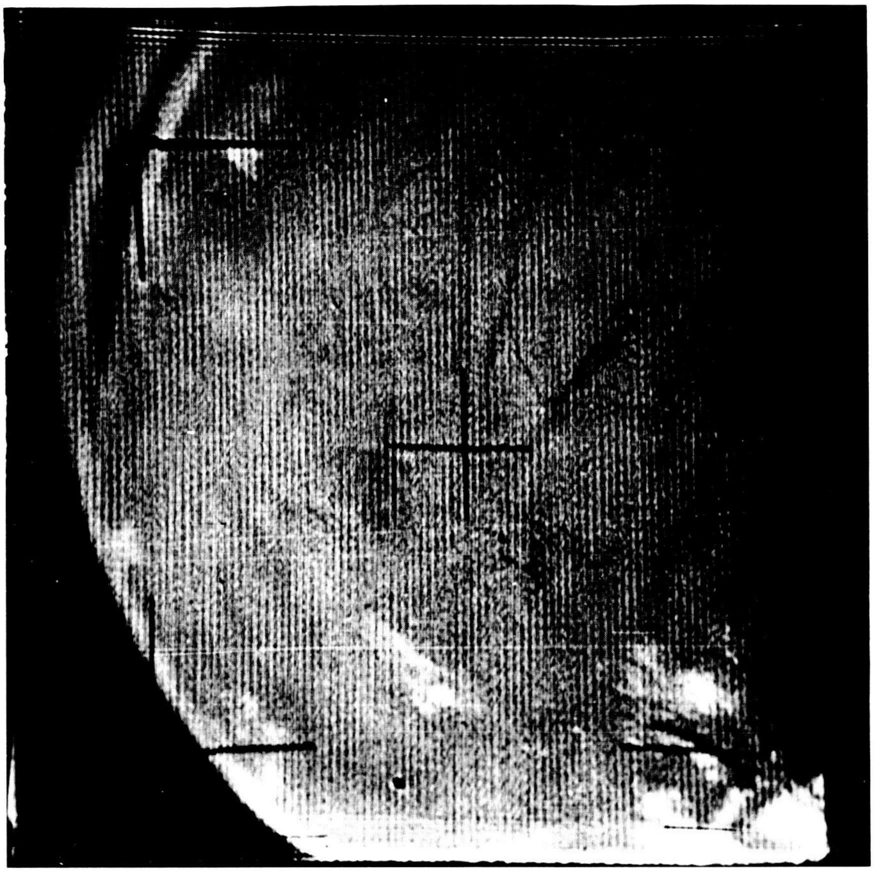
Sequence
0245 T1

Frame 14

Wide-angle

1200 GMT

6 July 1962



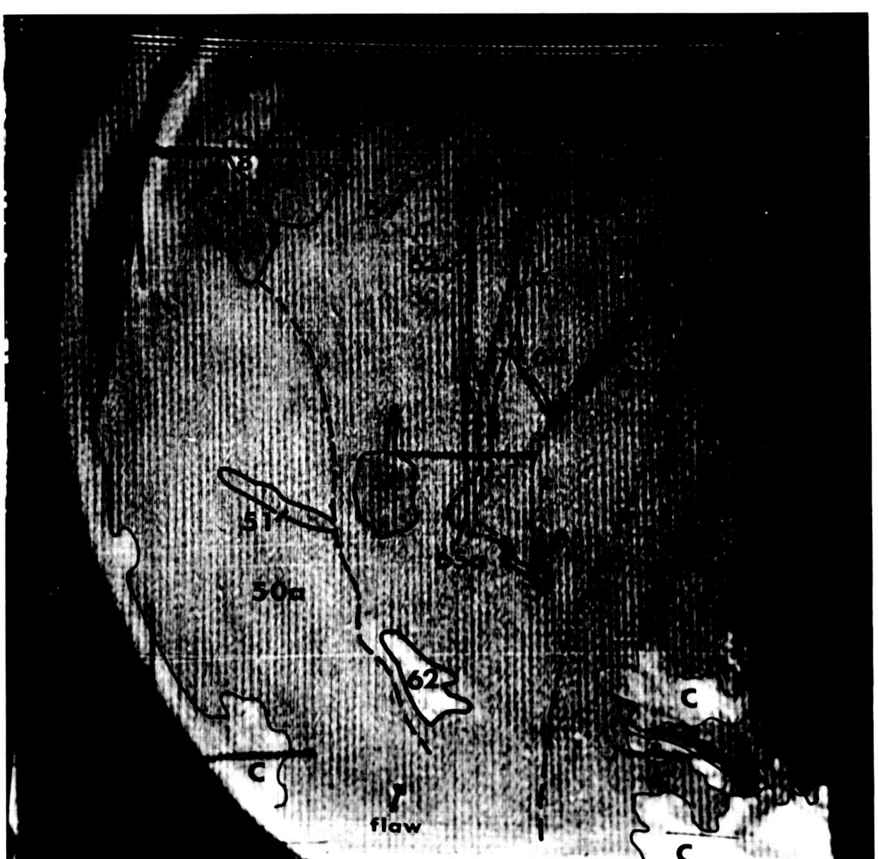


PLATE **21**

Tiros IV

Sequence
1290 T1

Frame 1

Wide-angle

0810 GMT

9 May 1962

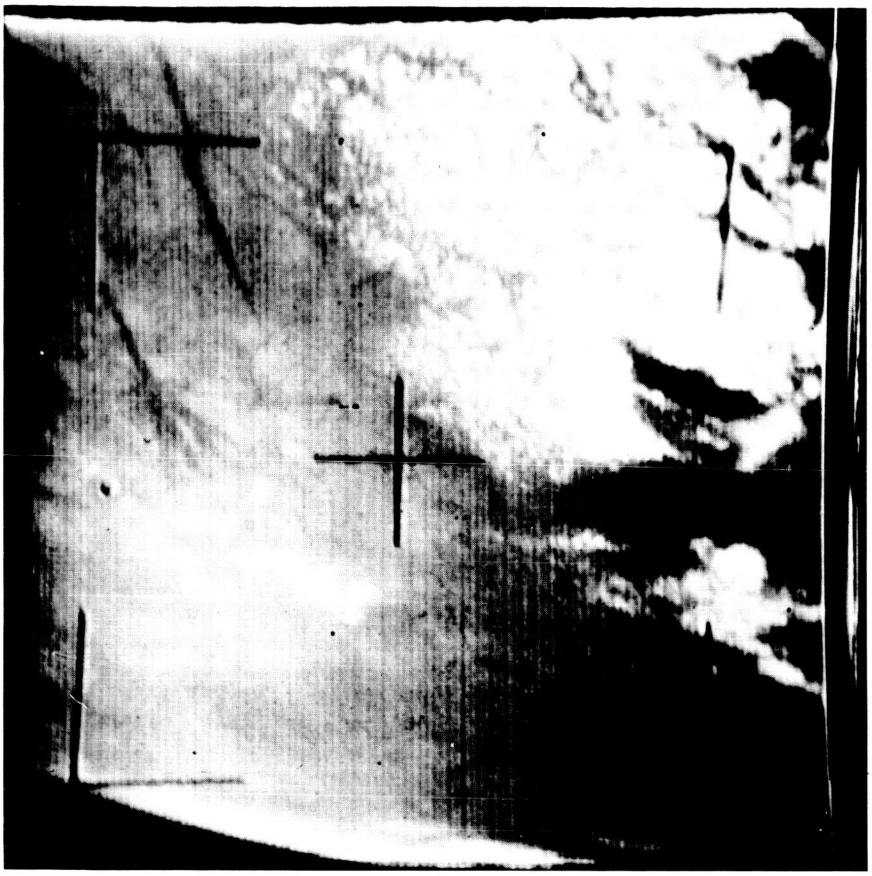


PLATE **22**

Tiros VI

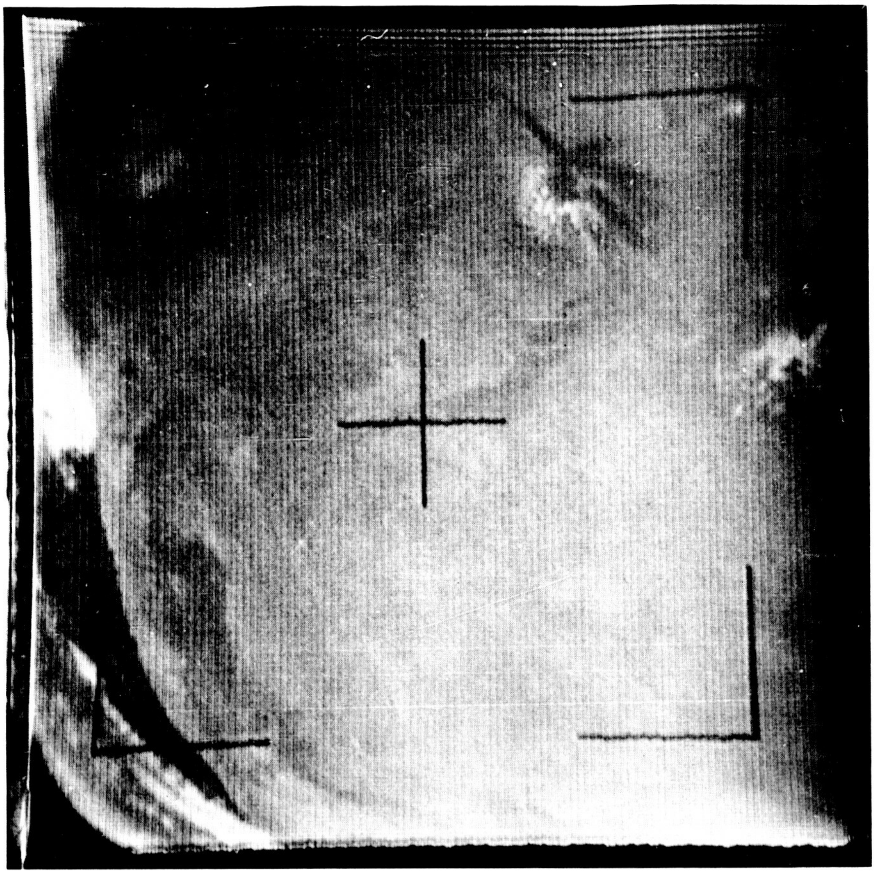
Sequence
0034 T2

Frame 11

Medium-angle

1240 GMT

20 Sept 1962



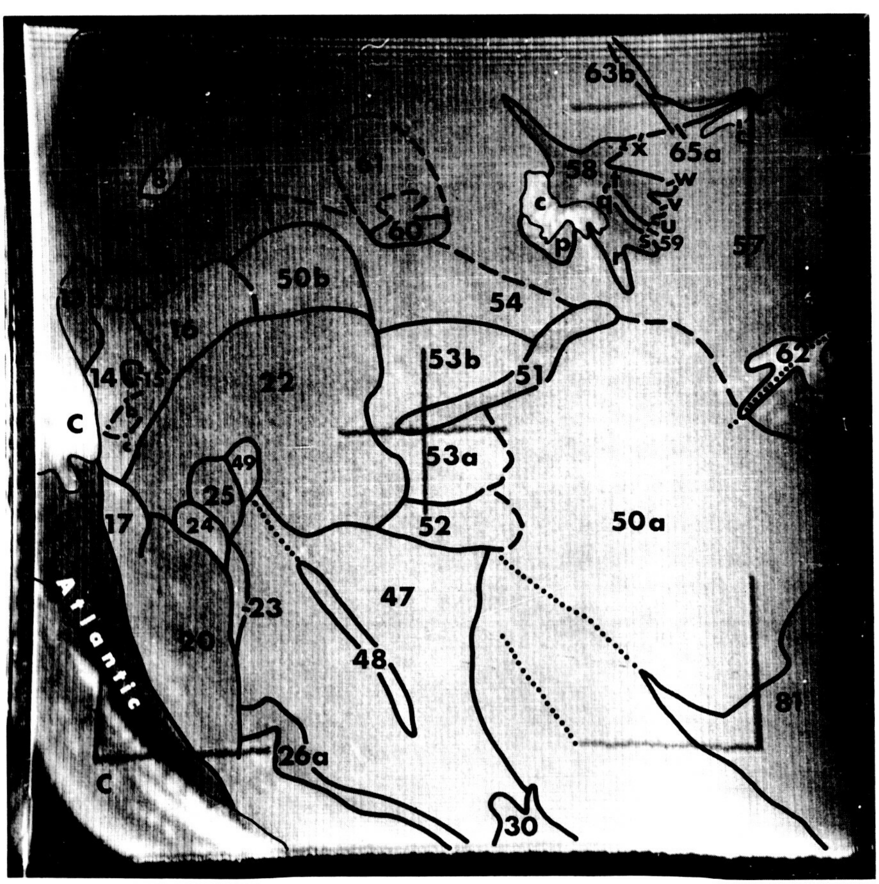


PLATE **23**

Tiros V

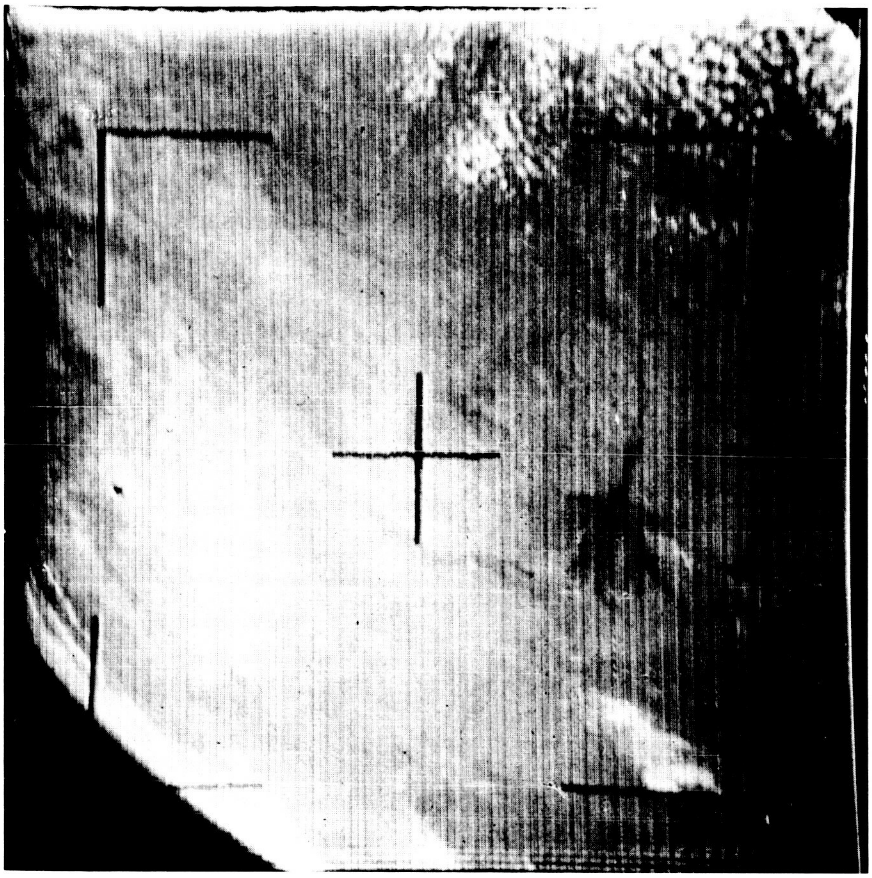
Sequence 0245 T1

Frame 11

Wide-angle

1200 GMT

6 July 1962



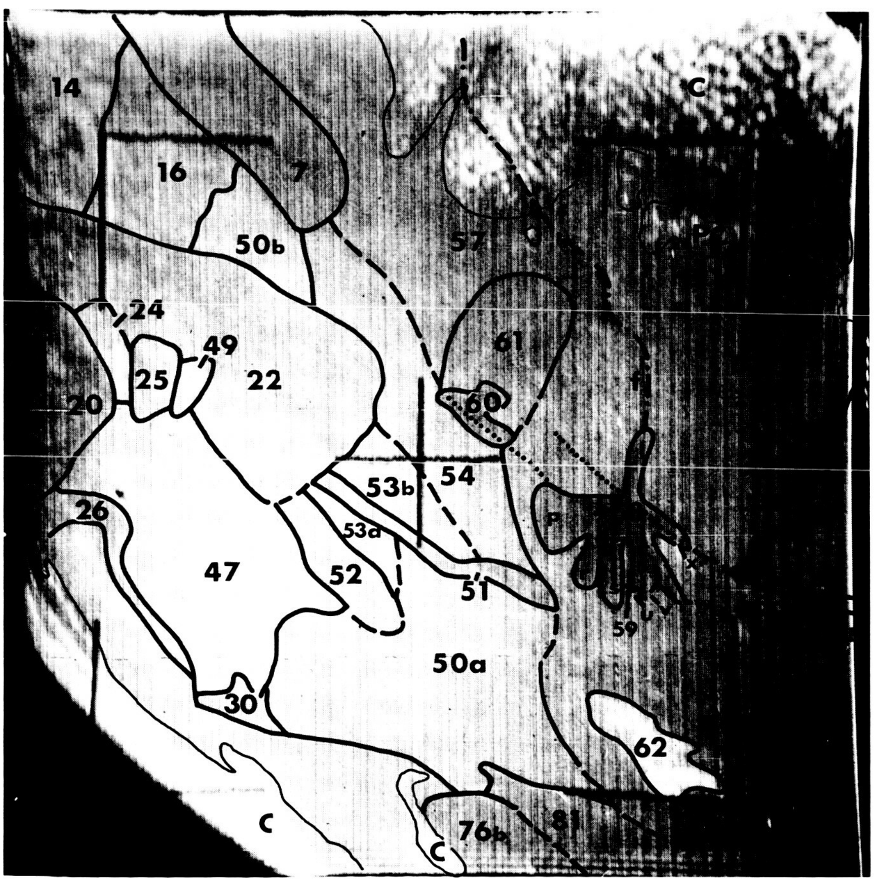


