

Working Paper
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Role of Landform in Differentiation of Ecosystems at the Mesoscale (Landscape Mosaics)

Abstract: A map showing the upper four levels of Ecomap down to the section level has been published for the entire U.S. These upper levels are based on macroclimatic conditions and the plant formations determined by those conditions. Delineation of the remaining, finer-grained subdivisions has been left for local development. Within the same macroclimate, broad-scale landforms break up the climatic pattern that would occur otherwise and provide a basis for further differentiation of mesoscale ecosystems, known as landscape mosaics. This paper suggests how different levels of landform differentiation could be correlated with landscape mosaics at different levels of resolution.

Introduction

Ecomap (1993) is an eight-level, nested, hierarchical and multi-factor approach to classifying and mapping ecosystem units (**Table 1**). The approach (herein referred to as the National Hierarchy) has been adopted by the Forest Service to provide a framework on which National Forest planning and assessment could be built.

Maps of the coarser levels of the National Hierarchy (domain, division, province, and section) have been published (Bailey et al. 1994). Delineation of the remaining, finer-grained subdivisions (subsection, landtype association, landtype, and landtype phase) has been left for local development. Experts from each Forest Service Region trying to complete Ecomap have been provided with limited suggestions about how that should be accomplished. There is a Terrestrial Ecological Unit Inventory (TEUI) tech guide, but it leaves a lot of decisions-making and standards-development up to the Regions. I have address the problems associated with this situation elsewhere (A Suggested Way to Improve the Subsection Mapping Process, see http://www.fs.fed.us/institute/news_info/ways_to_improve_subsection_mapping2.pdf).

This paper presents what I think one is trying to capture when one maps finer-grained subdivisions. As you will see, it emphasizes an understanding of the processes that operate to differentiate ecosystems at various scales. Namely, all natural ecosystems are recognized by differences in climatic regime (daily and seasonal fluxes of energy and moisture). Regional ecosystems (ecoregion domains, divisions, and provinces) are areas of homogeneous macroclimate (the climate that lies above the local modifying influences of landform and vegetation). Landform (geology and topography) is an important criterion for recognizing smaller divisions within macroecosystems as it exerts the major control over the climate at meso and micro levels. The following pages, which are adapted in part from Bailey (1987, 1996), suggest how I think different levels of landform differentiation could be correlated with section, subsection, and land type association in the National Hierarchy.

Role of landform

Macroclimate accounts for the largest share of systematic environmental variation at the macroscale or ecoregional level. At the mesoscale, landform (geology and topography) breaks up the broad patterns. For example, solar energy will be received and processed differently by a field of sand dunes, a lacustrine plain, or an upland hummocky moraine.

Within the same macroclimate, broad-scale landforms break up the east-west climatic pattern that would occur otherwise and provide a basis for further differentiation of mesoscale ecosystems, known as landscape mosaics. The character of a landscape mosaic with identical geology will vary by the climate zone. For example, vertical limestone would form quite different landscapes in a subarctic climate than in hot and arid climates. Limestone in a subarctic climate occurs in depressions and shows intense karstification, whereas in hot and arid climates, it occurs in marked relief with a few cave tunnels and canyons inherited from colder Pleistocene time.

Landforms (with their geologic substrate, surface shape, and relief) influence place-to-place variations in ecological factors, such as water availability and exposure to radiant solar energy. Through varying height and degree of ground-surface inclination, landforms interact with climate and directly influence hydrologic and soil-forming processes.

Landform is the best correlation of vegetation and soil patterns at meso- and microscales. This is because landform controls the intensity of key factors important to plants and to the soils that develop with them (Hack and Goodlet 1960; Swanson and others 1988). The importance of landform is apparent in a number of approaches to classification of forestland (for example, Barnes and others 1982). Even in areas of

relatively little topographic relief, such as the glacial landforms of the upper Midwest of the United States, landform explains a great deal of the variability of ecosystems across the landscape (Host et al. 1987).

