Glaciers of Asia—

GLACIERS OF AFGHANISTAN

By John F. Shroder, Jr., *and* Michael P. Bishop

SATELLITE IMAGE ATLAS OF GLACIERS OF THE WORLD

Edited by RICHARD S. WILLIAMS, JR., *and* JANE G. FERRIGNO

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By John F. Shroder, Jr.,[1] *and* Michael P. Bishop[1]

Abstract

The Hindu Kush mountains of Afghanistan range in elevation from more than 7,000 meters in the east, where most of the glaciers occur, to less than 500 m in the arid west. More than 3,000 small glaciers, with an estimated area of 2,700 km^2, provide vital water resources to the region, especially for irrigation. The glaciers are concentrated in the highest parts of the three main drainage basins in the country: (1) the Afghan-Iranian plateau endorheic basin, (2) the Indus basin, and (3) the glacier-dominant Turkistan endorheic basin. Most glaciers occur on north-facing slopes that are shaded by mountain peaks, and on east and southeast slopes that are shaded by monsoon clouds. Frequent snow avalanches, coupled with widespread stagnation or retreat, have produced numerous debris-covered ice and rock glaciers. Limited verification of analyses from older Landsat and some ASTER imagery is provided by Russian and United States 1:100,000- and 1:50,000-scale topographic maps, compiled from vertical aerial photographs acquired during the late 1950s, and by several large-scale glacier maps made in the 1960s and 1970s. Transparent image overlays, false-color enlargements, a few digital analyses, and stereoscopic satellite images were used in a limited analytical fashion to analyze typical glaciers in the region, including the small *Fūlādī Glacier*[2] in the *Kūh-e-Bābā*, the glaciologically assessed ice masses of *Mir Samir*, the high *Sakhi Glacier* on *Kūh-e-Bandakā*, the extensively analyzed *Keshnīkhān Glacier* and the long, debris-covered *Qādzī Deh Glacier* in the western Wākhān area, and the precisely mapped *Zemestan* and *Northern* and *Southern Issīk Glaciers* in the Afghan Pamirs.

Introduction

The high elevation and remote mountains of Afghanistan (fig. 1) have been traversed for millennia by caravans, explorers, and scientific expeditions; yet little detailed information is readily available regarding the terrain, ice, and snow in these mountains. Study of glaciers in such difficult and inaccessible country necessitates the use of satellite imagery. Fortunately, high-quality imagery, topographic maps, and ground photographs are available for limited verification of satellite analyses in some areas. This report provides glacier information based on these data sources, and also includes a general review of the limited literature covering Afghanistan's glaciers.

The glaciers of Afghanistan provide an important, but variable (5–25 percent) part of the meltwater used for critical irrigation through the summer dry season (Levedeva and Larin, 1991); however, the amount of meltwater provided is expected to decline as much as 14 percent if temperatures increase as little as 1 °C because of global warming (Levedeva, 1997). Shroder (1980, 1989a) initiated a glacier inventory to provide better information for water-resource analysis and development. The unstable military situation in the late

[1]Department of Geography and Geology, University of Nebraska at Omaha, Omaha, NE 68182

[2]The geographic place-names used in this section conform to the usage authorized for foreign names by the U.S. Board on Geographic Names as listed on the GEOnet Names Server (GNS) website: *http://earth-info.nga.mil/gns/html/index.html*. The names not verified or not listed on the website are shown in italics.

Figure 1.—Index map of Afghanistan showing the location of major geographic features mentioned in text — Hindu Kush, the Pamirs, Wākhān corridor, Badakshān, Daryā-ye Panj (river), Tirich Mir, Kūh-e-Bandakā *and* Kūh-e Bābā.

1970s disrupted the field-based effort, however, and forced the use of satellite imagery to accomplish the inventory. Early results were given to the U.S. Geological Survey in the early 1980s but they were not published. Then the ensuing two decades of ongoing war and religious and political upheaval, and the subsequent presence of western military forces further disrupted efforts to study glaciers in Afghanistan. The addition of seven years of catastrophic drought, starting in the late 1990s, and the related expansion of trafficking in drought-tolerant opium poppies, coupled with post-war reconstruction efforts, gave renewed impetus for water-resource assessments, a glacier inventory, and an analysis of glacier-related hazards. Water resources and the potential problems from ongoing climate change are viewed as critical to future political stability, with the National Aeronautics and Space Administration (NASA)-supported Global Land Ice Measurements from Space (GLIMS) Project [*http://www.glims.org*] and the U.S. Geological Survey tasked to provide additional baseline information for better predictive and reconstruction capabilities in Afghanistan (Shroder, 2004).

Occurrence of Glaciers

The mountains of Afghanistan generally decline in elevation from more than 7,000 meters (m) in the east to less than 500 m on the Iranian border. Several thousand small glaciers occur in the rugged alpine topography of the central and northeast Hindu Kush and in the Pamirs of eastern Afghanistan, with a total area estimated at approximately 2,700 km^2. In the central part of the country, three major basins meet: (1) in the Turkistan endorheic basin (does not drain to the sea), drainage is north or west into the Aral Sea basin between Uzbekistan and Kazakhstan; (2) in the Afghan-Iran plateau endorheic basin, drainage is south or west, and (3) in the Indus (exorheic) basin, drainage is to the east or south into Pakistan and thence to the Indian Ocean (fig. 2). Delineation and letter/numeral designation of the drainage basins of Afghanistan was originally done according to the revised guidelines of the Temporary Technical Secretariat (Müller, 1978) of the World Glacier Inventory (Shroder, 1980). The three main basins are subdivided into 77 smaller ones, of which 25 are glacierized (contain glaciers) (fig. 2) (Shroder, 1980). Nineteen of the glacierized basins have more than 75 percent of the total ice mass of Afghanistan (table 1) and drain into the Turkistan endorheic system, whereas the Afghan-Iran plateau basin has only seven small glaciers in one small drainage area.

A variety of snowline or equilibrium line altitudes (ELA) was determined in Afghanistan during the 1960s and 1970s. General altitudes in subtropical high Asia was first distinguished by von Wissman (1960); Grötzbach and Rathjens (1969) refined this work for much of the central and western Hindu Kush. Grötzbach and Hillebrandt (1964) and Gilbert and others (1969) contributed some detailed work in the central Hindu Kush; Desio (1975) extended these analyses to the north into the Pamirs of the Badakhshān region. In general, however, the glaciers of northern Badakhshān are the most poorly known in Afghanistan. Braslau (1972) and Patzelt (1978) provided additional ELA data for the Wākhān corridor. Porter (1985) first used Landsat imagery to determine the extent of late Pleistocene glaciers in Afghanistan, but not modern ice.

During the war years of the 1980s, snow cover mapping of Afghanistan's mountains was undertaken by Soviet scientists (Tsarev and others, 1986; Kravtsova, 1990) by using satellite imagery and field measurements to assess seasonal snow distribution and depth, dynamics of the snow boundary, seasonal snow-lines, and dates of formation, melting, and duration of snow cover.

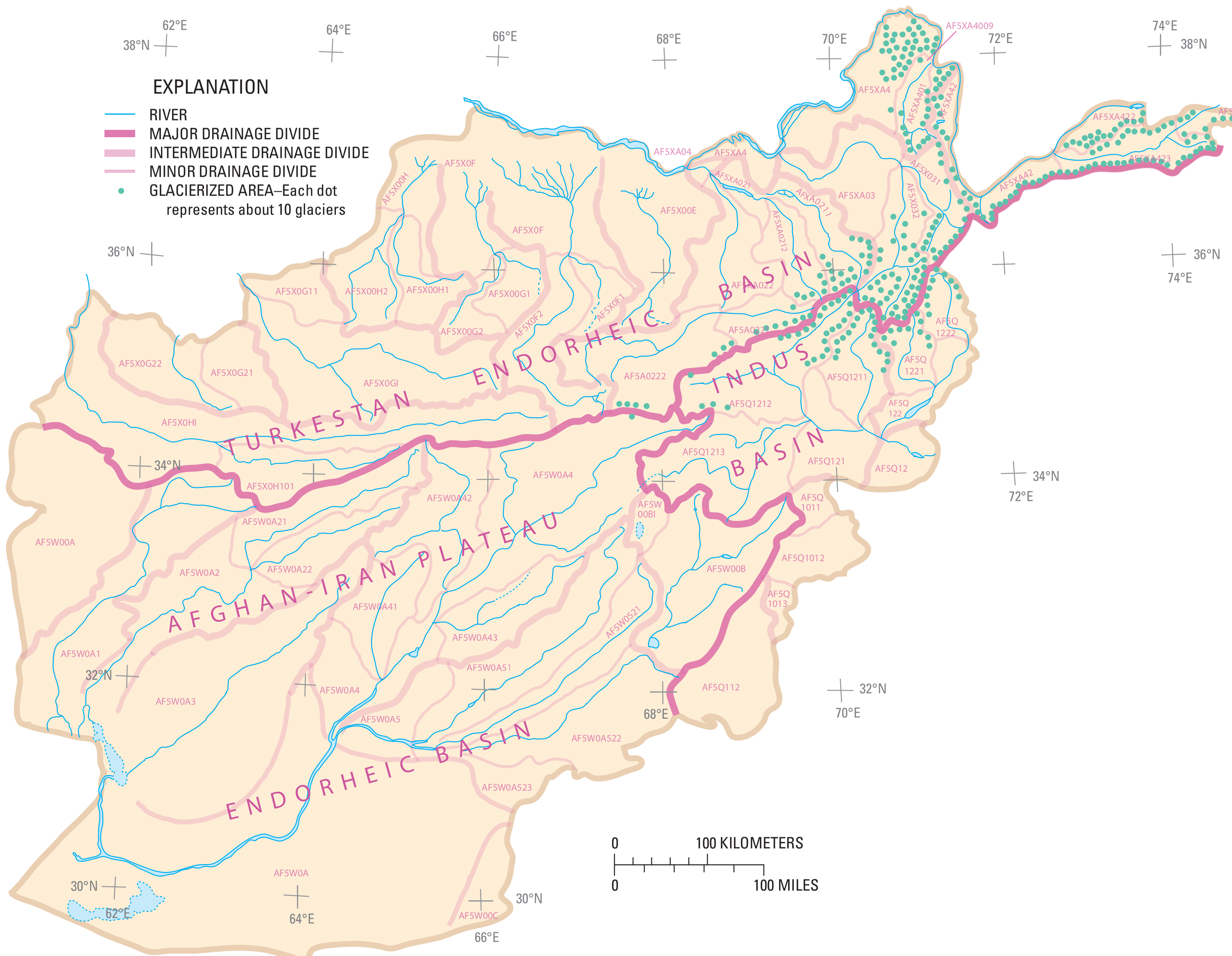


Figure 2.—Map of Afghanistan showing the three main drainage basins, the detailed delineation of 77 smaller drainage basins according to Temporary Technical Secretariat (TTS) for World Glacier Inventory (Müller and others, 1977; Müller, 1978) guidelines, and the generalized glacierized areas. Each dot represents about 10 glaciers (see table 1).

Table 1.—*Glacierized drainage basins in Afghanistan*

[Code letters and numbers identify individual drainage basins delineated on the basis of Temporary Technical Secretariat (TTS) for World Glacier Inventory guidelines (Müller, 1978; Shroder, 1980). The number of glaciers in parentheses are minimum counts made from inadequate maps, satellite imagery, or from both sources. Other numbers are more precise counts made from 1:100,000-scale maps. All total counts include a few ice-cored rock glaciers or debris-covered glaciers in which little or no surface ice is exposed]

Basins	Code	Number of glaciers
TURKESTAN ENDORHERIC DRAINAGES AF5X		
Vardūj	A031	(199)
Monjān	A0321	(220)
Upper Kowkcheh	A032	(57)
Yakhshendar (Anjumān)	A0322	(141)
Darang	A4003	6
Kulab	A4005	104
Sabz	A4006	54
Jaway	A4007	113
Maynay	A4008	91
Yarhk	A4009	65
Shīveh	A401	(137)
Chakmaktin Kol	A412	(80)
Upper Ab-Panj	A42	(275)
Pāmīr	A422	174
Wākhān	A423	(381)
Khānābād (Taliqan)	A0211	(183)
Chal Bangi	A0212	(60)
Andarāb	A0221	80
Surkh Ab	A0222	73
INDUS RIVER BASIN DRAINAGES AF5Q		
ʻAlīshang - ʻAlīngār	1211	178
Ghowr Band - *Panshir*	1212	262
Pīch	1221	(100)
Katīgal	1222	(103)
Upper Kabul	121	(13)
AFGHAN-IRANIAN PLATEAU DRAINAGES AF5W		
Upper Helmand	A4	7

Maximum snow storage accumulation was mapped, and indices of snow-pack instability were compiled (Tsarev, 1988). After the Soviet departure from the country in 1989, efforts continued during the following decade to assess and map at a small scale the climatic characteristics of the snow cover and avalanche regimes in Afghanistan (Kravtsova and Tsarev, 1997). Morphology, climate, mass exchange, and runoff of glaciers in Afghanistan were also studied (Lebedeva and Larin, 1991), and predictions were made regarding glacier conditions and runoff under the influence of global warming in the early 21st century (Lebedeva, 1997). For the World Atlas of Snow and Ice Resources (Kotlyakov, 1997; Kotlyakov and Lebedeva, 1998), ice of the Hindu Kush was mapped, at the very generalized scale of 1:5,000,000, in terms of such parameters as ice water-volume equivalent, temperature, precipitation, glacier regime, river runoff, avalanche activity, and late Pleistocene glaciation.

