HAWAII: THE VIEW FROM SPACE

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ABSTRACT

Aerial portrayal of Hawaii has advanced dramatically in the 20th century through the use of aircraft, mapping cameras, and photogrammetric instruments. In the past two decades, Earth-orbiting spacecraft have added new dimensions to the study of Hawaii's volcanoes, including synoptic views of all or most of the Island of Hawaii from hundreds of kilometers above the surface and repetitive coverage from automated satellites that record changes on the Earth's surface with time.

Astronaut crews in Apollo, Skylab, and Shuttle spacecraft have taken valuable photographs of short-lived events such as the 1983–84 eruptions on Kilauea and Mauna Loa. Landsat satellites have provided several digital images of high quality, and improved sensors now in use on Landsat for many parts of the world may be transmitting pictures of Hawaii in the near future. Multispectral scanners and a synthetic aperture radar system have been used on recent Shuttle missions and have provided digital images showing subtle volcanic features and even textural differences between lava flows from orbital altitudes of 230 to 290 km. Radar is particularly attractive for Hawaiian volcanoes because it is independent of surface illumination and weather and thus is useful day or night and in cloud-covered areas. Experimentation during the next several years on the Space Shuttle flights will improve present coverage even more as new improved methods continue to be developed.

INTRODUCTION

Since man first arrived in the Hawaiian Islands, his understanding of them has progressed, along with his technology, to new and improved perspectives. Early Polynesian canoes from the Markesa Islands carried the first humans to within sight of the broad volcanic shields and eroded seacliffs. Their view from the sea—a profile on the horizon commonly shrouded in clouds and mist—was a local view, constantly changing with location and lighting. Songs and chants were the basis for description of the islands; early cartographic definition was very unlike the accurate maps and charts of today.

For several centuries after their discovery, the islands were charted by ships' navigators with only the stars and Earth's magnetic field as control. Early maps depended on the artistic talents of the mapmakers while onboard ship or, as likely as not, back in their home ports of Europe and America. More precise definition of the land was achieved when surveyors marked points at the shorelines, on the mountain tops, and along the valleys and ridges between. Before the advent of modern transportation, these surveys were accomplished only with tremendous physical effort and endurance, and they required years of labor to complete.

In the 20th century, the use of aircraft and aerial photography has revolutionized the cartographic profession. The birdseye view of the Hawaiian Islands could be recorded on film at selected scales and over large areas in several days of flying. These photographs were then systematically converted by photogrammetric methods to accurate topographic maps, as a basis for displaying present and future use of the land, and, on the Island of Hawaii for frequent revision, showing new volcanic deposits as they occurred.

In the last two decades, the mapping of Hawaii has been both a stimulus to and a beneficiary of space exploration. The volcanic history and landforms of Hawaii have served as analogs for the study of similar features on other planets. For example, a comparison with analogous features on Mars was the basis for presenting the many excellent examples of oblique and vertical photographic views of the volcanic shields of Hawaii by Greeley (1974) and Carr and Greeley (1980). These photographs were taken between 1942 and 1975 from various altitudes, none of which approached orbital heights.

In spite of the tremendous advances in mapping accuracy made possible by aerial photography, drawbacks remain. Many standard aerial photographs are required to cover the island. The distortion introduced by terrain relief and the inability of aircraft to remain perfectly horizontal preclude the use of these photographs as accurate planimetric maps. Stereoscopic models of overlapping photographs permit precise three-dimensional contour mapping, but the numerous models required are expensive and consume many months of labor.

The view from space adds a totally new perspective to the utility of aerial photography. If there is a single most important aspect of images taken from Earth orbit, it is probably the synoptic view it offers, namely the broad view of a large part of the Earth's surface at one moment in time. Though standard aerial photographs provide high-resolution coverage, they are necessarily limited in the size of the area shown; the view from space is valuable in its instantaneous portrayal of a much larger area albeit in less detail. A second important aspect of space images, the possibility of repeated coverage on subsequent orbits, has many useful applications. A sequence of photographs or digital pictures of phenomena that change with time intervals of days, months, or years can be produced at relatively low cost, once the spacecraft is available. Obvious examples are volcanic eruptions, weather systems, forest

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fires, and agricultural conditions. Furthermore, special spectrometers can also view large areas in both the visible and infrared wavelengths to scan for zones of surface alteration, permitting concentrations of economically important minerals or potential geothermal resources to be identified.

The purpose of this paper is threefold: (1) to demonstrate some applications of space images for the improvement of existing maps; (2) to illustrate some aspects of the geology and structure of the Island of Hawaii, using a few examples of available photographs, satellite images, and radar data; and (3) to provide a selective listing of the better images available for the Hawaiian Island chain. Tables 8.1 and 8.2 list those images considered most useful based on minimum cloud coverage, geologic interest, and availabilty from the Earth Resources Observation Systems (EROS) Data Center as of this writing.

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APOLLO, SKYLAB, AND SHUTTLE PHOTOGRAPHY

Early photographs of Hawaii from space, taken on the Apollo 9 mission in March 1969, formed a panoramic series of four oblique views showing mostly clouds and were published as a mosaic in Dalrymple and others (1973). One of the better photographs of the island was taken from the Skylab spacecraft at an altitude of 435 km (270 mi; see figure 8.1). This vertical view provided an excellent cartographic delineation of the island's shoreline. More recent photographs, from the Space Shuttle missions since 1983, have normally been taken from lower altitudes (230–300 km; 143–186 mi), although Shuttle mission 41–C in April 1984 returned photographs from orbits as high as 500 km (310 mi).

All photographs cited were taken with hand-held NASA-modified cameras, primarily the Hasselblad 500 EL/M, using 70-mm (2.75-in) Kodak Ektachrome film. Advantages in the use of hand-held cameras to view the Earth include the ability to point the lens at targets of opportunity and the flexibility to interchange lenses of different focal lengths. A majority of the hand-held photographs of Hawaii taken from space to date have been taken through a telephoto lens (see table 8.1). The nominal ground resolution from a typical Space Shuttle altitude (284 km; 177 mi) using a 250-mm focal-length lens is about 25 m; the resolution using a 100-mm lens is about 60 m (Mohler, 1983). An example of a telephoto view of Mauna Loa Volcano's summit caldera and most of its two rift zones is shown in figure 8.2 for comparison with the wider angle view of figure 8.3.

The documentation of volcanic activity during and following an eruption is an obvious application of remote-sensing techniques on Hawaii. The beginning of the March–April 1984 eruption of Mauna Loa was precisely marked by a thermal sensor on a military satellite. On the shorter, manned Space Shuttle missions, special events can be targeted for photographic coverage, but the combined requirements of timing and good visibility are largely a matter of luck and perseverance on the part of the flight crews. One such opportunity permitted the plumes from the Mauna Loa eruption of 1984 to be photographed on four different days (table 8.1; fig. 8.3). Less prominent but quite visible was the plume from an eruption on Kilauea Volcano in late 1983 (fig. 8.4).

Perhaps the most photogenic of the five shield volcanoes on the Island of Hawaii is Mauna Kea, the most cited example of a tholeiitic shield capped by alkalic cones and flows in its later stages of development. The distribution of cinder cones on the summit and flanks of this symmetrical shield are shown in figure 8.5. The diversion of younger lava flows from Mauna Loa to the east and west around the base of Mauna Kea is also illustrated.

TABLE 8.1.—*Selected photographs of the Hawaiian Island chain taken by Gemini, Apollo, Skylab, and Space Shuttle missions*

[Data for Shuttle missions are taken mainly from NASA documents (Nowakowski, 1984a, b; Palmer, 1984; and Nowakowski and Palmer, 1984) but are modified where more information was available]

Mo	Da	Yr	Spacecraft	Mission	Scene identification	Orbit	Feature	Quality	Percent clouds	Center of scene Lat.	Center of scene Long.
02	11	73	Landsat	1	8120320180500	67-46	North Hawaii	8888	30	20.22	155.43
02	11	73	Landsat	1	8120320182500	67-47	South Hawaii	8888	20	18.78	155.16
03	01	73	Landsat	1	8122120181500	67-46	North Hawaii	8888	20	20.28	155.50
03	01	73	Landsat	1	8122120183500	67-47	South Hawaii	8882	20	18.84	155.85
10	09	77	Landsat	2	8299119392500	67-47	South Hawaii	8888	30	18.83	155.72
01	07	78	Landsat	2	82108119354X0	67-46	North Hawaii	8888	20	20.18	155.39
01	07	78	Landsat	2	82108119360X0	67-47	South Hawaii	8888	30	18.74	155.74
09	07	78	Landsat	3	83018620064X0	67-46	North Hawaii	8888	30	20.18	155.37

1 Image quality is scaled from 1 (poorest) to 8 (best). Columns under Quality represent, in order, Multispectral Scanner bands 4 (wavelength 0.5 to 0.6 microns), 5 (0.6-0.7), 6 (0.7-0.8), and 7 (0.8-1.1).

Cloud patterns and ocean roughness are remarkably well portrayed in the synoptic view from space. The typical cloud pile-up on the windward side of Hawaii in contrast with the open sky and smoother ocean surface on the leeward or Kona side (fig. 8.6) produces the illusion of an island sailing northeastward across the Pacific. The disturbance of windflow (orographic effect) across and around the five volcanic shields provides a fruitful area of research for atmospheric scientists.