PLATE **24**

Tiros VI

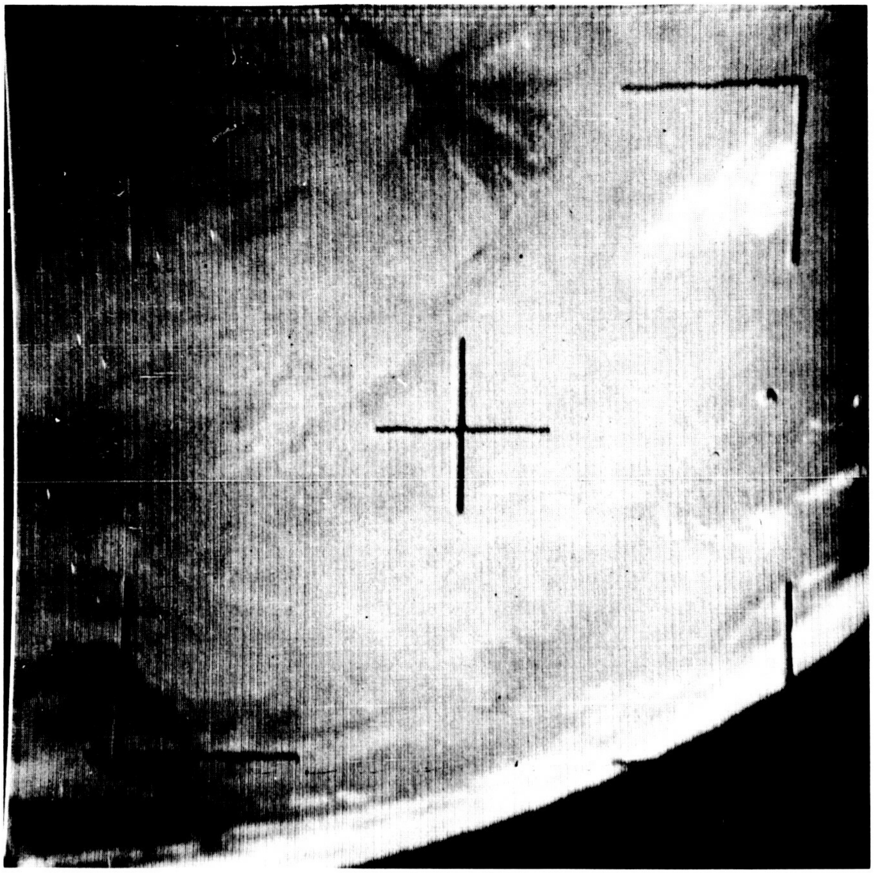
Sequence
0062 T2

Frame 14

Medium-angle

1225 GMT

22 Sept 1962



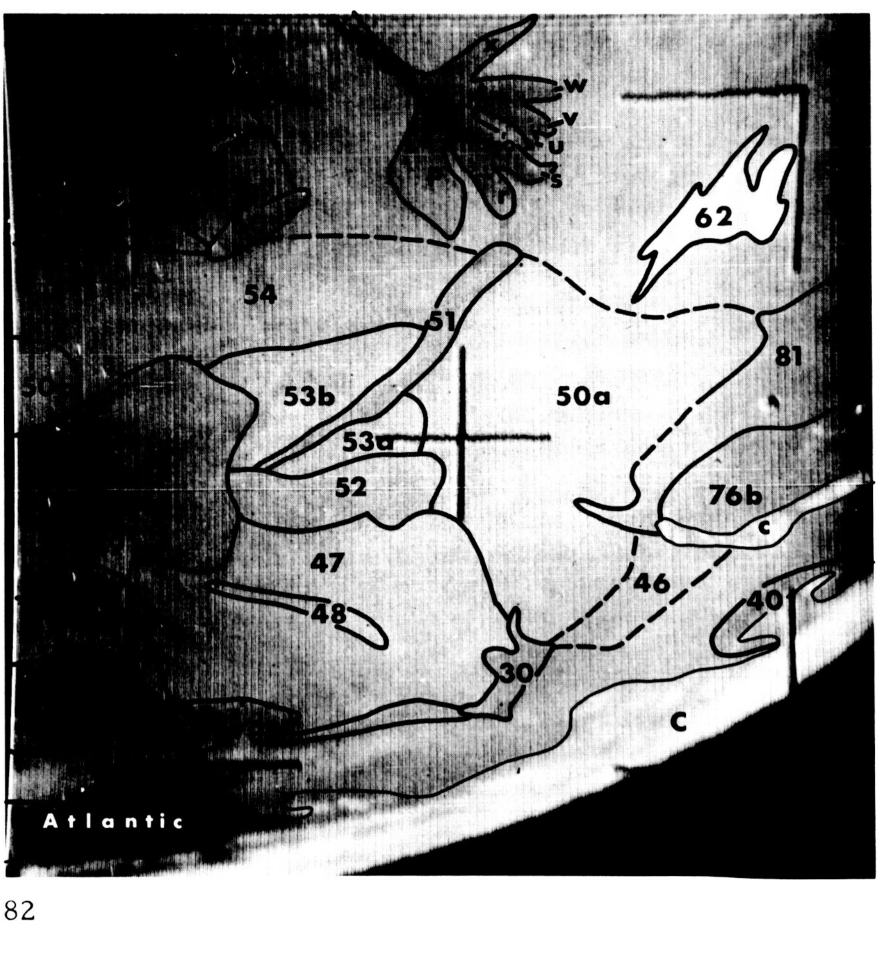


PLATE **25**

Tiros VI

Sequence
0062 T2

Frame 13

Medium-angle

1225 GMT

22 Sept 1962

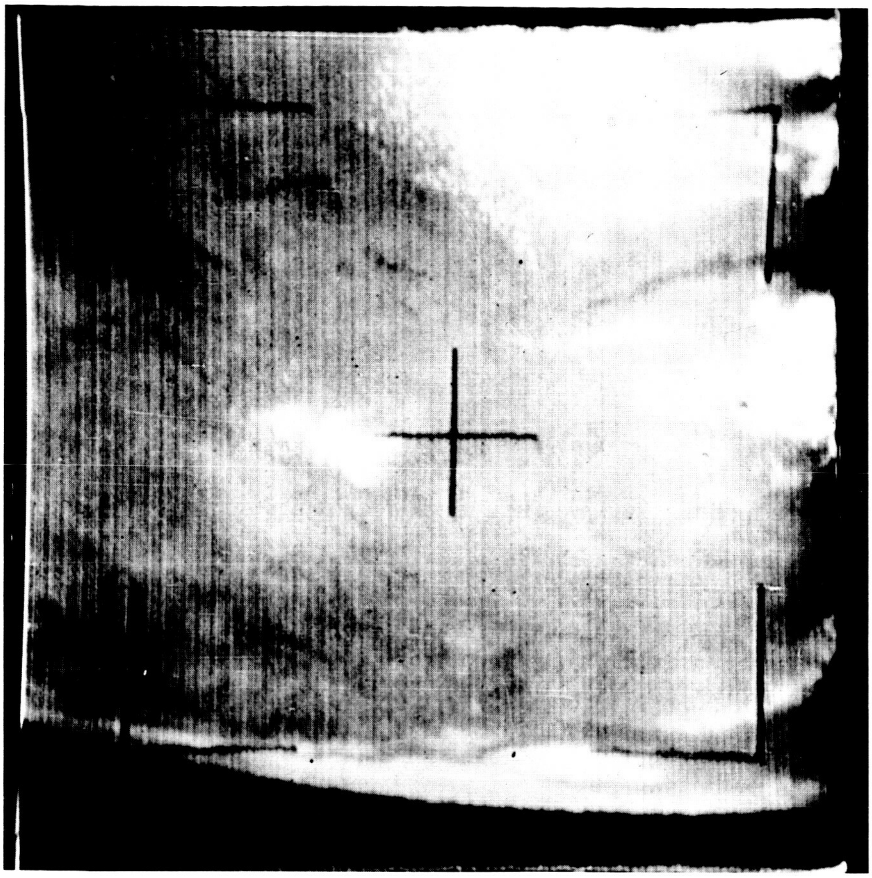


PLATE **26**

Tiros VI

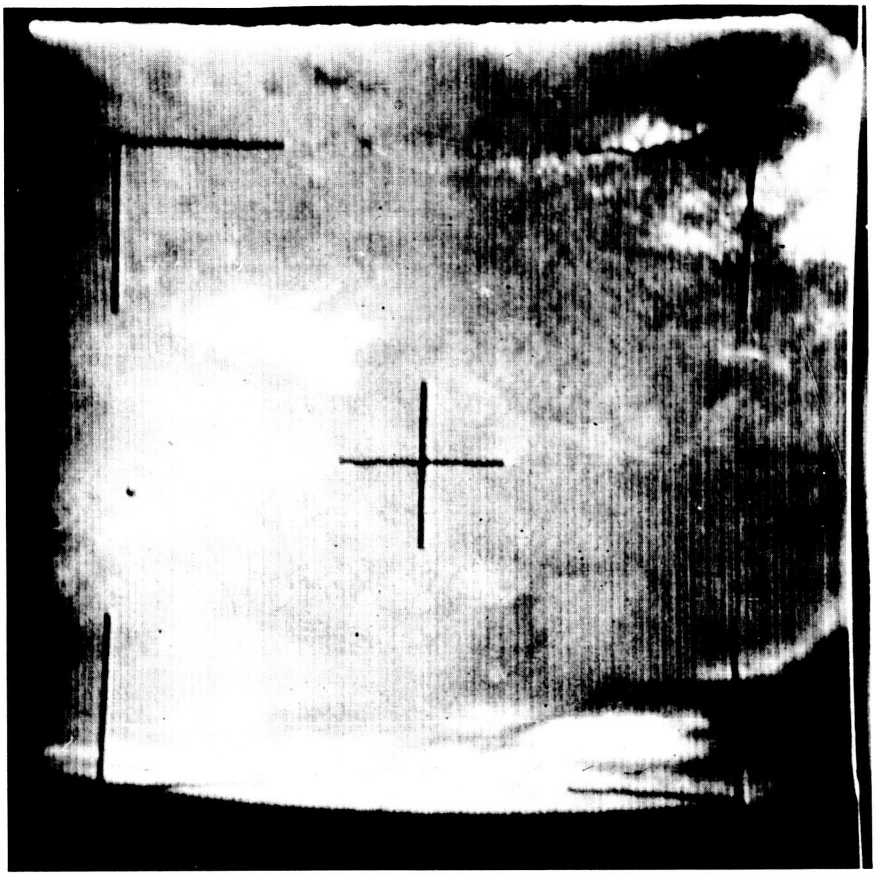
Sequence
0034 T2

Frame 10

Medium-angle

1240 GMT

20 Sept 1962



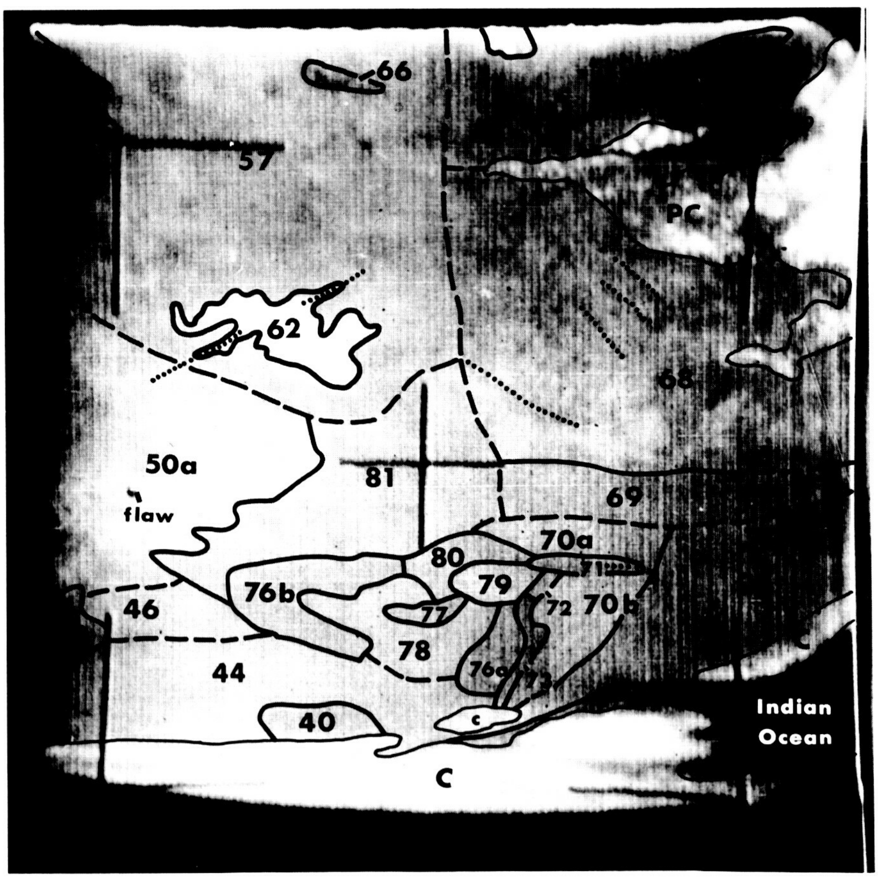


PLATE **27**

Tiros VI

Sequence
0034 T2

Frame 9

Medium-angle

1240 GMT

20 Sept 1962

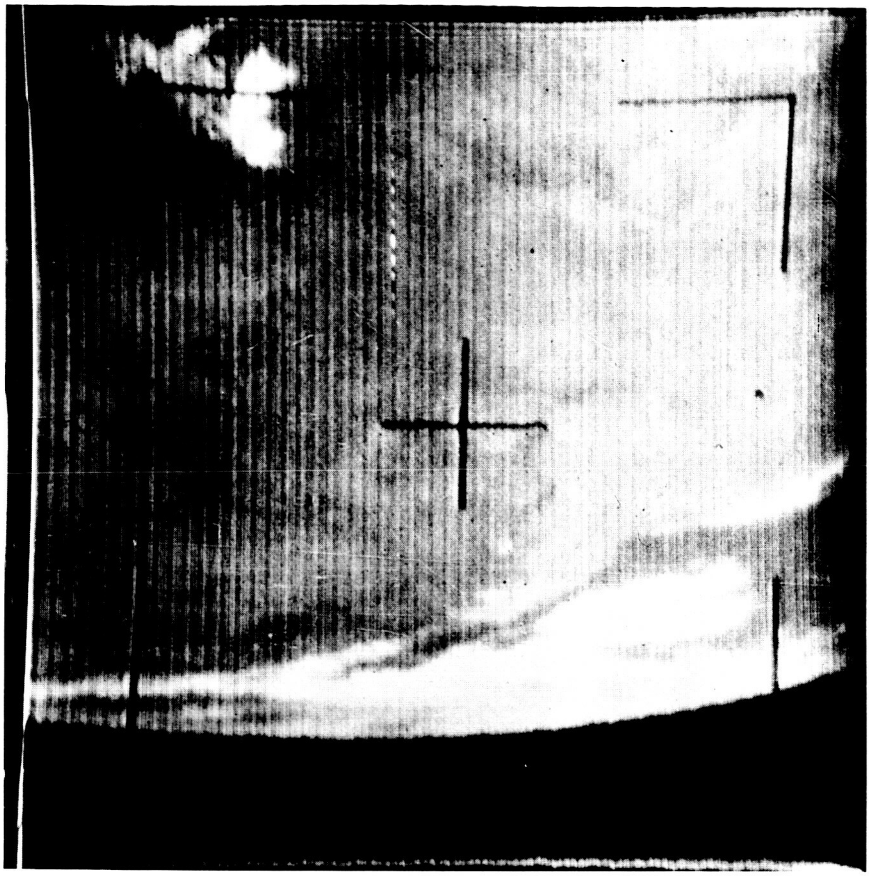