Snowline contours for glaciers of the central Hindu Kush and the Wākhān corridor range in elevation from 4,600 m to 5,200 m, with the highest values at the northeast and southwest ends of the ranges, where precipitation is less.

The lowest snowline values occur on the north-facing slopes, and presumably also to the north into the high Badakhshān Pamirs. The low ELA contours also form a prominent dip at the Sālang pass area, north of Kabul in the central Hindu Kush, where precipitation is highest in the country. This increase in the amount of snow is the result of the concentration of precipitation in the narrowest part of the range through which westerly storms pass, and also because monsoon precipitation sometimes influences the area (Sivall, 1977).

Glaciers in Afghanistan are generally small because the climatic snowline is above many peaks, and glaciers form only where ablation is retarded in shaded areas (Grötzbach and Rathjens, 1969). This produces a strong northerly glacierization in much of the central Hindu Kush; toward the Wākhān corridor in the northeast this tendency is less strong. Breckle and Frey (1976b) noticed relatively strong glacierization facing the east and southeast near the Pakistan border, where summer monsoon weather from India produces clouds that provide shade and slow melt. This part of Afghanistan is the site of the intertropical convergence zone (ITCZ) in summer, and is regularly influenced by monsoon precipitation (Sivall, 1977; Shroder, 1989b). The cloudiness to the southeast, especially over the glaciers in Pakistan, obscures much of the satellite imagery taken in late summer near the end of the ablation season.

Most of the glaciers of Afghanistan are mountain or valley glaciers that occur in cirques or simple basins. The higher peak areas have some compound basins. Nourishment is generally by avalanche, with the result that ice fronts are extensively debris-covered. Although there has been little study of glacier terminus activity, the large amount of debris cover gives the appearance of widespread stagnation, equilibrium, or retreat. In general, retreat is thought to be dominant throughout much of the Himalayan chain (Mayewski and Jeschke, 1979) and the Hindu Kush (Shroder, 1980).

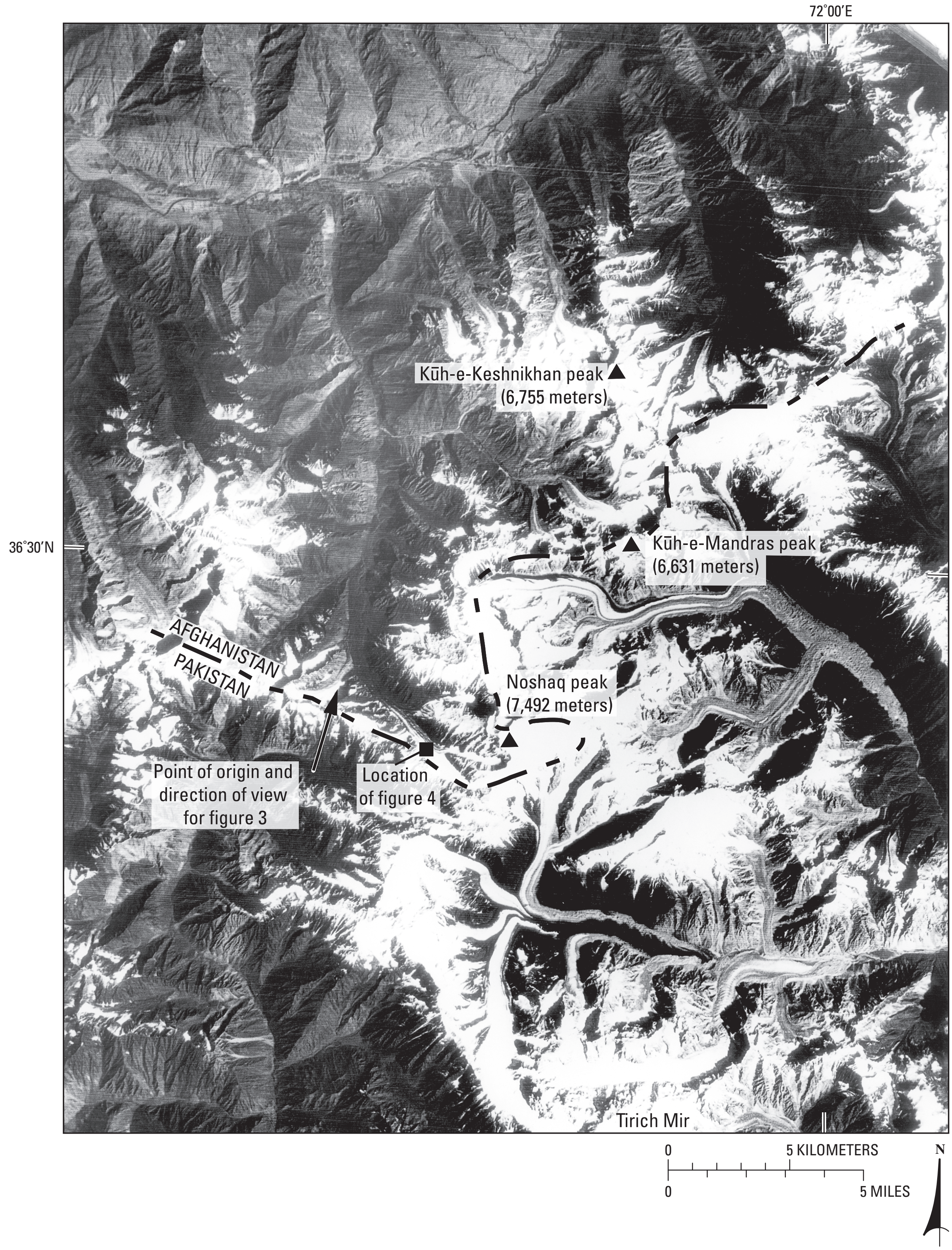
Numerous rock glaciers (Grötzbach, 1965; Shroder and Giardino, 1978) occur in Afghanistan; the most common are tongue-shaped and spatulate types, although many lobate valley-wall types also occur. Many have glaciers at their heads and water-filled kettle depressions lower down. Internal ice movement produces a steep rubble front at the angle of repose that is characteristic of rock glaciers. Outbursts of water from some of these rock glaciers or from moraines have been reported and these may be related to water-pressure induced movement (Scott and Cheverst, 1968). Grötzbach (oral commun., 1978) observed ice lenses, interspersed with open-matrix rock fragments in which water could be trapped, in some rock glaciers in the Hindu Kush. Many observations elsewhere indicate a relation between movement of some rock glaciers and internal water (Shroder and Giardino, 1978). Analyses of rock glaciers in Afghanistan with satellite imagery have produced few results. This is largely because, even with ground-based observations, there is as yet little agreement on the differences between rock glaciers, ice-cored moraines, some types of landslides, or boulder streams (Giardino and others, 1987). In addition, many of these landforms show only minor topographic variation, which makes differentiation with satellite imagery especially difficult.

The longest and largest glaciers in Afghanistan are located in the narrowest part of the entrance to the Wākhān corridor, along the north-facing left bank of the Daryā-ye Panj. In that area, the mountains on the Afghanistan-Pakistan border are more than 6,000 m high and at least 15 of the north-flowing glaciers are more than 10 km long. Several of these are also the largest in area and, although precise measures are not yet possible, the largest of these glaciers are about 75 to 100 km^2 in surface area. For example, from Noshaq peak (7,492 m), a subsidiary peak of the great Tirich Mir in Pakistan, *Qādzī Deh Glacier* flows more than 14 km down to an elevation of about 3,580 m (fig. 3). More than half of the lower part of this glacier is covered extensively with black slate and argillite fragments (fig. 4) derived from the Wakhan Formation (Buchroithner,

***Figure 3.**—(at left) Terminus of debris-covered* Qādzī Deh Glacier *in background; joined by* Ye Safed Glacier *entering on the far right (east). The varicolored* Rakhe Kuchek Glacier *in the foreground is covered in part by light-colored, probably granitic debris, and in part by dark argillite from the peak* Kharposhte Yakhi *(5,698 m) from which the photograph was taken. See figure 5 for location. Photograph by B. Ehmann.*

***Figure 4.**—(below) Argillite-covered glacier ice at an elevation of about 5,075 m on the* Qādzī Deh Glacier *below Noshaq peak (7,492 m). See figure 5 for location. Photograph by B. Ehmann.*

1978), or the Wakhan Slates (Desio, 1975). This large quantity of supraglacier debris is provided by profuse avalanches across the weak and friable rocks that make climbing here so hazardous (B. Ehmann, verbal communication, after the Noshaq expedition, 1978). This supraglacier debris cover produces the anomalous, nearly black glacier surfaces that are so prominent on the satellite imagery (fig. 5). The lack of contrast between buried ice and surrounding slopes adds to the uncertainty of determining the true size of some of these glaciers.



In addition to the authors mentioned previously, other observations and studies of Afghanistan glaciers have been made (table 2). Detailed field study was done only by Gilbert and others (1969), Grötzbach and Rathjens (1969), and Patzelt (1978). Minor field data were provided by Grötzbach (1964), Braslau (1972), Breckle and Frey (1976b), and Desio (1975). First, von Wissman (1960), then Maksimov and Perugina (1975) worked mainly from maps, and Shroder (1980) used maps, satellite imagery, and field observations to initiate a glacier inventory following Temporary Technical Secretariat for World Glacier Inventory guidelines (Müller and others, 1977; Müller, 1978). The needs of this inventory led directly to computer processing of satellite digital data of the *Keshnīkhān Glacier*, at the mouth of the Wākhān corridor (Braslau and Bussom, 1978a, b). Numerous other minor observations of glaciers and useful photographs and planimetric maps have been produced by various scientists and mountaineers (table 2).

Mapping of Glaciers

Detailed maps do not exist for most of the glaciers in Afghanistan because of poor accessibility and an unstable military and political climate. Fortunately, reasonably high-quality topographic maps exist for the entire country, although they are difficult to obtain. These maps were produced in the late 1950s, using stereographic, vertical aerial photography that was flown to produce the maps (Glicken, 1960; Anonymous, 1960). The southern two-thirds of the country was officially mapped by the United States and the northern one-third by the former Soviet Union (Reiner, 1966), although both countries subsequently made their own complete maps of the entire country clandestinely. Maps of the country were produced at scales of 1:50,000, 1:100,000, 1:200,000, and 1:250,000. Nearly complete sets of all scales are housed in the Afghanistan collection at the University of Nebraska at Omaha, and also in the scholarly map collections of various British, German, and Russian institutions. Although several problems of incompatibility exist between the American and Russian maps (Shroder, 1980), glaciers are shown reasonably well at 1:100,000-scale, as they existed in 1958–59, when the aerial photographs were acquired. Considerably greater detail is presented on the 1:50,000 series, the old Soviet versions of which are now more generally available. The original vertical aerial photographs were restricted but are now reported to be available in Kabul, Afghanistan. For a short time in the 1960s, photomosaics and a few stereoscopic pairs were available, and a few photomosaics of the glacierized areas are held by scientists today (Breckle and Frey, 1976b).

In spite of the political changes in recent years, obtaining maps in Afghanistan remains difficult. Consequently, some agencies have implemented more transparent means of accessing topographic data (Shroder, 2004). The Afghanistan Information Management Service (AIMS) and the Afghanistan Research and Evaluation Unit were set up with backing from the United Nations and the U.S. Agency for International Development (USAID) to help with this initiative. AIMS is actively producing high-quality, GIS-based maps at many scales, and is generating Landsat-based terrain maps with a variety of GIS overlays. Most significantly for the glacier inventory, all of the old Soviet-era topographic maps at 1:50,000-scale have been scanned, overlain with Roman alphabet conversions of the former Cyrillic characters, and made available for reconstruction and assessment efforts.