LANDSAT AND OTHER MULTISPECTRAL SATELLITE IMAGES

Digital images transmitted from Landsat, originally called Earth Resources Technology Satellite (or ERTS), provide repetitive coverage of the Earth from polar orbit using a scanner system that includes spectral bands from near infrared through the visible wavelengths. Landsats 1, 2, and 3 recorded scenes of Hawaii on four bands over the wavelength range of 0.5 to 1.1 microns. A typical image is approximately 185 km (115 mi) on each side and has a nominal resolution per picture element (pixel) of 80 m (Short and others, 1976). The amount of area included within Landsat images compared with photographs taken on Skylab and Shuttle missions is shown in figure 8.7.

In comparison with photographs taken from aircraft and manned spacecraft, the shortcomings of digital images from satellites are mainly their lower spatial resolution, their rigid format and direction of view, and the acquisition of data at only one lighting geometry (due to the sun-synchronous nature of the Landsat orbits; Short and others, 1976). The advantages of digital images recorded by satellites are: (1) they cover larger areas, (2) they have uniform resolution across the entire image, and (3) they include various spectral bands that can be filtered or enhanced after the image is recorded to delete atmospheric haze or to emphasize the surface distribution of different natural materials. In contrast, improvements to aerial photographs are normally made as the pictures are taken, requiring extensive experience and know-how. Corrections for haze, color, and lighting are difficult to apply in the photographic laboratory, but are generally possible for digital images via computer processing.

Image processing and enhancement of digital scenes such as from Landsat can be helpful in geologic interpretation and illustration of regional features on Earth as well as other planets. The Landsat scene shown in figure 8.8 was recorded in 1978. Other scenes (until late 1978; table 8.2) can be purchased from EROS in several formats. Repetitive overflights could eventually make it possible to acquire near-perfect images of the entire island chain, although the current spacecraft configuration prohibits the transmission of new images from Landsats 4 and 5.

Cartographic applications of Landsat data require that scenes be fitted to standard map projections and existing map products. Figure 8.8 has been geometrically adjusted to the universal transverse mercator projection, and the red and green color bands have been combined with an artificially generated blue band to create a simulated true-color rendition of Hawaii as described by Eliason and others (1974). Landsat scenes can be modified by computer to increase their interpretability. One example is the superposition of the scene on a digital elevation model (obtained from the U.S. Defense Mapping Agency) derived from the 1:250,000-scale map series. The registration procedure, whereby every pixel of the image is assigned a corresponding elevation value, is the most labor-intensive part of this technique.

The composite data set thus produced can be digitally rotated to an oblique aerial view. The vertical exaggeration, the vertical angle of the perspective view, and the look-azimuth desired can all be adjusted by an analyst for maximum interpretability. We chose the northwestward view shown in figure 8.9 to look across the rift structures of Mauna Loa and Kilauea Volcanoes. If one wanted to look for subtle structures (for example, parallel to a rift zone), the down-structure view could be generated just as easily. A three-times vertical exaggeration appears to best illustrate the relief of the volcanoes in this case. An additional processing technique, not developed in time for this report, is the removal of cloud cover from the image while retaining the terrain information from the elevation model. This effect can be created by digitally stenciling out the white pixels in the scene and replacing them with a digital shading of the elevation model.

A further enhancement of the oblique aerial view could include a second oblique view—slightly offset in azimuth but with other variables held constant—to provide a stereo pair. An example of this technique for another volcanic area is illustrated elsewhere (Anonymous, 1984a, 1984b). Subtle structures such as shallow craters and small cones and shields can be more easily recognized and interpreted in the stereoscopic view.

Unfortunately the number of geologically useful Landsat images of Hawaii is small due to the frequent canopy of clouds that cover much of the island. The Thematic Mappers on Landsats 4 and 5 have better spectral and spatial resolution than any previous Landsat. These spacecraft do not carry tape recorders, however, and the only areas on the Earth's surface that can be acquired are those in direct line of sight with a receiving station. As of this writing (1985) and because of the inability to record, there are no images of Hawaii yet available from these spacecraft (Landsats 4 or 5). This problem may be resolved when a tracking and data-relay satellite (TDRS-west) is launched in the near future. (Note: The TDRS satellite was lost in the shuttle *Challenger* accident in 1986, and its replacement and launching will be significantly delayed. Until that time, new Landsat images for the Hawaiian Islands will not be available.)

While Landsat is an established standard for orbital-digital images of the Earth, other sensors are under development, many of them using the Space Shuttle as a platform. One such experiment, the German MOMS-1 (Modular Optoelectronic Multispectral Scanner), was flown on the Shuttle in February 1984 and recorded the image of Hawaii reproduced in figure 8.10. The image has a spatial resolution of approximately 20 m in two spectral channels (0.60 and 0.90 microns), sufficient to identify features such as the new lava flows of the 1983–85 east-rift eruptions on Kilauea. Obvious applications for these images lie in their potential for mapping recent eruption areas, portraying patterns of flow distribu-

TABLE 8.2.—*Selected Landsat scenes of the Island of Hawaii*

[Images and photographs listed can be purchased from EROS Data Center, Sioux Falls, SD 57198]