PLATE **28**

Tiros VI

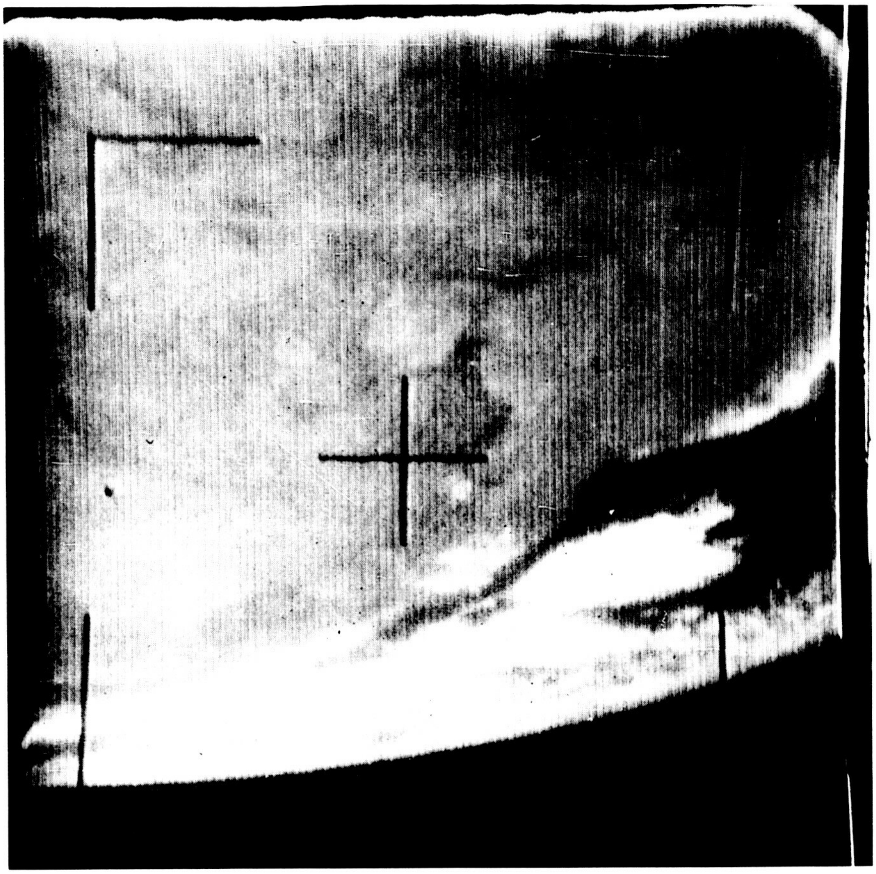
Sequence
0034 T2

Frame 8

Medium-angle

1240 GMT

20 Sept 1962



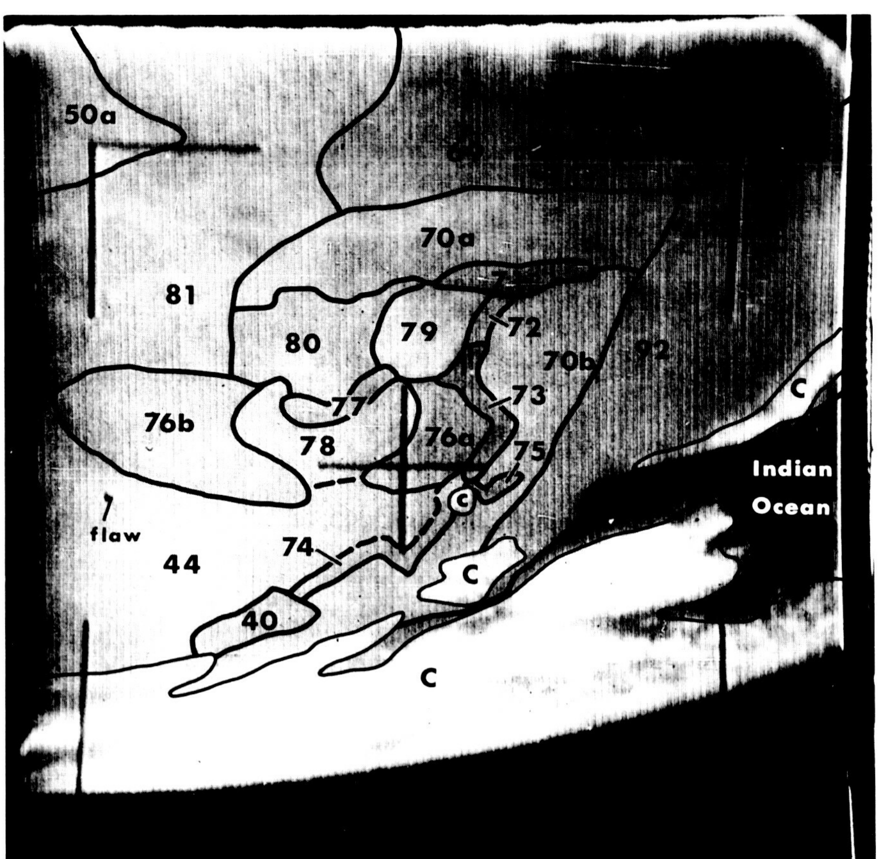


PLATE **29**

Tiros VI

Sequence
0034 T2

Frame 7

Medium-angle

1240 GMT

20 Sept 1962

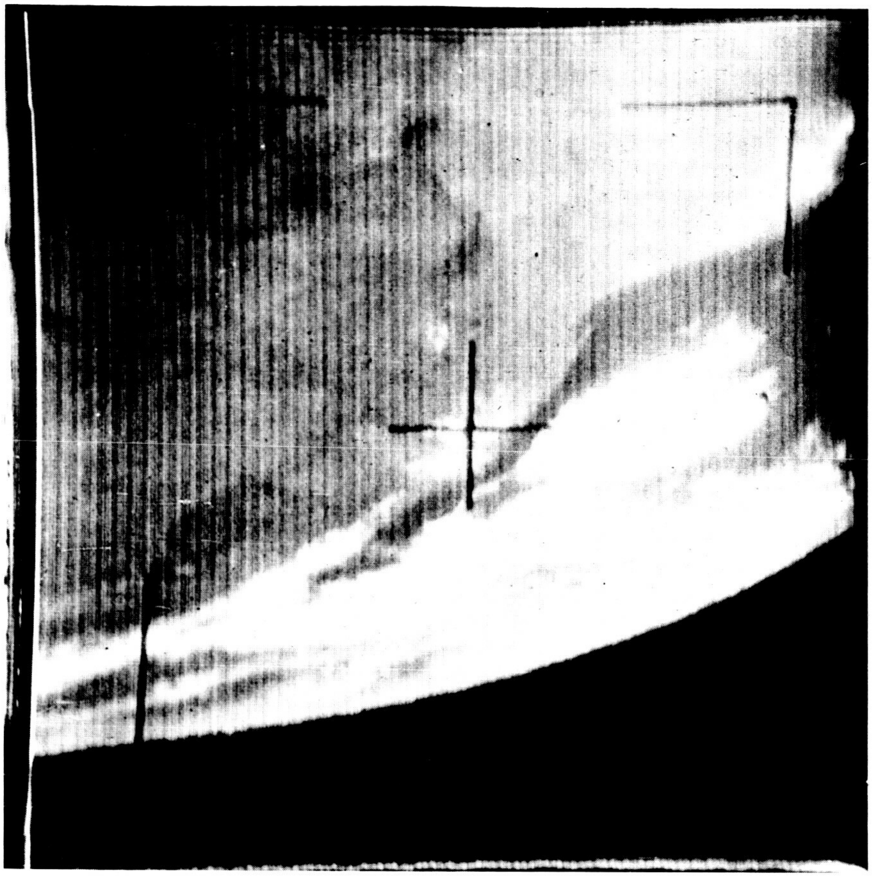


PLATE **30**

Tiros VI

Sequence
0034 T2

Frame 6

Medium-angle

1240 GMT

20 Sept 1962

PLATE **31**

Tiros VI

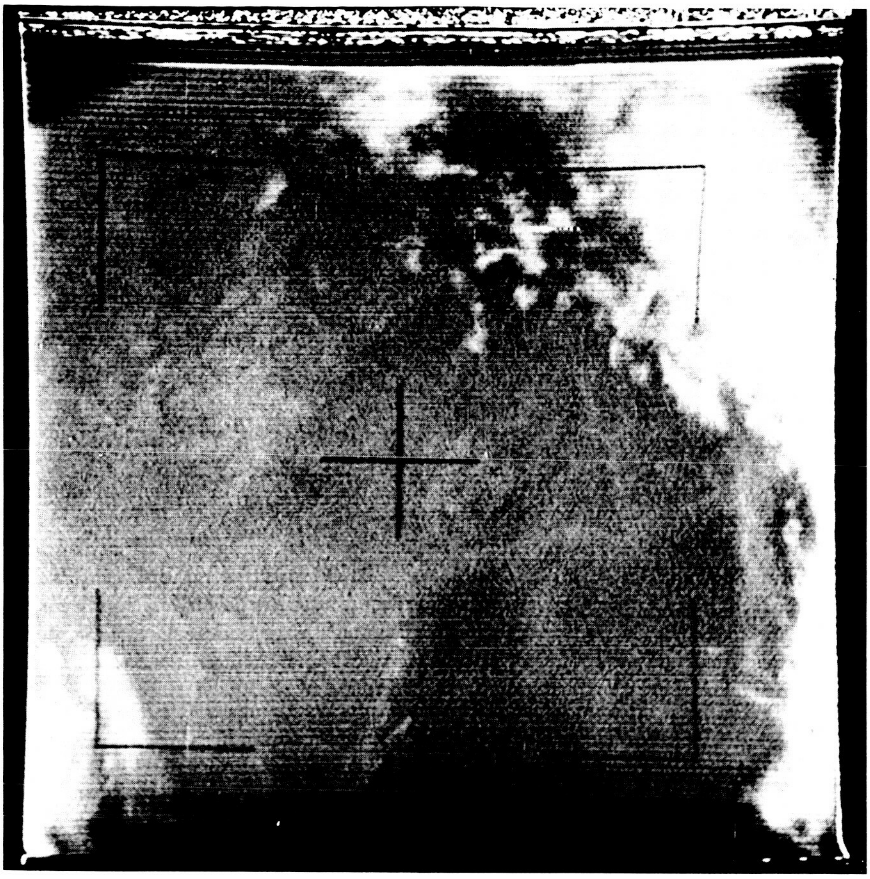
Sequence
0190 T2

Frame 31

Medium-angle

0845 GMT

1 Oct 1962



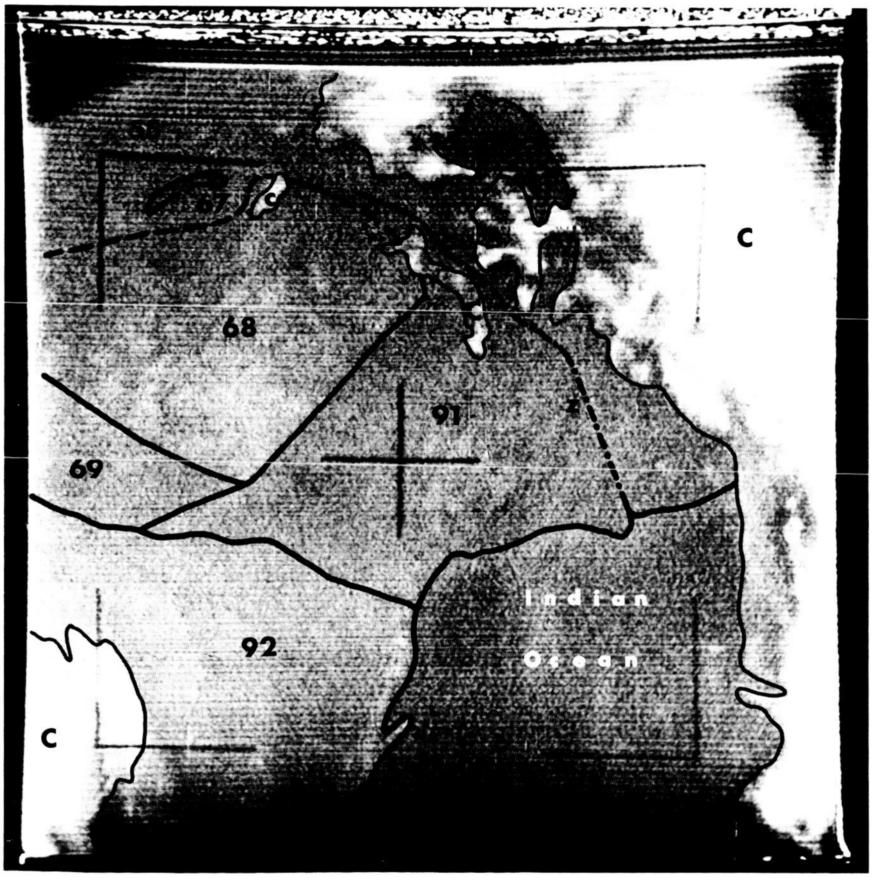


PLATE **32**

Tiros VIII

Sequence
4960 T1

Frame 18

Wide-angle

