DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

An Overview of Geologic Mapping Needs in the United States

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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INTRODUCTION

Geologic maps provide the foundation for nearly all basic earth-science research ranging from investigations on the regional framework of the Earth's crust to studies of many Earth processes. Geologic maps also are the chief geologic data base for many applications of earth-science information to societal problems. Needs for these maps have increased for nearly every traditional use, and new uses continually arise. To meet these growing needs, the U.S. Geological Survey (USGS) initiated a Federal/State cooperative geologic mapping program (COGEOMAP) in 1985. The program was designed to satisfy requirements for geologic maps in areas of mutual concern to Federal and State agencies, and has met with enthusiastic State participation.

In response to wide-ranging National requirements that exceed the objectives of COGEOMAP, a broader geologic mapping program is presently being developed by the USGS. Implementation of a National program will require careful planning and close coordination with other agencies and institutions that conduct geologic mapping in order to effectively meet increasing map needs without duplication of effort. A circular, to be published in two parts, will outline a plan for a National Geologic Mapping Program: (A) The National Geologic Mapping Program, and (B) An Overview of Geologic Mapping Needs in the United States.

Part A of the circular will present basic information on the value and uses of geologic maps, will outline the status of geologic mapping, and will suggest a plan for a National program. It is being written for the public and for decision-makers at Federal, State, and local levels.

Part B, of which this report is a working draft, will provide a region-by-region assessment of geologic map needs in the United States, serving as the technical planning document for the program. As such, it will be written for the trained geologist. Part B will represent an assessment by the USGS of geologic map needs, and will, when published as a Circular, incorporate suggestions derived from reviews by academia, State geological surveys, industry, and other Federal agencies. This Open-File Report, the preliminary version of part B, is assembled for purposes of extensive technical review by scientists of the USGS and other agencies.

The assessment presented here is national, broken down on a region-by-region basis in order to match geologic map requirements to earth science-related problems in distinct geologic provinces. For example, in southern California, large-scale geologic maps are needed to accurately portray faults, to show geologic controls for landsliding, and to develop a geologic framework for interpreting past, present, and future earthquake activity. In the northern Rocky Mountains, large- and intermediate-scale geologic maps are needed for mineral resource assessment and exploration and for land-use planning of large tracts of Federally administered public land. In the northeastern United States, large- and intermediate-scale geologic maps are needed to make land-use decisions in areas undergoing rapid urbanization, including preserving resources such as sand and gravel and including planning development to avoid problems such as contamination of water supplies by waste disposal. In contrast with these areas needing large- and intermediate-scale mapping, areas such as the Great Plains generally require small-scale mapping coupled with subsurface investigations of basement rocks.

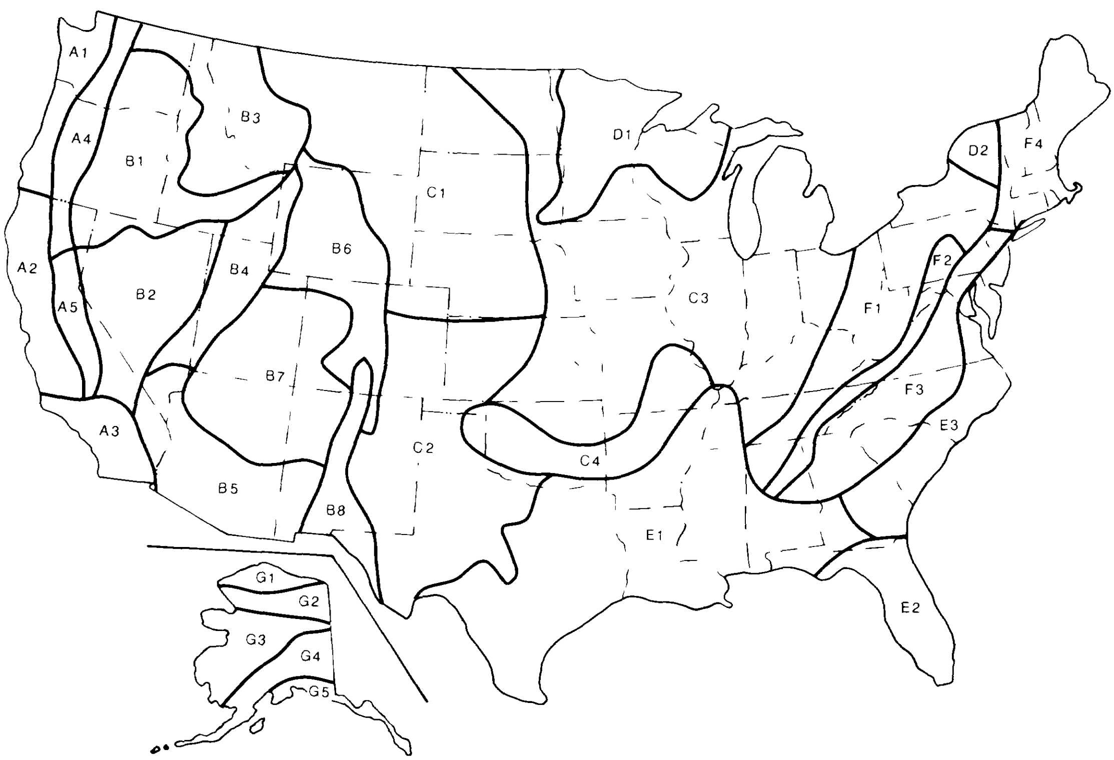
Whereas all regions in the Nation require additional geologic mapping, the problems to be addressed vary considerably, and as a result, so does the type of geologic expertise and mapping philosophy needed to make the maps. For example, the mapping of southern California will require geologists with expertise in bedrock, surficial, and structural geology. Seismic and other geophysical studies should be integrated with the mapping to provide a basis for specific hazard studies. The mapping of the northern Rocky Mountains will require expertise in sedimentology, igneous and metamorphic petrology, and structural geology. Geochemical and geophysical studies should be integrated with the mapping to provide a basis for specific mineral resource exploration and assessment studies. The mapping of the northeastern United States will require expertise in sedimentology, igneous and metamorphic petrology, structural geology, and especially in surficial geology to provide a basis for specific land-use studies. The mapping of the Great Plains will require close coupling with geophysical studies of basement configuration.

These few examples illustrate the range in regional problems and the consequent breadth of geologic mapping needed to provide a foundation upon which specialized studies to solve specific problems may be undertaken. Although geologic mapping commonly contributes directly to solving specific problems, the major function of the maps is to provide the geologic information base needed for current and future specialized studies.

Not only do geologic characteristics vary in different provinces, thus dictating different mapping requirements, but the status of geologic mapping also varies. The western United States is in general only modestly mapped, and therefore new mapping needs must be determined only in terms of regional problems that have been identified. In contrast, the Appalachian region is relatively well mapped, allowing needs to be quite specifically identified both topically and spatially. However, over most of Alaska the basic geologic framework has only recently started to be discovered and requires much future mapping to further identify regional geologic framework problems needing more detailed study.

The national assessment, done region by region, that follows describes the geologic characteristics of 32 geologic provinces grouped into 8 regions (fig. 1). For each province, the general geology is described, some of the major problems and(or) benefits that can result from geologic mapping are identified, and an assessment of geologic mapping needs is made. Because geologic maps are basic geologic data sources, the discussions are presented in terms of basic regional geologic problems; it is within this regional context provided by geologic maps that both basic research and applied topical research are conducted.

The information upon which this report is based was provided by numerous USGS scientists from all the major centers, mostly within the branches of Eastern, Central, and Western Regional Geology within the Office of Regional Geology, and the Branch of Alaskan Geology within the Office of Mineral Resources (Table 1). These contributions were assembled into four reports on Alaska and the eastern, central, and western United States by, respectively, O. J. Ferrians, Jr., J. W. Horton, Jr., E. R. Cressman and S. S. Oriel, and C. M. Wentworth. This Open-File Report was compiled from these four documents. We are grateful for the help given by E. H. Roseboom, Jr., Chief of the Office of Regional Geology and the driving force for this report, as well as by D. M. Morton, K. A. Sargent, Juergen Reinhardt, R. B. Taylor, J. C. Reed, Jr., E. T. Ruppel, C. A. Wallace, H. E. Malde, and M. K. Nance.



PHYSIOGRAPHIC PROVINCES

Western Cordillera (A)
- A1 Pacific Northwest
- A2 Northern California
- A3 Southern California
- A4 Cascade Range
- A5 Sierra Nevada

Basin and Range–Rocky Mountains (B)
- B1 Columbia Plateau/Snake River Plain
- B2 Basin and Range
- B3 Northern Rocky Mts. Thrust Belt
- B4 Central Rocky Mts. Thrust Belt
- B5 Southern Rocky Mts.
- B6 Foreland Province
- B7 Colorado Plateau
- B8 Rio Grande Rift

Great Plains–Midcontinent (C)
- C1 Northern Great Plains
- C2 Southern Great Plains
- C3 Midcontinent
- C4 Ouachita/Ozark Region

Canadian Shield (D)
- D1 Lake Superior Region
- D2 Adirondack Region

Coastal Plain (E)
- E1 Gulf Coastal Plain
- E2 Florida Platform
- E3 Atlantic Coastal Plain

Appalacian (F)
- F1 Appalachian Plateaus
- F2 Appalachian Fold and Thrust Belt
- F3 Southern-Central Crystalline Belt
- F4 New England Appalachians

Alaska (G)
- G1 North Slope
- G2 Brooks Range
- G3 Interior Basins
- G4 Aleutian Islands/Alaska Range
- G5 Southeast Alaska

Figure 1. Map of physiographic provinces of the United States, from questionnaire distributed by the committee on Geological Mapping (C. L. Mankin, chairman), Geological Sciences Board, National Academy of Sciences/National Research Council.

Table 1. Persons responsible for writing the major sections of this report.

Region	Bedrock geology	Surficial geology
Western Cordillera		
Pacific Northwest	R.W. Tabor, R.E. Wells,	B.F. Atwater
Northern California	C.M. Wentworth, M.C. Blake Jr., D.S. Harwood, E.E. Brabb, A.M. Sarna-Wojcicki	
Southern California	R.E. Powell	
Cascade Range	R.W. Tabor, D.A. Swanson, R.E. Wells, A.M. Sarna-Wojcicki	B.F. Atwater
Sierra Nevada	N.K. Huber, D.S. Harwood	
Basin and Range - Rocky Mountains		
Columbia Plateau/ Snake River Plain	D.A. Swanson, M.A. Kuntz	
Basin and Range	M.D. Carr, D.M. Miller, P.W. Lipman, M.N. Machette	M.D. Carr, D.M. Miller, M.N. Machette
Northern Rocky Mts. Thrust Belt	M.W. Reynolds, M.A. Kuntz, M.N. Machette	
Central Rocky Mts. Thrust Belt	M.W. Reynolds, P.W. Lipman, M.N. Machette, B.H. Bryant	
Southern Rocky Mts.	B.H. Bryant, P.W. Lipman, M.N. Machette	
Foreland Province	G.L. Snyder, W.R. Hansen, M.A. Kuntz	
Colorado Plateau	P.W. Lipman, M.N. Machette, B.H. Bryant	
Rio Grande Rift	P.W. Lipman, M.N. Machette	M.N. Machette
Great Plains - Midcontinent		
Great Plains	W.R. Hansen, E.R. Verbeek	E.R. Verbeek
Midcontinent	J.W. Horton Jr.	
Ouachita/ Ozark Region	E.E. Glick	
Canadian Shield		
Lake Superior Region	P.K. Sims	
Adirondack Region	J.W. Horton Jr., D.W. Rankin, N.M. Ratcliffe	B.D. Stone
Coastal Plain	J.P. Owens, G.S. Gohn, Juergen Reinhardt, Lucy McCartan, W.L. Newell	
Appalachians	R.C. McDowell, C.L. Rice, Louis Pavlides, D.W. Rantain	M.J. Pavich, B.D. Stone

Table 1. Persons responsible for writing the major sections of this report.--Continued

Region	Bedrock geology	Surficial geology
Alaska		
North Slope	I.L. Tailleur, A. Grantz, I.Y. Ellersieck, W.P. Brosge, D.J. Grybeck, R.L. Detterman	L.D. Carter, R.L. Detterman
Brooks Range	I.L. Tailleur, John Kelley, D.J. Grybeck, I.Y. Ellersieck, S.M. Karl, G.W. Moore, W.P. Brosge	T.D. Hamilton, R.L. Detterman
Interior Basins	A.B. Till, W.W. Patton Jr., S.E. Box, R.M. Chapman, T.P. Miller, W.L. Coonrad, M.M. Miller, F.R. Weber	J.R. Williams, W.E. Yeend, T.D. Hamilton
Aleutian Islands/ Alaska Range	R.L. Detterman, James Riehle, W.J. Nolcleberg, B.L. Reed, B. Csejtey Jr., H.L. Foster A. Grantz, James Dover, F.H. Wilson, W.H. Nelson, T.P. Miller, C. Wahrhaftig, D.H. Richter, F.R. Weber	R.L. Detterman, W.E. Yeend, J.R. Williams, F.R. Weber, S. Nelson, L.D. Carter, C. Wahraftig, O.J. Ferrians Jr.
Southeast Alaska	G. Plafker, D.A. Brew, S. Nelson, G.R. Winkler, A.B. Ford, R.A. Loney, D.J. Grybeck, F. Barker	J.R. Williams, G. Plafker, S. Winkler, O.J. Ferrians Jr.
Hawaii	D.A. Clague, J.P. Lockwood	

A. WESTERN CORDILLERA

A1. Pacific Northwest

General Geology

The Pacific Northwest province (fig. 2) consists of the fertile lowlands of the Puget Sound and Willamette Valley stretching southward through Washington and Oregon and of the rugged coast ranges west of the lowlands. The rocks exposed in the coast ranges and along the lowlands reveal a geologic record presently only partly understood but indicating at least 120 m.y. of convergence, collision, and continuing oblique subduction between the crustal plates of the Pacific Ocean and the buoyant, overriding continental lithosphere of North America. Most of the rocks of the region apparently were derived from materials accreted to the continental edge (accreted terranes) by the northeastward movement of oceanic plates relative to the continent. The continuing subduction gives rise to the possibility of great (M=8) earthquakes in this region, which includes the Seattle-Tacoma urban corridor.

The oldest documented accreted terranes crop out in the northern Cascade Range and San Juan Islands. This tract of mostly Paleozoic and Mesozoic terranes is cut by the north-striking Straight Creek fault, a major strike-slip fault thought to be analogous to the San Andreas fault in California. However, unlike the San Andreas, the Straight Creek fault is not known to be active today. This fault displaced rocks on the northward-moving oceanic plate at least 190 kilometers northward relative to rocks on the adjoining North American plate.

West of the Straight Creek fault, the mountains, foothills, and San Juan Islands consist of a collage of crustal fragments, including mostly Paleozoic and Mesozoic marine sedimentary rocks, ocean-floor basalt, ophiolites, high-pressure metamorphic rocks, and slivers of metamorphic and igneous rocks exotic to their associated terranes. The rocks of these far-travelled terranes formed in different environments than they occupy today. Thorough geologic mapping supported by isotopic and geophysical studies is needed before their complex history can be unraveled.