Mo	Da	Yr	Space-craft	Mission identificat.	Scene identification 1	Orbit	Feature	Focal length	Percent clouds 2	Perspective 3	Direction	Stereo 4	Center of scene Lat	Long 5
08	24	65	Gemini	V	S-65-45616	51	Hawaii to Kauai	80	80	Oblique	SW	No	20.0	154.0
10	15	68	Apollo	7	AS7-7-1740	51	Niihau	80	--	---do---	NE	No	23.0	160.5
10	15	68	Apollo	7	AS7-7-1741	51	Oahu	80	--	---do---	NE	Yes	23.0	158.5
10	15	68	Apollo	7	AS7-7-1742	51	Oahu, Maui	80	--	---do---	NE	Yes	23.0	157.0
10	15	68	Apollo	7	AS7-7-1743	51	--do--------------	80	--	---do---	NE	Yes	22.0	157.0
10	15	68	Apollo	7	AS7-7-1744	51	Maui, Hawaii	60	--	---do---	NE	Yes	22.0	156.5
10	15	68	Apollo	7	AS7-7-1745	51	Maui,Kahoolawe,Haw	80	--	---do---	NE	Yes	21.5	156.0
10	15	68	Apollo	7	AS7-7-1746	51	--do--------------	80	--	---do---	NE	Yes	20.0	155.5
10	15	68	Apollo	7	AS7-7-1747	51	Hawaii	80	--	---do---	NE	Yes	21.5	155.0
02	03	69	Apollo	9	AS9-3505 to-8	--	Hawaii to Niihau	100(?)	50	---do---	SW	Yes	20.0	154.0
12	07	73	Skylab	4	SL4-139-3997	--	Hawaii	100	10	Vertical	--	No	19.6	155.5
04	05	83	Shuttle	STS-6, S-06	40-745	22	Mauna Loa	250	85	---do---	--	Yes	19.5	155.5
06	18	83	--do---	STS-7, S-07	20-1029	5	Oahu,Molakai,Lanai	100	30	Oblique	N	Yes	22.5	158.0
06	18	83	--do---	----do-----	20-1030	5	Molokai,Maui,Lanai	100	30	---do---	N	Yes	23.0	157.0
06	18	83	--do---	----do-----	22-1134	6	Niihau	250	30	---do---	NE	No	22.0	160.0
06	18	83	--do---	----do-----	22-1135	6	Kauai	250	20	---do---	E	No	22.0	159.5
06	18	83	--do---	----do-----	22-1136	6	Oahu	250	20	---do---	E	No	21.5	158.0
06	18	83	--do---	----do-----	22-1137	6	Molak,Lanai,Kahool	250	15	---do---	E	Yes	21.0	157.0
06	18	83	--do---	----do-----	22-1138	6	--do--------------	250	25	---do---	E	Yes	21.0	157.0
06	18	83	--do---	----do-----	22-1139	6	Maui, Lanai	250	30	---do---	E	Yes	21.0	156.5
06	18	83	--do---	----do-----	22-1141	6	Hawaii	250	30	---do---	SE	Yes	20.0	155.5
06	18	83	--do---	----do-----	22-1142	6	--do--------------	250	30	---do---	SE	Yes	19.5	155.5
06	18	83	--do---	----do-----	22-1144	6	Hawaii, Maui	250	506	---do---	NE	Yes	19.5	156.0
06	19	83	--do---	----do-----	03-0084	22	Niihau	250	10	Vertical	--	No	22.0	160.0
06	19	83	--do---	----do------	03-0085	22	Kauai	250	20	---do---	--	No	22.0	160.0
06	19	83	--do---	----do------	03-0886	22	Pearl Harbor	250	25	---do---	--	No	21.5	158.0
06	19	83	--do---	----do------	03-0087	22	Molokai, Lanai	250	15	---do---	--	Yes	21.0	157.0
06	19	83	--do---	----do------	03-0088	22	Maui, Kahoolawe	250	15	---do---	--	Yes	21.0	157.0
06	19	83	--do---	----do------	03-0089	22	--do------------	250	15	---do---	--	Yes	21.0	156.5
06	19	83	--do---	----do------	03-0090	22	Mauna Loa Volcano	250	15	---do---	--	Yes	19.5	155.5
06	19	83	--do---	----do------	03-0091	22	--do--------------	250	15	---do---	--	Yes	19.5	155.5
06	19	83	--do---	----do------	03-0092	22	--do--------------	250	15	---do---	--	Yes	19.5	155.5
06	19	83	--do---	----do------	03-0093	22	--do--------------	250	15	---do--	--	Yes	19.5	155.5
06	19	83	--do---	----do------	03-0094	22	--do--------------	250	15	---do---	--	Yes	19.5	155.5
06	19	83	--do---	----do------	19-0874	22	Kauai	100	10	---do---	--	No	22.0	160.0
06	19	83	--do---	----do------	19-0875	22	Molokai & adjacent	100	10	Oblique	N	No	21.0	157.5
06	19	83	--do---	----do------	19-0876	22	Maui & adjacent	100	15	Vertical	--	Yes	20.5	156.5
06	19	83	--do---	----do------	19-0877	22	--do--------------	100	15	---do---	--	Yes	20.5	156.0
06	19	83	--do---	----do------	19-0878	22	Hawaii	100	15	---do---	--	Yes	20.0	155.5
06	19	83	--do---	----do------	19-0879	22	--do--------------	100	15	---do---	--	Yes	19.5	155.5
06	19	83	--do---	----do------	19-0880	22	--do--------------	100	15	---do---	--	Yes	19.5	155.5
06	20	83	--do---	----do------	03-0114	37	Mauna Kea Volcano	250	30	Oblique	SW	No	19.5	155.5
06	20	83	--do---	----do------	03-0115	37	--do--------------	250	30	---do---	SW	No	19.5	155.5
11	28	83	--do---	STS-9, 41-A	31-1015	4	Mauna Loa Volcano	250	05	Vertical	--	No	19.5	155.5
11	28	83	--do---	----do-----	31-1016	4	--do--------------	250	10	---do---	--	Yes	19.0	155.5
11	28	83	--do---	----do-----	31-1017	4	--do--------------	250	20	---do---	--	Yes	19.5	155.5
11	28	83	--do---	----do-----	31-1018	4	M. Kea, Hilo Bay	250	20	Oblique	S	Yes	20.0	155.5
11	28	83	--do---	----do-----	31-1019	4	Hawaii coast	250	10	Vertical	--	Yes	20.0	155.5
11	28	83	--do---	----do-----	31-1020	4	Mauna Loa Volcano	250	10	Oblique	SW	Yes	19.5	155.5
11	28	83	--do---	----do-----	31-1021	4	--do--------------	250	10	---do---	SW	Yes	19.5	155.5
11	28	83	--do---	----do-----	31-1022	4	Hawaii	250	10	---do---	SW	Yes	19.5	155.5
11	28	83	--do---	----do-----	31-1023	4	--do--------------	250	10	---do---	SW	No	20.0	155.5
11	28	83	--do---	----do-----	31-1024	4	--do--------------	250	10	---do---	SW	No	20.0	155.5
11	28	83	--do---	----do-----	32-1118	4	--do--------------	100	20	---do---	SW	No	19.5	155.5
11	28	83	--do---	----do-----	32-1119	4	--do--------------	100	20	---do---	SW	No	19.5	155.5
11	28	83	--do---	----do-----	32-1120	4	--do--------------	100	20	---do---	SW	No	19.5	155.5
11	29	83	--do---	----do-----	35-1596	20	Hawaii, Maui	100	15	---do---	SE	Yes	20.0	156.0
11	29	83	Shuttle	STS-9, 41-A	35-1597	20	Haw,Maui,Molok,Lan	100	20	Oblique	E	Yes	21.0	156.5
11	29	83	--do---	----do-----	35-1598	20	Lanai,Molok,Maui	100	20	---do---	E	Yes	21.0	157.0
11	29	83	--do---	----do-----	35-1599	20	Molok,Oahu,Kahool	100	20	---do---	W	Yes	21.5	158.0
11	29	83	--do---	----do-----	35-1600	20	Kauai, Niihau	100	20	---do---	W	No	22.0	159.5
11	29	83	--do---	----do-----	46-1836	20	Haw,Maui,Lan,Molok	250	30	---do---	NE	No	21.0	156.5
11	29	83	--do---	----do-----	46-1837	20	Hawaii	250	20	---do---	NE	No	19.5	156.0
11	29	83	--do--	----do-----	46-1838	20	Molokai,Lanai,Maui	250	40	---do---	NE	No	21.0	157.0
11	29	83	--do---	----do-----	46-1840	20	SE Haw, Kil. plume	250	20	---do---	NE	Right	19.0	155.5
11	29	83	--do---	----do-----	46-1841	20	Hawaii, Kil. plume	250	20	---do---	NE	Ctr	19.5	155.5
11	29	83	--do---	----do-----	46-1842	20	NW Haw, Kohala	250	20	---do---	NE	Left	20.0	155.5
11	29	83	--do---	----do-----	46-1843	20	Maui, Kahoolawe	250	30	---do---	NE	No	20.5	156.5
11	29	83	--do---	----do-----	46-1844	20	Maui, Lanai	250	30	---do---	NE	No	21.0	156.5
11	29	83	--do---	----do-----	46-1845	20	Lanai, Maui, Molok	250	30	Vertical	--	No	21.0	156.5
11	29	83	--do---	----do-----	46-1846	20	Molokai, Lanai	250	30	---do---	--	No	21.0	157.0
11	29	83	--do---	----do-----	46-1848	20	Kauai	250	40	---do---	--	No	22.0	159.5
02	04	84	--do---	STS-11, 41-B	41-2351	22	Honolulu, Oahu	250	10	Oblique	--	Yes	21.5	158.0
02	04	84	--do---	----do------	41-2352	22	--do--------------	250	10	---do---	--	Yes	21.5	158.0
02	04	84	--do---	----do------	41-2353	22	Molokai,Lanai,Maui	250	0	---do---	--	Yes	21.0	157.0
02	04	84	--do---	----do------	41-2354	22	Mol,Lan,Kahoo,Maui	250	10	---do---	--	Yes	21.0	157.0
02	04	84	--do---	----do------	41-2355	22	Maui, Kahoolawe	250	10	---do---	--	Yes	21.0	156.5