0545 GMT

27 Nov 1964

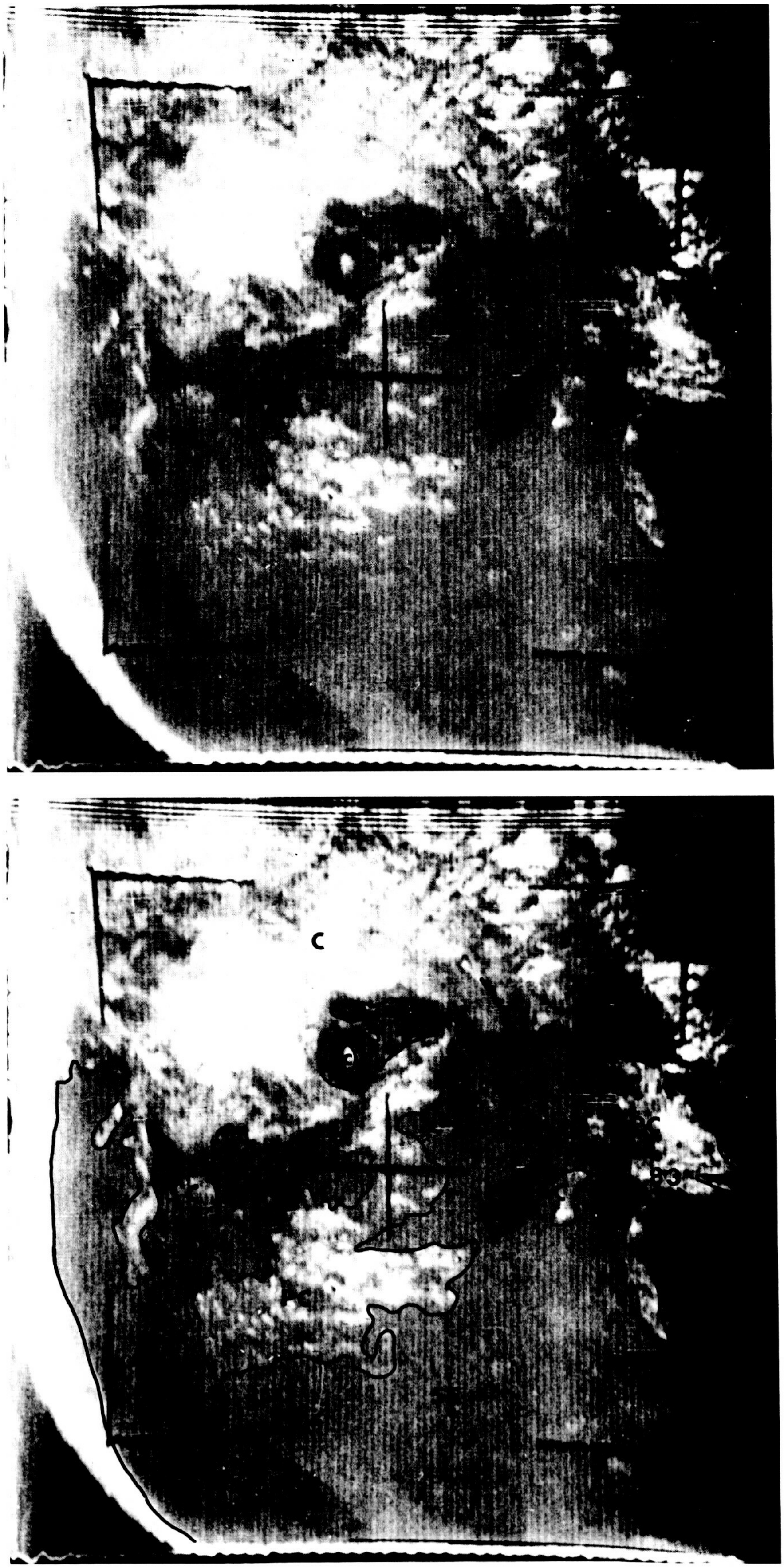


PLATE **33**

Tiros III

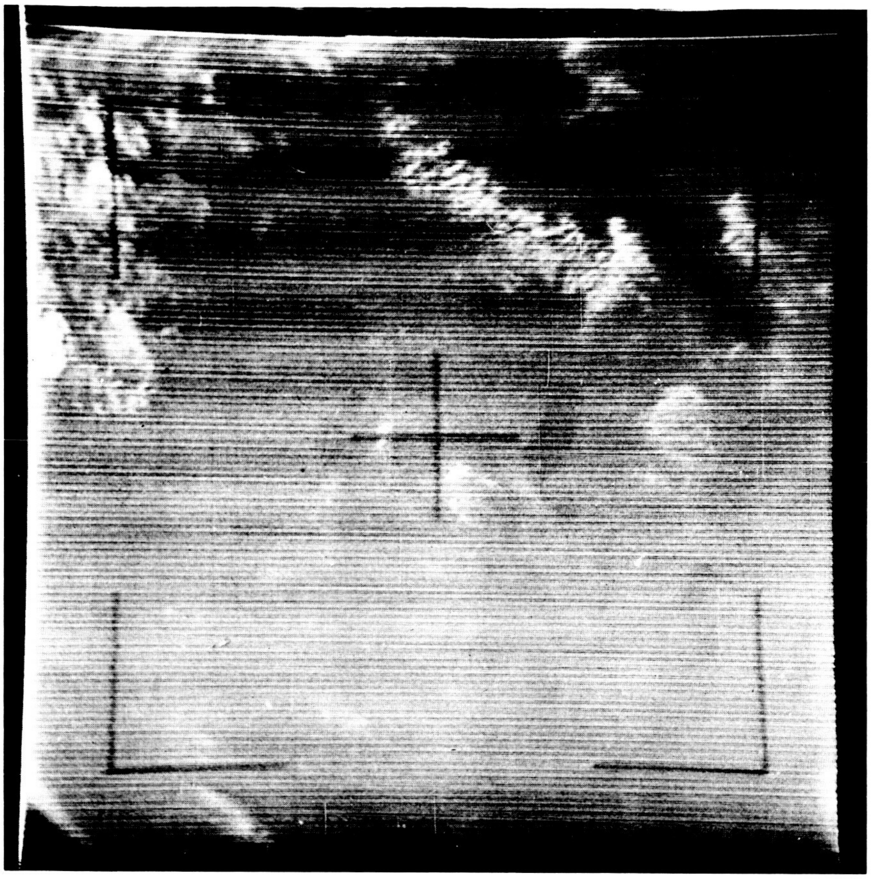
Sequence
0158 T1

Frame 18

Wide-angle

0937 GMT

23 July 1961



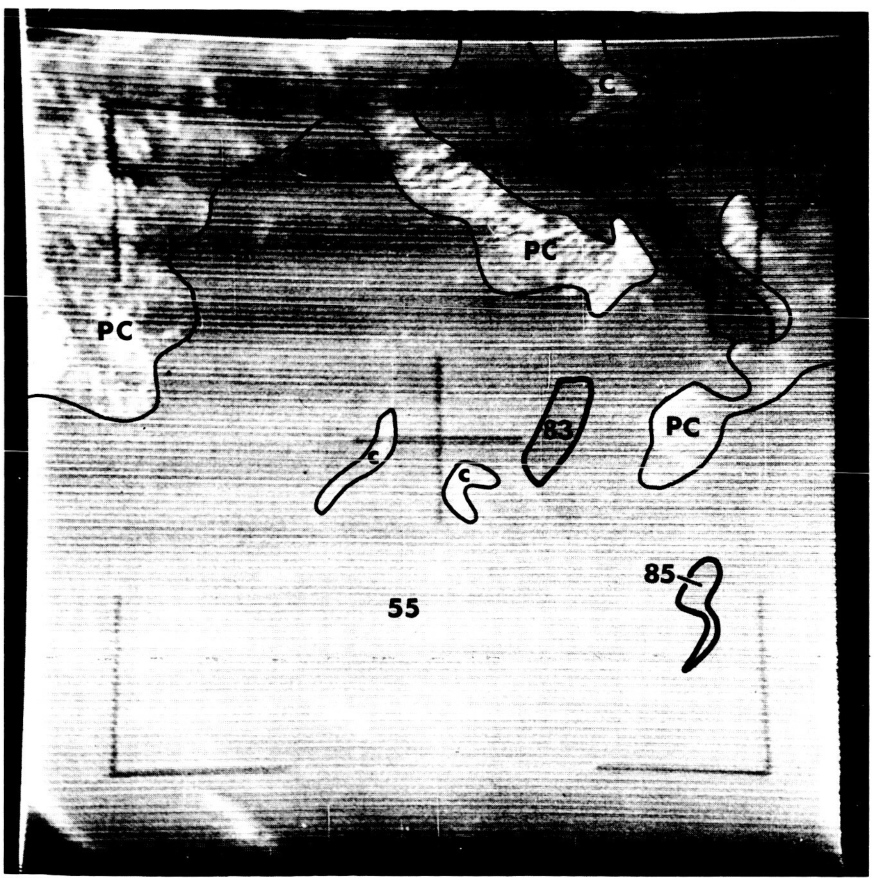


PLATE **34**

Tiros V

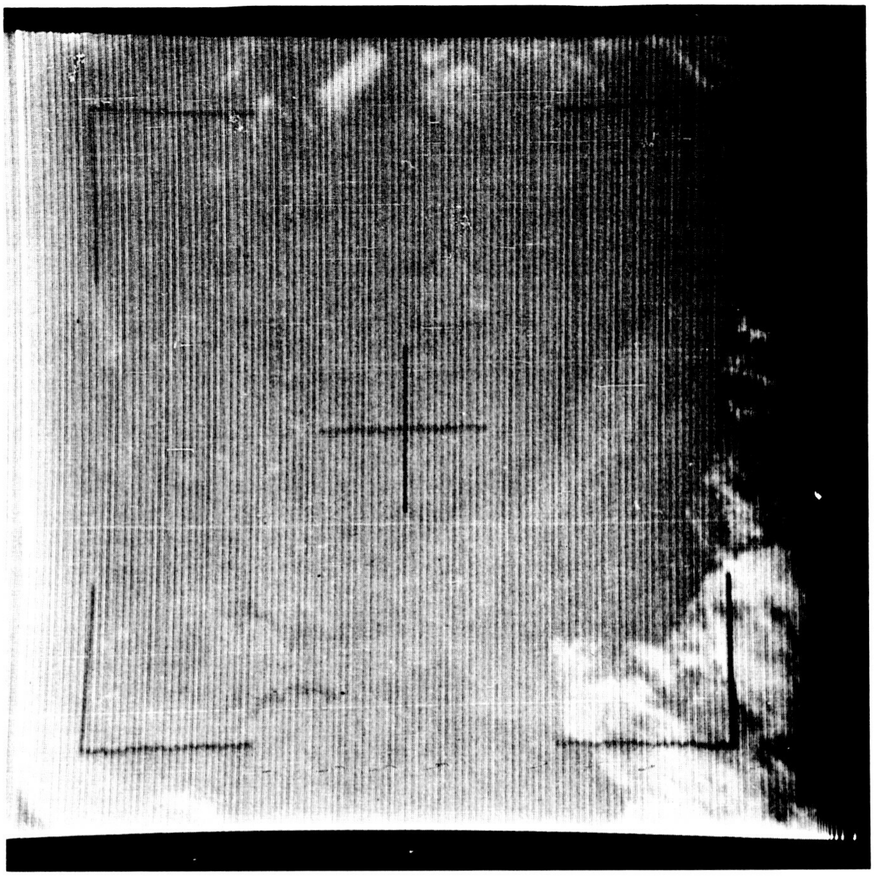
Sequence 0201 T1

Frame 22

Wide-angle

1158 GMT

3 July 1962



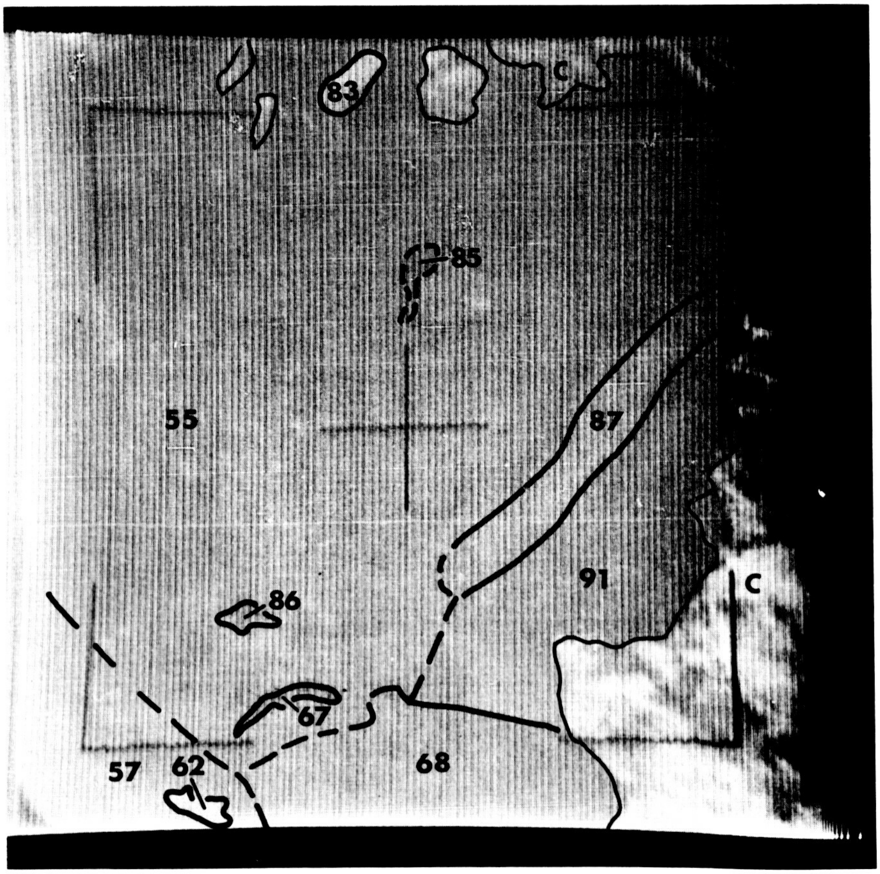


PLATE **35**

Tiros V

Sequence
0201 T1

Frame 19

Wide-angle

1158 GMT

3 July 1962

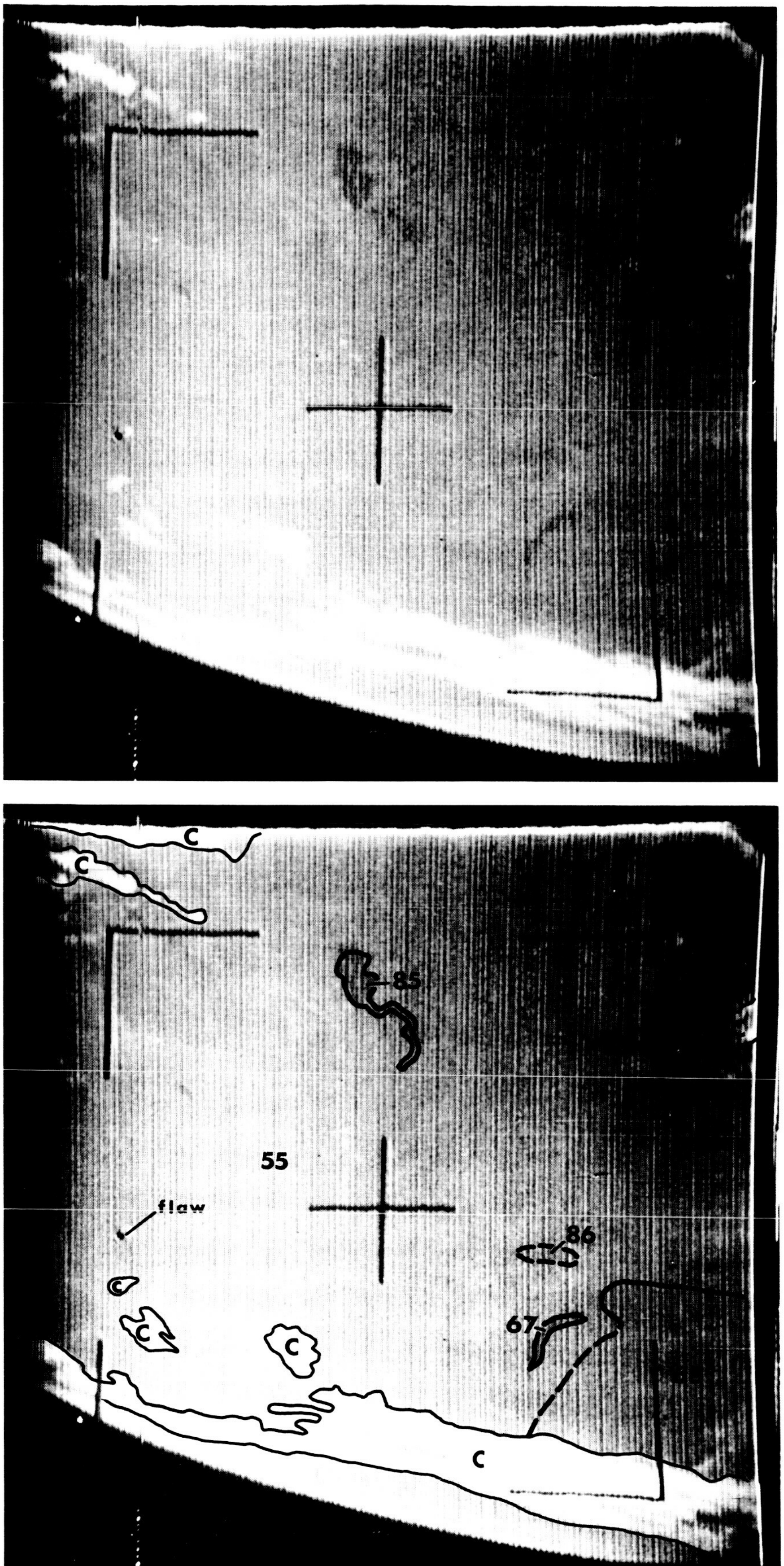


PLATE **36**

Tiros VI

Sequence
0262 T2

Frame 31

Medium-angle

0715 GMT