Figure 5.*—(at left) Landsat 3 return beam vidicon (RBV) satellite image showing glacierized areas extending from Tajikistan and Ab-i-Panj river in the Wākhān valley in the north to Tirich Mir peak (7,706 m) in Pakistan on the extreme south. (See figure 6 for location.) The large glacier flowing from center to right is the Darband and Udren system. The large and complex glacier system in the lower right third of the image is the upper and lower Tirich glaciers. All these large glacier systems originate on the Pakistan side of the Tirich Mir massif. International border is approximate. The Landsat 3 image (30553–05112, Subscene B; 9 September 1979; Path 163–Row 35) is from the U.S. Geological Survey, EROS Data Center, Sioux Falls, S. Dak. 57198.*

Table 2.—*Glacier information contained in scientific and mountain-climbing (mountaineering) publications on Afghanistan*

Report	Planimetric maps	Useful photographs or topographic diagrams	Minor observations of glaciers	Detailed analyses of glaciers	Detailed maps of glaciers	Digital satellite maps	Moraines and geomor-phology
Austrian scientific expedition in the Wakhan (1970, 1972)					X		
Bartolami (1972, 1973)	X	X					
Biel and Wala, (1972, 1973)	X	X	X				
Braslau (1972)		X		X			X
Braslau and Bussom (1978a)						X	
Braslau and Bussom (1978b)		X				X	
Breckle and Frey (1976a)		X					
Breckle and Frey (1976b)	X	X	X				
Chwascinski (1966)	X	X					
Desio (1962)							X
Desio (1975)	X	X	X				X
Diemberger (1966)	X	X	X				
Dozier (1970)	X	X	X				
Dunsheath and Baillie (1961)	X	X					
Exploration Pamir 75 (1978a, b)					X		
Frey (1967, 1968)	X	X					
Giger (1972, 1973)	X						
Gilbert and others (1969)	X	X		X	X		X
Grötzbach (1964)	X		X				
Grötzbach (1965)	X	X	X				
Grötzbach and Hillebrandt (1964)	X		X				
Grötzbach and Rathjens (1969)	X		X	X			X
Heiss (1972, 1973)	X	X					
Kick (1969)			X				
Klaer (1969)			X				X
Lister (1969)			X				
Maksimov and Perugina (1975)				X			X
Naumann (1974)	X						
Newby (1958)	X	X					
North (1970)	X	X	X				
Patzelt (1978)	X	X	X				X
Paytubi (1972, 1973)	X						
Rathjens (1978)			X				X
Schweizer (1969)			X				
Scott and Cheverst (1968)			X				
Scott (1972, 1973)			X				
Shroder (1980)				X			
Shroder and Guardino (1978)			X				X
Shroder and others (1978)							
Sidorov (1960)							
von Wissman (1960)				X			
Wala (1971)	X						
Wala (1973)	X	X		X			
Wala (1976a, b; 1977)	X	X					

Many of the glacierized areas occur in northeastern Afghanistan, along the high mountain borders with Pakistan and China. The Russians had trouble taking aerial photographs close to these borders and clouds obscured much of the landscape as well, so only planimetric maps produced by mountain climbers (mountaineers) were easily available for some of these border areas for many years. The comprehensive work of Wala (1971; 1973; 1976a, b; 1977) was the best source of information for many years, but several other scientists and mountaineers also contributed (table 2). Mapping of some glaciers in these areas was accomplished with imagery from the Landsat 3 return beam vidicon (RBV) sensor, because of its 30-m picture element (pixel) resolution and optical clarity, although even on these images many of the debris-covered small glaciers are difficult to discern. [Editors' note: Some of the Landsat 3 RBV images are archived by the author. The U.S. Geological Survey's EROS Data Center (EDC) no longer provides copies of Landsat 3 RBV images. EDC has permanently sequestered these historically important images, so they are no longer available for analysis in either digital or film formats.]

Only three high-quality, large-scale maps exist that show glaciers well in parts of Afghanistan. These are the excellent maps, by Kostka and his students (The Austrian Scientific Expedition in the Wakhan 1970, 1972; Exploration Pamir 75, 1978a, b), of the *Keshnīkhān Glacier* group near the west end of the Wākhān corridor as it was in 1970, and of the Afghan Pamir group in the central Wākhān as it was in 1975 (fig. 6). These maps show detailed moraine configurations, transient snowlines, accurate topography, and other important glacier landforms. The great detail of these maps at scales of 1:25,000 and 1:50,000 makes them excellent sources for verification of analyses of Landsat and other satellite imagery. The glaciological study by Gilbert and others (1969) of the *Mīr Samīr* glaciers is also useful, although the maps are far less precise than the Austrian examples.

Satellite Imagery in the 1970s

The lack of historical information, together with ongoing military and insurgent activities, increases the value of remote-sensing studies of the glaciers of Afghanistan. Satellite imagery represents the best available tool for constant and selective monitoring of glaciers (fig. 7, table 3). Of the two basic types of imagery available of Afghanistan during the 1970s, the greater resolution of the Landsat 3 RBV imagery (30-m pixels) offered more information than the Landsat 1, 2, and 3 multispectral scanner (MSS) (79-m pixels) imagery. However, few RBV images were acquired, and those are no longer available [see Editors' note in previous section].

Photographic Prints

Standard black-and-white and false-color composite prints of Landsat 1, 2, and 3 MSS imagery at a scale of 1:250,000 were used photogrammetrically in several preliminary studies for this project. P. Hearty first compared small-scale imagery of glaciers in northern Badakhshān with the Russian-made topographic maps and noted considerable differences. The apparent general retreat of glaciers was suspected to be partly an artifact of problems with scale and the absence of confirmatory field observations. T. Shipley photographically enlarged film positives of false-color composite images to a scale of about 1:175,000 and established mutual registration points for overlay with various topographic maps and the glacier maps of Kostka (Exploration Pamir 75, 1978a, b). Shipley thought he detected a slight advance of glacier fronts between the 1972 imagery and Kostka's field survey in 1975.

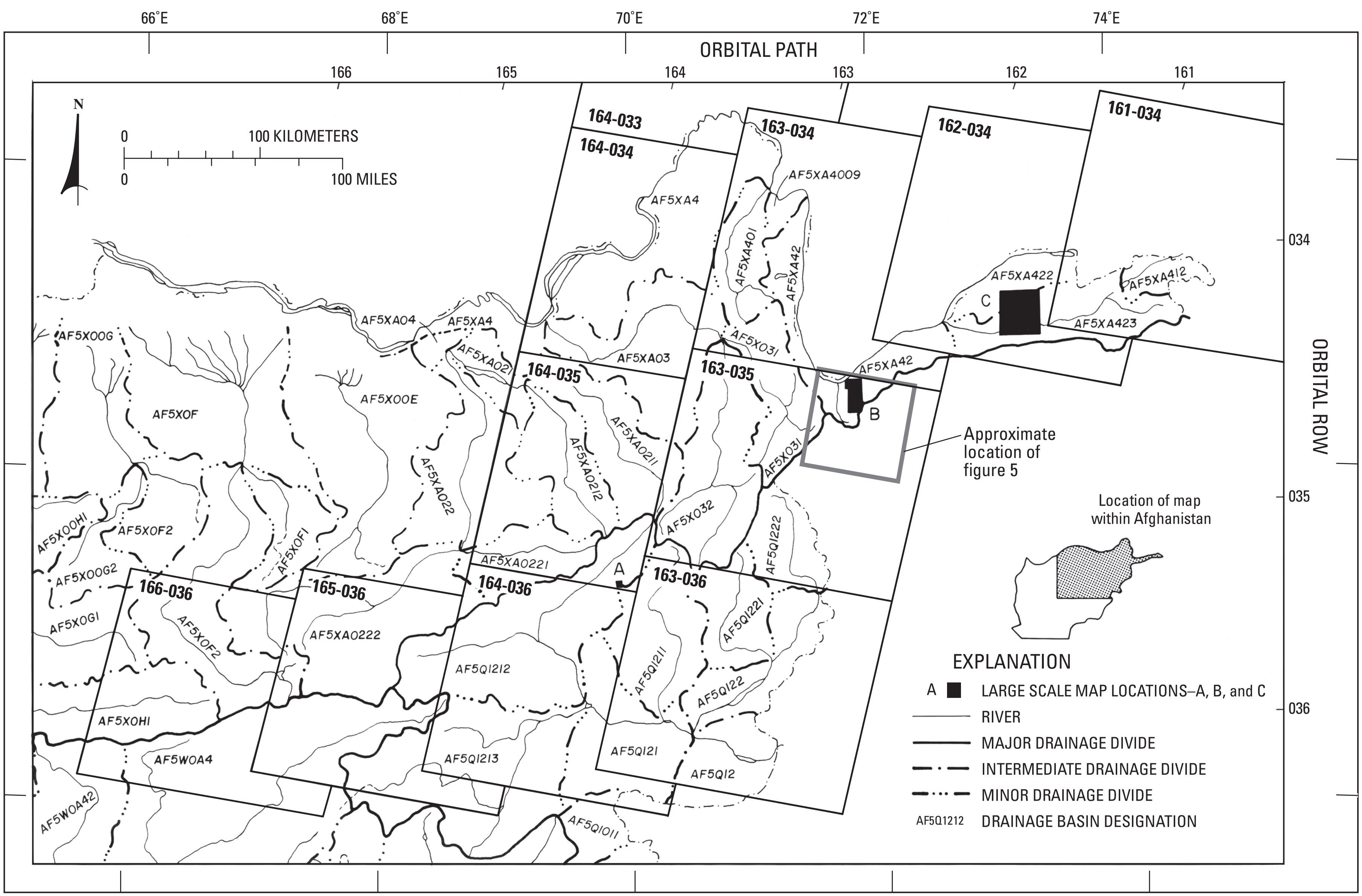


Figure 6.*—Index map of Landsat 1, 2, and 3 satellite imagery, drainage basins, and large-scale maps of glacierized areas of Afghanistan. Satellite images are listed by Path–Row numbers and keyed to table 3. Large-scale maps are listed by letters keyed to references: A – Gilbert and others, 1969; B – Austrian Scientific Expedition in the Wakhan 1970, 1972; C – Exploration Pamir 75, 1978a, b.*

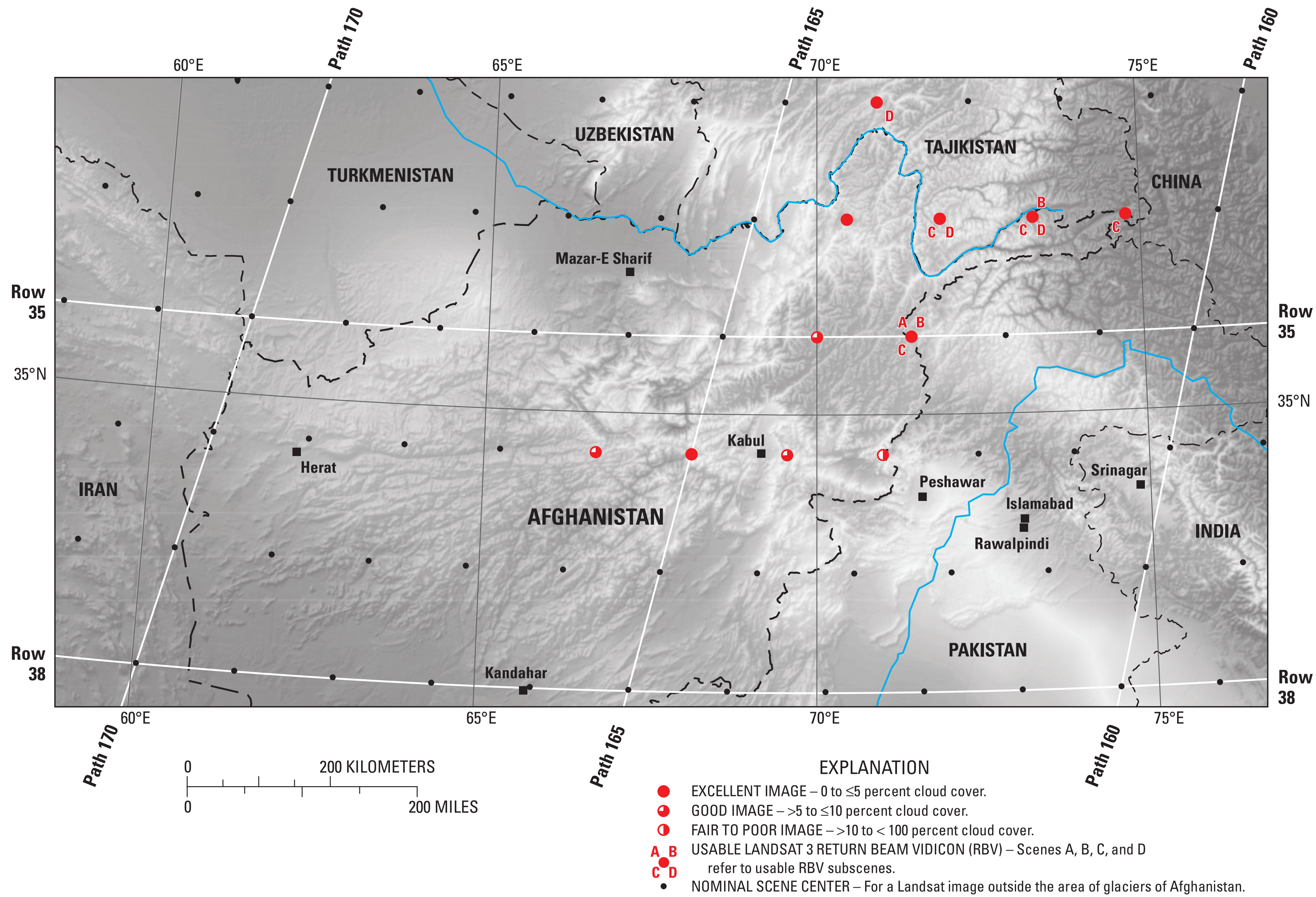


Figure 7.—*Map of optimum Landsat 1, 2, and 3 images of the glaciers of Afghanistan.*

TABLE 3.—*Optimum Landsat 1, 2, and 3 images of the glaciers of Afghanistan*

[Code column indicates usability for glacier studies; see figure 7 for explanation]