Principal landform classes

Landforms come in all shapes and scales. On a continental scale within the same macroclimate, we commonly find several broad-scale landform patterns that break up the zonal patterns. The landform classification of Edwin H. Hammond (1954, 1964), who classified land-surface forms in terms of existing surface geometry, is useful in determining the limits of various mesoecosystems or landscape mosaics. In the Hammond system, landforms are identified on the basis of three major characteristics: (1) relative amount of gently sloping (<8%) land, (2) local relief, and (3) generalized profile (i.e., where and how much of the gently sloping land is located in valley bottoms). On the basis of these characteristics alone, it is possible to distinguish landforms that range from nearly flat plains to rolling, irregular plains, to hills, to low mountains, to high mountains

The effect of landform on site patterns

According to its physiographic nature, a landform unit consists of a certain set of sites. A delta has differing types of ecosystems from those of a moraine landscape next to it. The sites are arranged in specific patterns, according to the way they break up the zonal climate. The mountains and tablelands of the west-central part of North American illustrate this. For example, the high Idaho Mountains and the high-relief tablelands of

the Yellowstone Plateau are both located in the Rocky Mountains, a temperate-steppe regime highland. **Figure A1** shows how these different landforms in the same climate affect site patterns. The Idaho Mountains are made up of various site-specific ecosystems in a complex pattern, including riparian, forest, and grassland. Deep dissection of the mountain range has resulted in variously oriented slopes with varying local climates. Steep slopes oriented at different angles to the sun add complexity to the otherwise simple arrangement of altitudinal zones. Slopes that face toward the sun not only absorb much more heat than those which receive the sun's rays obliquely, but they also receive many more hours of sunshine. The north sides of east and west valleys are much warmer than the south sides at the same altitude, and these temperature differences are reflected in striking contrasts in vegetation. The Yellowstone Plateau, on the other hand, does not have these spotty distribution patterns because its landform is relatively uniform.

We can be most accurately delineate units at this level by considering the toposequence (Major 1951), or catena, of site types, throughout the unit.

Geologic substratum

The geologic substratum is another source of variation within the principal landform classes. Hammond's classification emphasizes the character of the surface form, rather than the geologic structure and development history. As such, similar land surfaces may have different underlying rocks. For example, the Fall Line, which separates the Appalachian Piedmont from the Atlantic Coastal Plain on the Fenneman map (1928), appears on the Hammond map as only a few short segments of boundary. Although the Fall Line represents a major break in geologic structure, it forms a poor dividing line for

surface configuration. The narrower valley floors, more rolling divides, and higher elevation which distinguish the Piedmont surface from much of the inner Coastal Plain occur only in places distinctive enough to warrant setting apart by a Hammond class boundary. Nevertheless, the ecosystem patterns of these two geologic units are different because of differences in the variety of relief and roughness.

The effect of geology on zonal boundaries

Geologic factors may modify zonal boundaries. Isachenko (1973) described how this works: In uniform geological-geomorphologic conditions, the transition between adjacent zones is often extremely diffuse. Where, however, the surface is variegated, zonal boundaries assume a more distinct form. Thus, the northern boundary of the forest-steppe zone on the Russian plain lies along the interface of two distinct types of geology: elevated, dissected plains with loess-type carbonate soils, and low-lying, sandy forest areas. The former favors the growth of broad-leaved forests and the spread of steppe grasslands. The latter, by contrast, favors a southward shift of the tayga's swamps and conifer forests. Accordingly, the boundary between the forest (tayga) and the forest-steppe zones generally lies directly along the interface of such lithologic regions.

In the Baltic region, owing to the widespread distribution of carbonate rocks, the northern boundary of the mixed-forest zone is displaced far to the north, so that its actual position varies with the theoretical position. In fact, the zonal boundary would lie much further south if we used the zonal-climatic criteria. Kruckeberg (2002) gives additional examples of this process.

Geologic structure is an important factor in differentiating mountain landscapes. It is more complex than along the plains. In mountains, the lithology and position of the substrata changes more frequently. Unlike the plains, mountains are composed essentially of dense sedimentary and igneous rocks, constituting the immediate substrata for soil formation and plant cover. The effect of bedrock on these other ecosystem components is well known. The soil-forming processes differ on the sedimentary and massive-crystalline rocks. Weathering and soil formation change massive-crystalline rock more than sedimentary rocks. Acid and basic rocks have a different effect on the migration of chemical elements, and associated processes. The podzolizing process fully develops on acidic, crystalline rocks, rich in silicon. On basic rock, soils are rich in humus. Accordingly, the line dividing outcrops of different kinds of rock constitutes an important ecological boundary; on either side of this boundary different landscapes prevail.

The effect of substrata on soils and vegetation is most marked in dry or cold climates. Here, soil development is slow, so that the mineral composition of the parent material often predominates in the thin soil cover. The availability of water in different soils may differ so widely that different vegetation occupies them in the same desert climate. The result is a mosaic of ecosystems unmatched in most humid climates, where soil development and subtle vegetation differences tend to mask the effects of the underlying rocks.