TABLE 8.2.— *Selected Landsat scenes of the Island of Hawaii*— Continued

Mo	Da	Yr	Space-craft	Mission identificat.	Scene identi-fication 1	Orbit	Feature	Focal length	Percent clouds 2	Perspec-tive 3	Direc-tion	Stereo 4	Center of scene Lat	Long 5
02	04	84	--do---	----do------	41-2356	22	Hawaii	250	30	---do---	--	Yes	19.5	155.5
02	06	84	--do---	----do------	33-1458	53	Kauai	100	30	Vertical	--	No	22.0	156.5
02	06	84	--do---	----do------	33-1459	53	Maui,Kahool,Lanai	100	30	---do---	--	No	21.0	156.5
02	06	84	--do---	----do------	33-1460	53	Hawaii	100	30	---do---	--	Yes	19.5	155.5
02	06	84	--do---	----do------	33-1461	53	--do-------------	100	30	---do---	--	Yes	20.0	155.5
02	06	84	--do---	----do------	34-1554	53	Niihau	250	30	---do---	--	Yes	22.0	160.0
02	06	84	--do---	----do------	34-1555	53	Kauai	250	30	---do---	--	Yes	22.0	159.5
02	06	84	--do---	----do------	34-1556	53	Oahu	250	30	---do---	--	Yes	21.5	158.0
02	06	84	--do---	----do------	34-1557	53	--do-------------	250	20	---do---	--	Yes	21.5	158.0
02	06	84	--do---	----do------	34-1558	53	--do-------------	250	20	---do---	--	Yes	21.5	158.0
02	06	84	--do---	----do------	34-1561	53	Maui	250	30	---do---	--	Yes	21.0	156.5
02	06	84	--do---	----do------	34-1562	53	--do-------------	250	20	---do---	--	Yes	21.0	156.5
02	06	84	--do---	----do------	34-1563	53	Hawaii	250	5	---do---	--	Yes	19.5	155.5
02	06	84	--do---	----do------	34-1564	53	--do-------------	250	30	---do---	--	Yes	20.0	155.5
02	06	84	--do---	----do------	34-1565	53	--do-------------	250	30	---do---	--	Yes	20.0	155.5
02	06	84	--do---	----do------	34-1566	53	--do-------------	250	1	---do---	--	Yes	19.5	155.5
02	06	64	--do---	----do------	34-1567	53	--do-------------	250	5	---do---	--	Yes	19.0	155.5
02	06	84	--do---	----do------	34-1568	53	--do-------------	250	5	---do---	--	Yes	19.5	155.5
02	06	84	--do---	----do------	34-1569	53	--do-------------	250	15	---do---	--	Yes	19.5	155.5
02	08	84	--do---	----do------	43-2625	84	Kauai	250	30	Oblique	--	No	22.0	159.5
02	08	84	--do---	----do------	43-2626	84	Oahu	250	20	---do---	--	No	21.5	158.5
02	08	84	--do---	----do------	43-2627	84	Molokai, Lanai	250	30	---do---	--	No	21.0	157.0
02	08	84	--do---	----do------	43-2629	84	Hawaii	250	30	---do---	--	Yes	19.5	155.5
02	08	84	--do---	----do------	43-2630	84	--do-------------	250	30	---do---	--	Yes	19.5	155.5
02	09	84	--do---	----do------	45-2794	100	Hawaii Isl. chain	100	30	---do---	NW	No	19.5	155.5
02	09	84	--do---	----do------	45-2795	100	Hawaii	100	30	---do---	--	No	19.5	155.5
02	09	84	--do---	----do------	45-2796	100	--do-------------	100	30	---do---	--	No	19.5	155.5
02	09	84	--do---	----do------	46-2923	100	--do-------------	250	60	---do---	N	Yes	19.5	155.5
02	09	84	--do---	----do------	46-2924	100	--do-------------	250	60	---do---	N	Yes	19.5	155.5
02	09	84	--do---	----do------	46-2925	100	--do-------------	250	60	---do---	N	Yes	19.5	155.5
04	06	84	--do---	STS-13, 41-C	31-0968	6	Niihau	250	25	Vertical	--	No	22.0	160.0
04	06	84	--do---	----do------	31-0969	6	Kauai	250	25	---do---	--	No	22.0	159.5
04	06	84	--do---	----do------	31-0974	6	Mauna Loa plumes	250	80	Oblique	SW	Yes	19.5	155.5
04	06	84	--do---	----do------	31-0975	6	--do-------------	250	80	---do---	SW	Yes	19.5	155.5
04	06	84	--do---	----do------	32-1087	6	--do-------------	50	40	Vertical	--	No	22.0	160.0
04	06	84	--do---	----do------	51-2264	6	Kauai, Niihau	250	30	---do---	--	No	22.0	160.0
04	06	84	--do---	----do------	51-2265	6	Oahu	250	25	---do---	--	No	22.0	158.0
04	07	84	Shuttle	STS-13, 41-C	35-1538	21	Mauna Loa plumes	250	25	Oblique	SE	Yes	19.5	155.5
04	07	84	--do---	----do------	35-1539	21	--do-------------	250	25	---do---	SE	Yes	19.5	155.5
04	07	84	--do---	----do------	35-1540	21	Mauna Loa plumes	250	25	Oblique	S?	Yes	19.5	155.5
04	07	84	--do---	----do------	36-1633	21	M. Loa plume, Maui	50	40	Vertical	--	No	22.0	160.0
04	07	84	--do---	----do------	36-1686	37	Mauna Loa plumes	50	60	Oblique	SW	No	21.0	155.0
04	08	84	--do---	----do------	34-1411	37	--do-------------	250	30	---do---	NE	Yes	19.5	155.5
04	09	84	--do---	----do------	52-2537	51	--do-------------	250	50	---do---	SE	No	20.5	157.0
04	09	84	--do---	----do------	52-2538	51	--do-------------	250	50	---do---	SE	No	20.0	156.5
04	12	84	--do---	----do------	37-1807	96	--do-------------	250	40	---do---	E	No	19.5	155.5
04	12	84	--do---	----do------	37-1808	96	--do-------------	250	40	--do----	S	No	19.9	155.5
04	12	84	--do---	----do------	37-1809	96	Oahu	250	25	---do---	SW	No	21.5	158.0
04	12	84	--do---	----do------	37-1810	96	Hawaii	250	35	---do---	SW	No	19.5	155.5
04	12	84	--do---	----do------	52-2726	97	Mauna Loa plumes	250	40	---do---	NE	No	20.0	155.0
04	12	84	--do---	----do------	52-2727	97	--do-------------	250	40	---do---	NE	No	19.5	155.0
04	12	84	--do---	----do------	52-2728	97	--do-------------	250	40	---do---	NE	No	20.0	155.0
09	02	84	--do---	S84-14, 41-D	34-0075	53	--do-------------	250	30	---do---	--	No	20.0	155.5
09	02	84	--do---	----do------	34-0076	53	--do-------------	250	30	---do---	--	No	19.5	155.5
09	02	84	--do---	----do------	44-0093	84	Mauna Kea	250	10	Vertical	--	No	20.0	155.5
11	10	84	--do---	51-A	35-0013	38	Mauna Loa	250	15	Oblique	NE	Yes	19.5	155.5
11	10	84	--do---	----do------	35-0014	38	--do-------------	250	15	---do---	NE	Yes	19.5	155.5
11	10	84	--do---	----do------	35-0015	38	--do-------------	250	20	---do---	NE	Yes	19.5	155.5
11	10	84	--do---	----do------	35-0016	38	Hawaii	250	20	---do---	NW	Yes	19.5	155.5
11	10	84	--do---	----do-----	35-0017	38	--do-------------	250	20	---do---	NW	Yes	19.0	155.5
11	10	84	--do---	----do-----	36-0016	38	Mauna Loa, M. Kea	100	15	---do---	NE	Yes	19.5	156.0
11	10	84	--do---	----do-----	36-0017	38	--do-------------	100	15	---do---	NE	Yes	19.0	155.5
04	14	85	--do---	51D	S85-23-40-62	35	Kauai, Niihau	250	40	---do---	SE	No	26.0	160.0
04	14	85	--do---	51D	S85-23-40-82	36	Hawaii, west side	250	40	Vertical	--	Yes	17.0	156.0
04	14	85	--do---	51D	S85-23-40-83	36	--do-------------	250	40	---do---	--	Yes	17.0	156.0
04	16	85	--do---	51D	S85-23-42-98	66	Niihau, west Kauai	250	20	---do---	--	No		59.0
04	16	85	--do---	51D	S85-23-42-100	66	Hawaii, M. Loa	250	40	---do---	--	No	22.0	155.5
04	18	85	--do---	51D	S85-23-46-43	97	Hawaii to Oahu	250	50	---do---	--	No	16.0	152.0
06	21	85	--do---	51G	51G-47-13	100	Hawaii to Niihau	100	50	Oblique	E	Yes	----	-----
06	21	85	--do---	51G	51G-48-15	100	--do-------------	100	50	--do----	E	Yes	----	-----

1 Numbers to left of hyphen indicate magazines; numbers to right of hyphen indicate frames.
2 Photos with ›30 percent cloud cover are not included except where known to have useful information. Percent areas covered by clouds are mainly from NASA documents and generally cover a higher percentage of the land area within a scene. Some estimates have been revised slightly.
3 Some photographs designated as vertical are slightly inclined from true vertical.
4 Stereo "yes" indicates some overlap with adjacent photograph on left or right.
5 Longitude values are west of the Greenwich Meridian. Latitudes are north.

tion, and measuring areas covered by new lava flows (compare figs. 8.10*B* and 8.10*C*).

RADAR IMAGES

Additional studies of part of Kilauea Volcano from space have been conducted using an imaging radar system (SIR-B) that was flown on board the Shuttle in October 1984. Data were acquired across the southeastern part of the Island of Hawaii, extending from South Point, across Kilauea caldera to Hilo Bay (fig. 8.11).

The SIR-B radar operated at a wavelength of 23 cm, complementing information gained at visible and near infrared wavelengths by Landsat and MOMS–1. It was similar to the synthetic aperture radars flown on the Seasat satellite in 1978 described by Elachi (1980), and the Shuttle Imaging Radar (SIR-A) experiment flown on the Space Shuttle in 1981 (Elachi and others, 1982).

However, unlike these earlier orbital radar systems, SIR-B had the capability to vary the angle at which the radar beam encountered the surface, and obtained images of Hawaii at incidence angles of 28 and 48 degrees. Because orbital radars provide their own illuminating energy and are capable of penetrating clouds, they can provide useful images at all times (day or night) as well as in areas of frequently poor weather, such as Kilauea's east rift zone. Because of the choice of spacecraft orbits and the short duration (8 days) of the mission, only two SIR-B radar images (swathwidths of approximately 20 and 30 km on the ground) were obtained during the Shuttle flight. More complete coverage is anticipated on the reflight of the SIR-B experiment (SIR-B′) scheduled for early 1987.

Radar images display, in part, variations in surface roughness at a scale of a few centimeters to a few decimeters with a pixel size of about 15–20 meters, and many of the individual pit craters and lava flows can be recognized within the national park (fig. 8.12). In particular, variations in the surface texture of lava flows is clearly seen in the SIR-B images. Two examples are identified in figure 8.12; the December 1974 lava flow and the multiple flows within Kilauea caldera show diverse radar backscatter properties. The December 1974 flow erupted as pahoehoe close to Kilauea caldera, but at a distance of approximately 5 km from the vent the flow passed through the transition to aa. This transition (at point A in fig. 8.12) is indicated by an increase in radar brightness associated with the greater backscatter from the rough aa surface. In comparison, the near-vent pahoehoe surface produces a dark radar signal because of its smooth, specular surface.

Kilauea caldera provides further insights into the capability of the SIR-B radar system to distinguish between different surface materials. The caldera rim and the edge of Kilauea Iki pit crater are distinctive (B in fig. 8.12) due to the contrast between the crater floor (low radar return) and the surrounding rain forest (high radar return). Less obvious are the September 1982 pahoehoe flow (C) and other pahoehoe flows within the caldera, due to the uniformly low radar returns from those features as viewed at an incidence angle of 48 degrees.

Such a variation in the radar signature of the different flows is attributed to the decimeter-scale roughness of the lava flow surfaces. Similarly, brightness variations around Halemaumau pit crater (D in fig. 8.12) are attributed to variations in the number and size of boulders (decimeters to meters in diameter) scattered across the caldera floor during the 1924 phreatic eruption.

SUMMARY

Images from space of active or young volcanic areas like Hawaii provide graphic information having several advantages over typical aerial and surface photographs. Considering the larger areas covered and the greater applicability of image-enhancement techniques, views from Earth-orbital altitudes have proved to be a relatively economical form of cartographic data having significant value for the earth sciences. Furthermore, the choice of spaceborne sensor (photography, digital multispectral images, or synthetic aperture radar) permits different physical and compositional attributes of the Earth's surface to be studied. Thus with future Space Shuttle flights and the orbiting of new and currently planned automated satellites (having names like TOPEX, ERS–1, SPOT–1, and Radarsat), the volcanoes of Hawaii will come under more detailed scrutiny from space in the next few years.