Rocks in the range west of the Puget-Willamette lowlands indicate that plate convergence and accretion continued into the Cenozoic. In the Olympic Mountains and the Coast Ranges of southern Washington and Oregon, a thick accumulation of basalt, considered to represent a large seamount chain similar to the Hawaiian Islands, was accreted to the continental margin at about 50 Ma. The folded and faulted basalt is overlain by fossiliferous marine sedimentary rocks derived from sediments eroded from the continent. In the Olympic Mountains, Tertiary marine rocks, now highly deformed, were probably scraped off the oceanic plate and thrust beneath the seamount basalt. These sedimentary rocks are more or less the same age as the strata that overlie the basalt, and they must have been brought in obliquely to the site of accretion by the moving oceanic plate. Initial mapping suggests that large clockwise rotation of crustal blocks in the Coast Range and the Cascades probably occurred as the continental margin was dragged along by the northward moving oceanic plate. On the eastern flank of the Cascades in Washington, continental stretching and rifting caused major subsidence of crustal blocks and rapid sedimentation and volcanism in the rift valley.

Uplift of the continental margin above the underthrust oceanic crust produced the high ranges of the Cascades and Olympic Mountains, where a particularly complex series of glacial events is recorded as a result of continental ice moving from the north into the Puget lowland while alpine glaciers repeatedly grew and retreated in the mountain valleys. Deposits that formed in the valleys and along the margin of the continental ice where it dammed the mountain valleys suggest a constantly changing landscape of lakes, spillways, and deltas. At the edge of the Puget lowland, these deposits are of particular interest to man, who lives and builds on them and periodically suffers from their instability.

Geologic Mapping Needs

Accretionary terranes in the north Cascades. To understand the history and processes of accretion that established the Paleozoic and Mesozoic terranes in the Pacific Northwest and Cascades regions, the details of terrane distribution and terrane contacts need to be determined through careful geologic mapping. Recognizing these terranes and their bounding faults is not only important to understanding the processes of continental growth and mechanisms of deformation, but to evaluating more recent tectonics, in particular the currently active faults that can cause large earthquakes. Only geologic mapping allows the distinction of old faults from young faults. For instance, new evidence found during preliminary geologic mapping now suggests that structural models invoking regional emplacement of plate-like terranes along ancient low-angle thrust faults needs considerable revision. High-angle

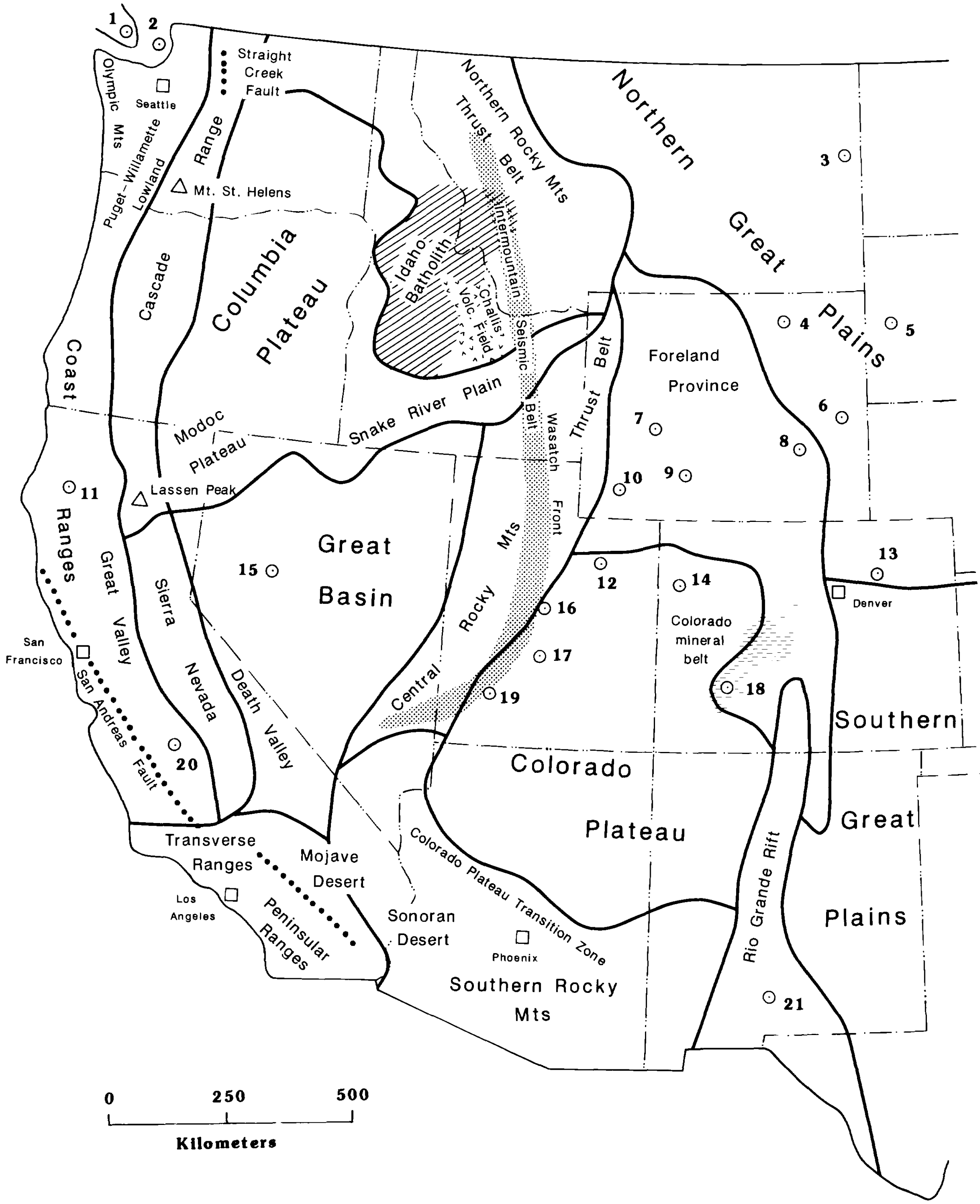


Figure 2. Physiographic provinces of the western United States, showing locations of features discussed in the text. Localities identified by numbers: 1, Vancouver Island, Canada: 2, San Juan Islands; 3, Williston Basin; 4, Powder River Basin; 5, Black Hills; 6, Hartville uplift; 7, Wind River Mountains; 8, Laramie Mountains; 9, Great Divide Basin; 10, Green River Basin; 11, Klamath Mountains; 12, Uinta Basin; 13, Denver Basin; 14, Piceance Basin; 15, Dixie Valley - Fairview Peak fault; 16, Nephi area; 17, Marysvale volcanic field; 18, San Juan volcanic field; 19, Cedar City area; 20, San Joaquin Valley; 21, San Andres fault system.

strike-slip faults, some with more recent offset history, may be equally important or more important for emplacement of the terranes. Adequate geologic mapping and deep seismic reflection studies, coupled with some refraction work, will help clarify the faults between terranes and the underpinnings of the thrust plates or strike-slip slivers.

U-Th-Pb and Rb-Sr isotopic studies of rock in the terranes is an important adjunct to the mapping. Resources, in particular metallic ore deposits, may be characteristic of one terrane and not another, and terrane identification may become an important resource exploration tool.

Regional geologic mapping at 1:100,000 scale in the western foothills and northern Cascades is needed to help delineate terranes and identify areas where more detailed mapping and study will solve regional resource and terrane-related problems. Detailed mapping of selected areas here and to the south is also necessary to establish a geologic framework that will provide the fundamental data base for both volcanic and earthquake-hazard studies in this region. Although no large earthquakes have occurred in historical times, the coastal Northwest--especially the Seattle-Tacoma area--has the potential for a great (M=8-9) earthquake. Much of this coastal area will have to be mapped at 1:24,000 scale to provide information for specific hazard-related studies. Since the Mount St. Helens eruption in May of 1980, the volcanic hazards have been self-apparent.

Docking of the Olympic terrane in the north Cascades. Previous work has suggested that the anomalous arcuate pattern in the rocks of the Tertiary accreted terrane of the Olympic Mountains may have been created when a linear basalt seamount chain was bent as it was pushed into the reentrant between Vancouver Island (an older terrane) and the pre-Tertiary rocks of the northern Cascades. Study of structures in the Mesozoic and Paleozoic terranes such as arcuate rock units, curved major fault zones, and systematic changes in outcrop-scale structures such as fold axes or foliation, could verify this hypothesis. If so, the current hypothesis that the Olympic terrane moved into place along one or more north-south strike-slip faults must be re-evaluated. Regional 1:100,000-scale geologic mapping is needed to solve this problem.

Rotational strain in west Oregon and Washington. Paleomagnetically documented large clockwise rotations in Cenozoic rocks of western Washington and Oregon have been explained in several ways, including: (1) rotation during collision and accretion of large crustal plates to the continental margin; (2) rigid plate rotation in front of an asymmetrically extending back-arc region; and (3) rotation of small crustal blocks in a simple shear couple. Understanding the mechanism of tectonic rotation depends in large part on accurate geologic mapping of the rotated terranes, many of which have not been mapped at a scale larger than 1:500,000, which is not sufficiently detailed to solve the problem. Determining stratigraphic onlap relationships and detailed geologic mapping are needed in the Tillamook Volcanics of northwestern Oregon, the western Cascades of Washington, and the Tyee basin of western Oregon to determine the relationship of the rotations to the local structural geology. It is imperative to distinguish between such major tectonic processes as regional shear and accretion of crustal plates in order to reconstruct the shape of the continent, understand the distribution and history of sedimentary basins and their contained petroleum reserves, and determine the large-scale rheological properties of the crust.

Cordilleran icesheet in the Puget lowland. Correlating terrestrial stratigraphy and changes in ocean volume remains a great challenge in Quaternary geology. The chronology and paleoclimatology records of marine deposits are commonly extended to terrestrial sections for which the dating is poor and the paleoclimatic context unclear, but only rarely have such correlations been tested with rigor. The Puget lowland provides exceptional opportunities for linking land and sea records. Not only does the lowland contain the most complete glacial record known in the western conterminus U.S., it also contains thick interglacial deposits formed at or near sea level. Furthermore, many of the lowland's deposits contain volcanic ash that could prove invaluable in correlation and dating.

Fortunately for Quaternary stratigraphic studies in the lowland, there is the reasonably well-understood sequence of deposits spanning advance and retreat of the Cordilleran icesheet and subsequent invasion of tidal water. This sequence invites sedimentologic study of laterally and vertically adjacent glacial, fluvial, lacustrine, and estuarine facies. Results of such a study could be used to intepret the paleoecology and relative ages of similarly complex but older deposits in the lowland, with abundant practical applications to problems of seismic shaking, seismic sea waves and seiches, waste disposal, and water resource quality and abundance.

Great subduction-zone earthquakes in the Northwest. There is no known evidence that great earthquakes have occurred during the late Quaternary in the Pacific Northwest. However, subduction-zone earthquakes should be striking the Pacific Northwest at intervals of about 500 years if, as recently argued by seismologists, the Juan de Fuca subduction zone is analogous to Japanese, Alaskan, Central American, and South American subduction zones in which much of the subduction occurs during large earthquakes. This hypothesis could be partly tested by geologic mapping of Quaternary lowland deposits and by mapping and dating landslide deposits in western Washington and Oregon. The landslide dates, if clustered, would help refine a search for the paleoliquefaction structures and seismic sea-wave deposits in the lowlands that, along with landslides, should have formed as a result of great subduction-zone earthquakes.

A2. Northern California

General Geology

The Coast Ranges of the Pacific northwest extend southward into California as a series of generally northwest-oriented ranges divided by rivers and alluvial valleys. The ranges are bounded on the east by the Great Valley, which is drained by rivers that breach the Coast Ranges only at San Francisco Bay. The northwesterly grain in the topography is produced by the underlying rocks, and appears to reflect the shape of the western margin of North America over the past 200 m.y. as this part of the continent formed.

For the past 20 m.y., the Coast Ranges have been transected by the San Andreas fault, which is responsible for many of the damaging earthquakes in California. The next important earthquake on the San Andreas fault is expected within a decade near Parkfield, midway between San Francisco and Los Angeles, and the next great earthquake is predicted to have a 50 percent chance of occurring in the next 30 years farther southeast. Deformation associated with the San Andreas fault has uplifted the southern Coast Ranges, probably in the past 2 m.y., and downfaulted many of the valleys.

The Northern California province consists of two very different kinds of crust, both about 100-175 Ma. The granitic and metamorphic rocks of the Sierra Nevada extend westward beneath the sediments of the Great Valley; similar rocks appear to have been offset northward from southern California to form the Salinian terrane west of the San Andreas fault in the Coast Ranges. West of this basement lies the huge mass of Franciscan rocks, which may have originally formed within separate terranes that originated as far south as the equator. These are thought to have been transported northward, amalgamated, and incorporated onto the continental margin by pre-San Andreas plate motions. Igneous activity that formed the Sierran granitic batholith and its partly preserved volcanic carapace occurred at about the same time Franciscan rocks were formed and thrust eastward and downward at the subduction zone along the continental margin. Nearly concurrently, several kilometers of sandstone and shale of the Great Valley sequence were deposited at the continental margin.

Subsequently, during the past 60 m.y., the Coast Ranges variably rose above the sea while deep basins were formed locally, particularly in the southern part of the Great Valley. Thick sequences of marine sandstone, shale, and siliceous rock accumulated in these basins and lapped onto the flanks of surrounding topographic highs. Volcanic rocks were extruded locally, some related to initiation of San Andreas movement and some later. These Cenozoic volcanic and sedimentary rocks preserve a record of the complex folding, faulting, and uplift responsible for the present Coast Ranges. The Cenozoic strata and Great Valley sequence contain significant resources of oil and gas. Important mercury deposits occur locally in the Franciscan terrane, and newly discovered gold deposits are now being exploited in shale of the Great Valley sequence west of Sacramento.

Geologic mapping over the past century has established the general distribution of rocks in the region, and work during and since World War II has framed specific geologic interpretations that bear on earthquake and landslide hazards, resources ranging from sand and gravel to oil and gold, and numerous fundamental geologic problems. This framework forms a basis for detailed mapping and specialized studies that will improve our understanding of one of the most complex and seismically active areas in the world.

Geologic Mapping Needs

Coast Range - Great Valley boundary. The abrupt change from alluvial lowland to uplifted mountains at the Coast Range - Great Valley boundary reflects a coincidence of structural features that includes the surface expression of the late Mesozoic oceanic-continental boundary. Here, blueschist facies Franciscan rocks are thrust eastward beneath coeval, but unmetamorphosed, marine strata of the Great Valley sequence along the Coast Range thrust. In the context of plate tectonics, this thrust has been assumed to extend eastward down to the mantle. These structural relations have long been considered a classic example of subductive accretion of trench and oceanic sediments beneath a continent. An alternative model has recently been raised by deep seismic reflection profiling, in concert with seismic refraction profiling and gravity and magnetic analysis, which suggests that the Franciscan assemblage was obducted as a tectonic wedge that overrode the continental margin and concurrently peeled up the overlying Great Valley sequence.

Such a history of eastward movement of a complex wedge of Franciscan rock, perhaps pushing before it wedges of Coast Range ophiolite and even Great Valley sequence, raises important geologic questions that can only be adequately investigated by a combination of geologic mapping, biostratigraphic analysis, and geophysical study. Geologic mapping is needed to establish whether wedge tectonics and associated thrusting may be common in the Coast Ranges. The concept could help to explain the large strike-slip faults at the northern end of the Great Valley sequence. Important thrusts may occur within the Great Valley sequence and possibly are represented by what are currently considered to be unconformities. Evidence on the timing of wedge emplacement and progressive movement should be recorded in the Cretaceous-Cenozoic stratigraphic record, requiring that detailed biostratigraphic studies accompany geologic mapping.