Path-Row	Actual scene center (latitude and logitude)		Landsat identification number (9-10 digits) or entity identification number (16 digits)[1]	Date	Solar elevation angle (in degrees)	Code	Remarks
161–34	37°31′N.	74°41′E.	2564–04522 (2161034007622190)	08 Aug 76	53	◕	No band 4
161–34	37°24′N.	74°34′E.	2924–04370 (2161034007721590)	03 Aug 77	51	◕	Good in Afghanistan. Clouds to north
161–34	37°06′N.	74°00′E.	30515–04595 Subscene C	02 Aug 79	55	●	Landsat 3 RBV image, archived by author
162–34	37°21′N.	73°13′E.	1047–05171 (1162034007225290)	08 Sep 72	50	◕	Few clouds
162–34	37°28′N.	73°12′E.	2565–04580 (2162034007622290)	09 Aug 76	53	●	Excellent in Afghanistan
162–34	37°24′N.	73°08′E.	2601–04570 (2162034007625890)	14 Sep 76	45	◕	Few clouds
162–34	37°35′N.	73°44′E.	30516–05053 Subscene B	03 Aug 79	55	◕	Landsat 3 RBV image, archived by author
162–34	37°01′N.	72°33′E.	30516–05053 Subscene C	03 Aug 79	55	◕	Landsat 3 RBV image, archived by author
162–34	36°52′N.	73°30′E.	30516–05053 Subscene D	03 Aug 79	55	◕	Landsat 3 RBV image, archived by author
163–34	37°32′N.	71°38′E.	1354–05231 (1163034007319390)	12 Jul 73	60	◕	Preceding winter snow
163–34	37°30′N.	71°47′E.	2566–05034 (2163034007622390)	10 Aug 76	53	●	
163–34	37°31′N.	71°46′E.	2584–05031 (2163034007624190)	28 Aug 76	49	●	
163–34	37°12′N.	71°08′E.	30553–05105 Subscene C	09 Sep 79	48	●	Landsat 3 RBV image, archived by author
163–34	37°04′N.	72°04′E.	30553–05105 Subscene D	09 Sep 79	48	●	Landsat 3 RBV image, archived by author
163–35	36°05′N.	71°11′E.	1354–05233 (1163035007319390)	12 Jul 73	61	●	Excellent in Afghanistan
163–35	34°04′N.	71°19′E.	2566–05041 (2163035007622390)	10 Aug 76	53	●	Excellent in Afghanistan
163–35	36°07′N.	71°19′E.	2980–04454 (2163035007727190)	28 Sep 77	39	◕	Shadows too large in cirques
163–35	36°29′N.	70°55′E.	30553–05112 Subscene A	09 Sep 79	48	●	Landsat 3 RBV image, archived by author
163–35	36°21′N.	71°50′E.	30553–05112 Subscene B	09 Sep 79	48	◕	Few clouds. Landsat 3 RBV image, archived by author
163–35	35°46′N.	70°42′E.	30553–05112 Subscene C	09 Sep 79	48	●	Landsat 3 RBV image, archived by author
163–36	34°39′N.	70°44′E.	1354–05240 (1163036007319390)	12 Jul 73	61	◑	Clouds and old snow
163–36	34°38′N.	70°53′E.	2566–05043 (2163036007622390)	10 Aug 76	53	◑	Cloud cover
163–36	34°39′N.	70°53′E.	2584–05040 (2163036007624190)	28 Aug 76	50	◑	Cloud cover
163–36	34°33′N.	70°49′E.	2926–04991 (2163036007721790)	05 Aug 77	51	◑	Cloud cover
164–33	38°53′N.	70°53′E.	1049–05281 (1164033007225490)	10 Sep 72	48	●	Excellent in Afghanistan

Table 3.—*Optimum Landsat 1, 2, and 3 images of the glaciers of Afghanistan*—Continued

[Code column indicates usability for glacier studies; see figure 7 for explanation]

Path-Row	Actual scene center (latitude and logitude)	Landsat identification number (9-10 digits) or entity identification number (16 digits)[1]	Date	Solar elevation angle (in degrees)	Code	Remarks
164–33	38°49′N. 70°47′E.	2531–05100 (2164033007618890)	06 Jul 76	57	◕	Preceding winter snow
164–33	38°48′N. 70°45′E.	2909–04544 (2164033007720090)	19 Jul 77	53	◕	Good in Afghanistan
164–33	38°30′N. 71°07′E.	30554–05161 Subscene D	10 Sep 79	47	●	Landsat 3 RBV image, archived by author
164–34	37°28′N. 70°24′E.	1049–05283 (1164034007225490)	10 Sep 72	49	●	
164–34	37°31′N. 70°21′E.	2567–05092 (2164034007622490)	11 Aug 76	52	●	
164–34	37°30′N. 70°18′E.	2585–05085 (2164034007624290)	29 Aug 76	49	●	
164–34	37°23′N. 70°17′E.	2909–04550 (2164034007720090)	19 Jul 77	53	◕	Preceding winter snow
164–34	37°33′N. 70°20′E.	2963–04520 (2164034007725490)	11 Sep 77	43	●	
164–35	36°02′N. 69°56′E.	1049–05290 (1164035007225490)	10 Sep 72	50	◕	Few clouds
164–35	36°02′N. 70°01′E.	1067–05290 (1164035007227290)	28 Sep 72	45	◑	Marginal. New snow
164–35	36°07′N. 69°53′E.	2963–04523 (2164035007725490)	11 Sep 77	44	◑	Good in band 7 only
164–36	34°36′N. 69°29′E.	1049–05292 (1164036007225490)	10 Sep 72	51	◕	Few clouds
164–36	34°36′N. 69°34′E.	1067–05292 (1164036007227290)	28 Sep 72	46	◑	Marginal. New snow
164–36	34°40′N. 69°26′E.	2963–04525 (2164036007725490)	11 Sep 77	44	◑	Marginal. Clouds, band 7 only
165–36	34°39′N. 67°55′E.	1410–05343 (1165036007324990)	06 Sep 73	51	●	
165–36	34°39′N. 67°59′E.	2982–04573 (2165036007727390)	30 Sep 77	40	●	
166–36	34°35′N. 66°42′E.	1069–05405 (1166036007227490)	30 Sep 72	45	◕	Few clouds

Digital Analyses

Several different digital analyses of the various glacierized areas in Afghanistan were made in the 1970s, using computer-compatible tapes (CCTs). Following these initial analyses (Shroder and others, 1978), a full research program to perform a satellite glacier inventory of Afghanistan was initiated. To further develop the methodology, several areas outside Afghanistan were selected by Rundquist (1978), in consultation with Fritz Müller, a Swiss glaciologist. Braslau and Bussom (1978a, b) worked on the *Keshnīkhān Glacier* because of the initial experimentation there, and because of Kostka's excellent base map (The Austrian Scientific Expedition in the Wakhan 1970, 1972). In their analyses, the *Keshnīkhān Glacier* was classified according to 11 symbols, each representing some number of pixel radiance values.

Radiance thresholds for each of the four bands were constantly adjusted until the computer output and the Kostka map bore a close resemblance to one another. At one point, in response to collegial criticism of the technique, Bussom manually rectified a computer printout to remove the skewed distortion of the image in order to demonstrate the close geometric registration possible between the two. Finally, a random sample of about 14 percent of the pixels was tested, using multivariate linear discriminate analysis to derive the percentage of pixels correctly classified within each band. About 90 percent accuracy was typically achieved. Results of the *Keshnīkhān Glacier* analysis was significant because the glacier is similar to the majority of glaciers in Afghanistan, and the successful computer mapping indicates the feasibility of monitoring other nearby glaciers where field-based observations have not been made or where adequate maps do not exist.

The preliminary success with digital analyses of CCTs were misleading in some cases, however, and a number of problems emerged:

1. The techniques and equipment were expensive, time consuming, and prone to operator error when the level of complexity eclipsed realistic interpretations.
2. The original hand-colored thresholding techniques of 25 years ago were inexpensive and made the technology easily available, but were too time-consuming to be of much real use, and are now outmoded technology.
3. The Landsat CCTs commonly deteriorated in storage (degaussed) over a few years if not periodically copied, and several of the Afghanistan tapes purchased in 1977–78 were unusable by the mid-1980s.

Nevertheless, thresholding done by skilled operators using the equipment available at many universities (Rundquist, 1978; Rundquist and Samson, 1980; Rundquist and others, 1980) indicated a potential for using satellite data for carrying out glacier inventories by applying more modern technologies.

Satellite Imagery since the 1970s

A plethora of new satellite images of Afghanistan have become available since the 1970s; these include SPOT (Satellite Pour l'Observation de la Terre), TM (Landsat Thematic Mapper), and ASTER (Advanced Spaceborne, Thermal Emission and Reflection Radiometer), some of which were also used in this study. As the USGS-designated GLIMS Regional Center for Southwest Asia (Afghanistan and Pakistan), the University of Nebraska at Omaha is undertaking regional glacier inventories of the Hindu Kush and western Himalaya, along with glacier-change detection with these satellite-image resources. The acquisition of terrabytes of high-resolution (15-m) stereographic data is enabling production of digital elevation models (DEMs) of these mountain regions with the ASTER system in the GLIMS project, and is allowing unprecedented glacier assessments (Bishop and others, 2000; Kieffer and others, 2000).

Case Studies of Glaciers

Five areas of Afghanistan were selected as most representative of the variations in size, character, altitude, and radiance values of the glaciers. Small glaciers of the *Kūh-e-Bābā* are the westernmost in the country. The *Mīr Samīr* region has a number of small glaciers that were studied glaciologically and mapped planimetrically by a British team in 1965 (Gilbert and others, 1969). *Kūh-e-Bandakā* has glaciers of small and intermediate size, with a general character typical of the central Hindu Kush. Glaciers at the entrance to the Wākhān corridor are either small, as in the case of the *Keshnīkhān*, or large, and atypically dark colored, as in the case of the *Qādzī Deh Glacier*. Glaciers in the Wākhān Pamirs are noteworthy because of their considerable volume, in spite of the area having the lowest annual precipitation in the high mountains of Afghanistan.

Kūh-e-Bābā

Most of the glaciers of the more habitable parts of Afghanistan are small remnants of the larger Pleistocene ice masses. They are difficult to detect on the small-scale satellite imagery and are easily confused with clouds and rocks of high reflectivity. Also, the pixel resolution of the older imagery was commonly insufficient to detect what could be significant changes in small glaciers. However, these smaller ice masses are as important to the local economies as are the larger glaciers. They are essential sources of late summer irrigation water, and considerable human effort is required at high altitudes each spring to maintain the makeshift diversion dams and ditches to exploit this water. At lower elevations, entire villages turn out to repair the irrigation structures along the major snow- and glacier-fed larger rivers.

A total of 18 small glaciers occur in the *Kūh-e-Bābā* range of central Afghanistan, averaging about 0.5 km^2 in area, and all have northern exposures (Shroder and Giardino, 1978). The range of the lowest elevation of exposed glacial ice is 4,075–4,657 m, with an average of 4,365 m. All of the glaciers terminate in large, tongue-shaped boulder deposits that can be variously classified as debris-covered glaciers, ice-cored moraines, or ice-cored rock glaciers, depending upon certain fine distinctions made between relative activity or inactivity, steep fronts or gentle fronts, and general surface morphologic differences. The lower altitude range of these rocky termini is 3,850–4,600 m, with an average of 4,232 m. In the late Pleistocene, these glaciers are believed to have terminated at elevations as low as 2,600 m near Burghasūn, in the Fūlādī valley above Bāmyān (figs. 8 and 9).

During July 1978, *Fūlādī Glacier* was visited by the senior author (fig. 10), and it had reduced in surface area by about 20 to 25 percent since the 1959 aerial photographs. Mean annual precipitation at *Fūlādī Glacier* is about 600 mm, and the climatic snowline is about 5,100 m (Grötzbach and Rathjens, 1969). This snowline is well above the tops of all the surrounding peaks except Fūlādī peak (5,150 m), so *Fūlādī Glacier* only survives in the shadow of the cirque walls on the northern exposures. It receives maximum exposure to Sun during midsummer. A negative mass balance on this glacier is evident based on the location of the transient snowline high in the cirque close to the bergschrund, the concave-up cross profile of the ice surface, and the extensive till cover on the margins of the ice.

Low-altitude aerial reconnaissance of the *Kūh-e-Bābā* in 1977 and topographic maps revealed 35 boulder deposits that do not have surficial ice exposed at their heads. Three have large kettle-like lakes on them, and many have major springs, all indicating the presence of buried ice. Twenty nine of these rock-glacier-like features face north, four face east, and one each faces south and west. The lower elevation range is 3,650–4,425 m, with an average of 4,078 m.