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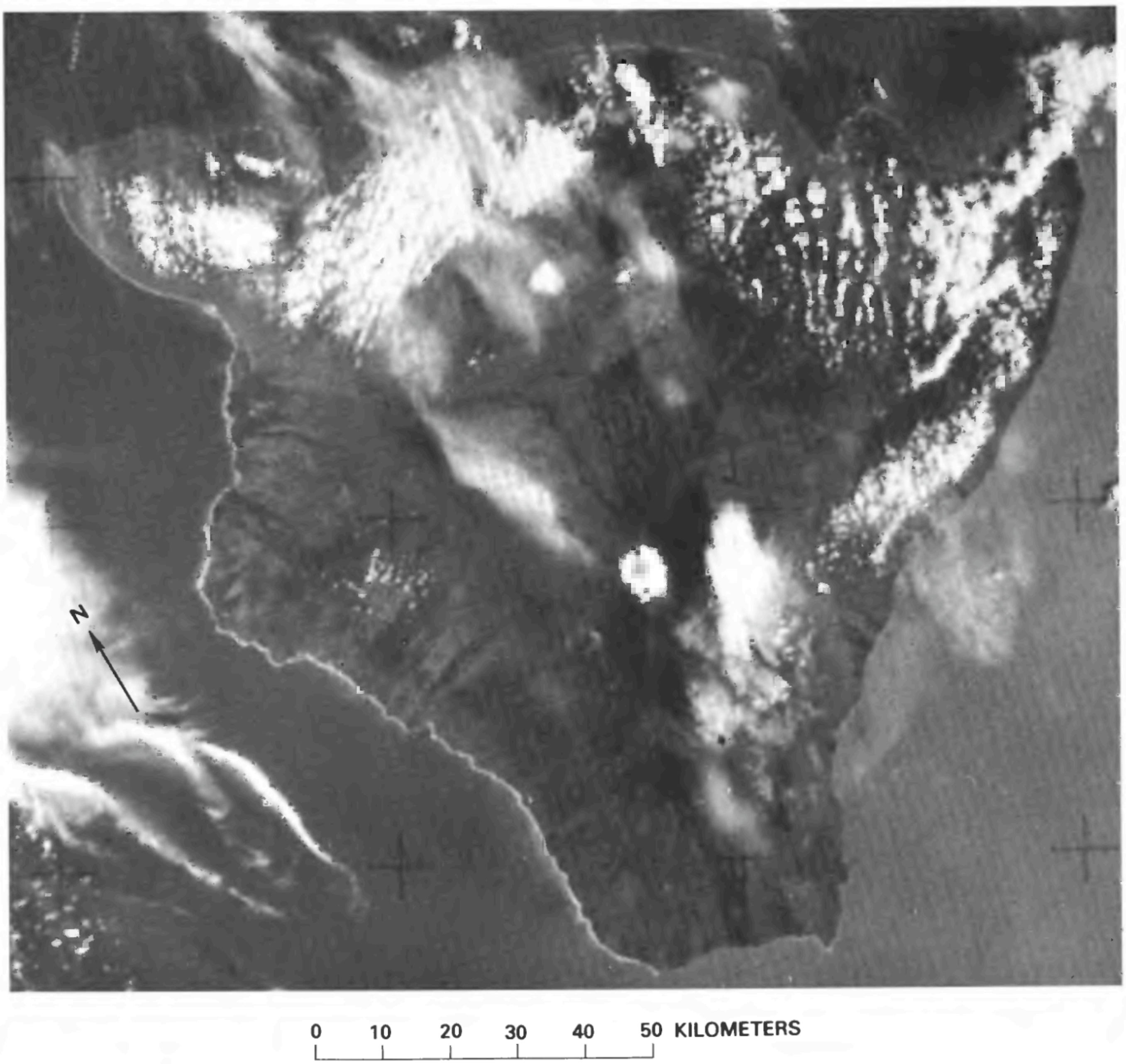


FIGURE 8.1.—View of Island of Hawaii taken on December 7, 1973, during Skylab 4 mission from altitude of about 435 km (270 mi). Snow-capped summits of Mauna Loa (4,170 m; 13,677 ft; center) and Mauna Kea (4,205 m; 13,796 ft; northeast) are 40 km (25 mi) apart. Reseau crosses provide calibration for photogrammetric applications. (NASA photograph SL4–139-3997; lens focal length, 100 mm).

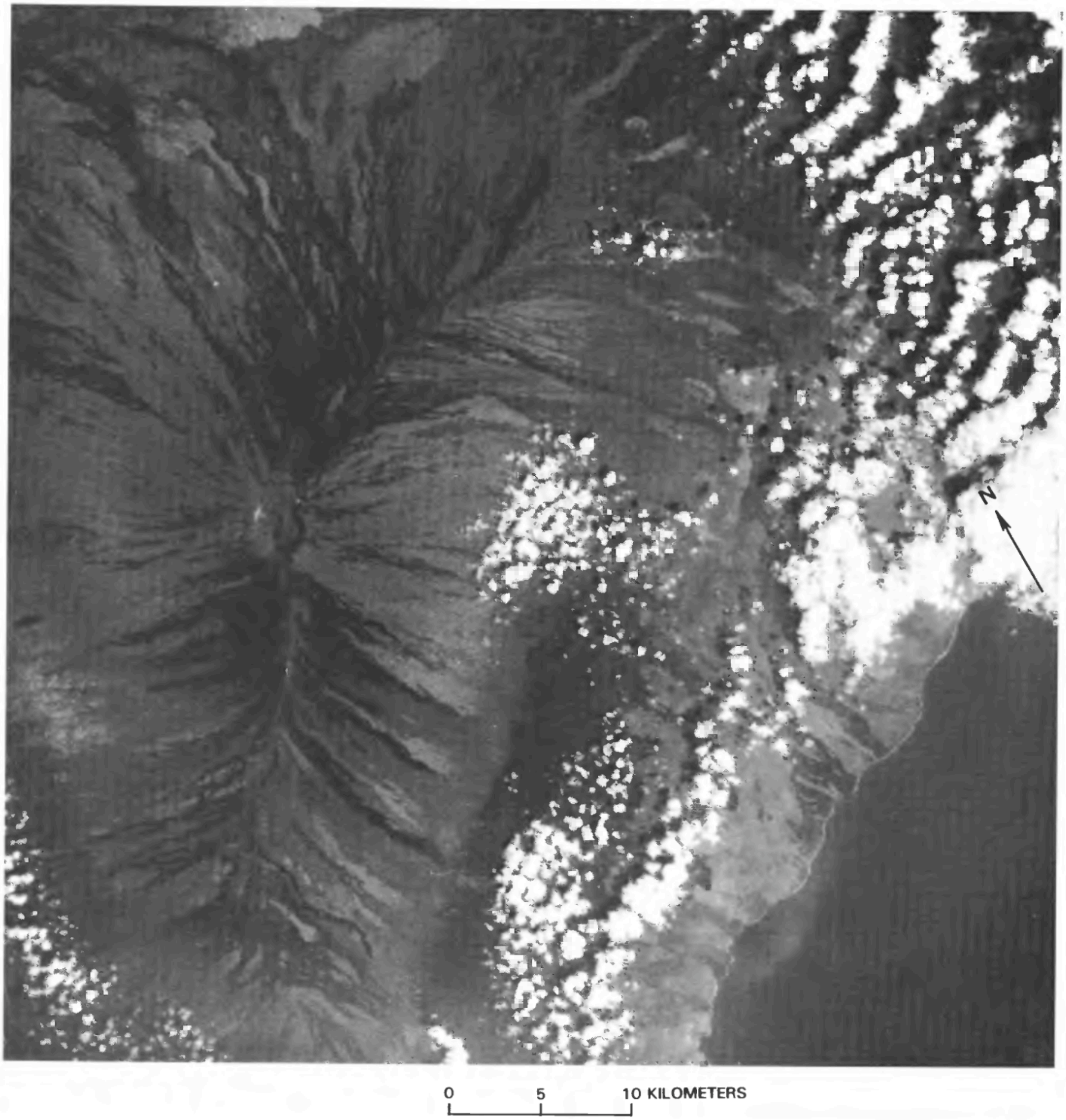


FIGURE 8.2.—Near-vertical view from Space Shuttle of Mauna Loa Volcano showing Mokuaweoweo caldera and young lava flows from northeast and southwest rift zones. (NASA photograph 41A–31-1017; lens focal length, 250 mm; November 1983).

FIGURE 8.3.—Oblique view from Space Shuttle of Island of Hawaii showing eruption plumes from Mauna Loa on April 7, 1984, twelve days after start of eruption. Higher plume (on right) is from degassing vent. Lower plume is from lava-producing vent (J.P. Lockwood, oral commun., 1985). Upper parts of new lava flows are visible as they move toward Hilo Bay (large reentrant on lower left). Active flow front is below clouds, lower on northeast rift. Often-present cloud bank obscures northeast rift zone of Mauna Loa and most of Kilauea Volcano to left. Mauna Kea Volcano is in central near-field. View southwest. (NASA photograph 41C–43-1539).