Levels of landform differentiation

We can consider landscape mosaics, or subcoregions, at three levels. Of these the broadest, sections, are based on broad land-surface form classes following the system of Hammond (1954, 1964). We determine subsections by subdividing sections into areas with homogeneity of lithologic structure, which reflects differentiation at a different scale. In other words, the major landform differences result from the overall shape of the surface. The next scale of landforms reflects differences in lithology within the overall shape. This can be illustrated by considering the Wind River Range in Wyoming. The area is a high, 4,200 m (13,800 ft.) mountain, in the temperate-steppe climatic regime. On the southwest side of the mountains, erosion has exposed a Precambrian granitic core (**Figure A2**). On the northeast side, exposed Paleozoic and Mesozoic rocks dip steeply to the northeast. These latter rocks, of varying degree of erosivity, form a broad band along the northeast side of the range.

These opposite flanks of the range have vastly different patterns of weathering, erosion, and chemical degradation. Hembree and Rainwater (1961) report that the rate of degradation by solution on the northeast flank is twice that on the southwest flank--about 49 and 26 tons per square mile per year, respectively. Conversely, the stream runoff on the southwest flank is about 1 1/2 times that on the northeast. This seeming anomaly is principally due to the erosive nature of the girdling band of Paleozoic and Mesozoic rock on the northeast flank.

Within a uniform geologic base, macrorelief and climate, there may exist mesorelief features that produce variation in local climate and microclimate. Sites, elsewhere defined as "land types" (Ecomap 1993), are formed within the limits of a single type of mesorelief, uniform bedrock, hydrologic condition, microclimate and soil.

Geographic associations of site units form the most detailed level of a hierarchy of landscape mosaics.

In the beginning of this paper, we discussed macrorelief that includes major continental features of azonal origin, i.e., those produced by tectonic movement and geologic structure (e.g., plateaus, mountain ranges). Mesorelief is the sculptural variety of those features. It comprises the detail against the background of major features, mainly caused by erosion and deposition (e.g., various erosional, glacial, wind-borne, and karst forms).

We may regard a uniform geologic structure, together with its set of sculptural variations as a geomorphic complex, or unit. Such a complex is commensurate with landscape mosaic. It has a uniform geologic base and is subject to the same geomorphologic processes. Examples of geomorphic complexes are: 1) crystalline shields with a complex of glacial erosional and fluvio-glacial depositional forms, 2) structural plateaus composed of limestones and dolomites and capped by glacial and karst forms, and 3) intermountain tectonic depressions filled with alluvium and other deposits.

The organic world of a landscape mosaic consists of a variegated complex of site-specific ecosystems. By contrast with a site, any one plant community does not characterize a landscape. A single landscape at the landscape-mosaic level may include plant communities belonging to different types of vegetation (e.g., almost every landscape in the tayga zone includes forest, swamp, and grasslands, and occasionally even tundra). Similarly, a specific plant community may extend over many landscapes.

A similar relationship exists between the landscape mosaics and soils. It is difficult to find landscapes with only a single type of soil. Various soils frequently

alternate over a small area, each associated with a single site. Accordingly, a landscape at this level corresponds to a soil association.

Landscapes at this landscape-mosaic level consist of a pattern (catena or association) of local ecosystems (microecosystems) matched to the sequence of topographic facets. Similar facets have similar local climate and hydrologic conditions. Many names have been proposed for these units. Milne, in his classic soil survey of East Africa (1936), proposed the term "physiographic complex" for the association and pattern of soil types in a natural region. He named the sequence of soils encountered between a hillcrest and the valley floor a "catena" (Latin "chain"). The Australians (Christian and Stewart 1968) call them "land systems," the Russians (Isachenko 1973) "landscapes." Wertz and Arnold (1972) use "land type association" and this term has been adopted by Ecomap (1993). The first example of such a landform-vegetation-soil catena is taken from Rowe and Sheard (1981) and is from the low subarctic ecoregion of the Lockhart River area of Canada.

The region is part of the Precambrian crystalline shield (the Canadian Shield) whose surface is mantled by various kinds of fluvio-glacial deposits. These include tracts of bedrock, thin drift, stratified drift (ridged or smooth), moraine (drumlinized, transverse-ridged, or smooth), alluvial, lacustrine, and peat terrain. The forest is open, boreal woodland (lichen woodland with bog forest in lowlands), known as tayga. It has a continental, subarctic climate.