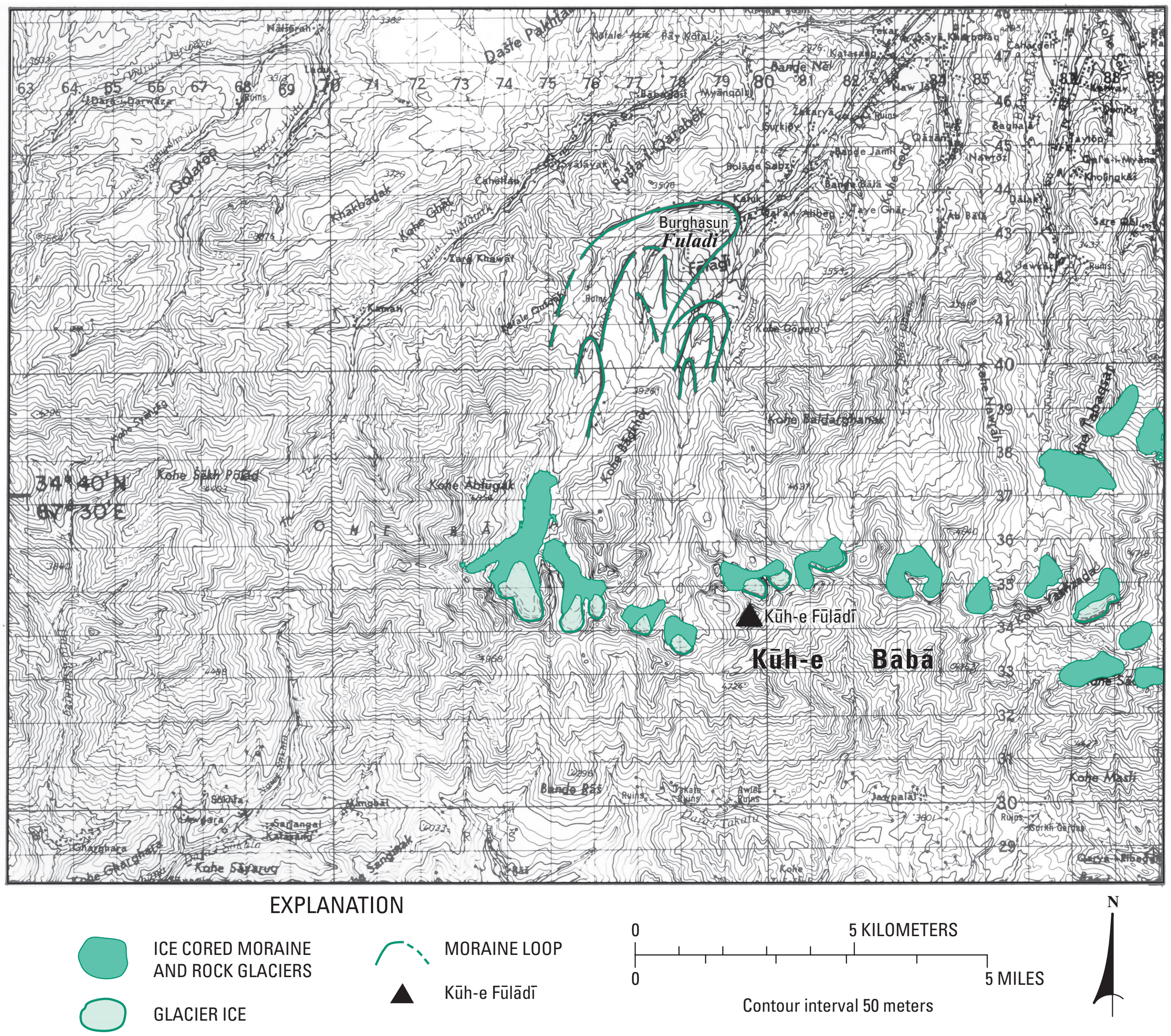


***Figure 8.**—Topographic map of* Fūlādī *valley and central* Kūh-e Bābā *range.* Fūlādī Glacier *is 0.6 km directly north of* Fūlādī *peak. The largest moraines emanate mainly from the western valley between* Ābtowgak *and* Bādkhūr *peaks; the eastern valley between* Bādkhūr *and* Bāldārghanak *peaks produced the smaller set of moraine loops. Geographic place-names on map may be variant.*

Analysis and monitoring with early satellite imagery of these small ice glaciers (fig. 11) and buried-ice glaciers or rock glaciers was difficult, and results were ambiguous for the following reasons:

- Retreat of the *Fūlādī Glacier* in 20 years was only a few partial MSS pixels in size and thus difficult to detect or compare with newer, higher resolution ASTER imagery.
- Strong shadows in the cirques obscured the ice or mimicked small water bodies in certain places.
- Debris cover commonly masked the buried ice.
- Tills, talus, and fractured source bedrock all appeared to have similar radiance values and thus were difficult to distinguish.
- Clouds and rocks of high reflectivity mimicked ice and snow.

Figure 9.*— View northwest from eastern end moraine toward large moraine loop above the village of Burghasūn. Compare with figure 8 for location, about 9 km north of Fūlādī peak. Photograph by J.F. Shroder, Jr.*

Figure 10.— Fūlādī Glacier *in July 1978. At this time, the transient snow line was close to or at the base of the steep firn slopes and the bergschrund below the large rock tower on the shoulder of* Fūlādī *peak. See figure 8 for location. The rocks of this area are granitic intrusions of early Tertiary age. Photograph by J.F. Shroder, Jr.*

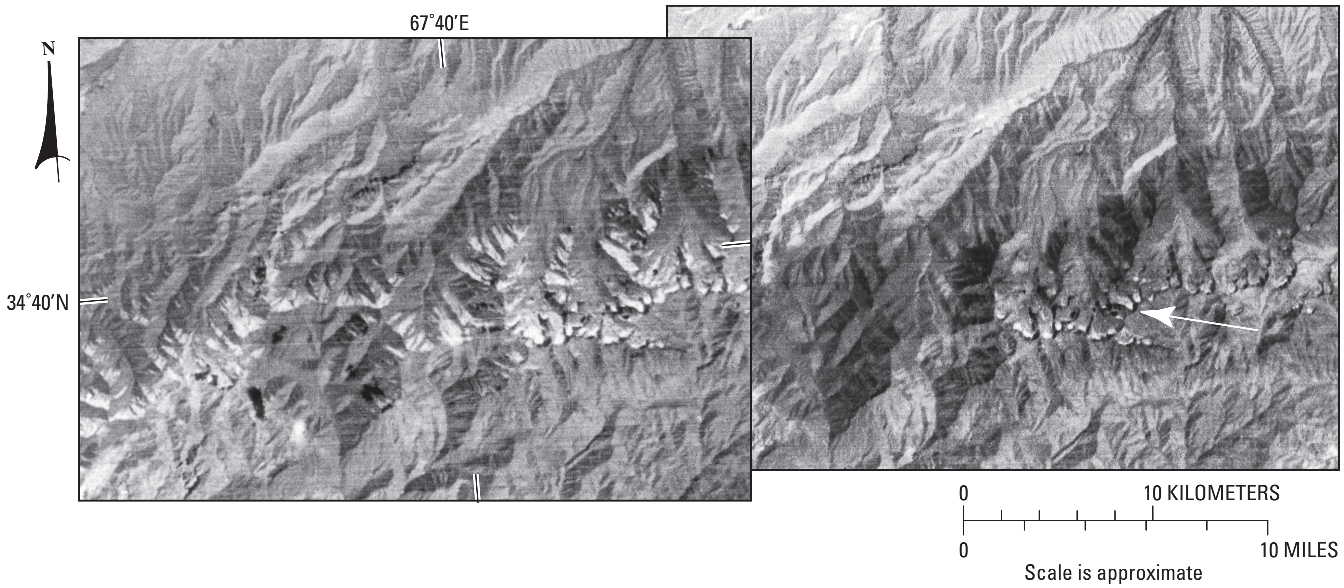


Figure 11.—*Stereoscopic pair of Landsat 1 images of the* Kūh-e Bābā *area. Arrow designates* Fūlādī Glacier. *Compare with figure 12, and with figure 8 for location. Landsat 1 MSS images (west, Landsat 1 MSS image 1069–05405, band 5; 30 September 1972; Path 166–Row 36; east, Landsat 1 MSS image 1410–05343, band 5; 6 September 1973; Path 165–Row 36) are from the U.S. Geological Survey, EROS Data Center, Sioux Falls, S. Dak. 57198. [Editors' note: Use stereoscope for viewing.]*

Nevertheless, satellite imagery of an area like the Fūlādī valley can be useful, especially in stereoscopy. In comparison with the topographic map (fig. 8), the stereoscopic views of figure 12 enable better determinations of ice, moraine, lakes, and other features merely because of their topographic location. The older French satellites (for example, SPOT) and the newer ASTER imagery have provided a regular source of stereoscopic imagery that facilitates analysis of high mountain areas and glaciers. Careful comparison of the 1973 MSS imagery (fig. 11) with the ASTER stereopair (fig. 12) reveals that *Fūlādī Glacier* has continued to downwaste so that it is highly incised inside its curvilinear terminal moraine. A small lake inside the moraine in 1973 was not observed in 1978 or 2003.

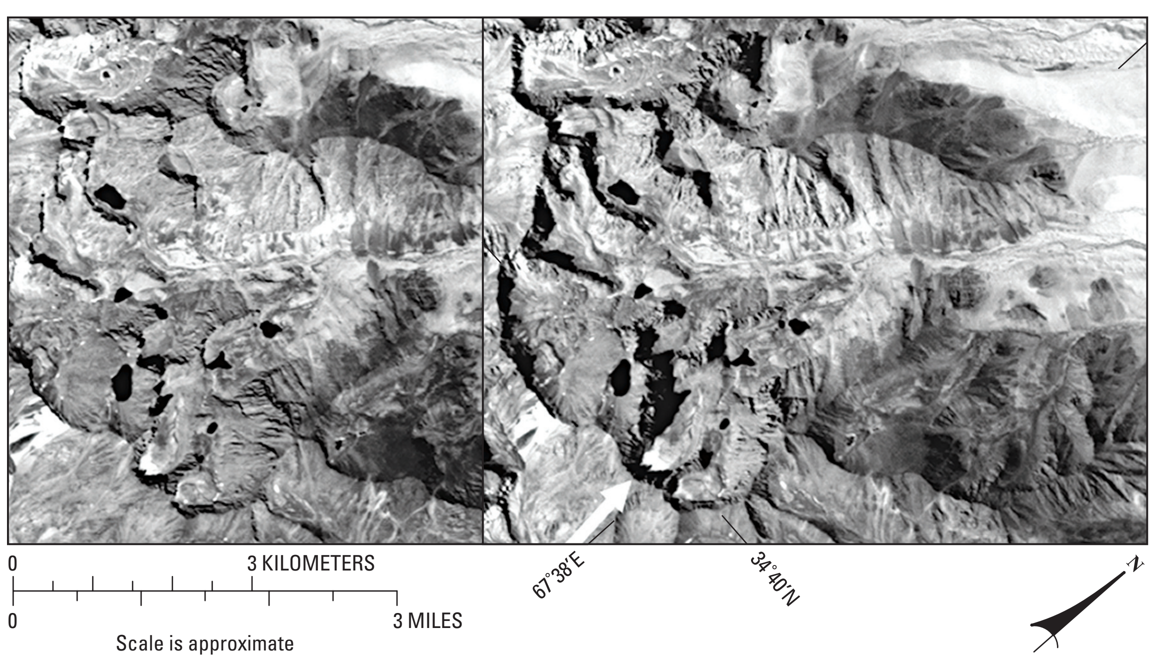


Figure 12.—*Stereoscopic pair of ASTER images of* Kūh-e Bābā *area. White arrow points to* Fūlādī Glacier. *North is to the right. Compare with figure 11. ASTER Scene AST_L1B-003_10022003061744_10162003100406; 2 October 2003. [Editors' note: Use stereoscope for viewing.]*

Mīr Samīr

The *East Glacier* (*Yakhchaal-i-Sherq*) and *West Glacier* (*Yakhchaal-i-Gharb*), below the north face of *Mīr Samīr* peak (5,809 m) in the central Hindu Kush (fig. 13), were first assessed glaciologically by a British team in 1965 (Gilbert and others, 1969). They studied snow accumulation, ablation, meltwater discharge, lichenometry, micrometeorological heat balance, and other glaciologic characteristics. Their simple planimetric maps of ice distribution and

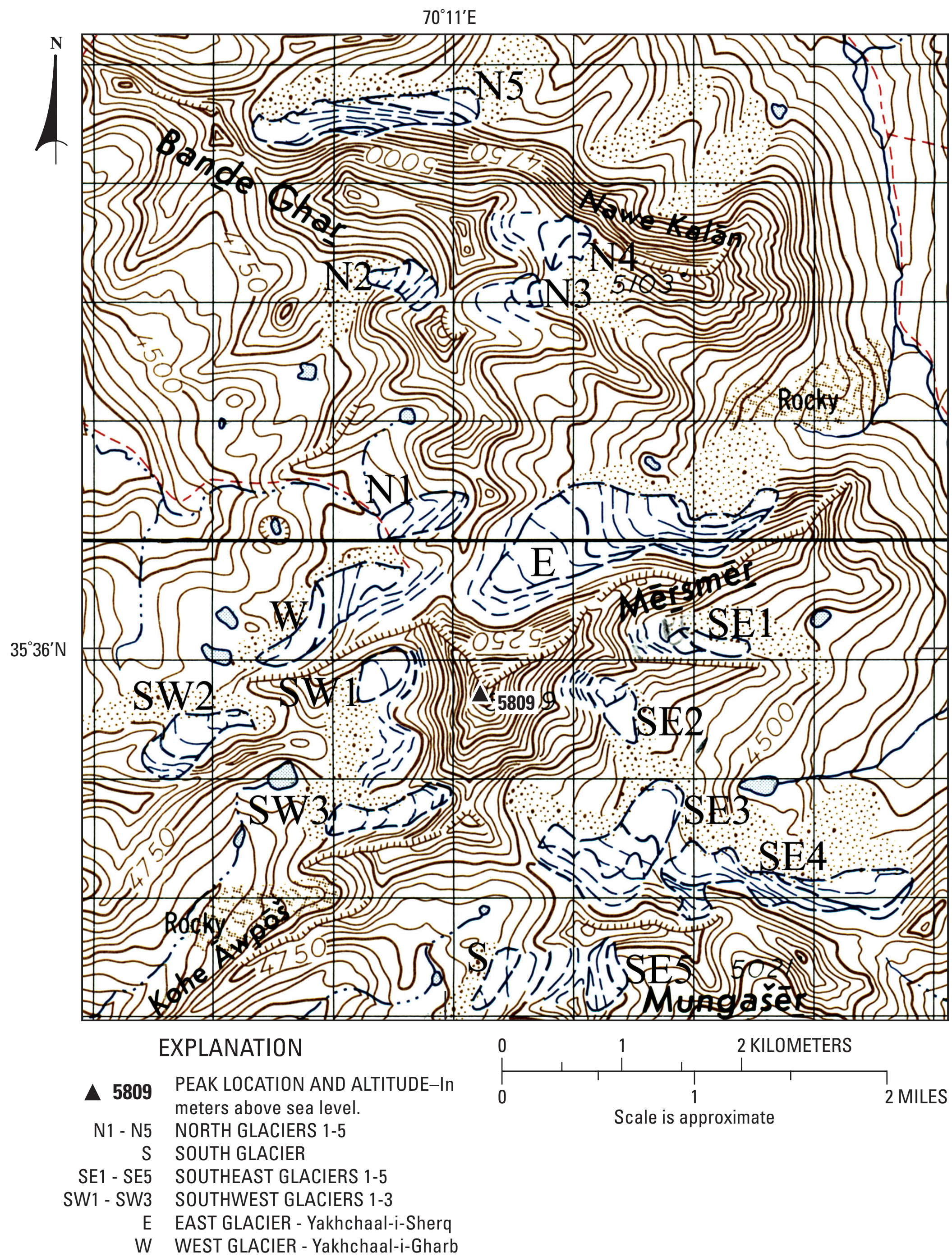


Figure 13.—*Topographic map of* Mīr Samīr *(Mērsmēr) area in the central Hindu Kush (source: U.S. Department of Defense (DOD) U.S. Army Topographic command; compiled in 1970 from Afghanistan, 1:100,000, Ministry of Mines, Fairchild Aerial Surveys, Sheets 505A & 505C, 1967 [surveyed 1957–59, reliability fair]. Map not field checked.*