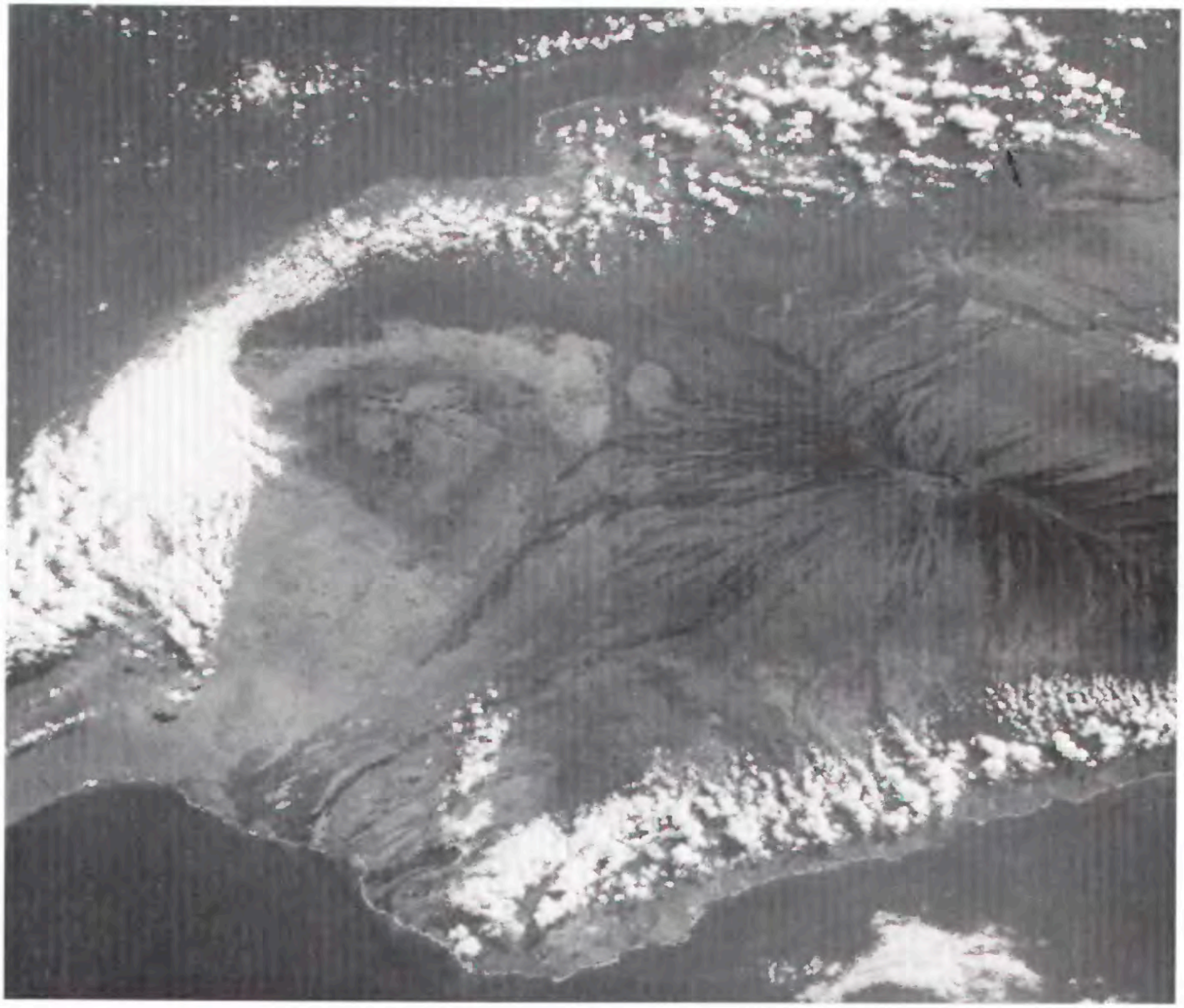


FIGURE 8.4.—Oblique view from Space Shuttle of Island of Hawaii, including Mauna Loa Volcano (right center), Kilauea Volcano and plume from phase 12 eruption of Puu Oo on the east rift zone (top right, arrow), Mauna Kea Volcano (left of center) with numerous cinder cones, Kohala Volcano (left edge), and Hualalai Volcano (bottom center, partly obscured by clouds), also with cinder cones. Note many young (dark) lava flows from Mauna Loa and Hualalai that have reached North Kona and South Kohala coasts. View east. (NASA photograph 41A–46-1841, November 30, 1983).

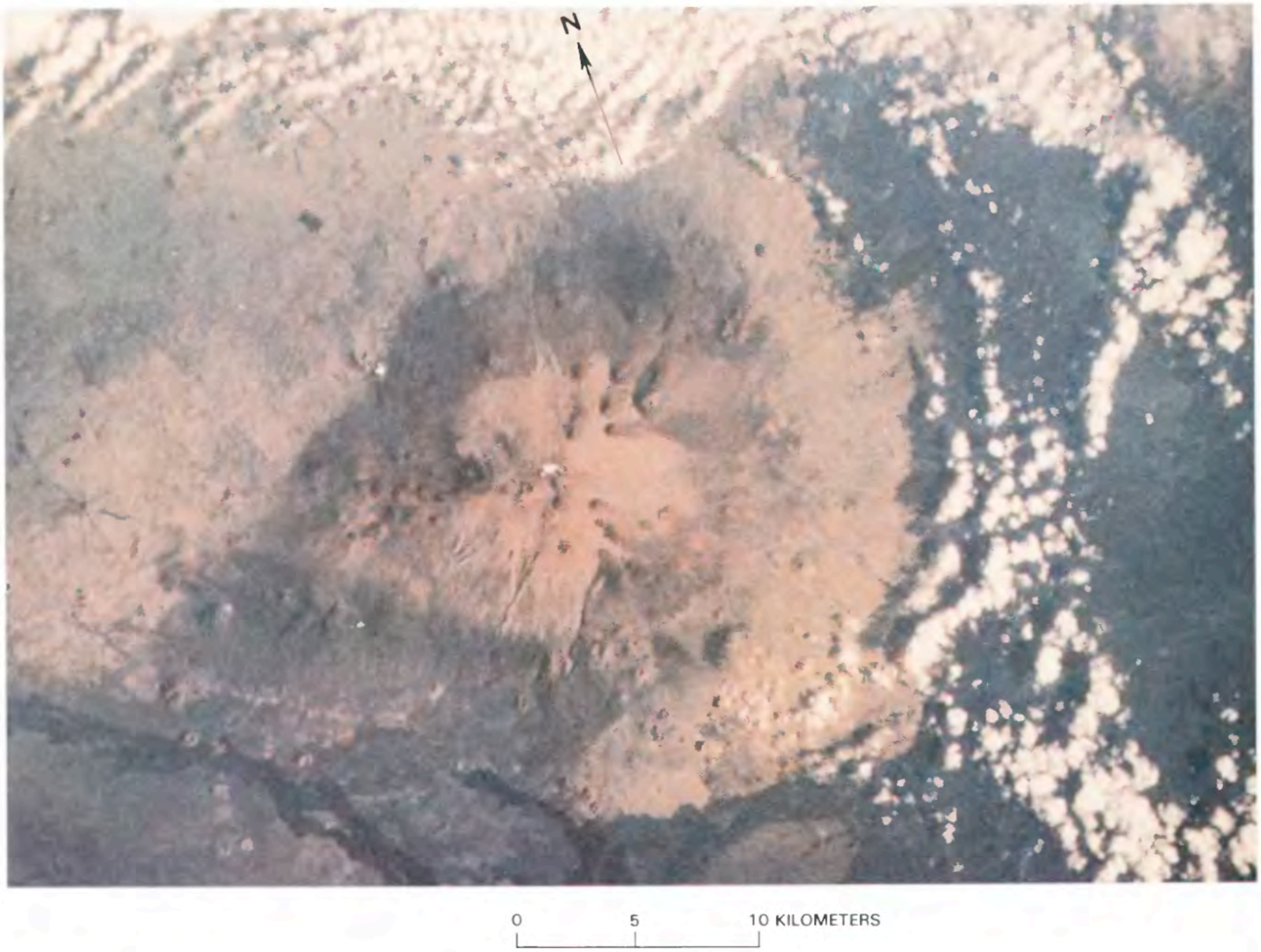


FIGURE 8.5.—View from Space Shuttle of Mauna Kea, showing distribution of alkalic cinder cones capping older tholeiitic shield. Young (dark) lava flows at bottom of photograph are from Mauna Loa. (NASA photograph 41B–34-1565, February 1984).

FIGURE 8.6.—Oblique view of Hawaii taken from Space Shuttle on December 3, 1983, at altitude of 240 km (150 mi). Cloud concentration is caused by northeasterly tradewinds against shield volcanoes, in contrast to clear sky and calm seas on leeward (Kona) side of island. Difference in ocean-surface texture is enhanced by sun illumination with respect to spacecraft. View southeast. (NASA photograph 41A–35-1596).

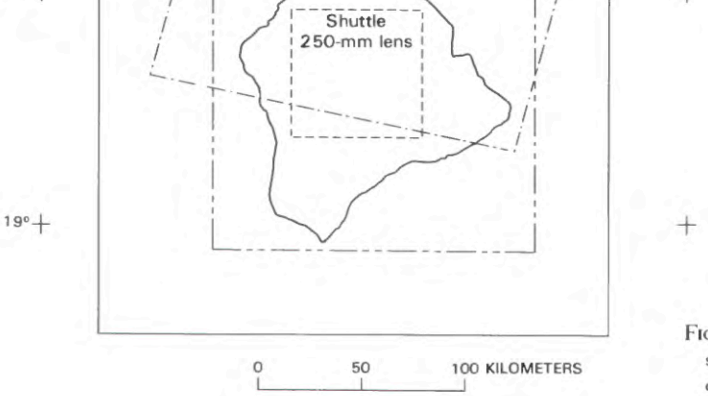


FIGURE 8.7.—Areas covered by typical Landsat, Skylab, and Space Shuttle scenes. The Skylab and Shuttle footprints are for a Hasselblad camera at altitudes of 435 km (270 mi) and 300 km (185 mi) respectively.

FIGURE 8.8.—Composite Landsat image of Island of Hawaii recorded on January 7, 1978, at altitude of about 915 km (570 mi). Image was geometrically corrected and processed to simulate true color by U.S. Geological Survey's Image Processing Facility at Flagstaff, Ariz. (Scene identification numbers 821081193-54X0 and -60X0).