The sites of this area represent about six types. The ecological interrelationships of the types are demonstrated schematically in **Figure A3**.

A second example illustrating the landscape ecosystem is from the montane zone of the Southern Rocky Mountains, a series of massive ranges separated from one another by broad valleys or extensive basins. While the mountain ranges differ in details among themselves, their common characteristics permit useful generalizations. The altitudinal strata of ecosystems occur within predictable elevation limits throughout the region because they are embedded in the same climate. Different patterns of site-specific ecosystems occur on different relief and geological structures within the range (see discussion of Wind River Range, above). Variation in sculptural forms is superimposed over the altitudinal climatic stratification and geologic structure. Most of the high peaks and plateaus of these mountain ranges have been glaciated. Surrounding them are subdued but deeply dissected uplands, some of which have been subject to cryic, or periglacial, processes. The upper valleys of streams flowing down from the central divide usually show the marks of active valley glaciation. They are deeply incised in narrow, steep-gradient canyons near the margins of the range.

Such differentiations are to be seen in **Figure A4**, a volcanic canyon landscape below the Lower Fall of the Yellowstone River. The hilly land in the background has the normal plant cover of the region, a montane coniferous forest. The canyon in the foreground, changes to treeless slopes interspersed with partially tree-covered slopes as well as areas of rock outcrop and talus. By modifying the macroclimate to topoclimate, such distinctive geomorphic units within a vegetation zone, support a separate landscape composed of a pattern of sites, or land types. This kind of unit is also defined as a landtype association (Ecomap 1993).

In summary, climatic zones determine macroscale ecosystem patterns. At the mesoscale, climate operated on a number of different kinds of surfaces (landforms) that modify the climate and break up the broad zonal pattern. We can identify landforms of different scales to establish a hierarchy of landscapes mosaics (**Table 2**).

Landforms in review

Landforms add another dimension of variation within the broad climatic regions. Geologic processes play an important, independent role in landform evolution through tectonic and volcanic activity that has shaped the continents and the major landform units within them. The surface of the continents is shaped into a remarkable variety of surface configurations, called landforms. They strongly influence the distribution of ecosystems through modification of the climate and strongly control land use. Inversely, climate influences landforms through the same factors of heat and moisture that control differences in soil and plant cover.

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Table 1. The National Hierarchical Framework of Ecological Units. From Ecomap (1993), in part.

Scale		Unit
Macroecosystem (Ecoregion)	Ecoregion	Domain
		Division
		Domain
Mesoecosystem (Landscape mosaic)	Subregion	Section
		Subsection
	Landscape	Landtype association
Microecosystem (Site)	Land Unit	Landtype
		Landtype phase

Table 2. A hierarchy of landscape mosaics

Section	Land-surface form (e.g., plateaus, mountains)
Subsection	Lithology
Land type association	Geomorphic complex or unit (uniform geologic structure subject to the same geomorphic processes)

Figure Captions

Figure A1. Landform effects on the montane zone in a temperate steppe mountain system, Idaho (top); tablelands, Yellowstone Plateau, Wyoming. Top photograph by John S. Shelton. Copyright (c) by John S. Shelton. Reproduced by permission of the photographer. Bottom photograph by USDA Forest Service.

Figure A2. Geological base of the landscapes of the Wind River Range, Wyoming. From Geologic Map of Wyoming by Love and Christiansen (1985).

Figure A3. Relationship of soil, vegetation, and topographic facets of typical landforms in the low subarctic ecoregion of the Lockhart River area of Canada. From Rowe and Sheard (1981).

Figure A4. Landscapes in a mountainous region (Yellowstone Plateau). Altitudinal limits are determined by climate, whereas different landscapes within an altitudinal belt are determined by geomorphic and geologic conditions. Photograph by George A. Grant, National Park Service.