6 Oct 1962

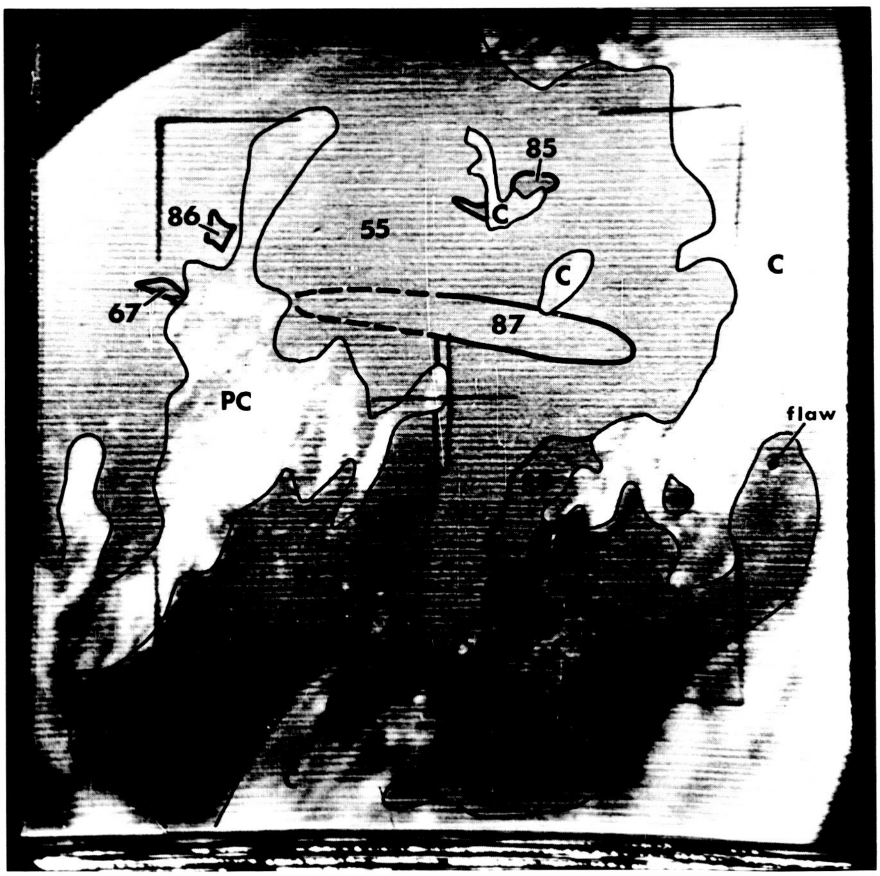


PLATE **37**

Tiros IV

Sequence 1332 T1

Frame 31

Wide-angle

0635 GMT

12 May 1962

PLATE **38**

Tiros VI

Sequence
0089 T2

Frame 22

Medium-angle

1031 GMT

24 Sept 1962

Legend

1 Montane evergreen forest.

2 Temperate and subtropical evergreen forest.

3 Montane communities, undifferentiated; may include any combination of forest, grassland, woodland, etc.

5 Montane grassland.

6 Temperate and subtropical grassland.

7 Moist forest at low and medium altitude; evergreen or partly evergreen; many areas of cultivation, secondary growth, or freshwater swamp.