lichen zones on the moraine allow a comparison with satellite imagery for change detection. Gilbert and others (1969) estimated that the *East Glacier* measured about 1 km^2 and the *West Glacier* measured about 0.5 km^2. These small glaciers could not be assessed with much precision with the early Landsat imagery but are clearly shown on the new 15-m resolution ASTER imagery. The five new images, obtained in the past two years between July and November, show the *Mīr Samīr* glaciers quite clearly. The ASTER image of 12 November 2002 is noteworthy because no new snow appears to have fallen so late in the melt season before winter amelioration began again (fig. 14). It is also possible that any earlier light snowfall could have already melted away by the time this scene was taken (Kravtsova, 1990). Two small linear proglacial lakes at the western margin of the main part of *West Glacier*, both about 60–100 m long and 75 m apart in 1965, by 2002 had fused into one rounded lake about 30 m in diameter. The 2002 imagery also showed that *East Glacier* has a new proglacial lake, measuring about 60 m long and 15 m wide, which did not exist 40 years ago. Additional lakes have also appeared around *Southeast Glaciers 3* and *4* (fig. 14).

Comparison between the U.S. Department of Defense (DOD) topographic map (fig. 13), made from the 1957–59 aerial photographs, and the British map of 1965 (Gilbert and others, 1969), indicates that the two maps were likely based upon the same source materials (Glicken, 1960; Reiner, 1966), although the British modified contours and glacier size and location according to their field observations. A number of possibly significant differences are visible through time. The *North Glacier* (N1), between *East* and *West Glaciers,* is prominent on the DOD map (1957-59) but minuscule on the British map (1965) and is only a minor snowfield on the 2002 ASTER imagery. Numerous other similar diminutions and changes in glaciers and lakes in the region are visible

Kūh-e-Bandakā

The *Kūh-e-Bandakā* (Bandakhor in some usages) group of mountains of the central Hindu Kush consists of several nearly parallel peaks and high ridges of Precambrian metamorphic rocks (fig. 15). These mountains are basically fault slivers isolated by strike-slip shear where the edge of the colliding Indian and Asian plates changes direction from northeast-southwest to north-south. This massif is directly astride the earthquake zone of highest frequency and magnitude in Afghanistan, and the several small- and few large-magnitude seismic events that occur there every few years may contribute a significant portion of snow avalanche and debris load to local glaciers.

The *Bandakā* massif is characterized by six major peaks that are more than 6,000 m in elevation and many others almost as high (fig. 16). The north-facing slopes of the main peak of *Bandakā* (6,843 m) are small and therefore its glaciers are smaller than those on the lower peak, *Bandakā Sakhī* (6,414 m), 4 km to the north. *Sakhī* peak has a large cirque and steep snowfield which is the source of avalanches on the north side that generate the *Sakhī Glacier* — the largest ice mass in the area. Comparison of the 1959 map (fig. 16) with the satellite imagery of the early 1970s (fig. 15) shows about 0.5 km of apparent retreat of the exposed ice front.

Meltwater from the *Sakhī Glacier* flows into the *Jay* river, which passes through several moraine areas and into two 1- to 2-km-long, flat-floored and boulder-covered, intermittent lake beds (Scott and Cheverst, 1968) before joining the main *Darreh-ye Sakhī* (river), which comes from another valley to the west.

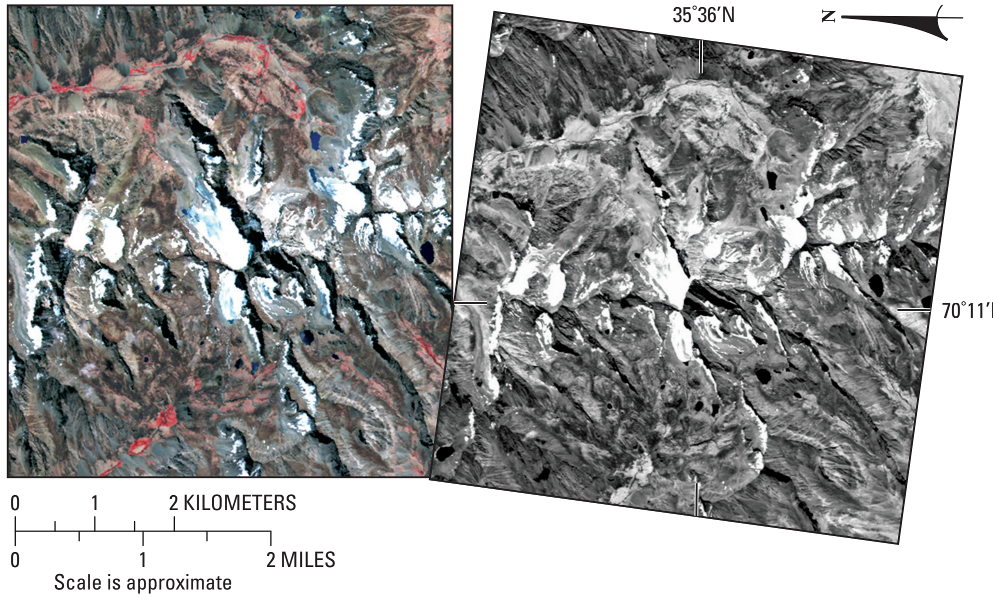


Figure 14.—*Stereoscopic pair of ASTER images of* Mīr Samīr *area. North is to the left. The image portrays the same area as figure 13. ASTER scene AST_L1B_003_08172004061706_08302004122236; 17 August 2004. [Editors' note: Use stereoscope for viewing.]*

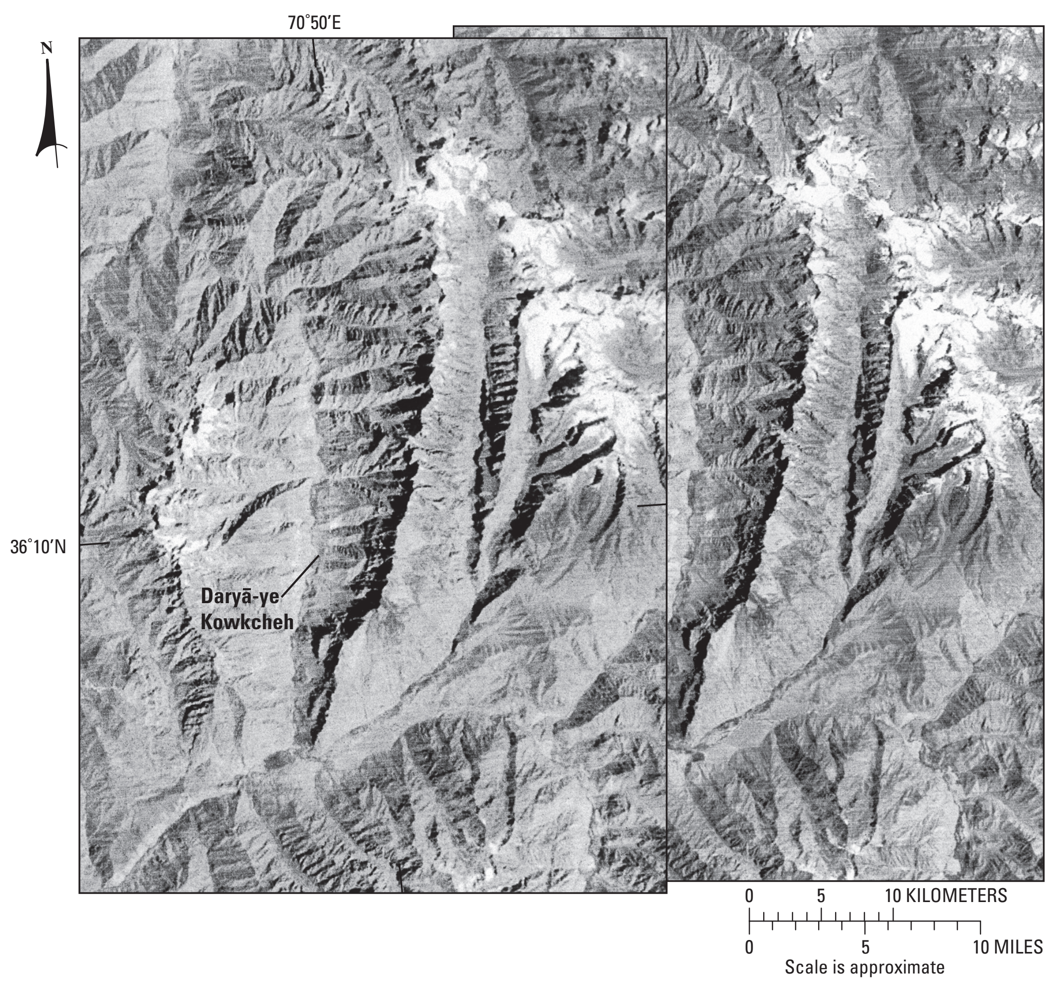


Figure 15.—*Stereoscopic pair of Landsat 1 and 2 images of the Bandakā massif. The westernmost glacierized range on the left bank of the Daryā-ye Kowkcheh (*Kokcha *river) has peaks up to 5,862 m in elevation. Features to the east of the river may be compared with the map of figure 16. Landsat 1 and 2 MSS images (west, Landsat 1 MSS image 1049–05290, band 5; 10 August 1972; Path 164–Row 35; east, Landsat 2 MSS image 2566–05041, band 5; 10 August 1976; Path 163–Row 35) are from the U.S. Geological Survey, EROS Data Center, Sioux Falls, S. Dak. 57198. [Editors' note: Use stereoscope for viewing.]*

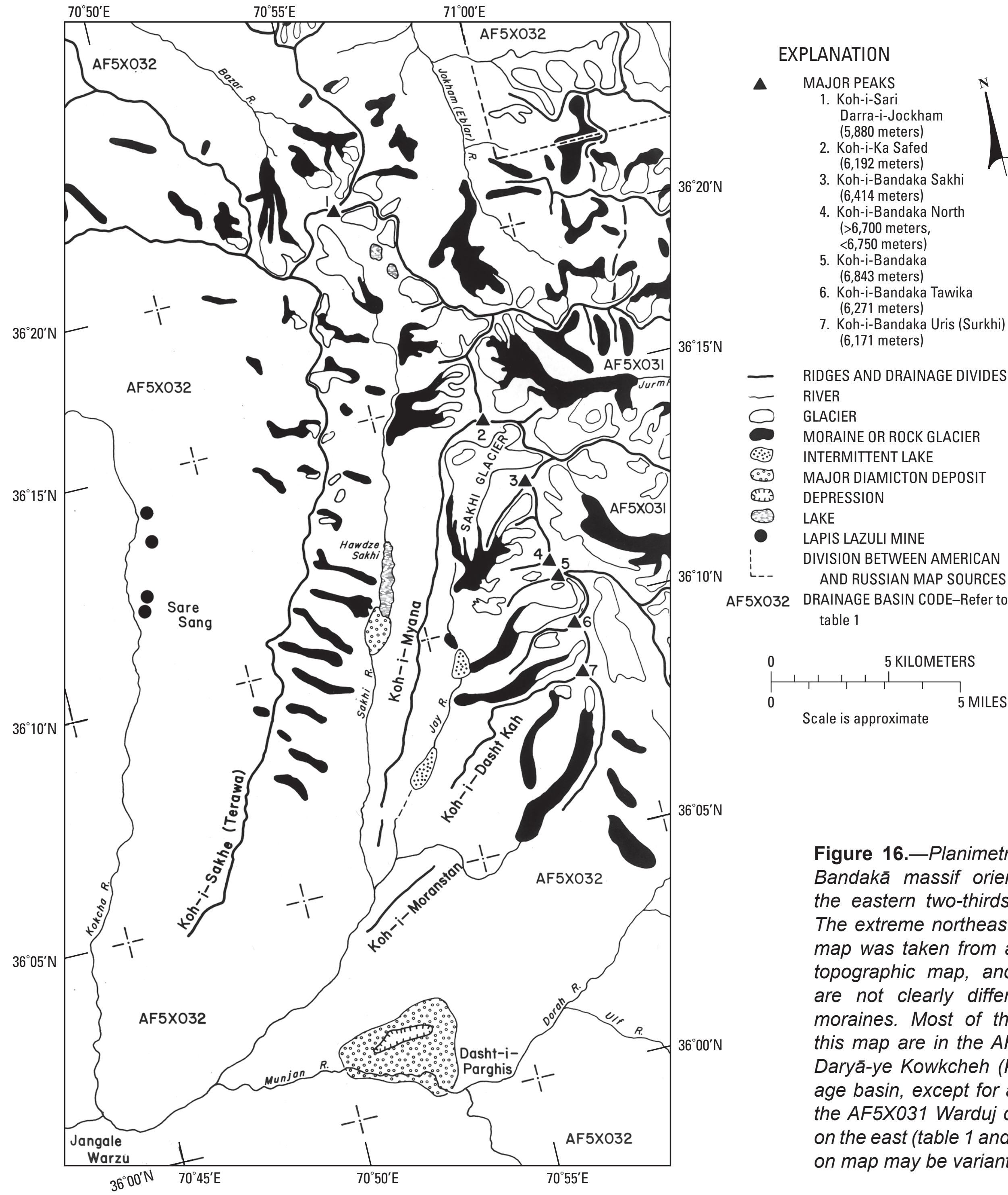


Figure 16.—*Planimetric map of the Bandakā massif oriented to cover the eastern two-thirds of figure 15. The extreme northeast corner of the map was taken from a Soviet-made topographic map, and the glaciers are not clearly differentiated from moraines. Most of the glaciers on this map are in the AF5X032 Upper Daryā-ye Kowkcheh (Kokcha) drainage basin, except for a small part of the AF5X031 Warduj drainage basin on the east (table 1 and fig. 2). Names on map may be variant names.*