Franciscan accretionary complex. The Late Jurassic and Cretaceous Franciscan assemblage represents an accretionary complex from which much can be learned about the formation and emplacement of exotic terranes against a continental margin. The extensive development of blueschist metamorphism in the Franciscan assemblage requires that it was carried to depths as great as 30 km in a subduction zone. Recent work in the Franciscan, particularly in the northern Coast Ranges, has identified several important problems that only can be addressed by detailed geologic mapping and geophysical studies.

The west-dipping basement underlying the eastern margin of the Franciscan mass can be traced westward geophysically. The buried lip of the late Mesozoic subduction zone can be similarly sought. The relationship of surface structure, established through geologic mapping, to subsurface structure should provide the gross structural anatomy of the Franciscan mass, help constrain the role of lateral faulting, and provide a model to explore for deep gas resources.

Detailed knowledge of the structural history of selected parts of the Franciscan assemblage will help determine the sequence of metamorphic and accretionary events and their geometries. Recent structural studies indicate several episodes of deformation, the styles and geometries of which require more than simple eastward underthrusting along a subduction zone. Returning blueschists to the surface from great depths, a long-standing problem, can also be answered by additional mapping and structural studies.

The origin of melanges, particularly in the central belt of the Franciscan, remains controversial. Deformation during subduction, gravity sliding, and deformation in response to triple-junction migration and associated strike-slip faulting, have all been proposed. Detailed geologic mapping in specific areas in the Coast Range can resolve these issues.

The interrelations of Franciscan emplacement, Klamath-Sierran interaction, and juxtaposed unmetamorphosed Coast Range ophiolite and coeval metamorphosed Nevadan ophiolites are all represented in the region centered on the Klamath - Coast Range - Great Valley (Yolla Bolly) junction in the northern Coast Ranges. Geologic mapping and geophysical studies here can better constrain events of the Nevadan and Coast Range orogenies and test emerging models of continental accretion.

Cenozoic basins. Unraveling the stratigraphy and history of the oil- and gas-bearing Cenozoic basins scattered through the Coast Ranges and in the Great Valley depends, ultimately, on the quality of biostratigraphic discrimination and correlation. Vast improvements in biostratigraphy, stimulated by deep-ocean drilling, have been made over the past 20 years, so onshore studies should be tied to offshore exploration of the continental shelf, where similar Cenozoic basins are located.

A wide range of investigations can be founded on the basic study of the stratigraphy, biostratigraphy, and sedimentology of the basins. These studies are not possible, however, unless structural relations within the basins are resolved by detailed geologic mapping. Integrating topical studies with geologic mapping should establish regional tectonic patterns, including correlation of offset basins by lateral faults. Thrust faults have been mapped locally in the Coast Ranges and San Joaquin Valley, but only recently are there indications that they may be of regional importance.

Refined stratigraphy and structural history will permit evaluation of petroleum formation and migration in the basins. Together with porosity studies, this research could lead to identifying new oil and gas resources.

The magnitude of lateral offset across the San Andreas fault was originally demonstrated through extensive geologic mapping and correlating Cenozoic rocks. These correlations should be re-examined by detailed geologic mapping and biostratigrapic studies, and alternative correlations tested.

Klamath Mountains. Geologic mapping and related studies indicate that upper Paleozoic volcanic rocks of the northern Sierra Nevada and eastern Klamath Mountains may not be parts of the same volcanic-arc sequence but may represent separate allochthonous sequences tectonically juxtaposed during the Permo-Triassic Sonoman orogeny. Detailed mapping in each area is needed to determine stratigraphy, distal and proximal facies, ages of rocks, periods of volcanic quiesence, and nature of nonvolcanic deposits. In addition, detailed geochemical-petrographic studies are needed to characterize volcanic suites and to determine volcanic/magmatic evolution of volcanic assemblages in the respective areas to establish the tectonics of "Sonomia". Either it is a collage of relatively small terranes or a mini-continent-sized fragment. Either case has major implications for Permo-Triassic paleogeography, tectonism, and the extent of the east Shasta copper belt.

Interpretation of recent geologic maps suggests that the Klamath Mountains - Oregon Coast Range are "decoupled" from the Sierra Nevada by the Battle Creek fault zone. Facies analysis of Cretaceous and lower Tertiary rocks on opposite sides of the Battle Creek zone likely will determine offset(?) stratigraphy, possible shorelines, possible paleochannels, biozones, and other features for testing this hypothesis. Paleomagnetic sampling north and south of the Battle Creek fault would assist in interpreting the relationships. Detailed magnetic and gravity surveys would determine if basement trends match across the fault, and seismic reflection profiles would help determine the dip and continuity of the fault zone at depth. This information would document and characterize a major Tertiary tectonic boundary within the North American plate between a northern "province" of clockwise rotation and shear and a southern "province" of compression and right lateral slip.

Late Cenozoic deformation. Much of the present topography of the Coast Ranges apparently formed by faulting, uplift, and subsidence during the past two million years or so. Marine Pliocene strata cap ridge crests 600 m above sea level in the northern Coast Ranges, for example, and deformed fluvial and lacustrine deposits of Pliocene and Quaternary age border such topographic lows as the San Joaquin and Santa Clara Valleys. Recent improvements in our ability to date these deposits, particularly through tephra chronology, biostratigraphy, and soil stratigraphy, have established the opportunity to learn a great deal about the recent deformational history of the region and its relation to detailed fault histories, broader tectonic patterns, changes in the pattern of drainage systems, and the evolution of the landscape. These, in turn, are critical to evaluation of earthquake and landslide hazards.

Detailed geologic mapping of selected areas of young deposits is needed to establish their precise distribution, stratigraphy, and structural history. Associated petrologic and sedimentologic study can address questions of provenance, transport, and depositional environments. Such work in the San Joaquin Valley, combined with newly developed soil stratigraphic technique, has demonstrated major Pliocene and Quaternary uplift of the eastern Diablo Range, led to an important new hypothesis that ties major alluviation events to the drying phase of climatic variation, and established a stratigraphy that can be carried west into the Coast Ranges.

Detailed geologic mapping is needed to establish equally detailed correlations of young strata across the San Andreas and other major faults to aid evaluation of earthquake hazards. The mapping will provide a framework to establish associations between uplift, erosional downcutting, and landsliding to aid evaluation of the hazards posed by the many large landslides in the Coast Range landscape.

San Francisco Bay region. The San Francisco Bay region, which includes Oakland, San Jose, and "Silicon Valley," encompasses the central fifth of the Coast Ranges and supports nearly a third of the 23 million people in California. Its varied geology, involving 350 mapped geologic units, represents many important geologic elements of the Coast Ranges. Preparing a modern geologic map of the region at a scale of 1:100,000 will provide a foundation to serve as a basis to make ever increasing numbers of land-use decisions, including those involving engineering, resources, and hazards evaluation.

Preliminary geologic maps that were compiled at 1:62,500 scale in the early 1970's, define many important structural and stratigraphic problems that now require detailed geologic mapping in selected areas. Extensive aeromagnetic and gravity coverage and some seismic refraction profiling already exist and await analysis within the context of a modern geologic map.

In addition to land-use decisions, a bay-region map would aid work on fundamental geologic issues previously described. It would tie directly to currently active work offshore of central California. It also would provide supporting information for ongoing landslide and regolith studies, work on ground water and toxic wastes, and evaluation of site studies for engineering construction. The map would provide a needed modern geologic base for the most densely instrumented seismic area in the country.

A3. Southern California

General Geology

The Peninsular Ranges and Sierra Nevada form a backbone extending southward from northern California. Sculpted on west-tilted crustal blocks, these ranges rise gradually eastward from the Southern California's coastal plain and Central Valley, and drop precipitously into the Salton trough and the Great Basin. The northwestern trend of this asymmetric spine is broken in Southern California by the west-trending Transverse Ranges and by the Mojave Desert's west-pointing wedge of alluvial basins and isolated mountains. Earth history as recorded in the rocks of Southern California falls into five time intervals, each with its own style: the late Cenozoic, early Cenozoic, Mesozoic, Paleozoic and Late Proterozoic, and Middle and Early Proterozoic Eras. The events in each of these intervals was influenced by the geologic framework inherited from preceding eras.

Southern California's intensely faulted and folded rocks and frequent earthquakes are a result of interaction between the North American and Pacific plates, which has torn the continental crust into large, shifting blocks. The Peninsular Ranges block has moved northwestward as the crust has been extended in the Gulf of California and Salton trough. Caught between the Sierra Nevada and Peninsular Ranges blocks, the Transverse Ranges have been strongly uplifted and the Mojave Desert block highly faulted.

Reconstructing the older tectonic patterns that were distorted by the late Cenozoic strike-slip faults reveals a different style of deformation in

Southern California during the early Cenozoic. The Mojave Desert and Transverse Ranges appear to be part of a great slab of the North American continent that was thrust oceanward over sedimentary and volcanic rocks that had accumulated along the Mesozoic continental margin. This slab was tens of kilometers thick and the hot rocks near its base were intensely sheared during emplacement of the slab. The underlying sedimentary and volcanic rocks were metamorphosed as the temperature and pressure were increased by the overriding slab. The zone at the base of this slab, modified by folding and faulting prior to exhumation in the late Cenozoic, is currently the target of extensive gold exploration. The presence of this slab probably influenced the location of crustal blocks and their bounding faults during subsequent deformation.

During the Mesozoic Era, the Peninsular Ranges batholith invaded belts of Mesozoic sedimentary and volcanic rocks and, chiefly along their eastern margins, Paleozoic sedimentary and volcanic rocks. Mafic plutonic rocks are predominant in the western half of the batholith and felsic plutonic rocks more abundant in the eastern half. In the intervening Mojave Desert and Transverse Ranges, however, the plutonic rocks are mostly felsic and the country rocks they invade are chiefly Paleozoic and Proterozoic. Mesozoic country rocks are not abundant in the Mojave Desert and Transverse Ranges, probably in part because they were removed by subsequent early Cenozoic underthrusting and earlier by Mesozoic folds and thrust faults that accompanied the regional thermal disturbance culminating in the batholithic intrusion. During Mesozoic folding and thrusting, Proterozoic basement rocks were uplifted and most of the overlying Paleozoic and Mesozoic sedimentary rocks strongly metamorphosed.

Late in the Proterozoic Era, the continental crust of North America developed a serrated edge with great salients and reentrants along its western margin as it was rifted from a larger supercontinent. What is now Southern California was located on one of the salients. For the rest of the Proterozoic and throughout the Paleozoic, miogeoclinal and eugeoclinal sedimentary rocks accumulated on Proterozoic basement rocks. These strata were telescoped by subsequent Mesozoic folding and thrusting.

Rocks of Early and Middle Proterozoic age in Southern California have been uplifted to expose a cross-section of igneous and metamorphic rocks formed deep in the crust. By analogy, regional mapping of these layers offers insight into modern deep crustal structure and processes, providing a useful guide to interpreting seismic profiles.

Geologic Mapping Needs

To begin refining the poorly understood geologic framework summarized above, geologic mapping is needed in three key areas of Southern California: (1) along the eastern flank of the Peninsular Ranges, (2) along the southern flank of the Transverse Ranges, and (3) in the Mojave and Sonoran Deserts between Baker, California, and Yuma, Arizona. Because older geologic features appear to influence the location and development of younger features, these areas are chosen to clarify several critical elements of the regional geology.

Margin of the continent. The nature of the boundary of Paleozoic and Proterozoic rocks and the influence of that boundary on Mesozoic depositional trends, on emplacement and composition of the Mesozoic batholith, and on styles of Cenozoic deformation need to be studied by detailed geologic mapping in the Transverse and Peninsular Ranges. In Southern California, Paleozoic depositional trends appear to have been truncated prior to intrusion of Mesozoic plutonic rocks, but because the plutonic rocks apparently followed and obscured the feature responsible for that truncation, its nature is controversial. Detailed geologic mapping is needed to resolve whether the apparent truncation is due to cryptic Mesozoic or Paleozoic strike-slip faults or to changing depositional trends that wrap around the rifted salient of Proterozoic basement.

Batholith. Three dimensional compositional variations in the Mesozoic batholith, and the influence of these variations on crustal structure and on Cenozoic deformation require geologic mapping in all three areas. Applications include mineral resource exploration and assessment.

Vincent thrust. The number, position, direction, and displacement of the lower Cenozoic thrust faults that placed the Mojave Desert - Transverse Ranges continental slab over metamorphosed Mesozoic sedimentary and volcanic rocks (Pelona and Orocopia schist), and the influence of the slab geometry on development of contrasting styles of deformation in the late Cenozoic require mapping in the Transverse Ranges and nearby areas.

Detachment faults. The development and subsequent exhumation of late Cenozoic ductile deformation zones in the crystalline rocks of Southern California, and their connection with shallower brittle detachment faults, requires extensive detailed mapping in virtually all of Southern California. Gold deposits have recently been identified in and near detachment fault zones. The relation of detachment faulting to evolution of strike-slip faults such as the San Andreas requires study.

Youthful faulting. Late Cenozoic interaction of left- and right-lateral strike-slip faults, deformation and locking of strike-slip faults, and uplift and reverse faulting associated with the strike-slip faults require geologic mapping. Exploration for mineral resources and research related to seismic hazards in Southern California depend on understanding these faults and how they relate to the geologic framework, all of which are best developed by geologic mapping.

A4. Cascade Range

General Geology

The Cascade Range consists of episodically active volcanoes resting on a platform of older, eroded volcanic rocks. Like the rocks of the Pacific Northwest province, those of the Cascades resulted from subduction of the Pacific plate under the continent.

Parts of the northern Cascade Range consist of accreted crustal fragments. For example, the Paleozoic and Mesozoic rocks east of the Straight Creek fault, along the crest of the northern Cascades, have been highly metamorphosed. These rocks are accreted oceanic terranes like those west of the fault, which are relatively unmetamorphosed, indicating large vertical uplift along the Straight Creek fault in the relatively recent geologic past. The rocks east of the fault are so highly recrystallized that detailed mapping and special study will be needed to understand their history.

Magmas, generated as a result of subduction, erupted after the accretion of the basalt seamount chain. The Cascade volcanic arc has been very active during the last 40 m.y., and magma continues to erupt today in volcanoes such as Mount St. Helens.

Geologic Mapping Needs

Relation of Tertiary magmatism to east Pacific plate motions. Changes in subducting plate velocity and motion vectors may cause changes in magma generation that in turn are reflected in the amounts and kinds of magma intruded or extruded. These concepts need to be tested with the long and complex record of plutonic and volcanic activity in the Cascade arc. A recent detailed model of relative plate motions for the last 50 m.y. needs to be tested by careful mapping and study of the plutonic and volcanic stratigraphic history. In the Washington Cascades, a fairly complete Tertiary volcanic stratigraphy has been established, but parts such as the Chilliwack composite batholith and isolated downfaulted areas of Tertiary volcanic rocks require study. Geologic mapping at 1:100,000 scale in northern Washington is needed to establish the stratigraphic history of these rocks. The younger part of the Tertiary record, that of the Oligocene, Miocene, and Pliocene (38-2 Ma), needs to be improved considerably by 1:100,000-scale geologic mapping in south-central Washington with some detailed mapping at 1:62,500 scale.

Cenozoic strike-slip faulting in the Cascade arc. The Sumatran arc in the western Pacific Ocean is characterized by oblique subduction and major strike-slip faulting, and it may be a modern analog of the Tertiary Cascade arc, explaining the paleomagnetically determined rotations and northward translations in the Cascade forearc region. In this model, a north-south right-lateral strike-slip fault in the Cascade Range is a tectonic boundary accomodating the outboard rotations and translations. Such a fault should pass through the western Cascades of Washington, where present-day right-lateral slip has been documented by fault plane solutions along the St. Helens seismic zone. Geologic mapping is required to provide a basis for interpreting extensive trilateration, magnetotellurics, and seismic monitoring that is currently underway. Many other geophysical and topographic lineaments pass through this essentially unmapped area that separates rocks with shallow paleomagnetic inclinations on the west from normal rocks on the east. Basic 1:100,000-scale geologic mapping in the western Cascade Range of southern Washington would help determine whether or not a major, active strike-slip tectonic boundary exists in the region. It would also document the style of deformation and provide lithologic and structural contraints on geophysical modeling.