Figure A1

(fig 8.8) Wind R. Range geology 55% 2-color

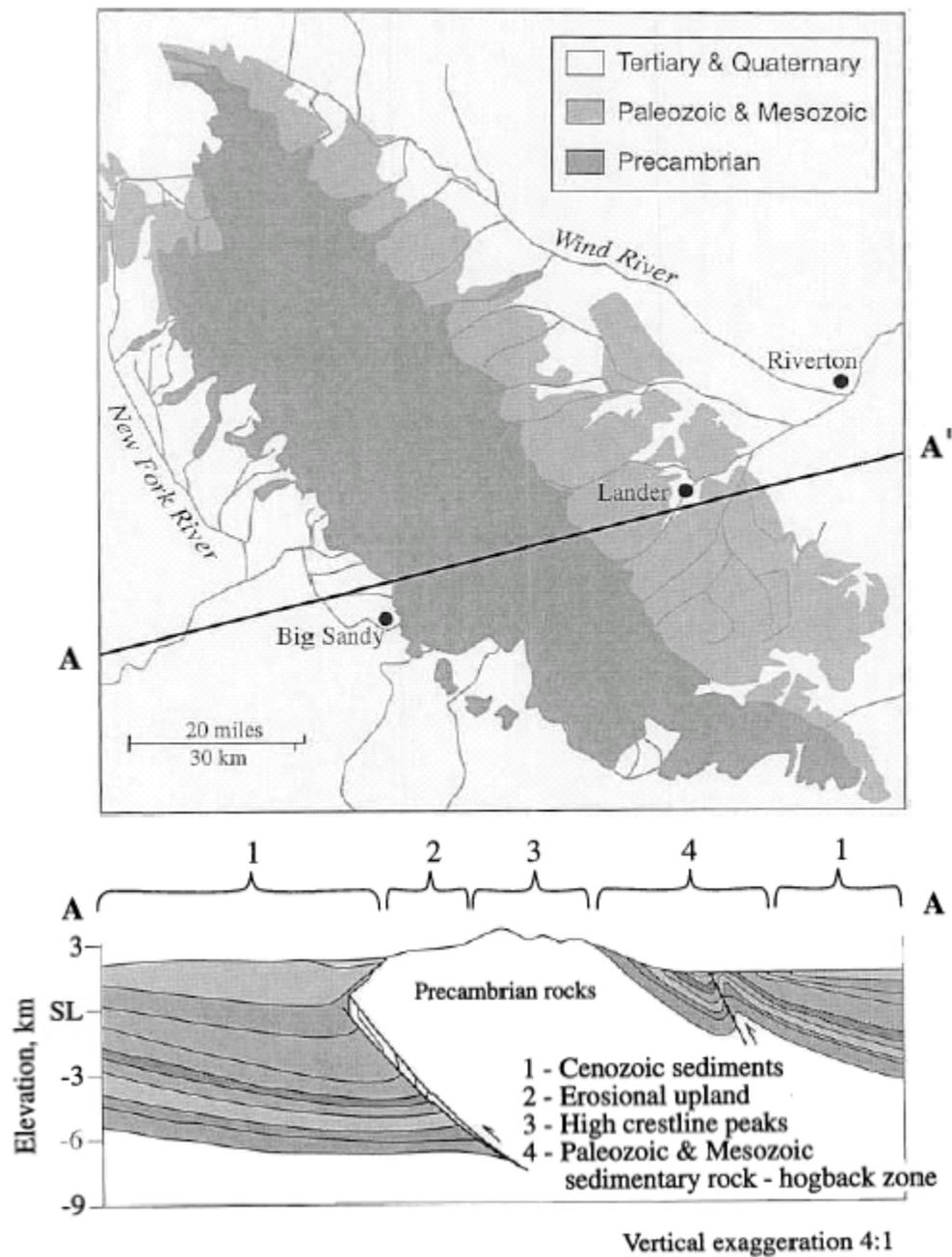
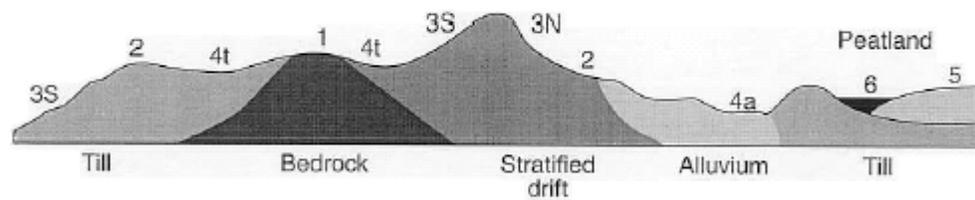