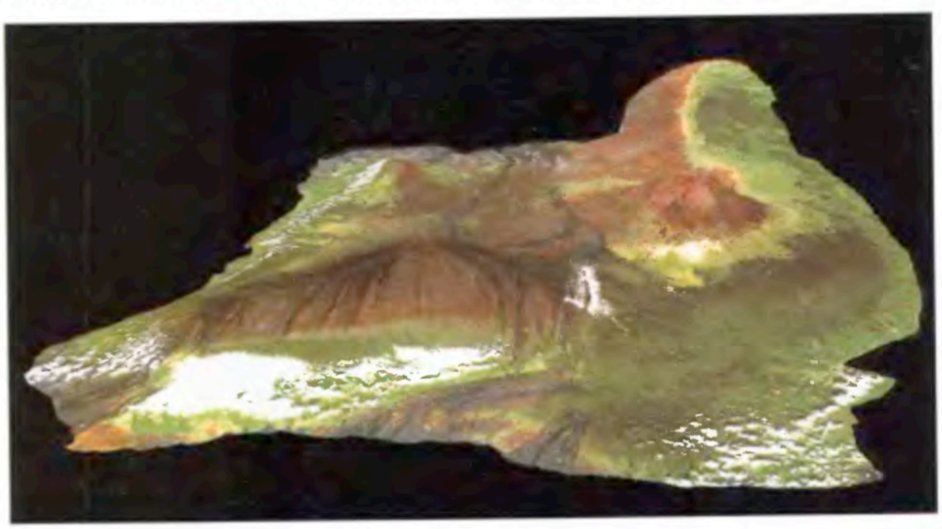


FIGURE 8.9.—Landsat image (same as fig. 8.8) digitally converted to oblique view looking northwest to illustrate Mauna Loa and Kilauea basaltic shields. Prepared by U.S. Geological Survey Image Processing Facility at Flagstaff, Ariz.

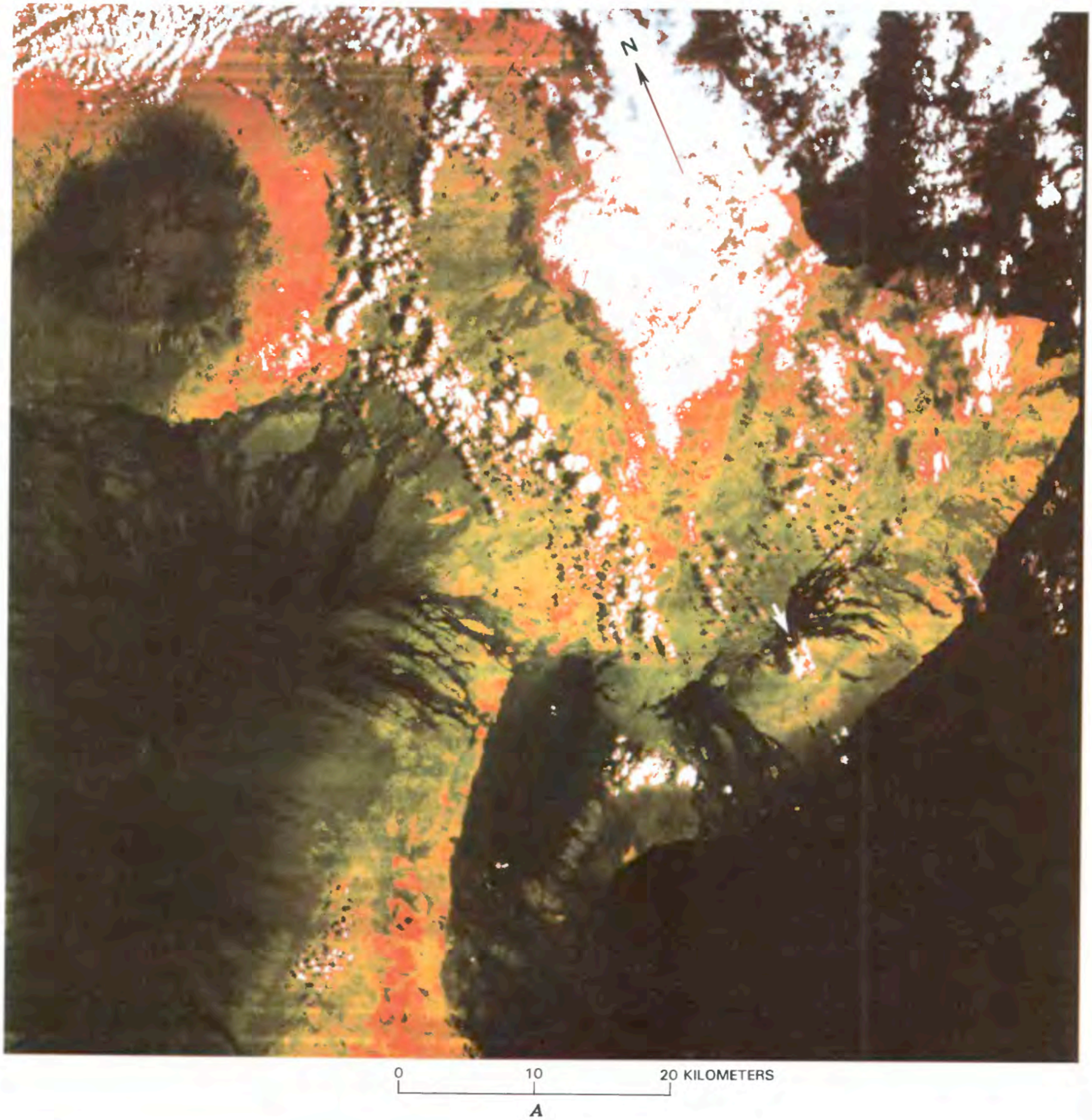
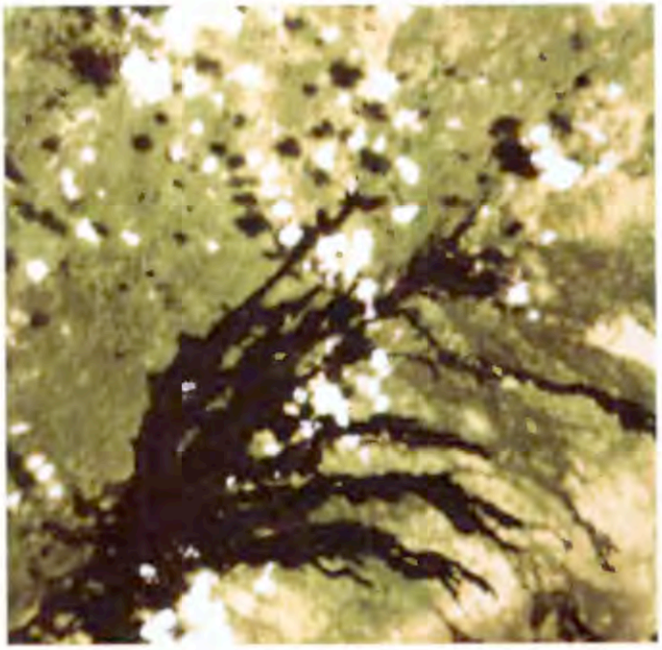


FIGURE 8.10.—Scene of eastern Hawaii from German MOMS–1 experiment on February 6, 1984, at 0930 H.s.t. from Space Shuttle. Lava flows are from Puu Oo vent (arrow in *A*). Color representation for two channels of MOMS–1 instrument is based on image-enhancement technique using HSI display mode (hue, saturation, and intensity shown in blue, green, and red channels of display system). Ratio between two channels (at 0.60 and 0.90 microns), combined with the HSI display mode, enhances weak variations in image contrast. White features are clouds. ***A***, Northeast quarter of original scene. ***B***, Enlarged subscene (750 by 750 pixels) of Puu Oo eruption area. ***C***, Eruption area (E.W. Wolfe, written commun.) showing new flows through episode 14 in January 1984, that can be directly compared with *B*.