8 Forest-savanna mosiac; patches of moist forest, not confined to stream sides, surrounded by savanna of tall grasses.

9 Coastal forest-savanna mosiac; like 8, but trees and grasses less tall.

10 Dry deciduous forest (and savanna), with abundant Baikiaea plurijuga; completely deciduous for several weeks; grass absent or rare.

15 Cape macchia; evergreen shrubs with hard, leathery leaves, generally small; trees rare; grassland spasmodic.

16-22 Woodlands, savannas* (and steppes); grasses from 80 cm to 3-4 m high, with fire-tolerant trees 7-25 m high; density of tree-growth varies widely; shrubby undergrowth may or may not be present.
- 16 Relatively moist types, undifferentiated; without Isoberlinia, Brachystegia, or Julbernardia; dense, tall grass is characteristic.
- 18 Southeastern areas, with abundant Brachystegia and Julbernardia; locally 'myombo'; river valleys may be occupied by treeless grasslands, or by evergreen moist forests if well-drained.
- 19 Southwestern areas (principally on Kalahari sand); same as 18, but with additional distinctive species, and patches of treeless steppe
- 20 Relatively dry types, undifferentiated; both acacias and broad-leaved.
- 22 With abundant Colophospermum mopane.

24 Grass steppe* on Kalahari sand.

25 Wooded steppe with abundant Acacia and Commiphora; trees mainly deciduous and thorny, and very variable in density.

27 Grass steppe, Luanda type; grassland dominated by Setaria welwitchii.

28 Karroo succulent steppe; mainly succulents less than 40 cm high, some heath-like shrublets and taller succulents, grasses common only in the east, trees only along streams and on mountain slopes.

29-31 Subdesert steppe; low perennial plants widely spaced; annuals including grasses flourish for a few weeks after rain.
- 29 Karroo shrub and grass.
- 30 Transitional and mixed Karroo; temperate grassland invaded by Karroo.
- 31 Tropical types; similar to 29, but species differ.

32 Desert; almost no vegetation.

S Swamps; dominated by tall grasses and sedges.

D Dry lake beds, occasionally flooded.

* For definitions of 'savanna' and 'steppe' see ref 7, p 6.

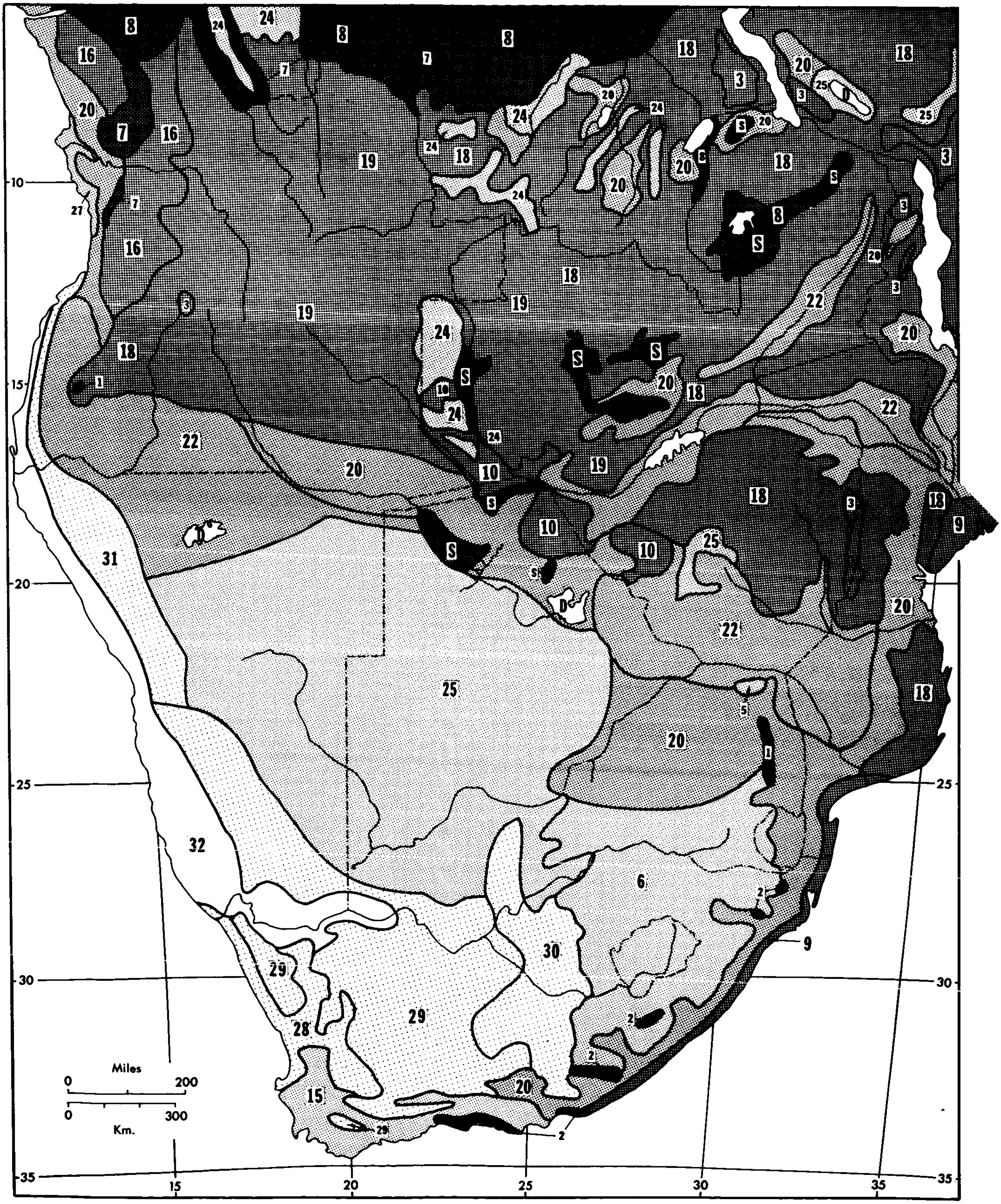


Figure 4. Vegetation (after ref 7). Legend opposite.

Legend

A Rock & rock debris
An Desert detritus, sands
Ar Desert detritus, not differentiated

B Lithosols, not differentiated
Bb Lithosols on rocks rich in ferromagnesian minerals
Bc Lithosols on ferruginous crusts
Bc' Lithosols on calcareous crusts
Bf Sub-desert soils
Bh Weakly developed soils on loose sediments not recently deposited
Bo Juvenile soils on recent alluvium

C Rendzinas, brown calcareous soils

Da Vertisols derived from rocks rich in ferromagnesian minerals
Db Vertisols derived from calcareous rocks
Dj Vertisols of topographic depressions

F Highveld pseudo-podsolic soils

G Brown & reddish-brown soils of arid and semi-arid tropical regions

H Eutrophic brown soils of tropical regions

I Brown mediterranean soils

J Ferruginous tropical soils

K Ferrisols, not differentiated
Ka Ferrisols, humic

L Ferrallitic soils, not differentiated
Lc Ferrallitic soils, yellowish-brown
Ln Ferrallitic soils, red
Ls Ferrallitic soils, humic

M Halomorphic soils, not differentiated
Ma Solonetz & solodized solonetz
Mb Saline, alkali, & saline alkali soils

Na Hydromorphic soils, mineral
Nb Hydromorphic soils, organic

Combinations of symbols represent associations or complexes. The sequence of symbols is not related to the importance of constituent soils within the association.

Underlining replaces the symbol B in associations.

For definitions of terms see ref 30.

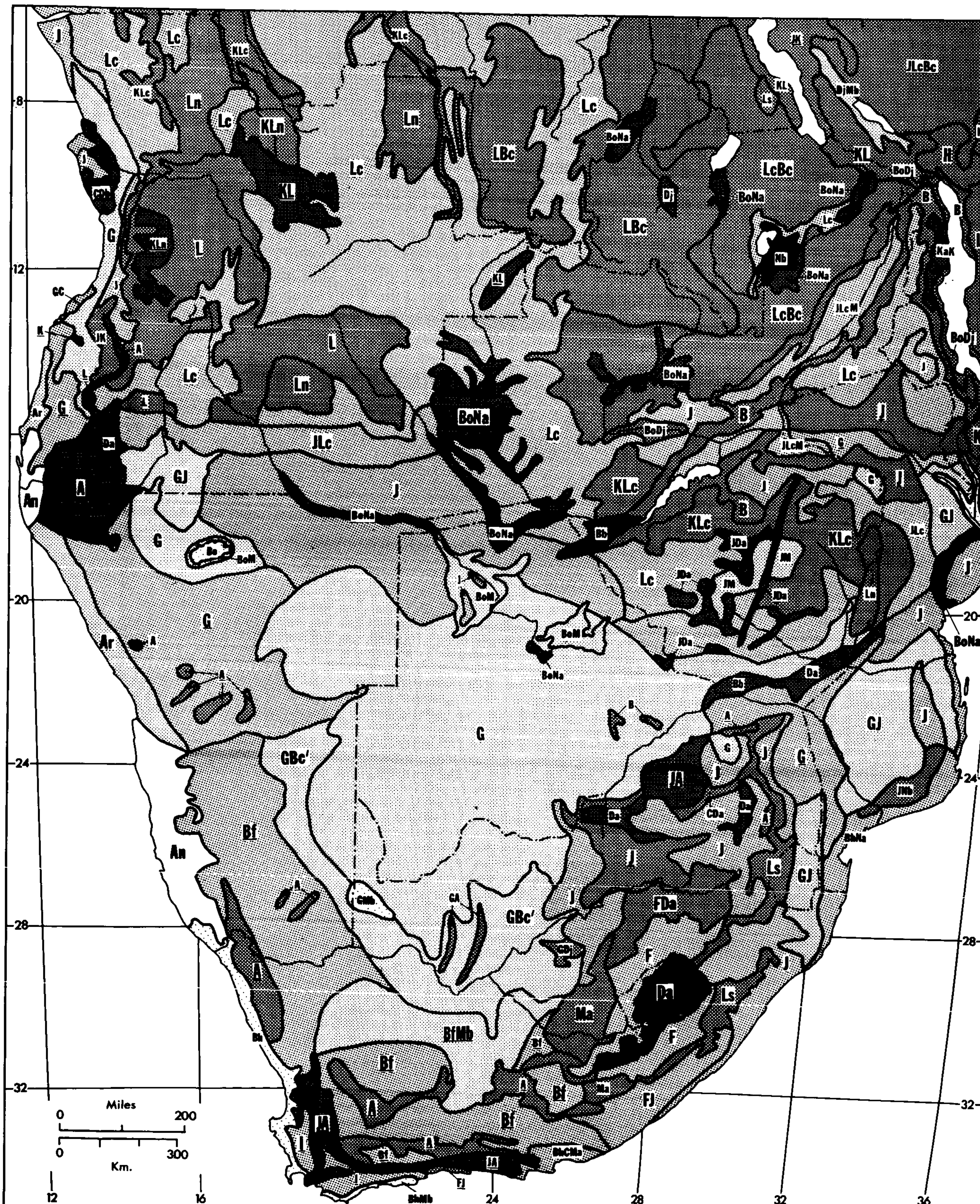


Figure 5. Soils (after ref 10). Legend opposite.