Volcanic evolution of the early Cascade arc. The area between Olympia, Washington and Portland, Oregon is one of two areas in the Pacific Northwest not covered by surficial material of the Puget-Willamette lowland, and thus stratigraphic relationships between the Paleogene marine forearc sequence of the Coast Range and early Cascade volcanic rocks can be determined. Widespread arc volcanic rocks of the Northcraft Formation and related sequences may be in excess of 40 Ma and record the earliest Cascade volcanism. Preliminary chemical analysis suggests that some of these rocks are similar to contemporaneous, high-titanium Goble and Tillamook forearc volcanics, which are not typical of subduction-related volcanism. These rocks need to be mapped at 1:62,500 scale, and regional stratigraphic and compositional correlations established (for example, their relation to the arc volcanics of the Clarno Formation of Oregon). The magmatic and tectonic implications of such unusual chemistries in the arc and the possibility of a relationship to major Eocene continental extension in the Pacific Northwest should be examined. It is necessary to understand the complete volcanic history of the Cascades in order to understand and predict future eruptions.

Late Quaternary eruptive histories of Cascade volcanoes. Public awe and fear of active volcanoes give special impetus to study of the processes and products of volcanism in the upper Cenozoic Cascade arc. Geologic mapping is vital to studies of active volcanoes in clarifying the extent, age, and genesis of volcanic materials such as the mudflows of Mount Rainier, the giant landslide near Mount Shasta, the pyroclastic flows and surges of Mount St. Helens, and the airfall tephra layers from Glacier Peak and Mount Mazama.

A5. Sierra Nevada

General Geology

The Sierra Nevada is an asymmetric mountain range extending half the length of eastern California, with a long, gentle western slope and a short steep eastern escarpment, the result of block faulting and differential uplift. Because the differential uplift, which is still going on, is greatest in the south, erosion has exposed progressively deeper levels of the crust southward, providing an opportunity to study vertical as well as lateral variations in mountain-building processes.

Most of the southern and central Sierra is composed of granitic rocks of the Sierra Nevada batholith, with smaller satellitic bodies of granite exposed in the north. The granitic rocks intrude Paleozoic and Mesozoic sedimentary and volcanic rocks that are now weakly to strongly metamorphosed and mildly to complexly deformed. Details on the origin and evolution of the metamorphic rocks are matters of continuing debate, but it is generally agreed that large belts of these rocks were accreted to the western margin of the continent over a long period of geologic time.

Superimposed on the granitic and metamorphic rocks in the northern third of the range are volcanic rocks that represent a southern extension of extinct Cascade Range volcanism. These volcanic rocks provide valuable temporal and compositional data on the changes in volcanism that resulted from evolving plate-boundary conditions along the continental margin. Furthermore, the ages of these volcanic rocks provide essential data on lateral and temporal variations in the rate of uplift of the Sierra Nevada.

Geologic Mapping Needs

Sierra Nevada batholith. Detailed geologic mapping has identified mid-level granitic bodies in the central part of the batholith and provided a valuable data base to establish the ages and environments of emplacement. Inferences on deep level igneous and metamorphic rocks in that region have come primarily from xenoliths included in volcanic rocks, gravity and magnetic data, and limited seismic refraction and reflection studies. Recent reconnaissance mapping at the southern end of the range has identified an extensive terrane of mafic igneous rocks and high-grade gneiss that may represent the root zone and metamorphic substrate of the batholith. Detailed mapping is needed at the southern end of the range to distinguish and characterize the possible "root-zone" rocks. The mapping should be supported by whole-rock and mineral chemistry, geochronologic work, and isotopic studies, all directed toward determining the level and environment of formation. This information and the geologic maps that establish the framework within which it is interpreted are basic data that can be applied to other batholithic areas, as well as providing information for studying ore-forming processes and for mineral deposits exploration.

Although the general distribution of relatively high-level granitic bodies of the batholith is now well known in the northern Sierra Nevada, additional detailed mapping is required to determine their internal structures, compositional variations, and the distribution and mineral compositions in their contact aureoles.

Studies should be directed toward a small-scale compilation map of the batholith designed to accompany a summary report detailing the lateral and vertical variations in the igneous rocks and the attendant conditions of their emplacement. Additional deep-seismic reflection and refraction studies should be dictated by detailed mapping of the batholith and framework metamorphic rocks.

North Sierra framework rocks. Metamorphic rocks in the northern Sierra Nevada are divided into two belts by the Melones fault zone, a major tectonic boundary separating rocks of the continental margin from possibly exotic terranes accreted to that margin in Jurassic time. East of the Melones fault zone, weakly metamorphosed but complexly deformed Paleozoic rocks record periods of major eastward thrusting in the middle Paleozoic and in the late Paleozoic or early Mesozoic. Debate continues about the exotic or North American origin of these transported Paleozoic rocks. If exotic, the number of terranes, distribution, structural history, and the distance they have traveled needs to be established. These questions can be answered only by detailed geologic mapping to determine the geologic histories of the suspect terranes. Mapping must be supported with whole-rock chemistry, geochronology, and paleontologic studies, particularly radiolarian and conodont analyses.

West of the Melones fault zone, Paleozoic and Mesozoic rocks--unlike those to the east and probably exotic to North America--form long, narrow belts separated by major faults of the Foothill fault system. The paleogeographic origin of these transported terranes is not known and their structural histories remain a matter of speculation. Detailed mapping is required to adequately define the terranes and the nature and histories of their bounding faults. Detailed gravity and magnetic studies and deep seismic reflection profiles are needed to provide constraints on deer structural configurations.

Although the Foothill fault system originated as a Mesozoic structural zone, limited surficial studies and sporadic earthquake activity along various faults within it indicate that strain is still being released along this ancient zone of dislocation. To adequately evaluate the potential earthquake hazards to large dams and other structures built and proposed within and west of the foothills, late Cenozoic deformation on the Foothill fault system should be determined by detailed mapping supported by geomorphic analysis, trenching, soil analysis, and geochronology.

Tertiary volcanic rocks. North of the central part of the range, Tertiary volcanic rocks form a progressively larger part of the Sierra Nevada until they completely bury the metamorphic and igneous rocks in the area of Lassen Peak. Although the gross distribution of the volcanic rocks has been known since the turn of the century, few modern studies, augmented by isotopic age determinations, have been made and little is known of the temporal, chemical, and spatial evolution of these volcanic rocks. According to the plate-tectonic paradigm, the volcanic rocks formed by oceanic crust of the Pacific plate being subducted or forcefully underthrust beneath the North American continent. When the continent overrode the Pacific Ocean spreading center, the tectonic configuration of the western continental margin changed from one of subduction and underthrusting of oceanic crust to one of non-subduction and lateral movement along the San Andreas fault system. This change in plate juncture theoretically calls for progressive northward cessation of volcanism in the Sierra Nevada as the San Andreas fault lengthens, an hypothesis that could be tested in detail by geologic mapping and geochronologic analyses. In addition, the Tertiary volcanic rocks provide the best means to determine the amount and rate of uplift of the Sierra Nevada block. Studies from the central Sierra Nevada have been successful in determining the parameters of uplift, and similar studies are needed in the northern Sierra Nevada.

Glacial deposits. The glacial chronology of the Sierra Nevada remains poorly known despite many attempts at relative and isotopic dating of moraines. The moraines, subject to complete removal or burial during succeeding glaciations, record only some of the major glaciations and little of the minor ones. Materials suitable for isotopic dating of the moraines are abundant compared with those in many other mountain ranges but have not, for example, allowed determination of whether the penultimate major Sierra Nevada glaciation occurred during or before the Wisconsin.

During the past 30 years, mapping in the San Joaquin Valley by geologists and soil scientists has revealed a glacial-outwash stratigraphy that seems far more complete and suitable for dating than glacial deposits in the mountains. Further mapping, complemented with drilling, could refine that stratigraphy for application not only as a proxy record of Sierra Nevada glaciation but also as calibration for the dating of alluvium by means of soil-profile development.

Mineral resources. The Sierra Nevada has been a major source of minerals since the discovery of gold in 1848. At the present time this region is the source of large quantities of sand and gravel, crushed stone, limestone and limestone products including cement; substantial amounts of asbestos, barite, other industrial minerals, and tungsten; and smaller amounts of gold, silver, copper, zinc, and molybdenum. The Sierra will continue to be an important source of minerals, particularly as higher grade deposits elsewhere become exhausted.

The western Sierra Nevada foothill belt has been the source of most of the Sierran mineral-resource production. Presently this region is part of the fastest growing area in California and land-use decisions have become critical, particularly because of renewed interest in gold mining along the Mother Lode. The California Division of Mines and Geology has initiated mineral-land classification in this region in response to the California Surface Mining and Reclamation Act of 1975. New geologic mapping would provide a firmer foundation for these studies and subsequent land-use decisions, including those that could preclude mining.

B. BASIN AND RANGE - ROCKY MOUNTAINS

B1. Columbia Plateau/Snake River Plain/Modoc Plateau

General Geology

About 200,000 km^2 of the Columbia Plateau is covered by flood basalt of the Columbia River Basalt Group, erupted between 17 and 6 Ma, with more than 95 percent coming from about 17 to 14 Ma. Single flows have a volume between less than 1 km^3 to more than 700 km^3, perhaps averaging 10-30 km^3. All known vents are in the eastern one-half to two-thirds of the province. Single vent systems are linear, north-northwest trending, and dike-fed. Some flows moved long distances from their vents; the farthest known advance is about 500 km from north-central Idaho to the Pacific Ocean. The flows built a relatively featureless plain or plateau with no known shield volcanoes. The basalt was, however, slowly deforming as it accumulated, and the results of that deformation today are the roughly east-striking anticlines and synclines of the western plateau, the Blue Mountains uplift in the southeastern part of the plateau, and the general saucer shape of the plateau with its downdropped low point in the Pasco Basin on the Hanford nuclear reservation. After the basalt was emplaced, north-northwest-, northwest-, and locally northeast-striking strike-slip faults developed in the western part of the area, apparently part of a distributed right-lateral and subsidiary left-lateral shear zone. Available evidence suggests that no one fault has large displacement, but little presently is known about the faults.

Pre-basalt exposures in several mountains of central and eastern Oregon and western Idaho contain a record of late Paleozoic to Mesozoic sedimentation, and Mesozoic intrusion, metamorphism, and deformation. Many of these rocks belong to one or more terranes that were juxtaposed with the western Idaho batholith during late Mesozoic time.

The Snake River Plain is a poorly-known structural and depositional trough, about 50 to 100 km wide, that extends for a distance of about 650 km across southern Idaho. The western half of the plain formed initially as a graben during Columbia River volcanism about 17-14 Ma, and is filled by basaltic lava flows and terrestrial sediments. Bounding faults form the margins of the western plain and geophysical evidence suggests that flows and sediments here filled a fault-block depression. The western plain apparently was the locus of sporadic eruptions of silicic volcanic rocks.

The eastern Snake River Plain is also a structural and depositional basin, but its origin is poorly understood. Bounding faults have not been observed and geophysical evidence suggests that basin-range structures extend at least part way into the province. Current hypotheses suggest that the eastern plain represents the track of a northeast-trending crustal melting process that migrated from near the southwestern corner of Idaho to the Yellowstone National Park area from about 15 Ma to the present. The eastern plain is a bimodal rhyolite-basalt volcanic province, with silicic volcanic centers (calderas) that now lie mostly buried by younger basaltic flows. Directional structures in silicic ash-flow sheets along the margins of the eastern plain indicate caldera sources along the plain axis. Younger basaltic volcanism is concentrated along fissure-controlled vents aligned parallel to basin-range structures at the margins of the eastern plain. These structures are generally perpendicular to the axis of the eastern Snake River Plain. Both silicic and basaltic volcanism of the eastern plain is mainly Neogene at the southwestern end and Quaternary at the northeastern end.

The Modoc Plateau, mostly in northern California east of the Cascade Range, consists of several faulted and gently tilted depositional basins containing fluvial and lacustrine deposits interlayered with lava flows. The basins are bounded and cut by sets of north- and northwest-striking faults having dominantly normal displacements that mark a transitional zone between the extensional tectonic regime of the Great Basin to the east and the convergent and transform-fault regimes to the west.

Geologic Mapping Needs

Columbia River Basalt Group. Reconnaissance 1:250,000-scale geologic maps exist for most of the Columbia Plateau, but regional geologic problems require large areas to be mapped at a scale of 1:100,000 or larger. These problems relate to flow distribution, paleogeography, and synvolcanic warping.

During the last 25 years, the basalt has been divided into a number of formations and members on the basis of lithology, chemistry, magnetic polarity, and general stratigraphic context. To use this stratigraphy effectively, future geologic mapping will require numerous chemical analyses (several tens of analyses per 15′ quadrangle) and extensive use of portable fluxgate magnetometers.

The Washington side of the Columbia Gorge between White Salmon and Cape Horn has been studied only in reconnaissance and contains large faults and folds of west-southwest strike and possibly north-striking normal faults, but these structures are poorly understood. This area needs to be mapped at a scale of 1:24,000 or 1:48,000 to better define these structures and their context with the formation of the Cascades, which trend almost perpendicular to the largest structures. Rocks in the area include the Wanapum and Grande Ronde Basalts and lower Tertiary volcanic and volcaniclastic rocks; the Wanapum and Grande Ronde would serve as stratigraphic markers and timelines for the mapping.

The southeastern quarter of the Pendleton 2^{o} sheet, particularly south of Interstate 84 and east of 118^{o} 30´, contains the most complex stratigraphy on the plateau. Relations are complex, both magnetically and chemically, and there may be many local vents that are currently unrecognized. Mapping at 1:24,000 scale is needed here and in the southwestern part of the Pendleton sheet to unravel relations between the Grande Ronde and Picture Gorge Basalts. The two formations do not appear to be interbedded here as elsewhere. Refinement of the contact relations between the two units is needed to determine if large volumes of different magmas coexisted.

Mesozoic emplacement of terranes. Pre-Cenozoic rocks of the greater eastern Oregon region require detailed mapping to determine their stratigraphic affinities and the complex history of Mesozoic deformation and plutonism. Granitoids may represent a part of the Cordilleran magmatic arc, providing a vital link between the Sierran and Idaho batholiths. Virtually all of the scattered exposures of these rocks in central and eastern Oregon and southwestern Idaho require study.

Flood deposits from Pleistocene Lake Missoula. Flood deposits covering parts of the eastern Columbia Plateau need to be remapped in view of the recent discovery that the Lake Missoula floods were many (about 100 in the late Wisconsin alone), periodic (at intervals of 1-50 years), and actualistic (analogous to modern floods from certain lakes in Iceland, Norway, British Columbia, and Alaska). Previous mappers presupposed one or a few late Wisconsin floods, and were unaware that tens of latest Wisconsin floods were much smaller than earlier late Wisconsin floods. Many of the classic features of the Channeled Scabland--giant current ripples, pendant bars, and plunge pools--may have been produced by these small young floods, or they may have had a composite origin. New mapping could segregate such features by the age and magnitude of flooding.