B

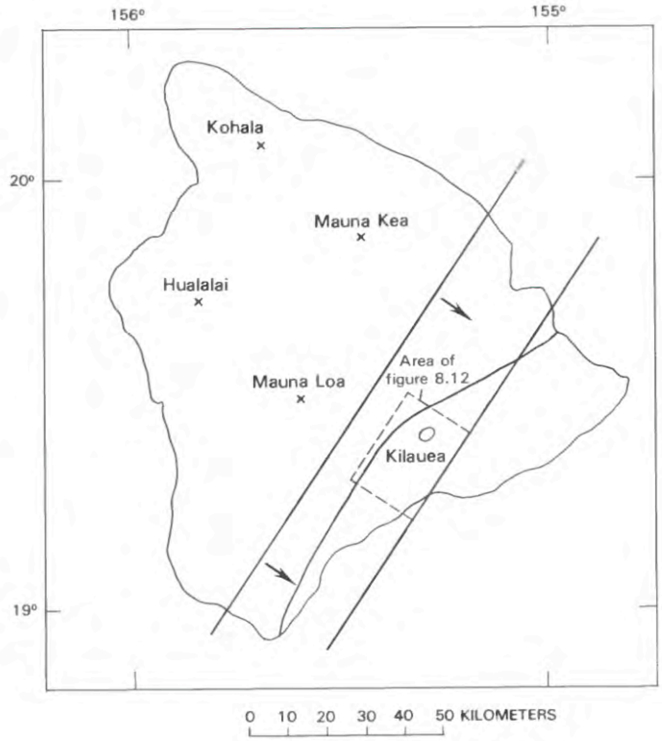
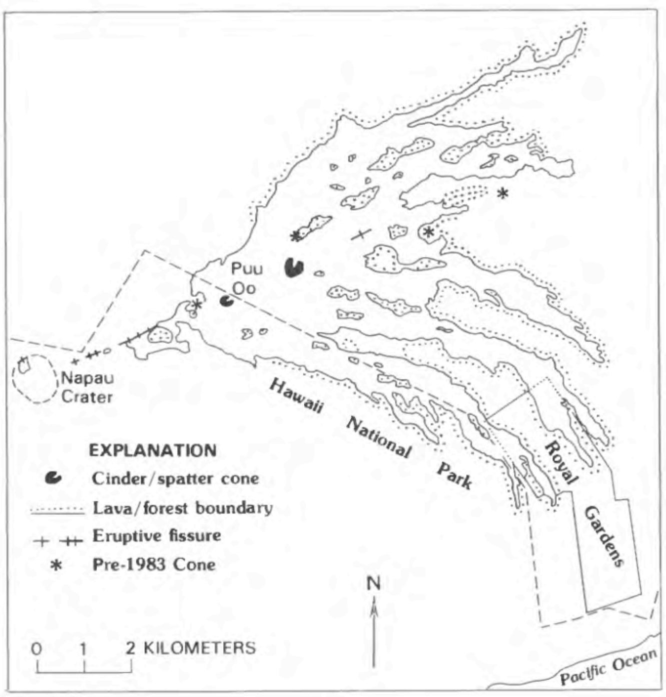
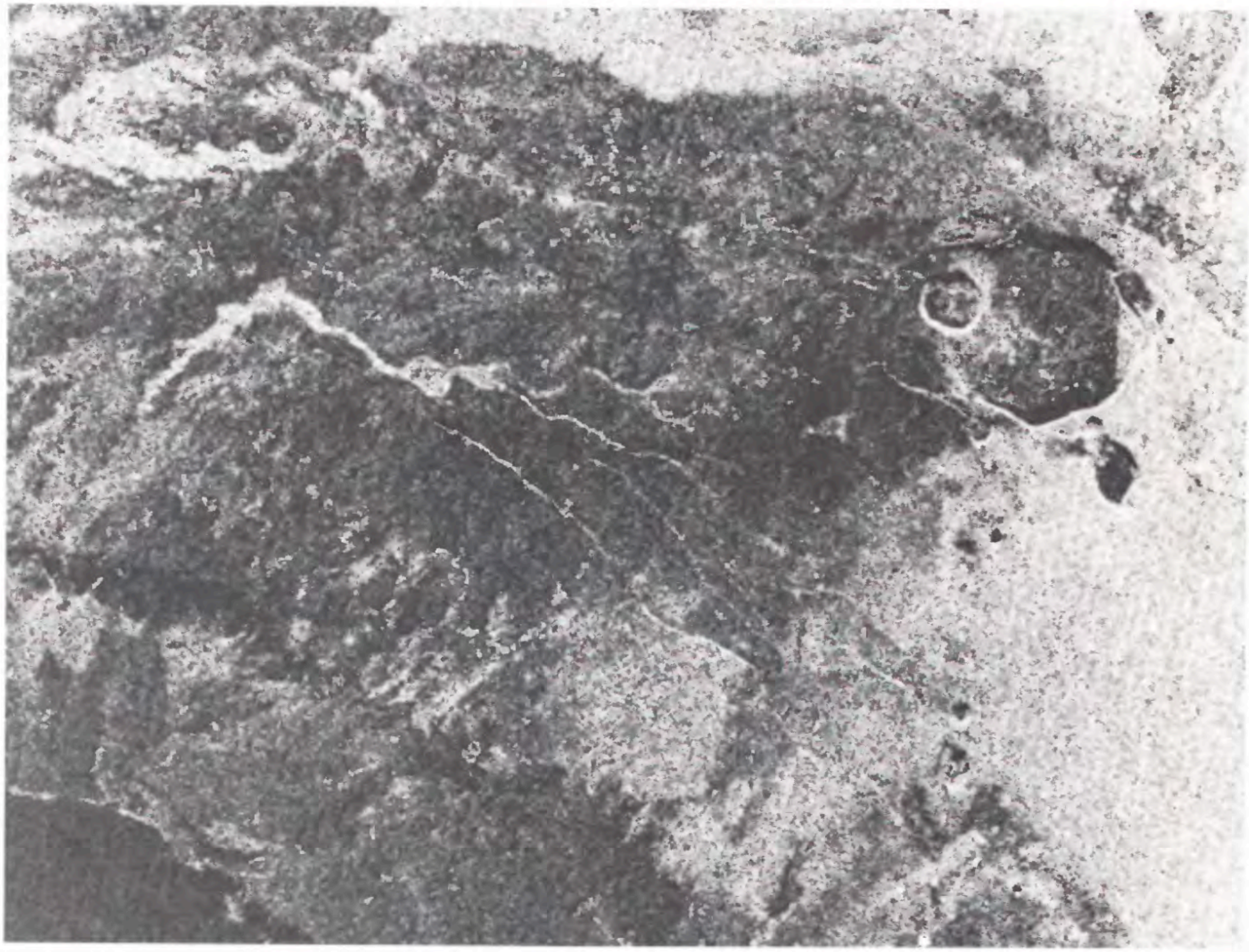


FIGURE 8.11.—Location of SIR-B radar images (area between parallel lines) that were acquired over southeast Hawaii in October 1984. Radar look-direction (arrowed) was toward southeast, and Shuttle flew from southwest to northeast on both data takes.



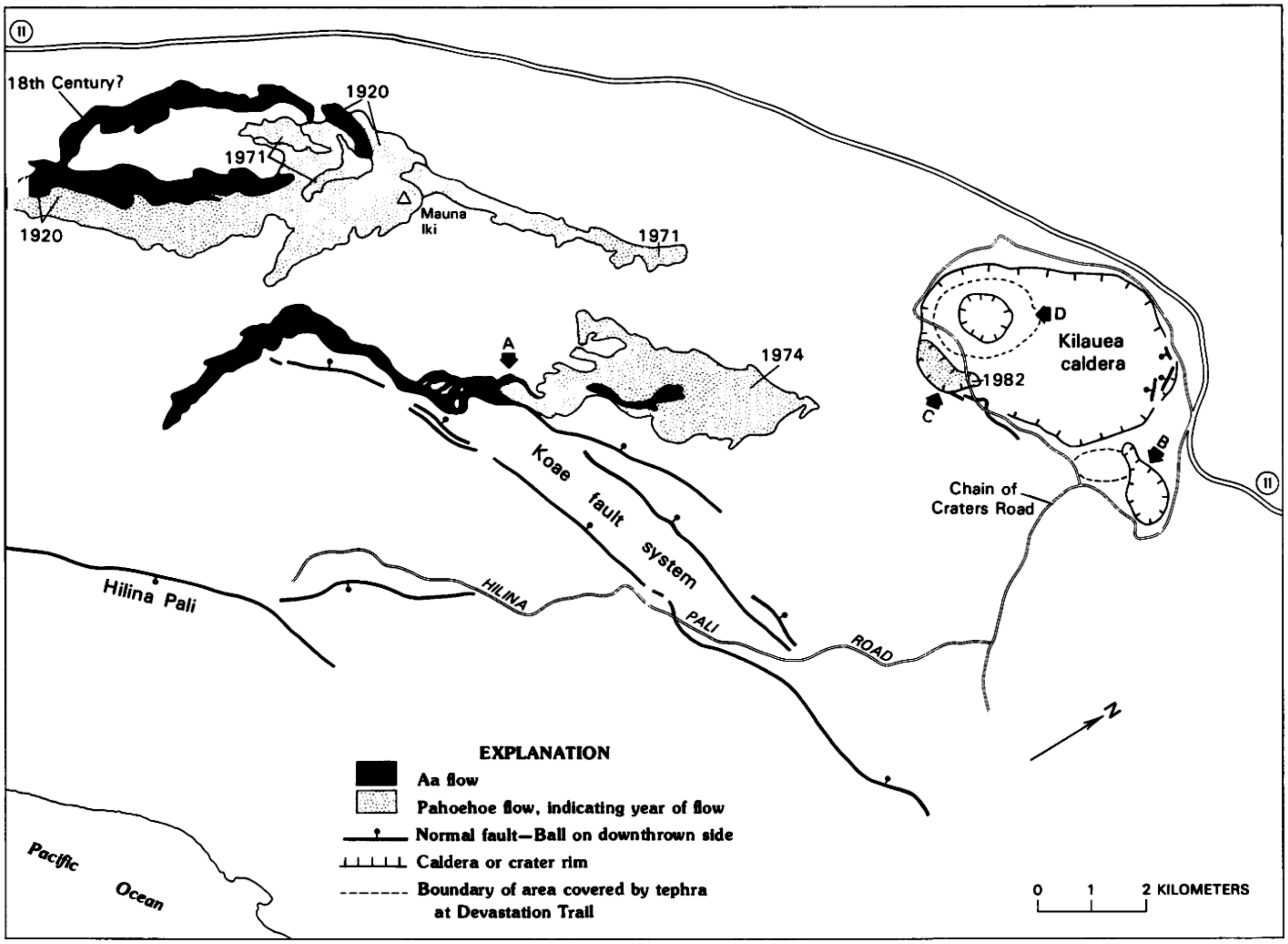
C

FIGURE 8.10.—Continued.



A

FIGURE 8.12.—Radar image and map of Kilauea summit area (see fig. 8.11 for location. ***A***, Subscene of SIR-B Data Take number 115.2, acquired at incidence angle of 48 degrees. Nominal image resolution is approximately 20 meters per pixel. ***B***, Same area indicating location of prominent lava flows, craters, and pali. A, transition from aa to pahoehoe on December 1974 lava flow; B, Kilauea Iki pit crater; C, September 1982 pahoehoe flows where low radar returns are evident; D, variations in radar brightness around Halemaumau pit crater (dotted line) are attributed to spatial variations in size and number of boulders ejected onto surrounding terrain by 1924 phreatic eruption of Halemaumau.



B

FIGURE 8.12.—Continued.