Legend and Stratigraphic Table
(the latter mainly after ref 14)

1	Other Tertiary to Recent Deposits		Tertiary to Recent	CAINOZOIC
	Kalahari Sands	KALAHARI SYSTEM	Tertiary to Recent	CAINOZOIC
	Kalahari Limestone Group	KALAHARI SYSTEM	Tertiary to Recent	CAINOZOIC
	Botletle Beds	KALAHARI SYSTEM	Tertiary to Recent	CAINOZOIC
2	Post-Karroo eruptive rocks			
3	Various		Cretaceous	MESOZOIC
4	Basalt (Stormberg Series)	KARROO SYSTEM	Triassic to Lower Jurassic	MESOZOIC
5S	Sandstone (Stormberg Series)	KARROO SYSTEM	Triassic to Lower Jurassic	MESOZOIC
5B	Beaufort Series	KARROO SYSTEM	Triassic to Lower Jurassic	MESOZOIC
5E	Ecca Series	KARROO SYSTEM	Upper Carboniferous to Upper Permian	PALEOZOIC
5D	Dwyka Series	KARROO SYSTEM	Upper Carboniferous to Upper Permian	PALEOZOIC
6	Witteberg Series Bokkeveld Series Table Mountain Series	CAPE SYSTEM	Devonian to Middle Carboniferous	PALEOZOIC
7	Schwartzrand & Schwartz-kalk etc. Series	NAMA SYSTEM		PALEOZOIC
7	Matsap Beds	WATERBERG SYSTEM		PROTEROZOIC
7		LOSKOP SYSTEM		PROTEROZOIC
10	Bushveld Igneous Complex & other post-Archean pre-Karroo eruptive rocks			PROTEROZOIC
8	Pretoria Series Dolomite or Campbell Rand Series Black Reef Series	TRANSVAAL SYSTEM	? =OTAVI SYSTEM (S.W.A.) & BEMBE SYSTEM (Angola)	PROTEROZOIC
9		VENTERSDORP SYSTEM WITWATERSRAND SYSTEM DOMINION REEF SYSTEM	? =OENDELONGO SYSTEM (S.W.A.)	PROTEROZOIC
11	Basement granite		Basement complex	ARCHEAN
12	(Ultrabasic & basic rocks & metamorphosed derivatives)		Primitive systems; Basement complex	ARCHEAN
12	(Metasediments & sediments)	MALMESBURY & OTHER FORMATIONS	Primitive systems; Basement complex	ARCHEAN
12	(Metasediments & sediments)	KHEIS OR SWAZILAND SYSTEM	Primitive systems; Basement complex	ARCHEAN

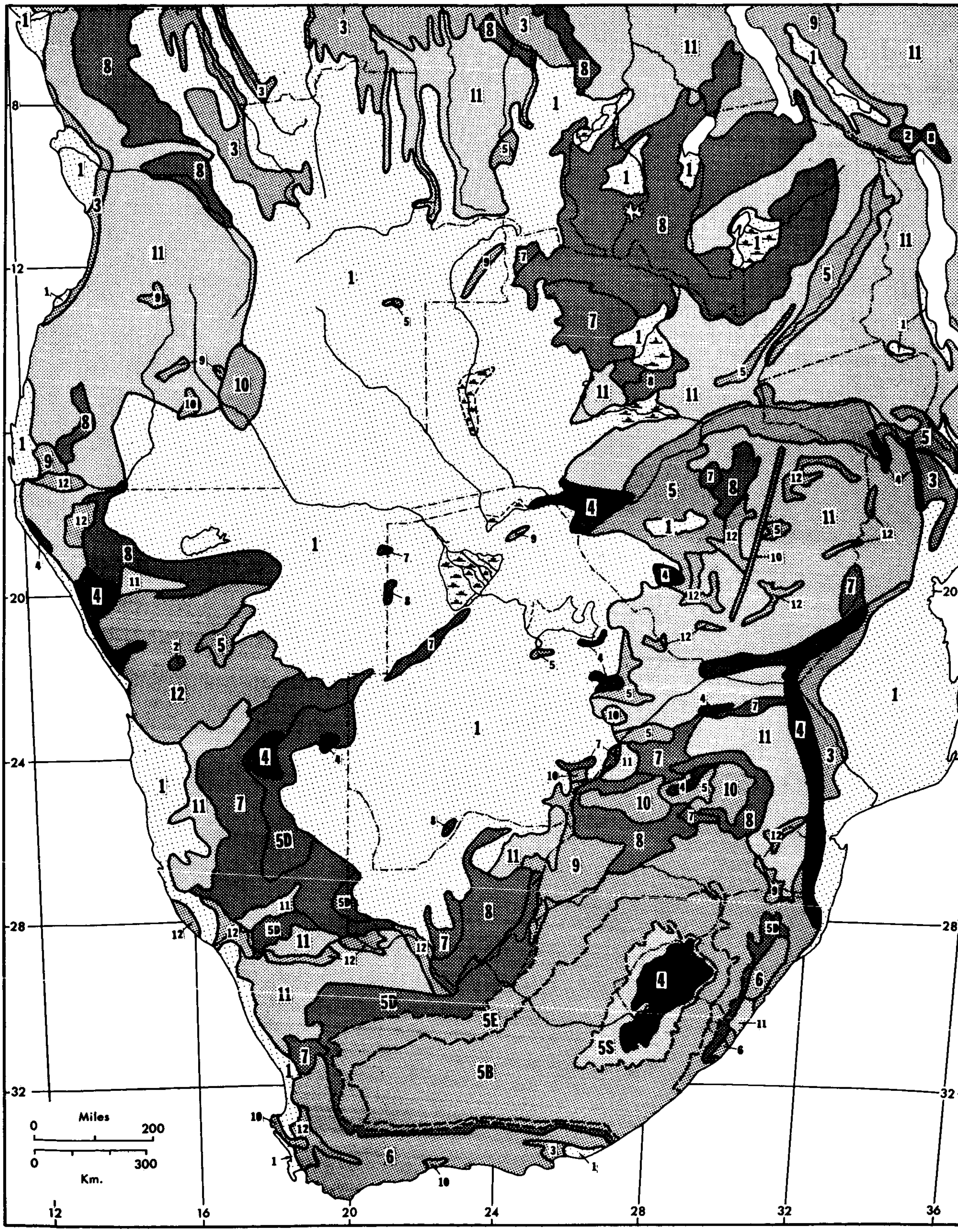


Figure 6. Geology (after ref 1, map I; and ref 13). Legend opposite.

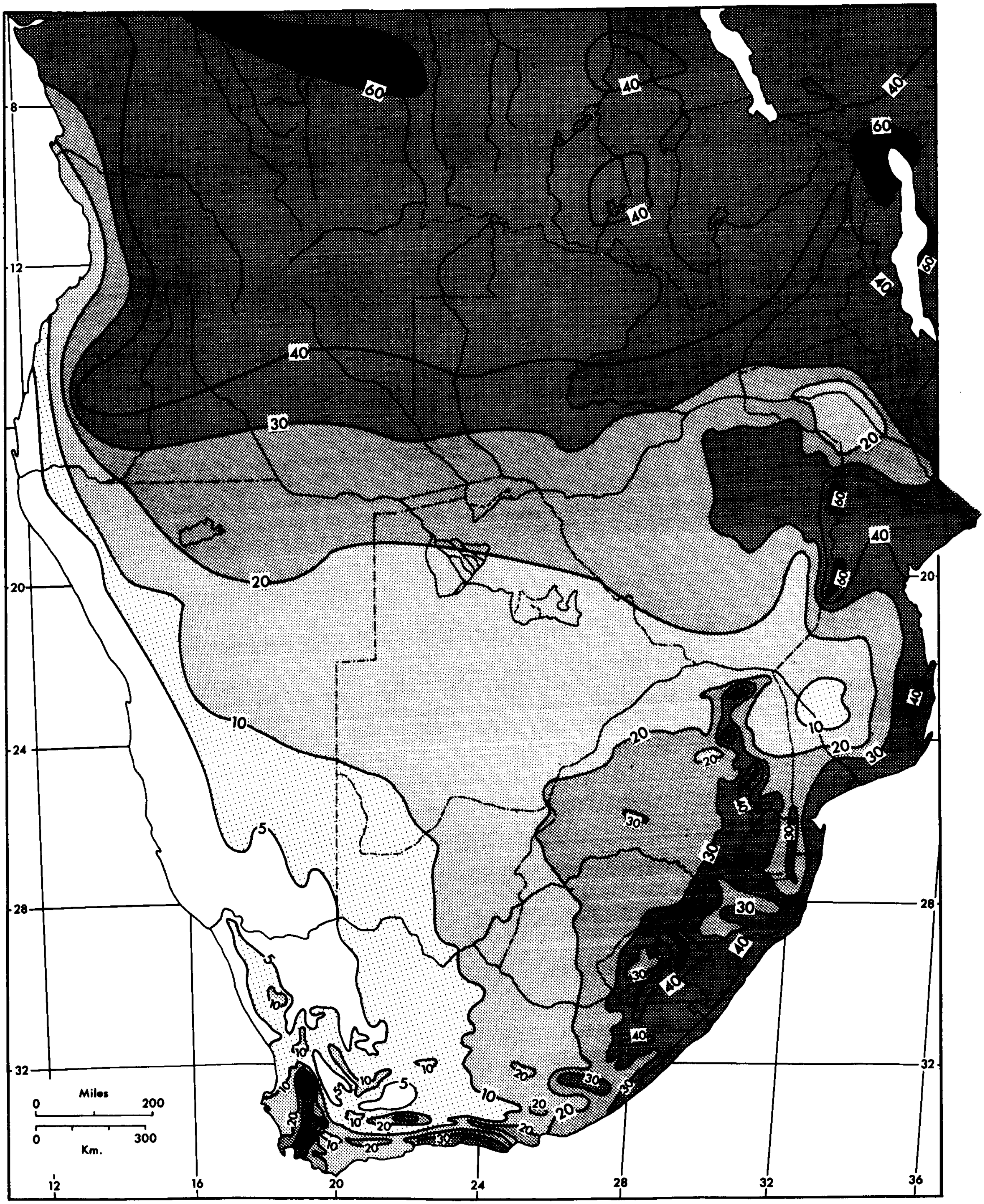


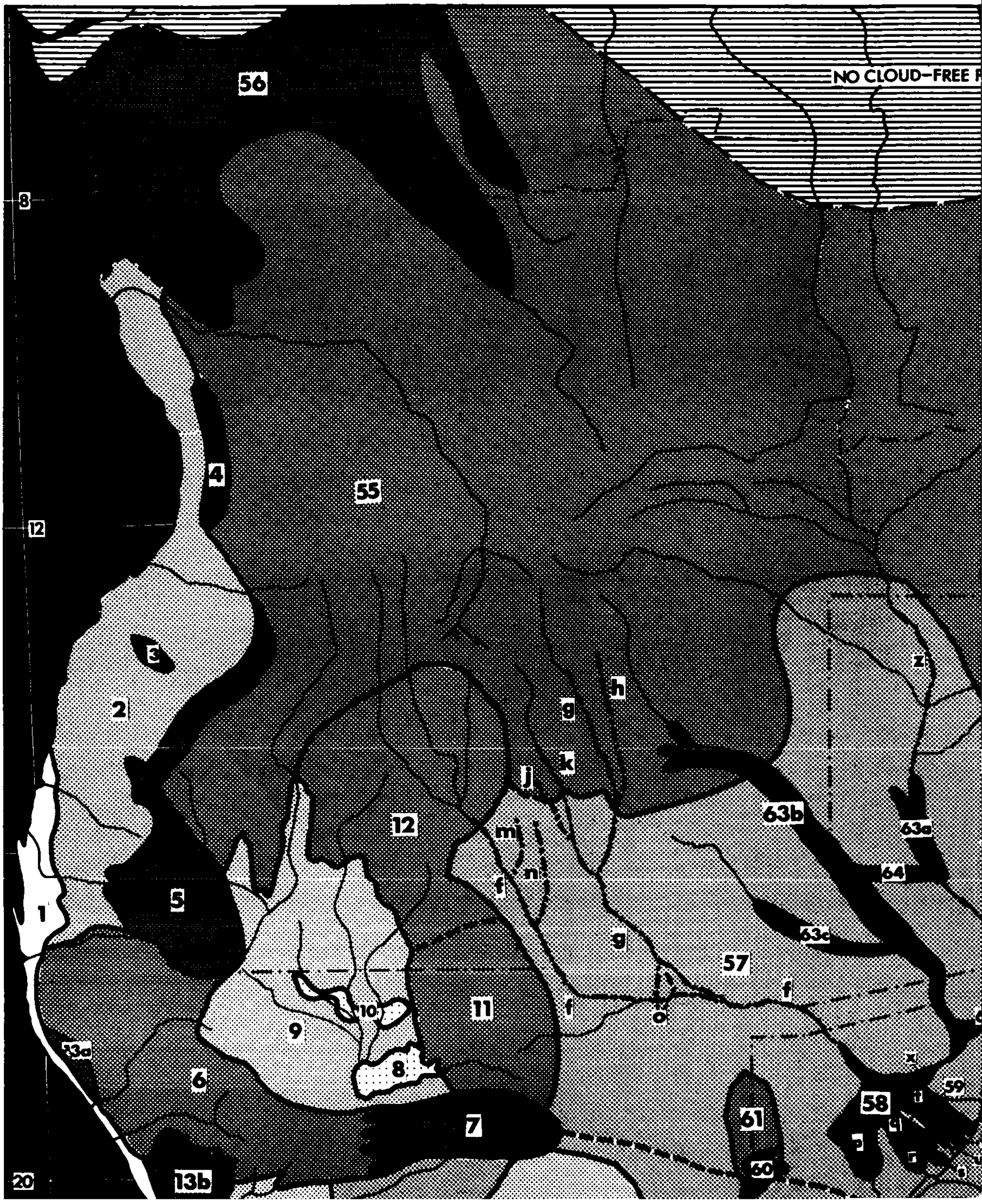
Figure 7. Mean annual rainfall in inches (mainly after ref 1, map III).