Snake River Plain. During the last 15 years, 1:24,000-scale mapping has been completed for most of the Snake River Plain, but little of this mapping as been compiled or published at regional scales. Existing map and field data warrant compilation and publication of 1:250,000-scale maps. Additional regional radiometric and magnetic studies may be necessary to complete stratigraphic correlations between local and regional packages of surface, basaltic flows. The 1:250,000-scale geologic maps would increase understanding of the geologic history, tectonic evolution, and regional geologic framework of an important part of the Cordillera.

Late Cenozoic history of the north Modoc Plateau. Well-bedded diatomite in stratigraphically similar sections in the basins between fault blocks in the northern Modoc Plateau suggest the previous existence of broad alluvial plains and lake basins that have been faulted and tilted within the last 3-4 m.y. Furthermore, chaotic drainage systems attest to geologically recent changes in base levels due to tectonic or volcanic damming. The sedimentary deposits contain numerous tephra layers that provide an opportunity for regional correlation and an understanding of the late Cenozoic depositional and tectonic history of this area. A recently-drilled 330-m-deep core at Tule Lake that penetrated to 3.4 Ma strata provides a stratigraphic reference section and age control.

Systematic mapping, correlation, and geomorphic analysis of these rocks on a large scale (1:24,000), combined with isotopic age control and tephra correlation, are needed to unravel the stratigraphic, tectonic, and drainage history of this region. This regional study could be integrated with mapping and subsurface geophysical work in the Medicine Lake, Shasta, and Lassen areas.

B2. Basin and Range

General Geology

The Basin and Range is characterized by a series of discontinuous mountain ranges and sedimentary basins covering most of Nevada and parts of east-central California and western Utah. It is a region of active faulting, earthquakes, and volcanism, resulting from extension of the crust in response to crustal plate interactions along the western margin of North America. The extension has produced tilted and rotated mountain blocks. The tilted blocks, the high parts of which form the ranges, are partly buried by their own erosional debris and by volcanic rocks, which erupted in conjunction with extension of the crust. The extensional processes that presently characterize the Basin and Range have operated at varying rates in the region for approximately the past 40 m.y.

The extensional structures fragment rocks that record a long and complex pre-Tertiary history for the Basin and Range region. From Late Proterozoic to Devonian time, cratonal miogeoclinal and eugeoclinal sedimentary rocks were deposited on a slowly subsiding Archean and Proterozoic continental shelf. A poorly understood mountain building event (Antler orogeny) affected the western shelf edge at the end of the Devonian. During this event, a wedge of deep ocean-basin sediments was scraped off its original foundation and thrust eastward over the shallower outer continental shelf. The emplacement of this wedge created an emergent highland along the western continental shelf and a foreland basin to the east. As this highland was eroded, the debris was deposited on the continental shelf, which resumed its state of slow subsidence and sedimentation for another 100 m.y.

In the Late Permian, a volcanic archipelago formed along western North America in response to subduction of the Pacific crust beneath the continent, At first the volcanic arc was discontinuous and associated deformation of the continental margin was localized, but during much of the Mesozoic a belt of volcanic, plutonic, and metamorphic rocks and deformed rocks evolved that affected the entire continental margin of western North America. During this period, the margin was transformed into an impressive mountain belt, similar in size, proportion, and origin to the present-day Andes of South America. It was this mountain edifice that was fragmented during the past 60 m.y. of crustal extension and now forms the shattered mountain blocks of the Basin and Range region. These blocks are now spread over an area at least twice the width of the original pre-extensional terrain.

Geologic Mapping Needs

Continental shelf terrane. The ancient western continental margin of North America is preserved in fragments distributed across Nevada, western Arizona, and eastern California. Reconstructing the original geometry and history of the ancient continental margin by detailed geologic mapping in selected parts of this region is important for mineral and energy resource evaluation as well as for resolution of fundamental scientific questions such as truncation of the Paleozoic miogeocline.

Carbonate rocks deposited on the ancient continental shelf of North America now form the principal groundwater bearing units in the deep hydrologic systems of the Basin and Range. Such rocks are widespread in eastern and southern Nevada, Utah, and the Death Valley area. The general geologic framework of the carbonate terrane is known from geologic mapping done in the 1950's and 1960's. Detailed 1:24,000-scale mapping in areas of potential water-resource development is necessary to understand the relationship of groundwater reservoirs to variations in rock type. Intermediate-scale mapping (1:100,000) is needed to evaluate flow within and between groundwater basins. Additionally, geologic mapping in the carbonate terrane will contribute to our basic understanding of the evolution of passive continental margins.

The geology of the transition zone between the ancient outer continental shelf and the ocean basin, which is represented by rocks in the eastern Sierra Nevada and western Basin and Range, is poorly known. Recent applications of new paleontologic techniques to geologic mapping in this area have demonstrated geology more complex than interpreted from the previous generation of mapping. The new techniques provide tools necessary to unravel the complex geology by detailed geologic mapping (1:24,000 scale) and synthesis (1:100,000 scale).

The wedge of ocean-floor rocks emplaced over the western part of the continental shelf at about 350 Ma is currently a source for strata-bound mineral deposits such as barite, massive sulfides, and some gold. Detailed mapping of the ancient ocean-floor terrane (1:24,000 scale) using modern paleontology, coupled with a survey of organic geochemistry, will provide a basis for future mineral exploration. In addition to primary ore deposits, the ocean-floor rocks are the source for secondary ore deposits that migrated during later geologic events. To understand the processes that controlled the formation of these deposits, the mechanics for emplacement of the ocean-floor wedge over a continental margin must be understood. This emplacement is a fundamental problem of plate tectonics that can be addressed by further mapping of the oceanic rocks.

Some lead-zinc deposits and hydrocarbon resources in Nevada occur at the transition between black shales of the western continental shelf and carbonate rocks of the eastern continental shelf. Geologic mapping and geochemical studies are needed to understand the depositional relationships in the shelf terrane and the subsequent thermal and structural histories in order to explore for these mineral and energy resources.

Magmatic arc terrane. Parts of the volcanic arc that evolved between 250 and about 70 Ma occur in fragments extending over the entire Basin and Range. The anatomy of this arc is poorly understood, but because of its dissection by younger crustal extension, the Basin and Range provides an unique laboratory for studying the evolution of a volcanic arc. The relationship of arc magmatism and deformation to contemporaneous deformation in the petroleum-producing overthrust belt to the east; the time/space relationships between overthrusting, magmatism, and regional recrystallization within the volcanic arc; and the geometric and age relationships between the volcanic arc and the rocks on which it is built are all important problems that can be addressed by geologic mapping in the Basin and Range.

The volcanic arc provided a heat source for much of the mineralization in the Basin and Range, and many of the arc rocks contain ore deposits. Consequently, understanding the relations between mineralization and the evolution of the arc terrane by mapping, coupled with geochemical and geophysical studies, is fundamental to mineral exploration.

Crustal extension. The process of crustal extension is currently a major research focus by the geologic community. Some areas, such as the Death Valley area and several metamorphic core complexes, provide excellent opportunities for addressing some of the basic problems of crustal extension and should be a focus for future detailed geologic mapping. In addition, mapping in many other parts of the Basin and Range will elucidate the geometry and processes of extension. Approaches that are especially fruitful combine detailed geologic mapping to determine structures and Cenozoic stratigraphy with geochronology, paleontology, geochemical, and geophysical studies.

Active faulting, seismicity, and volcanism. As a result of continuing crustal extension, most of the Basin and Range is active with respect to faulting and seismicity, and parts of the region have experienced recent volcanism. For example, major earthquakes on the Dixie Valley - Fairview Peak faults and the Mount Tobin fault of northwestern Nevada and in central Idaho have occurred during the past 60 years, but little is known about their Holocene and Pleistocene history. Detailed mapping of fault zones could resolve slip rates for the past 250,000 years and be used as a rough predictive tool for seismic hazards.

The detail and amount of mapping of surficial deposits is inadequate for most of the Basin and Range. Using the new techniques for differentiating and dating Quaternary deposits that have developed in the last 10 years, a detailed stratigraphy for young sedimentary deposits and soils is needed as a basis for all mapping that addresses contemporary geologic problems, especially those related to earthquakes. Detailed (1:24,000 scale) mapping is needed in zones of seismicity to identify surface ruptures, to reveal patterns of spacial and temporal clustering of faults, and to form a basis for studies to determine recurrence intervals throughout the Basin and Range. Mapping in areas of recent volcanism (western and northern Basin and Range, southern Nevada), coupled with geophysical and geochemical studies, are needed to assess the hazards from future volcanism.

Groundwater recharge. Mapping of surficial deposits representing the last few million years, combined with soil, paleontology, and geochemical studies, can provide a basis for understanding past fluctuations in climate. Knowledge about past climates is fundamental to understanding recharge history of groundwater resources and to determining whether or not groundwater in the Basin and Range is a renewable resource in a time frame that will support further development in the region.

Land-use decisions. Because of the geologic environment, arid climate, closed groundwater systems, and sparse population, the Basin and Range is considered a favorable area for disposal of hazardous wastes, thus the proposal for a high-level nuclear-waste repository site in southern Nevada. Active crustal deformation and volcanism in the region, however, must be carefully evaluated because they pose potential hazards to safe waste isolation. Here the success of a program vital to the national interest is dependant on detailed geologic mapping to provide a basic geologic information source and a framework in which to interpret specialized studies associated with site evaluation. Much of the geologic mapping already has been done, but more is needed to accurately evaluate the potential for faulting and volcanism near the site.

A thorough understanding of the neotectonic history of the Nevada Test Site is needed. Detailed mapping and study of neotectonic features in the Test Site region are pivotal elements in the evaluation of the local tectonic setting and will provide valuable calibration for scarp-degradation studies in moderately arid regions.

B3. Northern Rocky Mountains Thrust Belt

General Geology

The Cordilleran overthrust belt of the U.S. extends from the Canadian border to southern Nevada, and ranges from 240 to 360 km wide. Across this belt, continental crust has been telescoped a few kilometers to hundreds of kilometers from west to east. The history of telescoping has been long and complex, and the resulting geometry of the deformed rocks reflects this complexity. Subsequent regional extension along listric normal faults in places has further complicated the configuration of the rocks. Major deposits of phosphate, coal, copper, lead, zinc, silver, and gold occur over the length of the thrust belt. Petroleum potential is high in the eastern part of the overthrust belt and in the foreland basins just to the east. Segments of the belt coincide with the active intermountain seismic belt of the Rocky Mountain States. Resolving the structure and history of the overthrust belt is thus essential to understand the exploration and assessment of resources and the geologic hazards.

Approximately 80 percent of the foreland part of the overthrust belt is covered by modern small-scale (1:250,000) geologic maps. Less than 60 percent is covered by large and intermediate scale (1:24,000 to 1:100,000) geologic maps. All of the foreland must be mapped at small scale, and most should be mapped at large scale in order to analyze the history, structure, resources, and geologic hazards of this vast complex terrane.

The hinterland or western part of the thrust belt lies closer to the contemporaneous magmatic arc and includes metamorphic core complexes, many of which are believed to have formed in part when the thrust sheets were transported eastward. This part of the thrust belt is understood far less because of greater complexities and less complete mapping. A better knowledge is critical to genetic interpretations of thrusting and to formulating exploration strategies for resources, mainly metallic. The hinterland was complicated especially by overprinting of extensional deformation during formation of the Basin and Range province.

The Belt basin of western Montana, northern Idaho, and eastern Washington consists of well-preserved Proterozoic rocks as much as 17,000 m thick. The original basin was substantially foreshortened during Cretaceous time by thrust faults, and an extensive system of strike-slip faults may have been active as early as Middle Proterozoic and was intermittently active into the Tertiary. The Belt basin has high mineral potential, consisting mostly of stratabound Ag-Cu and Pb-Zn deposits as well as other important vein, porphyry, and skarn mineral deposits. Oil and gas potential of Paleozoic and Mesozoic rocks under the thrust plates of Proterozoic rocks is currently being explored by several companies.

Precambrian to middle Tertiary plutonic rocks, all representing a wide compositional range, are abundant in the Rocky Mountain region, including the Northern Rocky Mountains Thrust Belt province. These include the Idaho batholith in northern and central Idaho and western Montana, and the Boulder batholith in southwestern Montana. Lower Tertiary volcanic fields and numerous plutons that may have been associated with other fields now removed by erosion span large areas in southwestern Montana and adjacent Idaho and Wyoming. Most of the major base metal and precious metal ore deposits and potentially economic geothermal systems of the western U.S. are in, or intimately associated with, igneous rocks.

Geologic Mapping Needs

Thrusting in north Montana, Idaho, and east Washington. In this area, small-scale mapping in progress must be completed in order to understand the stratigraphy, geometry and timing of thrust faulting, transcurrent faulting, and normal faulting across the entire Belt basin, thrust belt, and foreland basin. Concurrently during completion of this phase of mapping, a second phase of large-scale geologic mapping should be done in areas critical to understanding specific problems related to the geometry, timing, and mechanics of thrust faulting, associated resources, and geologic hazards. Detailed geologic mapping in the thrust belt will establish the geometry of these structures. Geologic mapping in thrust terranes such as this, closely supported by geophysical mapping and seismic-reflection surveys, will develop a geologic framework with reliable information on rocks and structures at depth. This data base can be augmented by, and tested with, rapidly growing subsurface information from petroleum exploration to further refine the structures at depth and to provide tools for accurate exploration and resource assessment.

Thrusting in southwest Montana and east-central Idaho. Just north of the Snake River Plain, mapping is required to understand regional thrust faults and igneous rocks. Some mapping should be done at 1:250,000 scale (Dubois and western Ashton 2^{o} sheets), but also at a larger scale in several relatively large areas. This mapping will not only define the geologic relations in zones of overlapping but markedly different ages of thrust faults, but it will accurately establish the stratigraphy of the thrust belt and tie it to the foreland basins to the east where exploration for petroleum is being focused. The Montana - central Idaho area also contains Archean blocks, the stratigraphy of which needs to established by geologic mapping.

East and north flanks of the Idaho batholith. In the Northern Rocky Mountains Thrust Belt, extensive geologic mapping is required on the eastern and northern flanks of the Idaho batholith to identify the continuity of thrust faults mapped to the north and southeast, to understand the relative timing of thrust faulting, igneous activity, and transcurrent faulting, and to discover the relation between older thrusts and younger extensional faults. The rocks in this region are not well known, partly because access in this rugged, isolated area is poor. Detailed study of the northern thrust belt and western parts of the central belt provides an opportunity to understand the relation between deformation and contemporaneous magmatic arcs, and this research may yield an understanding of the interaction between segments of the continent where thrust deformation has been dominant and adjacent segments that were transported horizontally hundreds of kilometers as accreted terranes on the western margin of the continent.

Belt basin. Research in the Belt basin during the last 25 years has involved mostly 1:250,000-scale geologic mapping and topical and localized studies of geochemistry, geophysics, stratigraphy, structural geology, and mineral deposits. The 1:250,000-scale geologic mapping has identified many geologic problems involving the origin and development of the basin, and these problems should now be addressed through a unified basin-analysis to relate evolution of the basin to the distribution and origin of mineral and fuel deposits. To provide a data base to accomplish the basin analysis, geologic mapping at 1:100,000 or larger scales is needed at many places in the basin. The mapping is necessary for stratigraphic analysis of the Belt formations, including study of measured stratigraphic sections, primary and secondary sedimentary structures, lithofacies studies, depositional environments, paleocurrents, composition and tectonic origin of source terranes, and structural restoration of formations. Stratigraphic analysis of lower parts of the Belt sequence is important because these units record the oldest sedimentation and have the greatest potential for stratabound Pb-Zn ore deposits. Stratigraphic analysis of upper parts (Missoula Group) of the sequence are important because they include the most widely distributed units; research on these rocks will give the greatest stratigraphic and structural control bearing on the over-all evolution of the basin. Geophysical studies, especially seismic reflection and refraction, gravity, and magnetics, should be integrated with the geologic mapping to refine third dimensional aspects of the basin.