The *Sakhī* river has its origin in glaciers and glacial lakes at the head of a south-facing, 4-km-wide, compound cirque basin below the peak, *Kūh-e-Sari Darreh-ye-Jow Khām* (5,880 m). *Hawdze Sakhī* (figs. 15 and 16) is a 3-km-long lake impounded behind a probable moraine dam; the *Sakhī* river passes through the moraine to re-emerge 1.5 km below.

In addition to several medium-sized glaciers around the *Bandakā* massif, there are also a large number of ice-cored moraines and rock glaciers in all the mountain ranges in the area. These features are covered with rock fragments that have nearly the same radiance values as the surrounding slopes. The result is that differentiation on the satellite images can be difficult unless collateral information is available, such as stereoscopic overlap (fig. 15), high-quality topographic maps, or digital analyses in selected cases.

The Dasht Parghish diamicton deposit, at an elevation of 2,750–3,250 m, sits astride the Monjān river and is prominent on maps and satellite imagery (fig. 12). Several large depressions up to 1.5 km long are evident, and suggest that the deposit may be a remnant end moraine produced by a major Pleistocene glacier from the Monjān or Dorāh valleys. Alternatively, the deposit may be a fault- or landslide-generated mass, inasmuch as it is located directly across a major strike-slip fault zone in an area of high seismic activity.

Keshnīkhān Glacier

The *Keshnīkhān Glacier*, at the western end of the Wākhān corridor, was chosen for inclusion here because it has been extensively studied (Braslau, 1972; The Austrian Scientific Expedition in the Wakhan 1970, 1972; Braslau and Bussom, 1978a, b; and Shroder and others, 1978), and because it is similar to the majority of glaciers in Afghanistan. It is a relatively small, steep ice mass, 15 km^2 in area and 4 km long (fig. 17). Braslau (1972) was impressed with the continuous belt of morainic material from 2,600 m elevation near the Daryā-ye Panj river valley, all the way up to the ice front — a vertical range of almost 2,000 m. There is, however, a major break in slope in this long moraine at about 3,600 m elevation, the place chosen by the Russian cartographers to delineate the terminus of the glacier ice/moraine mass, although they set the elevation at about 3,460 m. The actual stagnant terminus occurred at about 4,400 m in 1970 and the transient snowline was at 5,000 m. The actual equilibrium line altitude (ELA) at that time was estimated to be about 5,100–5,200 m. Based on elevation, a small ablation zone, and other general glacial characteristics, the glacier was judged to be receding (Braslau, 1972).

The original Landsat MSS imagery of 1973 was assessed in detail by Braslau and Bussom (1978a, b), as noted above in the section on “Digital analyses.” Therefore, the 12 July 1973 image (fig. 18) is included for comparison to the ASTER image of 31 August 2000 (fig. 19). Because of the additional month and a half of melt season between the two scenes, the variance between the obvious transient snowlines is not viewed as significant of long-term trends. Nonetheless, a comparison of the approximate ELA on the 1970 image (fig. 17) with the ELA on the 2000 ASTER image (fig. 19) shows the likely uphill movement of the ELA on the left (western) side and a new emergence of medial moraine-producing rocks on the right (east).

Wākhān Pamir Glaciers

The part of the Pamirs in the middle of the Wākhān panhandle of Afghanistan has nine peaks in the central part of the range that are more than 6,000 m high. The most areally extensive glaciers of Afghanistan occur there because of the large size and general high altitude of the massif, in spite of a mean annual precipitation of less than 100 mm (Lalande and others, 1974). Glacial meltwater from the Wākhān Pamir Mountains feeds the Pāmīr, Wākhān, and Daryā-ye Panj tributaries which flow into the major Amu Darya river of Tajikistan and Uzbekistan, and its Garagum (Karakum) canal outtake into Turkmenistan. The core of the range is light-colored granitic rocks of Late Cretaceous-Tertiary age, with peripheral rocks of the Wakhan Formation (Buchroithner, 1978). Most of the large moraines therefore are composed of light-colored granitic rocks (fig. 20).

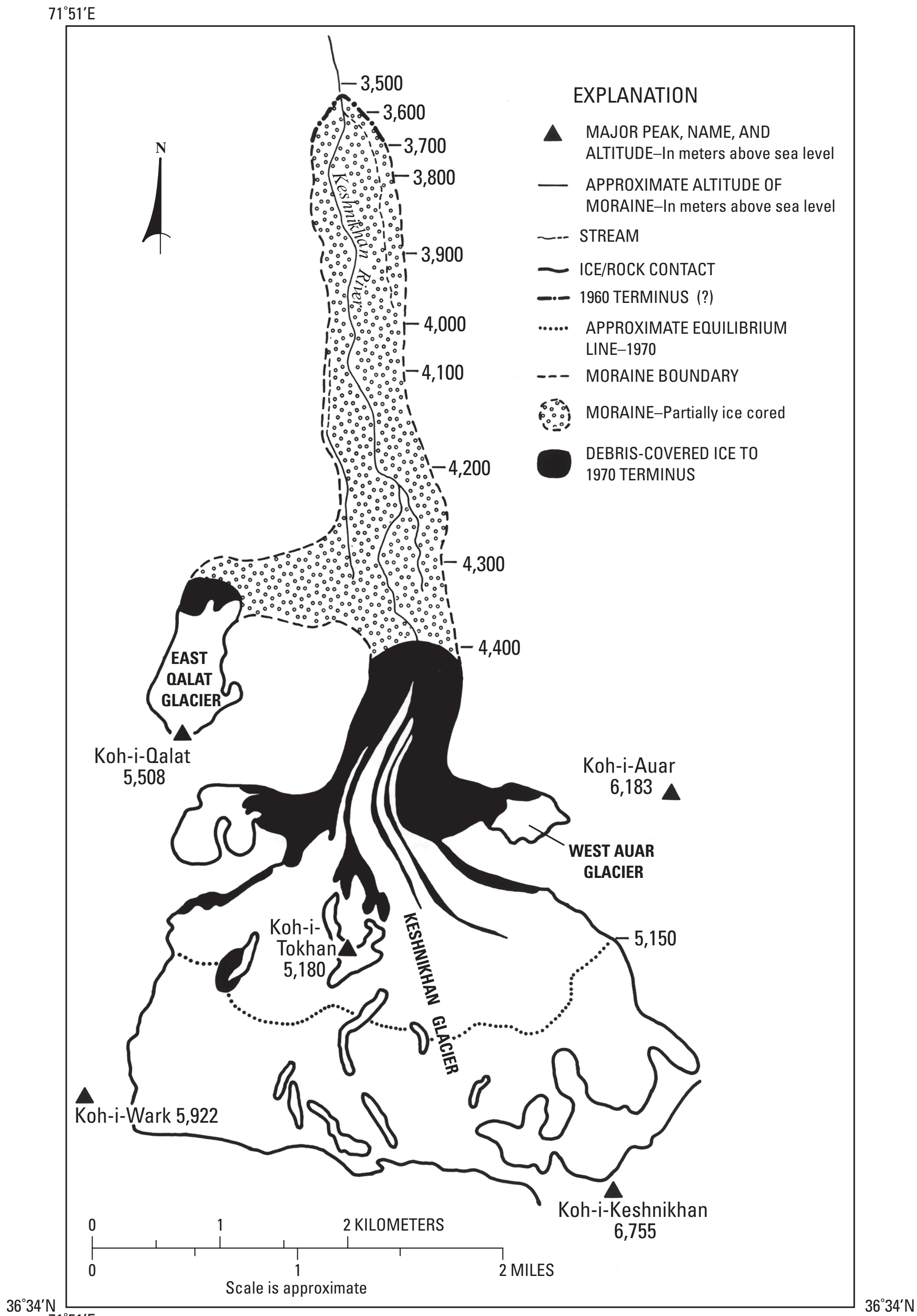


Figure 17.—*Planimetric map of* Keshnīkhān Glacier *adapted from Austrian Scientific Expedition in the Wakhan 1970 (1972). The approximate terminus of 1970 was delineated by Braslau (oral commun., 1977) and was only a few hundred meters below exposed ice. Compare with figure 5 for location. Names on map may be variant names.*

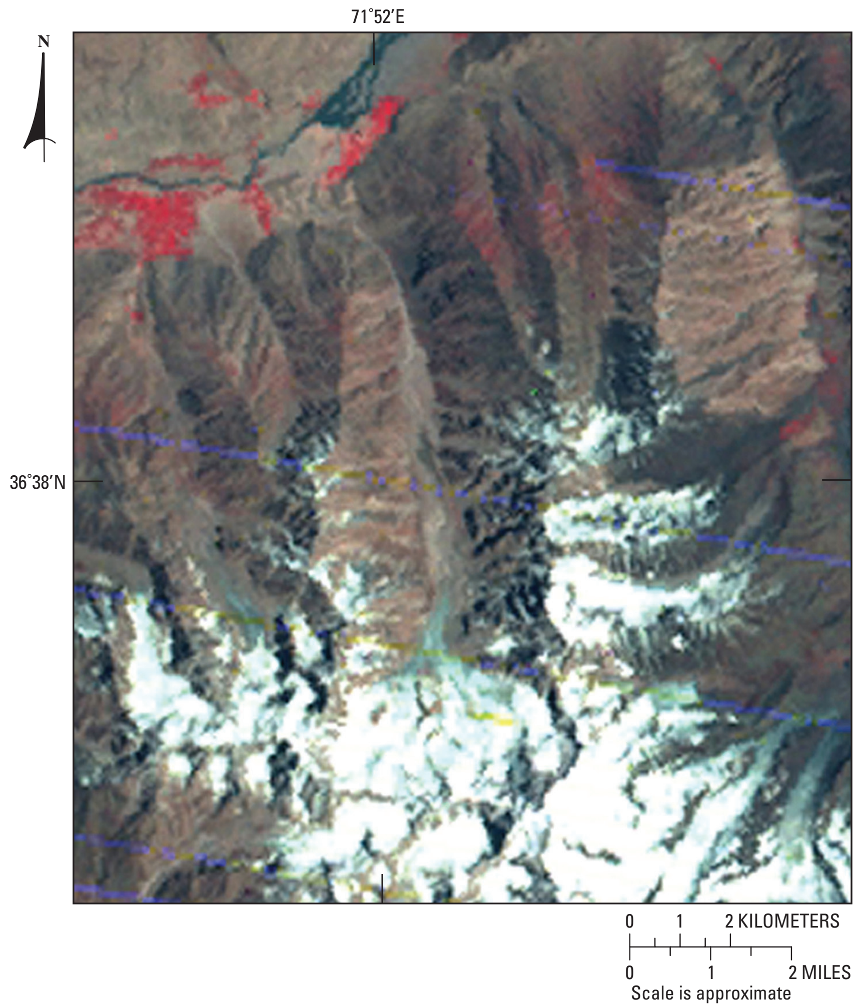


Figure 18.—*Landsat MSS image of* Keshnīkhān Glacier *area (approximate lat 36°35'N., long 71°52'E.) taken 12 July 1973. The Ab-i-Panj river is in the upper left. Compare with figures 5, 17, and 19.*