FOLD OUT 1

1 OF 5

Figure 8. Tone areas of southern Africa. Shadings represent the tone in which each area usually appears on Tiros pictures, relative to the tones of adjacent areas. Comparisons between widely separated areas are not necessarily valid. Numbers and letters correspond to those used on the plates and in the Key to Tone Area Numbers (pages 28-52) and Key to River Valley Letters (page 56).

2 of 5


NO CLOUD-FREE
56
55
4
8
12
2
3
5
1
13a
6
13b
20
7
8
9
10
11
12
j
k
g
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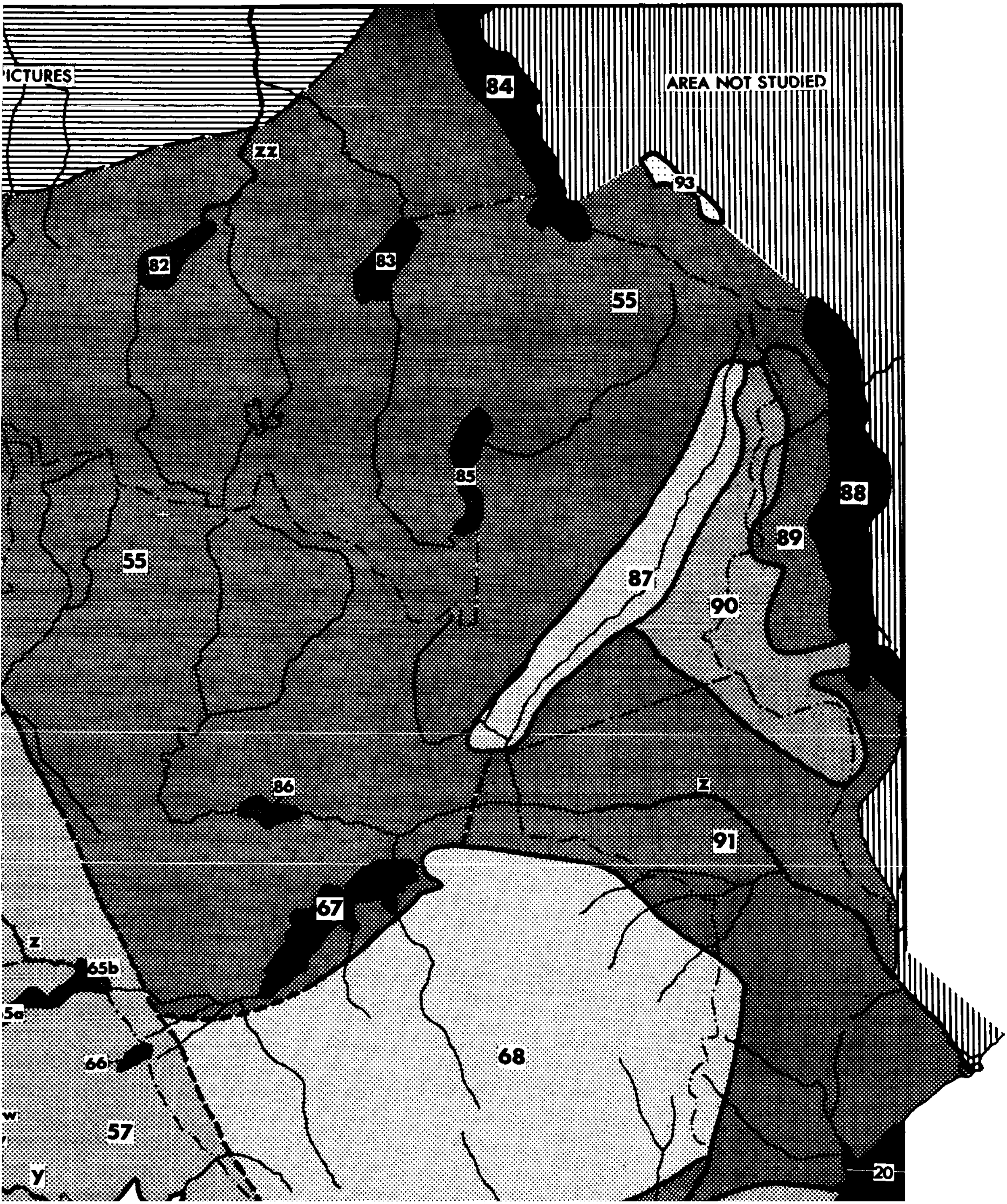
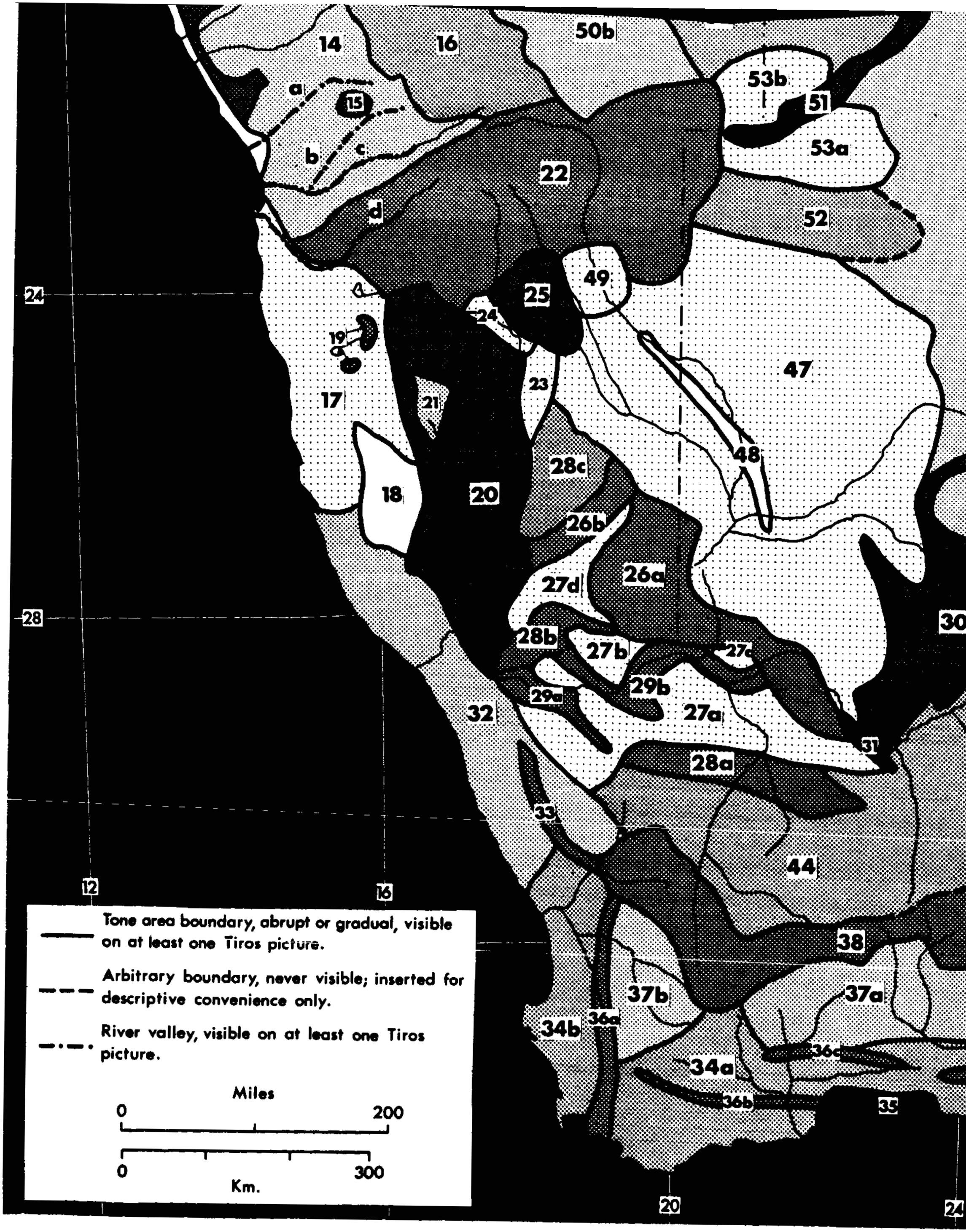
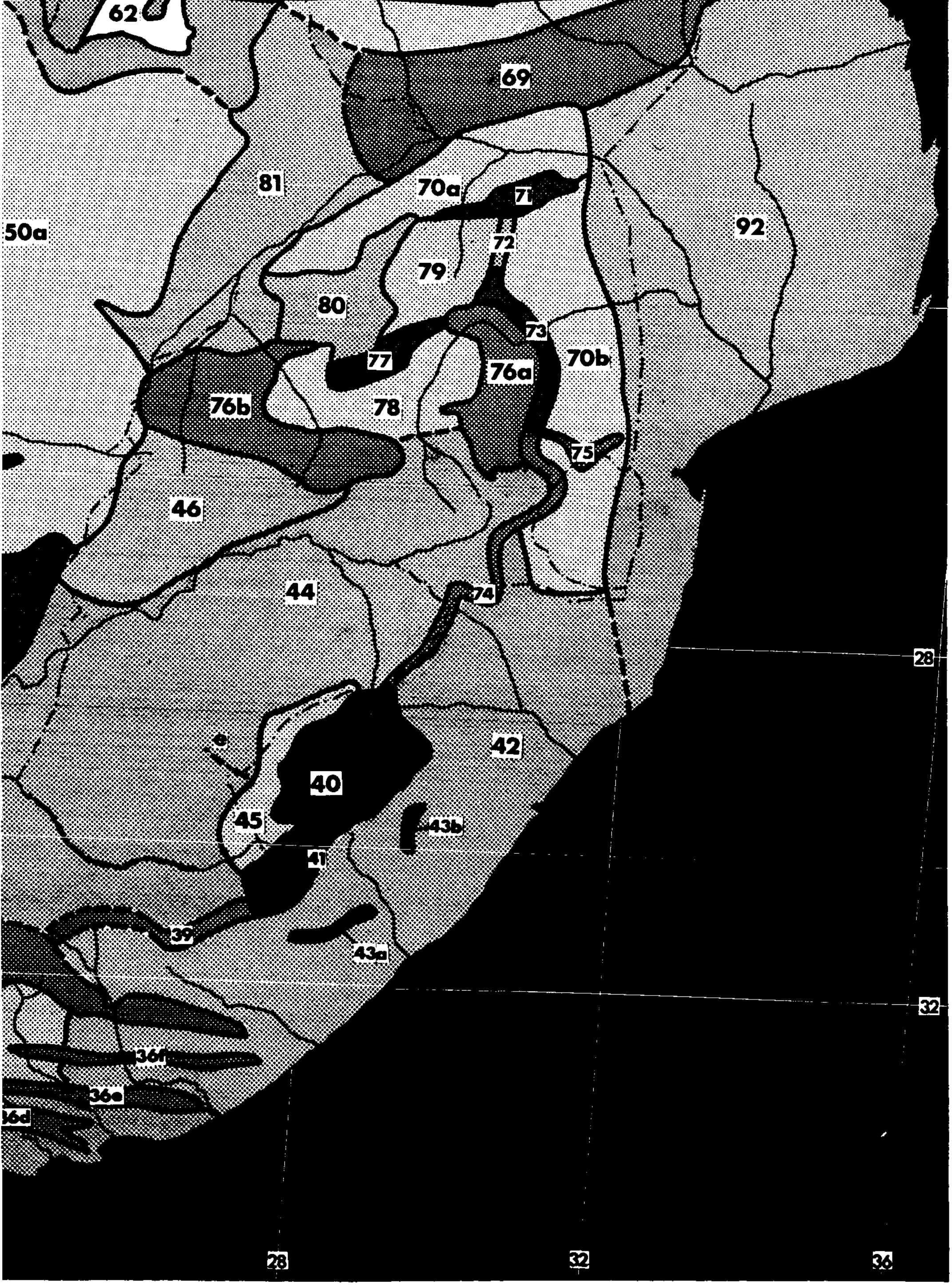
f
g
57
f
o
63b
63a
64
63c
z
x
58
59
61
60


PICTURES
AREA NOT STUDIED
84
ZZ
93
82
83
55
85
88
89
55
87
90
86
Z
91
67
Z
65b
5a
66
68
W
57
Y
20


14
16
50b
53b
51
53a
a
15
b
c
d
22
52
49
25
24
47
19
17
21
23
48
28c
18
20
26b
26a
27d
30
28b
27b
27c
29b
29a
27a
32
31
28a
33
44
38
37b
37a
34b
36a
36c
34a
36b
35
24
28
12
16
20
24
Tone area boundary, abrupt or gradual, visible on at least one Tiros picture.
Arbitrary boundary, never visible; inserted for descriptive convenience only.
River valley, visible on at least one Tiros picture.
Miles
0
200
0
300
Km.

4 of 5


62
69
81
70a
71
50a
72
92
79
80
73
77
70b
76a
76b
78
75
46
44
74
28
42
40
45
43b
41
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43a
32
36f
36e
36d
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32
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