Mesozoic-Tertiary magmatic-arc suites: The significance of widely distributed magmatic-arc rocks across the Cordilleran region, their inferred association with convergence along the western margin of the American plate, and their widespread disruption by concurrent, or immediately subsequent, extension are poorly understood and controversial. Some of these igneous rocks have not been mapped and many have not been mapped in a way to permit the petrogenetic studies needed to evaluate their orgin in terms of modern igneous concepts. These rocks host many of the richest ore deposits in the U.S.; additional large- and intermediate-scale mapping and related geologic studies will provide the basis for research on sources of ore-forming solutions and relations of mineralization to the magmatism and associated extensional structures. One area where information and geologic mapping is most needed is the Eocene magmatic rocks of the northern Rocky Mountains. The Challis volcanic field of Idaho and numerous isolated Challis-age fields, as well as plutons whose overlying volcanic ejecta have been removed by erosion, are in need of an integrated study. Geologic mapping of the Elk City 2^o quadrangle, for example, would establish a regional perspective of some of these fields.

Intermountain seismic belt. The intermountain seismic belt of the Northern and Central Rocky Mountain Thrust Belts is the second most seismically active belt in the conterminous U.S. after the San Andreas system. Most of the population of Utah and a significant part of the population of Idaho and Montana fall within it. The neotectonic setting of the northern part of this belt has not been studied, however, even though the two largest recent earthquakes in the continental United States occurred on faults within the belt: the 1983 M_s=7.3 Borah Peak, Idaho, earthquake and the 1957 M_s=7.5 Hebgen Lake, Montana, earthquake. Geologic mapping would provide a basis to determine the interactions between deformational processes active in the Basin and Range, Snake River Plain, and northern part of the thrust belt. Regional relationships of the fault system would be established by mapping the Bozeman 2^o quadrangle, which also covers the area in which the northern part of the Yellowstone Park earthquake swarm occurred. This quadrangle contains abundant Precambrian rocks, and preliminary evidence suggests that Cenozoic faults may be related to reactivated Precambrian structures.

The Borah Peak earthquake occurred along the Lost River fault of central Idaho. Detailed geologic mapping along the fault's 175-km length (and other similar faults in the region) would establish the location, length, and movement histories of individual segments. This mapping would provide a much needed geologic and tectonic framework for ongoing and future seismological studies.

Idaho batholith. Several important base and precious metal mining districts are in and around and genetically associated with the Idaho batholith, yet knowledge of this region is fragmentary. The batholith's origin, distribution of rock and chemical types, internal structure, and distribution of pendants are known only in a general way for the northern and southern parts of the batholith, and almost nothing is known for its central part. In addition, the relations of the batholith to accreted terranes along its western margin, to the foreland thrust belt, and to the intermountain seismic belt are largely conjectural. Parts of the batholith are seismically active, yet other parts cut by apparently young faults are essentially aseismic. Parts of the batholith have high heat flow, and areas in the central and southern parts are potential geothermal resource targets. Mapping of the batholith and adjacent areas may provide an explanation for these variations. In addition, roof pendants in the batholith must be mapped to correlate strata and thrust plates from one side to the other.

B4. Central Rocky Mountains Thrust Belt

General Geology

The Central Rocky Mountains Thrust Belt extends from the southeastern margin of the Snake River Plain southward through western Wyoming and southeastern Idaho into western Utah and southeastern Nevada. The general overthrust geology is similar to that of the Northern Rocky Mountains Thrust Belt province, described above. The thrusted rocks generally belong to the Sevier orogenic belt within which relatively thick miogeoclinal sequences of Proterozoic, Paleozoic, and Mesozoic strata were thrust eastward in late Mesozoic and early Tertiary time. The rocks of the province are greatly extended along Cenozoic normal and strike-slip faults, so the younger geology is similar to that of the Basin and Range province described above. Part of the area lies within the eastern Great Basin.

Geologic Mapping Needs

Thrusting in north Utah and northeast Nevada. Small-scale mapping (1:250,000) already underway should be completed in northern Utah and northeastern Nevada, the foreland and hinterland of the thrust belt. Major problems remain to be resolved in this area, such as the magnitude of overthrusting, structural complexity resulting from temporally overlapping thrust faults, and timing and geometry of overlapping thrust and low-angle normal faults. While completion of this initial phase of mapping will provide a framework to solve these problems, a second phase, comprising larger-scale geologic mapping, should be undertaken in areas critical to understanding specific problems related to the geometry, timing, and mechanics of thrust faulting, associated resources, and geologic hazards. The geometry and timing of thrust faults can be resolved more precisely if subsurface data are utilized to augment geologic mapping. The resulting 3-dimensional framework will be used to develop geometric and genetic reconstructions so as to understand the relations between faulting, folding, sedimentation, and the generation, migration, and entrapment of petroleum. Overlapping low-angle faults that originated partly during thrust faulting and in part during younger regional extension complicate the thrust belt; only detailed geologic mapping can resolve the relations and timing.

Wasatch front. The tectonically active Wasatch front, the subject of detailed studies to evaluate earthquake hazards associated with the intermountain seismic belt, is undergoing extension and associated young volcanism. Distributions of basaltic rocks, patterns of high-angle normal faults, and styles of apparent low-angle faults indicated by seismic profiling suggest that structures similar to the Tertiary detachments in Arizona may now be forming. Additional geologic mapping and geophysical studies are needed to understand the complex tectonic setting. Mapping of surficial deposits and soils will establish much-needed information on recurrence intervals of earthquakes in the area.

Delta-Nephi area. Large-scale mapping in the Nephi region of Utah is needed to define the role of salt tectonics during the Sevier deformation and in subsequent crustal extension. Seismic profiles, available in part from commercial sources, would help define the crustal architecture of this area. Detailed mapping in the area of the deep seismic reflection (COCORP) profile would provide basic information for petroleum resources, earthquake hazards, and engineering geology.

B5. Southern Rocky Mountains

General Geology

The Southern Rocky Mountains province consists largely of the province more generally known as the southern Basin and Range. Thus the geology of the province is similar to that already discussed above as the Basin and Range province. The northern part of the Southern Rocky Mountains province includes the Colorado Plateau - Basin and Range transition zone. Geophysical studies show that this physiographic transition reflects changes in the extending underlying crust. The crust in the Southern Rocky Mountains (Basin and Range), which has been extended, is thinner and consequently hotter than in the Plateau; the geophysical boundary between the crust of the Basin and Range and Colorado Plateau provinces coincides with the physiographic transition. The transitional zone between extended and normal crust is presently widening and has had a complex geologic history.

South of Lake Meade, in southern Nevada, the transition zone trends southeastward and crosses into a terrane that was uplifted during the late Mesozoic and eroded down to Precambrian gneiss and granite. These exposures of old crust afford opportunities to study the origin and history of the continental crust underlying much of the southwestern U.S. In Arizona, the transition zone separates the area on the south--characterized by igneous rocks and deformation of late Mesozoic and Cenozoic age--from that on the north that had only local igneous activity and was uplifted without accompanying internal deformation.

The transition zone is economically and culturally important. It contains some of the richest ore deposits in Arizona, including uranium occurrences with unknown potential and the well known copper deposits of the Cerbat Range, Bagdad, Jerome, Miami-Globe, and Clifton-Morenci districts. Yavapai County ranks highest amoung Arizona counties in gold production and is high in silver, copper, and other metals. Hot springs and wells occur in the Verde Valley, 70 km south of Flagstaff. Culturally the zone is already experiencing population pressure because the Phoenix urban area is growing rapidly. The transition zone forms a significant part of the Phoenix watershed. Geologic information is needed for intelligent development and management of important water and mineral resources.

Geologic Mapping Needs

Colorado Plateau transition zone in Arizona. The nature and development of the transition from stable craton of the Colorado Plateau southward into the Southern Rocky Mountains (Basin and Range) province, and associated precursor low-angle detachment faults, are fundamental problems in the structural evolution of the eastern Cordillera. The detachment faults are, at least in part, concurrent with widespread Tertiary volcanism and regional thermal anomalies. This problem, a current target for COCORP and other geophysical studies of the Pacific-Arizona Crustal Experiment (PACE), requires regional mapping at 1:100,000 scale, supplemented locally with more detailed mapping. Medium- to large-scale mapping along the COCORP line where it passes through the transition zone in west-central Arizona would provide a framework to interpret the deep reflection data.

Medium-scale mapping of Precambrian rocks in the transition zone should be accompanied by detailed geochronologic studies to define the history of crust formation in Early Proterozoic time and the extent of Middle Proterozoic plutonic activity. Mapping of much of this region is incomplete.

Detailed work is needed in the Southern Rocky Mountains to provide information to determine the distribution of upper Mesozoic igneous rocks that have mineral-resource potential. Large-scale mapping of areas containing metamorphic rocks of Early Proterozoic age are needed to define stratigraphic relations and alteration patterns associated with massive sulfide deposits.

Large-scale mapping combined with reflection seismic and gravity studies is needed to decipher the geometry and tectonic history of basins in the transition zone. These basins are large groundwater reservoirs.

Porphyry copper deposits. Major porphyry copper deposits are associated with the silicic volcanic and plutonic rocks of southern Arizona. Some of these intrusive and extrusive bodies are being recognized as Cretaceous in age. More geologic mapping of these rocks is needed to establish their relations with other upper Mesozoic - Tertiary magmatic-arc suites, as proposed above for the Northern Rocky Mountains Thrust Belt.

B6. Foreland Province

General Geology

The Foreland province consists of numerous mountain ranges in Wyoming, Colorado, northeastern Utah, and north-central New Mexico. Most of these ranges are cored by Precambrian rocks and are separated from each other and from adjoining basins by high-angle faults.

The Precambrian continental core underlies much of the western U.S. but projects through its covering of younger rocks in less than 10 percent of the area. Most of these Precambrian metamorphic and intrusive rocks are exposed in isolated mountainous uplifts of the Foreland province. These rocks are generally less understood than younger rocks due chiefly to their complex history of over 3 b.y.. A concept just beginning to be understood is that the oldest rocks of Wyoming and adjoining states, which are of Archean age, formed the framework for younger events. Thus Proterozoic sedimentary and volcanic rocks accumulated on this Archean basement and were subjected to multiple intrusive episodes, various types of structural or tectonic rearrangement, extensive metamorphic recrystallization and including remelting, and deposition of numerous hydrothermal ores.

Significant energy and water resources occur in structurally downwarped basins within the Foreland province. Basins east of the Rocky Mountain front include large downwarps such as the Williston, Denver, and Delaware basins that flank mountains on one side or abut eroded uplifts that may or may not have modern topographic relief. None of these basins on the Great Plains retains hydrographic form.

As the Rocky Mountains rose, the adjacent basins subsided, and many thousands of feet of sediments accumulated in them. Intertonguing deposits along the basin margins are now sites of possible oil and gas resources. Uplift and erosion of the mountains and basin margins gradually exposed the pre-basin rocks, which commonly are completely stripped of sedimentary strata.

Faulted basin margins of the Foreland province have received increased attention by the oil industry because of their favorable oil and gas possibilities. Detailed geologic mapping along the basin margins is needed to verify their geometry and history. Preliminary work indicates that many large marginal faults, previously thought to be steep or nearly vertical, are moderate- to low-angle thrust faults that override the basin margins. These structures are known to be oil and gas traps at other locations. The Denver Basin, which has an estimated ultimate production of nearly 500 million barrels of oil and more than 2 trillion cubic feet of natural gas, contains some of the greatest undeveloped petroleum resources in the Nation. The Powder River, Wind River, Piceance, Uinta, and San Juan basins are comparable. In addition, three basins, the Piceance, Uinta, and greater Green River, contain nearly all the potentially economic oil shale deposits in the nation and some of the largest known deposits of natural soda and related evaporite minerals.

The Colorado mineral belt is a long, narrow zone of base and precious metal deposits extending northeast from the San Juan volcanic field to the eastern margin of the Front Range near Boulder. The belt includes such famous mining districts as Leadville, Climax, Breckenridge, Idaho Springs, and Central City. These districts lie within igneous bodies or their associated vein deposits. The plutonic rocks of the Colorado mineral belt are of diverse ages, compositions, sizes, and structural settings; combinations of these attributes control the ore deposits.

Geologic Mapping Needs

Precambrian terranes. To understand the complexities of the Precambrian core rocks of the Foreland province, the distribution and interrelations of the various rock units must be defined by geologic mapping. Mapping is needed to site any deep research holes into Precambrian rocks that might be scheduled by the Deep Observation and Sampling of the Earth's Crust (DOSEC) consortium.

Surface geologic mapping and petrographic, geochemical, and geochronological studies of the Precambrian core rocks will provide a framework for studies on magma mixing and differentiation processes, such as (1) stratified ultramafic plutons like the Stillwater complex; (2) the influence of crustal composition on igneous magma melted from, or passed through, it; and (3) the effect of one magma on later magmas. Studies such as these are important to ongoing mineral resource programs.

Mapping in the Foreland province will provide information on ancient Earth conditions and processes. Moreover, the Precambrian rocks now exposed include compositions and structures representative of the deepest crust. Sequential earth processes such as the accumulation of the atmosphere and the oceans may have caused unique deposits at certain times such as banded iron formations that can be studied only in older rocks.

Detailed geologic mapping of east-trending transects in the following three areas is needed for mineral-resource exploration and by defense agencies for communication and missile deployment: (1) Bighorn, Beartooth, and Tobacco

Root Mountains region; (2) Hartville Uplift, central and northern Laramie Mountains, and south-central Wind River Mountains; and (3) Proterozoic terranes from southeastern Wyoming to the northern Park Range and from the Front Range to the Sawatch Range, both in Colorado. Rocks in these regions should be compared with those exposed in the Black Hills and with Proterozoic rocks from deep drill holes east or southeast of the Black Hills. Precambrian rocks of the northern Wind River and Owl Creek Mountains form a short transect that links (1) and (2) above. Study of the eastern Owl Creek Mountains could be supplemented by investigation of cores of Precambrian rock from petroleum exploration in the region.

Green River and Great Divide Basins. Detailed geologic mapping is needed to support basin analysis studies of basins in the Foreland province. Detailed mapping of basin margins and foreland uplifts will define times of deformation, facies variations, and environments of deposition. These data and the studies based on them bear directly on the exploration and development of basin resources. Geophysical data, especially seismic profiling where available, should be intergrated with the mapping of basin margins.

The Green River and Great Divide Basins remain poorly understood. Detailed mapping will provide information on the style, magnitude, and chronology of movements on bounding structures such as the north flank fault of the Uinta Mountains and the Wind River thrust and on such intrabasin structures such as the Church Buttes - Moxa arch. Mapping will improve our knowledge about energy and mineral resources, which include abundant oil and gas, coal, trona, and soda. This mapping should be supplemented by stratigraphic investigations, borehole geophysical logs, and regional geophysical data to produce small-scale basin-wide stratigraphic and structural maps.

Colorado mineral belt. Systematic study of ages, composition, volumes, and structural setting of plutonic rocks in the Colorado mineral belt, based on detailed field mapping, could help to define which classes of plutons are ore-bearing and merit intensive exploration.