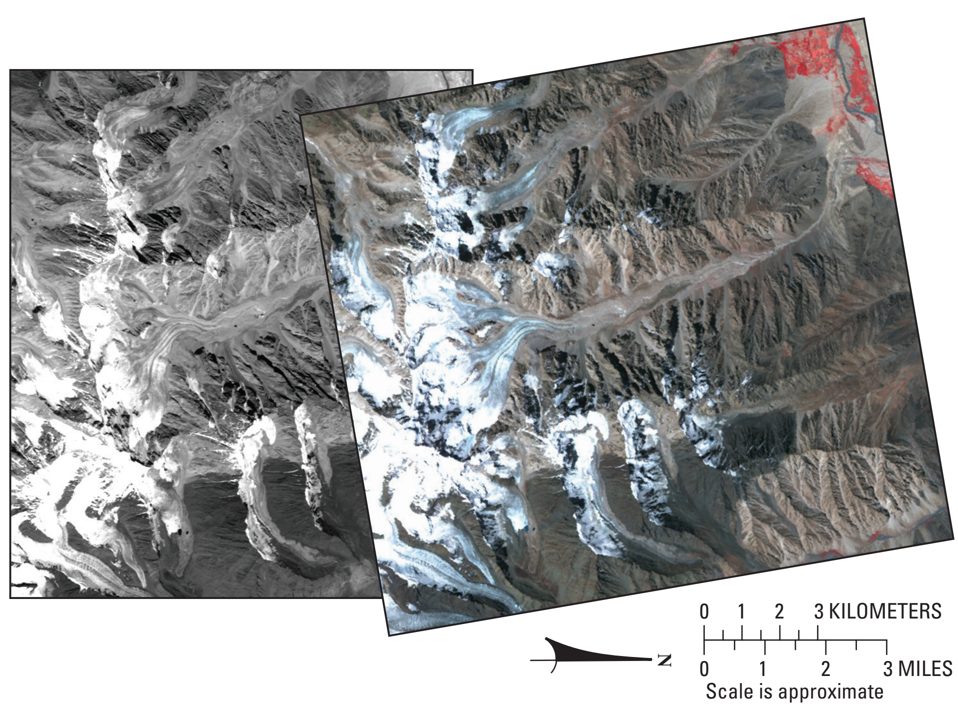


Figure 19.—*Stereoscopic pair of ASTER images of* Keshnīkhān Glacier *(approximate lat 36°35'N., long 71°52'E.) and environs. Compare with figures 5, 17, and 18. North is to the right. ASTER scene AST_L1B-003_08312000062611_ 09182003202055; 31 August 2000. [Editors' note: Use stereoscope for viewing.]*

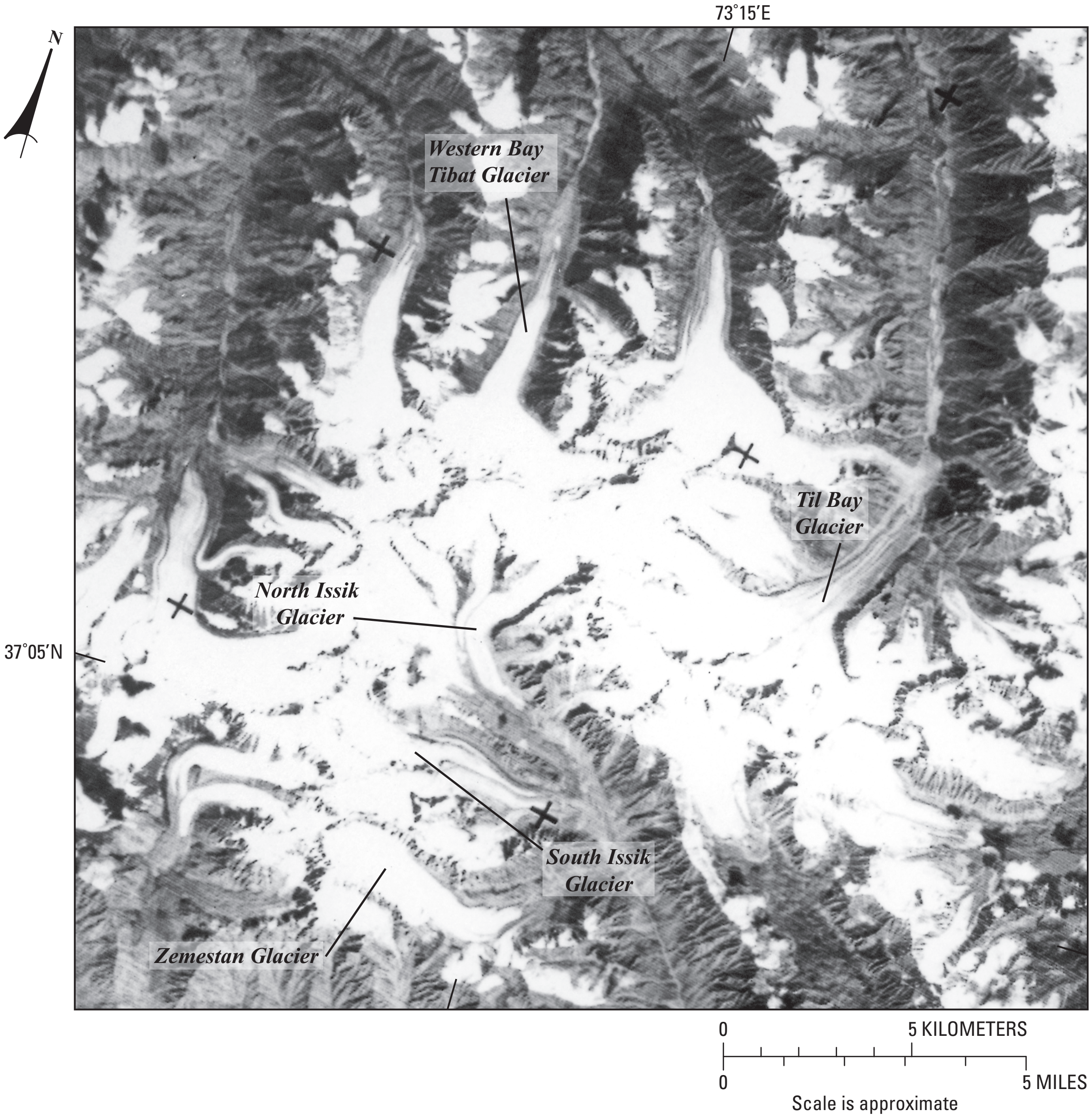


***Figure 20.**—Landsat 3 RBV image of the central Wākhān Pamir. Compare with figure 21. The Landsat 3 RBV image (30534–05053, subscene D; 21 August 1979; Path 162–Row 34) is from the U.S. Geological Survey, EROS Data Center, Sioux Falls, S. Dak. 57198.*

The three main glaciers of interest occur on the south side of the range at the head of the Issīk valley. The *Northern* and *Southern Issīk Glaciers* and *Zemestan Glacier* are surrounded on three sides by six of the highest peaks in the area (more than 6,000 m in elevation). Maps of the glacier termini made by Russian topographers from 1960 vertical aerial photographs appear to be based on an average between clean ice, debris-covered ice, and ice-free moraine; but these are actually an inaccurate representation of the real fronts, as indicated by the detailed mapping by Kostka and coworkers (Exploration Pamir 75, 1978a, b) (fig. 21). The work of Patzelt (1978) and his support team on the *Southern Issīk Glacier* shows two lateral moraines produced by short-lived prior advances — one in the 19th century (ca. 1850), and one in the early 20th century (ca. 1920). The ice has since retreated from both moraines.

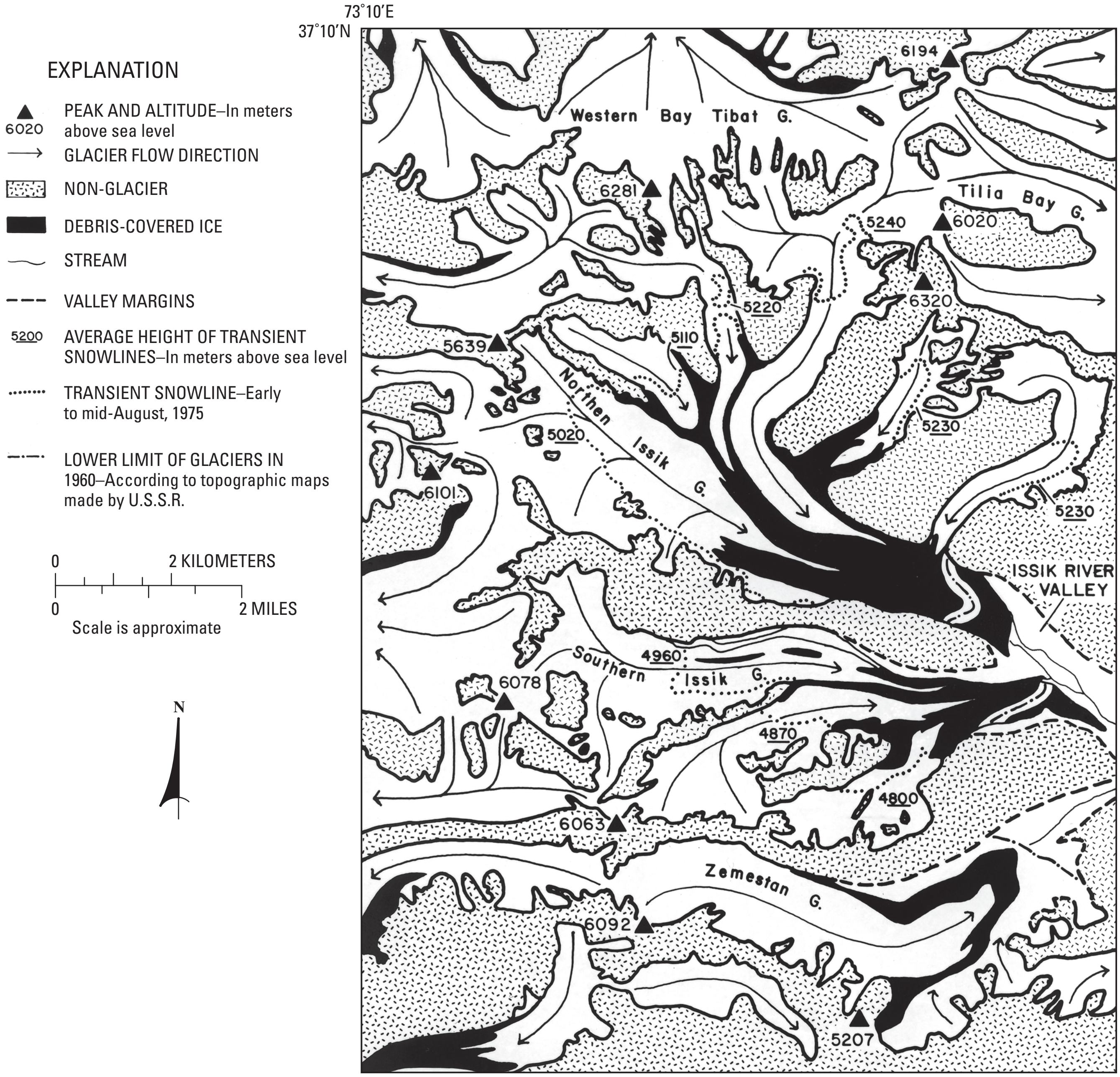


__Figure 21.__—Topographic map of south-central part of the Wākhān Pamir. After Exploration Pamir 75 (1978b). The map covers part of the area of figure 20.

The younger moraine closely corresponds to the glacier front as mapped by the Russian topographers, but this is probably just fortuitous as none of their other determinations coincide. Several other glaciers in the area also reached their maxima within the last century and have not retreated since, apparently due to the slow response time of the ice masses rather than to any climatic control. Lichens and desert varnish have not developed on these moraines and no other older moraines occur below them, so a clear differentiation can be made based on color and radiance between glacierized and unglaciated terrain.

The transient snowlines at various sites on the three glaciers in August 1975 ranged from 4,800–5,420 m, with a mean of about 5,100 m. The lower snowlines occurred in north-facing cirques and the higher occurred on southern aspects (fig. 21). In general, the glaciers of the Issīk valley seem to be retreating or downwasting somewhat, as is so common throughout Afghanistan.

The glaciers of the Issīk valley were analyzed by several remote sensing students using a variety of transparency-overlay and digital techniques. The students reported various observations of glacier advance or retreat. But these academic studies illustrate the potential pitfalls of using satellite imagery without proper controls. Apparent glacier movements were created by almost undetectable differences in scale and unrectified geometric differences between imagery and map overlays, by differences in Russian and Austrian maps, by problems in distinguishing parts of some glaciers from snow fields, clouds, or old moraines, and by seasonal variability. Ultimately, visual comparisons at the same scales of early imagery (for example, Landsat 1 MSS image 1047–05171; 08 September 1972; Path 162–Row 34) with later RBV material (fig. 20) showed little significant change in the Issīk valley.

Conclusions

Glaciers in Afghanistan are generally small and debris covered and have been retreating or down wasting for a long time; however, only limited recent change in the glaciers of the higher, colder northeast has been observed in our limited comparisons of the earlier MSS to later ASTER imagery. Some new meltwater lakes may pose a threat from glacier lake outburst floods (GLOFs), but in general, their small size and considerable incisement inside high moraine walls reduces hazard potential. Nevertheless, without a thorough assessment using high resolution ASTER imagery and new digital elevation models (DEMs), considerable uncertainty exists about the possibility for future GLOFs.

Difficulties posed by the rough terrain and the ongoing insurgent activities have limited available information and access to the glaciers of Afghanistan; therefore, satellite imagery is extremely valuable in conducting glacier inventories. The generally small size and dark debris cover of many of the ice masses make interpretation of small-scale imagery difficult, but stereoscopic and higher resolution imagery provides the additional information needed in such cases. Renewed inventory and assessment of the glaciers of Afghanistan as a part of the Global Land Ice Measurements from Space (GLIMS) Project is continuing to allow detailed investigation of the characteristics of the glaciers of the country; in this project, the authors maintain the USGS- and NASA-supported Regional Center for Southwest Asia.

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