Figure A2

(fig 8.9) Land and vegetation relationships 1-color

Low-Subarctic Catenas



	Drainage classes	Vegetation
1	Excessively drained knolls	Rock lichen & rock-lichen woodland
2	Well-drained flats & convexities	Lichen woodland & heath-lichen woodland
3	Well-drained side slopes	
S	south aspect	Shrub-heath & shrub-heath woodland
N	north aspect	Moss-lichen woodland
4	Imperfectly drained	
t	toe slopes	Moss forest
a	alluvium	Shrub-herb forest, shrub thicket
5	Poorly drained flats & concavities	Bog woodland, heath-lichen bog
6	Saturated lowlands	Sedge fen, shrub-sedge fen

Figure A3

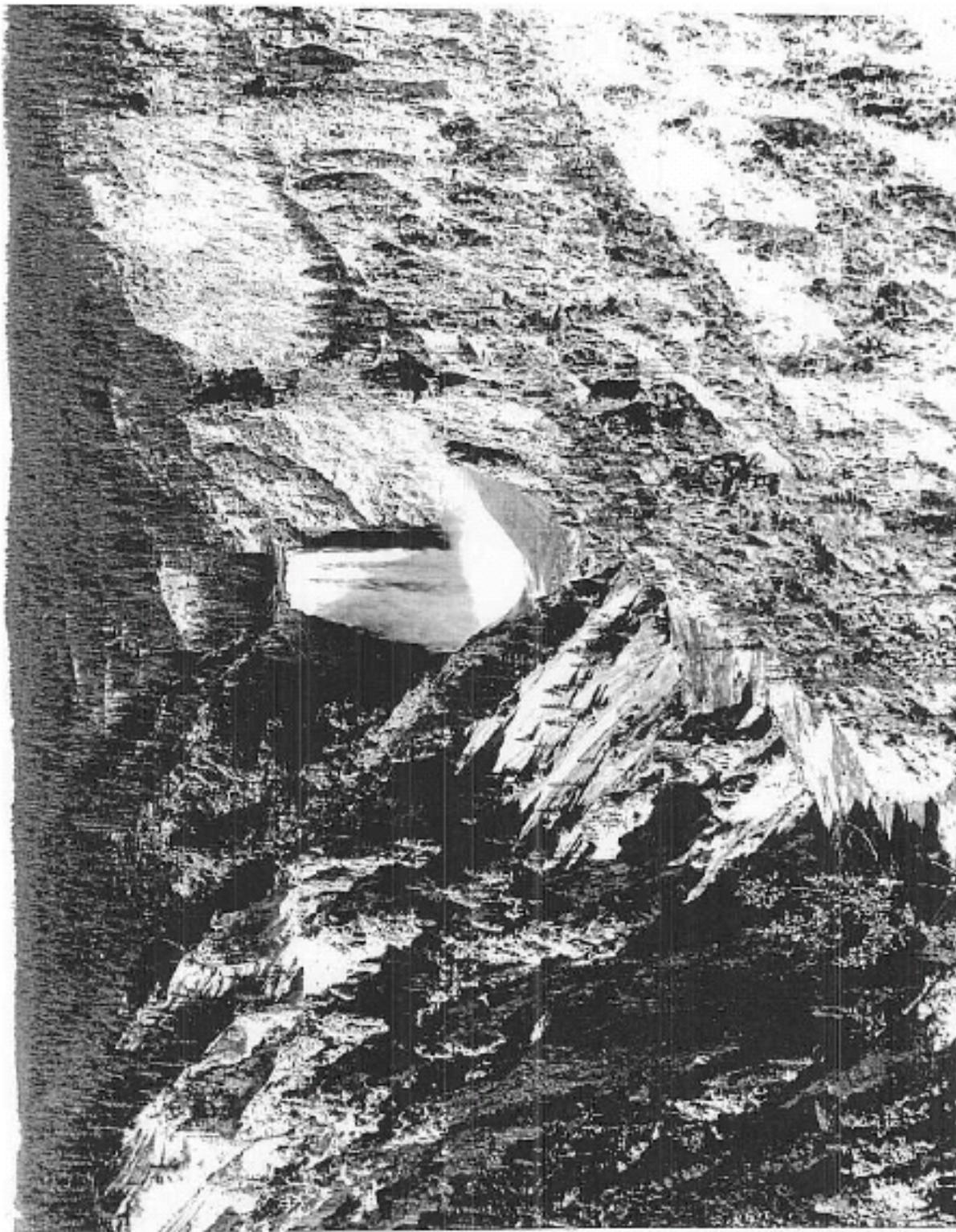


Figure A4