B7. Colorado Plateau

General Geology

The Colorado Plateau is a stable area of thick crust characterized on the surface by mostly flat-lying sedimentary rocks. The province as defined here includes many of the transition zones between it and adjacent provinces, such as the San Juan area on the southeastern side, the Mogollon area on the south, and the High Plateaus on the west. These transition areas contain numerous Tertiary volcanic rocks and structures that are similar to, but on a smaller scale and degree of development than, those of adjacent provinces.

Geologic Mapping Needs

Some of the igneous rocks of the Colorado Plateau have not been mapped in terms of current concepts of igneous processes, and in only a few places has sufficient mapping control been generated to permit the petrogenetic studies needed to evaluate modes of magma genesis. The rocks host many of the richest ore deposits in the U.S. Additional large- and intermediate- scale mapping and related geologic studies should help constrain sources of ore-forming solutions and relations of mineralization to magmatism and associated extensional structures.

San Juan volcanic field. Several richly mineralized caldera systems exist within the San Juan volcanic field of Colorado. These include the

Silverton and Bonanza calderas, for which no geologic mapping has been completed for 50 to 80 years; and the central San Juan caldera cluster, a leading site for proposed scientific deep drilling into a mineral deposit, and for which 1:24,000-scale topographic bases have just become available.

High Plateaus. The history of faulting and deformation along the transition between the stable Colorado Plateau province and extensional Basin and Range province is not well understood mainly because until recently there has been little focused study of the problem. Geologic mapping from the southern terminus of the Wasatch fault zone (near Gunnison, Utah) south to the Grand Wash fault of northwestern Arizona is needed to resolve the type, times, and amounts of displacement along the transition zone. The mapping should tie into the recent mapping of the volcanic rocks of the Marysvale field in the central High Plateaus. Some data suggest that faults in this region have a strong lateral component of movement--a concept not widely applied in the extensional regime of the Basin and Range.

Cedar City area. The area near Cedar City, Utah, is included within the Colorado Plateau but more correctly belongs in the Great Basin. Here the intermountain seismic belt swings sharply westward from the Wasatch front. This west-trending part of the intermountain seismic belt marks a major crustal boundary, across which gravity, magnetics, heat flow, crustal P-wave velocities, and depth to the M-discontinuity change from north to south. Mineral deposits are sparse south of the zone, old Precambrian rocks are absent north of it, and Phanerozic rocks thicken north of it. The area is near the southern end of the Sevier thrust belt. The Virgin River oil field in Sevier structures is one of the few oil fields in the Great Basin. The belt here localizes east-striking faults and igneous centers and contains several major mineral deposits. Despite the importance of this area, its geology is poorly known. The area includes, to the west, the Bull Valley Mountains, a largely unknown volcanic field containing areas of altered and mineralized rocks that are largely unexplored. Farther west, mapping is needed in the Caliente depression of Nevada, a caldera complex that was the apparent source for many of the Miocene regional ash-flow sheets of southwestern Utah and southeastern Nevada. Large-scale mapping is required throughout the larger Cedar City area, and 1:250,000-scale mapping of the Cedar City and Caliente 2^{o} quadrangles should also be done.

B8. Rio Grande Rift

General Geology

The Rio Grande Rift, extending from southern Colorado into Mexico, is a major intracontinental rift. It has been the site of several contrasting phases of extension and volcanism that are not constrained regionally. Like the Basin and Range, the Rio Grande Rift is the result of an extensional tectonic regime expressed by high- and low-angle brittle normal faults at shallow levels in the crust and by ductile flow in deeper hotter levels. Such extension both causes and can result from rise of magma through the crust, leading to volcanic activity at the surface. Faulting and volcanism are associated with some of the world's most destructive earthquakes, as well as with geothermal energy resources and with sources of base- and precious-metal ore deposits. In addition, such regimes create structural basins that become traps for petroleum and water resources. An intracontinental rift such as the Rio Grande Rift marks sites of slower linear extension that have not completely thinned and separated the crustal plate.

Geologic Mapping Needs

Colorado - New Mexico State line. Mapping of a transect across the Rio Grande Rift near the Colorado - New Mexico boundary, probably at 1:100,000 scale, would provide control for a sector that contains abundant igneous rocks and large-scale extensional structures. Major molybdenum and other metallic ore deposits are present within the area covered by the transect. In addition, the current relative seismic quiescence should be evaluated because geologic evidence of major fault movements in the Holocene suggest the potential for large earthquakes.

Neotectonics. Investigations of young deformation at the northern and southern margins of the Rio Grande Rift would complete a reconnaissance study of neotectonics in the Rio Grande Rift that is currently underway.

The San Andres fault system extends 180 km along the eastern flank of the San Andres, Organ, and Franklin Mountains of southern New Mexico and western Texas. This fault is noteworthy for several reasons. First, two major Air Force bases and White Sands Missile Range are adjacent to the fault, and El Paso (population 500,000) lies astride it. Second, preliminary reconnaissance work indicates that the fault has a history of recurrent-segmented movement from the middle Pleistocene to the Holocene. Finally, due to military restrictions, few modern geologic maps are available. National and scientific interests would be served by new detailed mapping.

C. GREAT PLAINS - MIDCONTINENT

C1 and C2. Northern and Southern Great Plains

General Geology

More than one-sixth of the area and one-fifth of the population of the United States are in the Great Plains (fig. 3). Geologic mapping of this vast region is needed to resolve geologic problems concerned with water, mineral, and energy resources and management of agricultural, grazing, and urban lands. The Northern Great Plains and Southern Great Plains provinces share geologic, resource, and land-use problems, and they are described together.

The Great Plains is directly underlain by flat-lying to gently dipping rocks and sediments of Cenozoic age. The oldest of these rocks, of Paleocene and Eocene age, are preserved in local basins in North Dakota and eastern Montana and are host to great reserves of minable coal and some hydrocarbons. Rocks of Oligocene and Miocene age crop out farther south, in South Dakota, and still younger strata of Miocene, Pliocene, and Pleistocene age are well preserved in western Nebraska, eastern Wyoming, Colorado, Kansas, Oklahoma, Texas, and New Mexico. Periods of uplift of the Rocky Mountains are reflected in Cenozoic deposits in the Great Plains, and the Great Plains themselves were broadly warped during several intervals of Cenozoic deformation. Holocene sediments are widespread across the Great Plains and locally contain artifacts of the earliest man known to have lived in the U.S.

Geologic Mapping Needs

Stratigraphic sequences of the Great Plains are best exposed in the major drainages of the region, providing a strategy for their investigation. A transect along the Platte River in Nebraska (Scottsbluff, North Platte, Broken Bow, and Fremont 2^{o} map areas) is recommended as a pilot study before others are defined. This would extend and synthesize work now being done by several organizations, and it could be followed by transects across the northern and southern parts of the Great Plains.

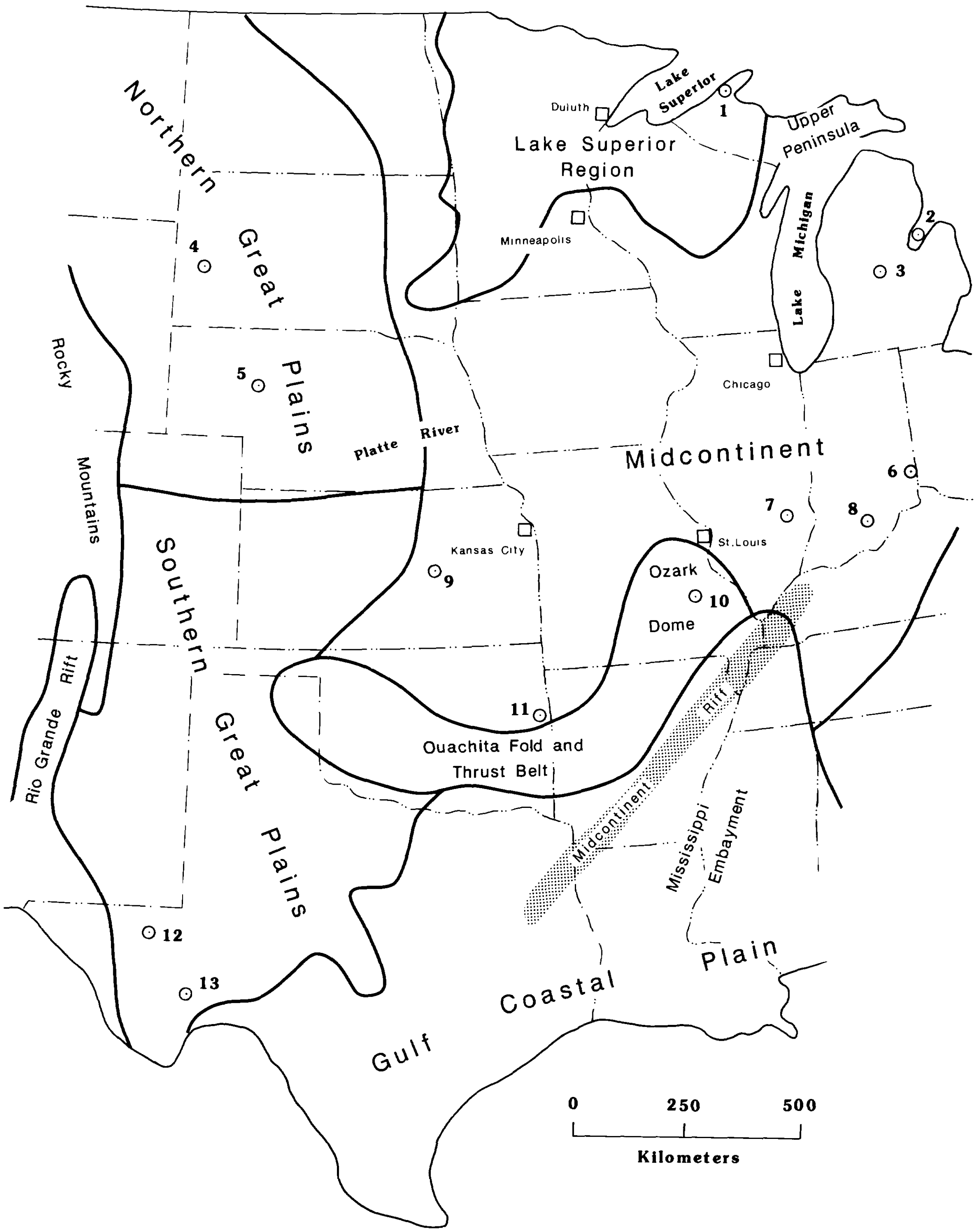


Figure 3. Physiographic provinces of the central United States, showing locations of features discussed in the text. Localities identified by numbers: 1, Keweenaw Peninsula; 2, Saginaw Bay; 3, Michigan Basin; 4, Black Hills; 5, Chadron arch; 6, Cincinnati dome; 7, Illinois Basin; 8, Salem; 9, Nemaha arch; 10, St. Francois Mts.; 11, Arkoma basin; 12, Delaware Basin; 13, Marathon Basin.

Cenozoic history of the east Rocky Mountains. The Cenozoic stratigraphic record of the Great Plains is reasonably complete and includes extensive rocks of all epochs. Episodes of uplift and erosion in the eastern Rocky Mountains are recorded in the distribution and facies of Great Plains strata; their uplift history is best studied in the Plains states. Such studies will be aided by extensive recent work on the isotopic ages, paleomagnetism, and heavy-mineral suites of airfall tuffs present throughout the Cenozoic deposits of the Great Plains. Volcanism began in Oligocene time and continued intermittently through Miocene, Pliocene, and into Quaternary time to at least 600,000 years ago. The tuffs provide valuable marker horizons for regional correlation and dating of specific events recorded in the stratigraphic sequence. Detailed geologic mapping and related studies are needed to address these problems.

Cenozoic deformation of the Great Plains. The Great Plains region was broadly warped by Cenozoic crustal movement, and zones of significant thickening of Cenozoic sedimentary rocks mark structural hingelines that border some of the major basins. The Cenozoic history of such ancient structures as the Chadron arch, Black Hills uplift, and Nemaha anticline can be inferred from studies of surface and subsurface stratigraphic sequences in the intervening basins and, where the rocks are preserved, on the uplifts themselves. Such studies in conjunction with analyses of available geophysical data should further our understanding of how ancient structures in old crustal rocks influenced the development of the midsection of the North American continent. Detailed geologic mapping is needed to provide basic information and a geologic framework for these studies.

Oil, gas, and coal resources. The basins of the central and Southern Great Plains are prolific sources of petroleum, natural gas, and, in the northern part, coal. Exploration and development strategies for these resources in the Plains states and in geologically similar regions are predicated on knowledge of hydrocarbon genesis, maturation, and migration in basin environments. Detailed basin analyses, based partly on a framework provided by geologic mapping of the basin flanks, are essential to structural interpretations and to studies of basin evolution.

Hydrology. Geologic mapping in the Great Plains is needed to improve our knowledge of the three-dimensional distribution of various rock types and thus to better understand groundwater flow in the region. Vast areas of cropland depend upon irrigation from shallow aquifers, some of which are now becoming depleted at alarming rates. Successful management of the limited water resource requires an adequate understanding of aquifer geometry, lithology, and interaction with other aquifers, obtainable from geologic maps that portray the distribution of various stratigraphic units. Similar maps are needed in areas proposed for waste disposal where impermeable minerals (salt, gypsum) are possible repositories for the waste. The capacity for storage containment requires knowledge of the stratigraphic framework and hydrogeologic setting.

Climate. The Great Plains region is the world's most prolific source of grain foods and cattle. This situation can persist only so long as the region's climate deviates little from the present norm, yet mounting evidence from many areas suggests that climatic fluctuations are a normal--and inevitable--aspect of recent geologic history. Paleoclimatic studies are thus of increasing importance, and they should seek to predict future long-term climate changes and their effects. Cenozoic deposits of the Great Plains contain much evidence of past climate changes; the mapping and dating of such deposits is basic to any paleoclimate study.

C3. Midcontinent

General Geology

The Midcontinent province is an area of low altitude (150-300 m) and only slight local relief. It is underlain by a broadly warped sequence of Paleozoic sedimentary rocks that is generally less than 1,000 m thick, but in places reachs more than 4,000 m. Large domes such as the Cincinnati Arch, basins such as the Illinois and Michigan Basins, and zones of steeply dipping faults--some strike-slip--are conspicuous structural features. The northern part of the region is mantled by glacial drift that forms broad plains of locally thick sand, gravel, and clay. Moraines, rising several tens of meters above the drift plains, are conspicuous topographic features in many areas. Mineral resources include coal, oil and gas, sand and gravel, and many minor metallic and nonmetallic deposits.

In addition to large sand and gravel resources, surficial deposits in the glaciated Midcontinent region store vast quantities of potable groundwater; they also cover potential mineral deposits in the underlying basement rocks. Detailed geologic mapping is essential to proper utilization of resources and analysis of possible toxic-waste disposal techniques. Concepts needing clarification through geologic mapping include: the mode of deglaciation that governed the character and distribution of many surficial deposits, glacial stratigraphy and mineralogy, isostatic rebound of the Earth's crust after ice melting, and the location of buried preglacial valleys.

Geologic Mapping Needs

Eastern Interior (Illinois) Basin. Detailed mapping of Carboniferous strata in southern Illinois is extending northward the stratigraphy developed by detailed mapping in western Kentucky. The area being mapped includes only part of the Mississippian type area that provides the stratigraphic and nomenclatural framework for a large part of the Midcontinent. Extension of detailed mapping to the entire Mississippian type area is needed to include Upper Mississippian units. Additionally, detailed mapping in the Borden and Salem areas of Indiana is necessary to resolve stratigraphic problems related to the development of the Borden clastic wedge. Mapping the many thin Upper Mississippian and Pennsylvanian clastic and carbonate units in the Eastern Interior Basin will allow correlation across the Cincinnati Arch as well as analysis of the role of upper Paleozoic tectonism on the North American craton.

Detailed mapping in western Tennessee emphasizing lithostratigraphic units is necessary to establish a link between the Carboniferous stratigraphy mapped in Kentucky and the Black Warrior Basin in Mississippi and Alabama. The study of Mississippian facies will provide better understanding of regional stratigraphy and the Mississippian tectonic framework. This framework is needed to resolve problems of Mississippian clastic sources in the Midcontinent arising from converging clastic wedges in the Mississippian of Alabama. These mapping projects involve rocks that produce significant amounts of coal, oil, and gas.

Interlobate area of south Michigan. The thickest and perhaps most complex covering of glacial deposits in the United States occurs in the northern part of the southern peninsula of Michigan. Thick drift more than 250 m thick is common across large areas. Three lobes of ice traversed Michigan in the late Wisconsin. The stratigraphy and the detailed distribution of sediments is unknown across most of the state, but it is certain to be complex, especially in the interlobate area northwest of Saginaw

Bay. Detailed mapping is needed to determine relative ages of the complex array of interlobate moraines and outwash sands and gravels deposited during the latest interval of deglaciation, and mapping would improve understanding of ice retreat in the area and ice lobe interactions in general. There is some evidence suggesting a record of as many as seven glacial advances. Analysis of well records and a limited drilling program should be integral to a study of these deposits.

Driftless area of west-central Wisconsin. Small-scale reconnaissance mapping in west-central Wisconsin indicates an old till plain devoid of ice-contact or outwash deposits, with a highly generalized southern border beyond which the land was not glaciated. The map pattern of this old glacial deposit differs markedly from areas covered by ice during the late Wisconsin, where end moraines and ice-contact deposits are common. Is the older glacial surface featureless because weathering and erosion have removed much of the drift, or were the glacial conditions fundamentally different from those operating in the late Wisconsin? This question could be addressed by detailed mapping across the old drift area. The true southern extent of glaciation in the area could also be determined.

Isostatic rebound of the Lake Michigan basin. Evidence for isostatic rebound occurs along the shorelines of many lakes in the northern U.S. Among some elongate, north-trending lakes, late Wisconsin shorelines are strongly elevated to the north, indicating that the land beneath the northern end of the lakes, nearer the center of the ice cap, was once depressed more than the land to the south. The dating of ice retreat and crustal rebound has implications for the climatic history of the late Pleistocene, crustal rheology, and modern man. Geophysical evidence suggests that parts of the Canadian crust are still rebounding from the last glaciation; these movements are therefore currently affecting water levels in the Great Lakes. Detailed geologic mapping and a detailed study of glacial deposits, specifically ice-contact lake deltas and lake-related deposits along the Michigan and Wisconsin shores of Lake Michigan, would provide data on crustal rebound and contribute to knowledge of Great Lakes history and recent climatic fluctuations.

Northwest Indiana. The surficial and subsurface glacial geology of northwestern Indiana is poorly understood. Recent small-scale mapping identified end moraines, lake clay, and vast areas of windblown and water-laid sand and gravel. This mapping along with some well data suggest that the region is underlain by complexly interbedded lake clay, till, and sand and gravel. Sand and gravel, detected beneath moraines, form thick bodies that may be responsible for the surface expression of the moraines. The stratigraphy, which is partially based on accumulation of till into moraines during periods of glacial stillstands, may need to be revised. Outwash and windblown sand extend beyond the moraines bordering the lake deposits, forming a large apron. This sand, and the drift deposits that they cover, locally exceed 60 m thick.

Detailed geologic mapping is needed to understand the late glacial conditions that produced the vast sand deposits, the complex subsurface and surficial stratigraphy of the lake plain and belt of moraines bordering Lake Michigan, and the nature of the drift beneath the widespread sand. This effort must include drilling and analysis of well data to adequately evaluate the complex stratigraphy and the resources of the subsurface drift. These resources include groundwater, the quality of which must be protected in this heavily industrialized area. To accomplish this, a detailed knowledge of aquifer geometry and recharge areas is critical.

Lake Erie basin of northwest Ohio. During the late Wisconsin, a large part of northwestern Ohio was inundated by glacial lake waters ponded in the basin now containing Lake Erie. During deglaciation, as the ice receded northeastward, the lake level was lowered in stages as new outlets were uncovered around the retreating ice. Small-scale reconnaissance mapping by analysis of landforms on topographic maps with some field verification indicates that only thin deposits of lake clay were deposited by the lake. A thick, continuous blanket of lake clay presumably was not deposited because the lake did not occupy the entire basin for a sufficient period of time. Were these lake clays deposited in a simple series of lakes of decreasing size, or in a larger number of smaller lakes that ponded on the Lake Erie plain? Detailed mapping is needed to solve this problem, for if there were indeed several lakes where past reconnaissance has mapped only one, then the history of deglaciation in the Lake Erie basin must be revised. A program of shallow drilling in the lake clays, with detailed study of lithology and mineralogy and radiocarbon dating of lake-laid organic material should be part of the study.

Geologic hazards in the Cincinnati area. Detailed geologic mapping is needed in the urban area that includes Cincinnati, Ohio, a severely landslide-prone region. Topical studies related to landslide processes have been carried out by the Branch of Engineering Geology and Tectonics, but without the benefit of large-scale (1:24,000) geologic maps. Detailed knowledge of the detailed distribution of bedrock and surficial units is needed because lithology is one of the chief factors contributing to landsliding. A concerted effort to prepare bedrock and surficial maps (at 1:24,000 scale) in this region would do much to clarify stratigraphic and lithologic relationships in an area where facies changes are numerous. Colluvial thickness and lithologic maps would have widespread use in understanding and predicting landslide processes and identifying landslide prone areas.

C4. Ouachita/Ozark Region

General Geology

The Ouachita fold and thrust belt consists of complexly deformed thin-skinned thrust sheets of Paleozoic rocks that for the most part do not involve basement. It differs in several respects from the other three orogenic systems (Cordilleran, Innuitian, and Appalachian) bounding the North American craton. In general, oceanic deep-water marginal basin facies have been thrust northward onto a thick miogeoclinal carbonate shelf facies; the latter is favorable for hydrocarbon source beds, reservoirs, and traps, and the former contains varied mineral resources. Although autochthonous Paleozoic carbonate shelf-facies rocks have been drilled beneath the thrust plates of the Ouachita-Marathon system in the Marathon Basin of Texas, they have not been identified in the Arkoma Basin beneath the Ouachita orogen in Oklahoma or Arkansas; seismic records suggest that they occur there. Although the plate-tectonic setting of this orogen remains poorly understood because continent reconstructions for middle Paleozoic time are inadequate, the deep-water marginal basin strata apparently accumulated in an ocean basin south of the central craton before the late Paleozoic collision of South America and Africa with North America.

Northward thrusting dies out in the southern part of the adjacent Arkoma Basin along a poorly defined frontal zone. The northern half of this basin has produced natural gas for more than 80 years and exploration is underway in the southern half for deeper reservoirs where a thick (6,000 m or more) sequence of detrital, possibly synorogenic, rocks of Carboniferous age overlies the carbonate shelf facies. The source of at least some of this detritus was to the north or northeast. A major negative gravity anomaly along the Ouachita frontal zone of western Arkansas and eastern Oklahoma may record either an older (Precambrian?) basin or anomalously thick crust.

Farther north in central Arkansas and eastern Oklahoma, the shallow-water shelf facies of the Ozark region abuts the Arkoma Basin along well-defined south-dipping normal faults. Fault displacements aggregate about 1,000 m in western Arkansas and 2,000 m beneath the Mississippi embayment in northern Mississippi, but faults are not evident at the surface just west of the embayment in east-central Arkansas, where the overlying clastic sequence may be draped over the faulted underlying carbonate shelf sequence. A recent earthquake swarm centered along the projection of this fault system near Enola, Arkansas, indicates that it is still active.

The Carboniferous detrital sequence thins northward across the southern Ozark region and ends at the Boston Mountain front in northern Arkansas. Beyond that front, progressively older Paleozoic rocks are exposed toward the Ozark dome and drape off the steep-sided Precambrian knobs of the St. Francois Mountains. Lead, zinc, and barite are produced from Paleozoic carbonate strata in northern Arkansas and southern Missouri.

Geologic Mapping Needs

Much of the Ouachita/Ozark region is covered by intermediate-scale geologic maps and some is covered by large-scale modern maps, but detailed mapping of key areas based on current concepts is needed, especially in Oklahoma. About 40 percent of the Ozark region is mapped or is being mapped at a scale of 1:250,000 and parts are being mapped in detail at 1:24,000.

Current detailed geologic mapping in the Ouachita Mountains is directed toward complete coverage of the Oklahoma segment and toward selected coverage of problem areas in the Arkansas segment by the USGS and State geological surveys. Extensive geophysical support is needed to obtain a three-dimensional view of this controversial orogen and of the authochthonous sequence beneath; sufficient petroleum borehole data are available to define the geometry.

Frontal zone of Ouachita belt. Geologic mapping is needed in the frontal zone of the Ouachita fold and thrust belt in both Arkansas and Oklahoma. This mapping is necessary to establish the relationship of the Ouachita orogen with surrounding rocks, to aid in the exploration for natural gas, and to develop the depositional and orogenic history of the Ouachita belt.

Ste. Geneviere fault zone. Preliminary mapping along the Ste. Geneviere fault zone of Missouri indicates that recurrent vertical movement, alternately in opposite relative directions, has resulted in complex relationships in the Paleozoic units there. Mapping along this structure is now needed to supplement and test geophysical data suggesting that the zone marks the boundary of two major continental blocks.

D. CANADIAN SHIELD

D1. Lake Superior Region

General Geology

The landscape of the Lake Superior region, which includes all or parts of Minnesota, Wisconsin, and Michigan, is subdued and is inherited largely from Pleistocene continental glaciations, which produced a variety of erosional and depositional landforms. Glacier ice scoured the bedrock in the northern parts of the region, as over most of Canada, and deposited materials of diverse lithology and provenance as much as 200 m thick over much of the remainder of the region.

Except for the glacial deposits, the rocks are Precambrian and occur along the southern margin of the Superior province of the Canadian Shield. Except on the north, adjacent to Canada, the Precambrian rocks thicken to the west, south, and east. The Precambrian rocks in the region record an extended interval of crustal development and evolution that spans nearly 3 b.y. of earth history. This interval of geologic time is not continuously recorded in layered and intrusive units, but instead it is punctuated by specific rock-forming and tectonic events that can be deduced from geologic relations and placed in a chronometric framework by isotopic dating.

The Lake Superior part of the Canadian Shield is a collage of Archean cratonic elements (3.6-2.5 Ga), an Early Proterozoic (1.85 Ga) orogenic belt (Penokean orogen) that marginally affects the Archean craton, and a Middle Proterozoic (1.2-1.0 Ga) intracratonic rift assemblage, as well as intracratonic igneous and sedimentary rocks (about 1.76-1.63 Ga) and younger anorogenic intrusions (about 1.5 Ga). The rocks represent several major crust-forming events, including reactivation of Archean basement gneiss locally within the Penokean orogen and erosion and deposition of epicratonic successions.

The Archean sequence includes a composite crustal segment consisting of an Archean gneiss terrane (3.6-2.5 Ga) and a Late Archean (about 2.70 Ga) greenstone-granite terrane; these terranes are juxtaposed along a tectonic boundary termed the Great Lakes tectonic zone. The gneiss terrane is exposed in southern Minnesota and within the Penokean orogen in the cores of mantled gneiss domes and fault-bounded blocks in the Upper Peninsula of Michigan. The greenstone-granite terrane of Late Archean age, which makes up the southernmost part of the Superior province of Canada, consists generally of greenschist-facies volcanic and volcanogenic rocks and intrusive tonalite, granodiorite, and granite.

The rocks of Early Proterozoic age are a composite of two contrasting terranes, an epicratonic sedimentary-volcanic succession (Marquette Range Supergroup and equivalents)--which contains the great iron-formations of the Animikie basin--and an island-arc terrane that was accreted to the North American continent at about 1.85 Ga. The terranes constitute a linear fold belt (Penokean orogen) more than 650 km long extending from central Minnesota through northern Wisconsin and northern Michigan into Canada.

The intracratonic igneous and sedimentary rocks post-date the consolidation of the Superior Archean craton and the Early Proterozoic Penokean orogen and formed the southern margin of the vast composite craton called Proto-Laurentia. Following mild deformation and metamorphism of these rocks at about 1.63 Ga, the anorogenic Wolf River batholith and related plutonic rocks were emplaced (about 1.48 Ga). The Wolf River is a composite intrusion consisting of anorthosite and mangerite and a rapakivi granite suite, and it is a component of the 1.4-1.5 Ga Proterozoic anorogenic province of North America.

The youngest major terrane in the region, the Middle Proterozoic (Keweenawan; about 1.3-1.0 Ga) Midcontinent rift system, is an intracontinental assemblage of igneous and sedimentary rocks that formed in a rift that aborted before significant crustal separation was achieved. The rocks are dominantly basalt and rhyolite occupying a central horst; gabbro-anorthosite complexes intruded at the margins of the rift, along an unconformity between rocks of Archean to Early Proterozoic age and the younger Keweenawan lava flows; and mainly red-bed but locally carbon-rich sedimentary rocks.

Since the late Middle Proterozoic, the region has been stable and except for the effects of Pleistocene glaciation apparently has been in isostatic equilibrium.

Valuable mineral deposits occur in each of the terranes of Archean and Early Proterozoic age except the Archean gneiss. Iron-formation from the epicratonic rocks of Early Proterozoic age in the Animikie basin has been by far the principal source of metallic ore in the region, the total production having a value of about $20 billion. Copper, valued at several billion dollars, has come entirely from Middle Proterozoic lava flows and sedimentary rocks in the Midcontinent rift system in Michigan (Keweenaw Peninsula). Other major types of deposits, as yet unmined, are volcanic-hosted massive sulfide deposits in the Wisconsin magmatic terrane of Early Proterozoic age and gabbro-hosted copper-nickel-cobalt deposits in the Middle Proterozoic (Keweenawan) Duluth Complex in northeastern Minnesota. In recent years, the sedimentary rocks of the Midcontinent rift system have been an exploration target for petroleum.

The Pleistocent glacial deposits contain extensive sand and gravel deposits, and together with Paleozoic aquifers, supply much of the area's water resources.

Geologic mapping needs

Precambrian basement. Although broad aspects of the Precambrian geology of the Lake Superior region are known, many unanswered questions of scientific and economic concern remain. To answer these questions, both detailed and regional geologic mapping are needed.

Among the unresolved problems are (1) the nature, composition, and age of the "basement" in the region, and its extent to the west, south, and east into the subsurface, where it is covered by younger, flat-lying rocks; (2) the petrogenetic processes that produced the volcanic and plutonic igneous rocks of the oceanic-arc terranes in the area; that is, to what extent were the rocks extracted from deep-seated (mantle) sources or formed by partial melting of older crust; and (3) the location of significant faults and shear zones and what their tectonic history was. These questions must be answered to accurately reconstruct the architecture of this segment of the earth's crust and its role in the plate tectonic assembly of the backbone of the North American continent. An understanding is not only fundamental to the reconstruction of this crust but it is fundamental to learning the evolution of the Phanerozoic basins that surround the Lake Superior region. These basins overlie Precambrian rocks, and their sedimentation history, structural development, and mineral and fuel resources depended to a substantial degree on the reactivation and mobility of the Precambrian basement. For example, many folds and faults that provided traps for oil and gas in the Phanerozoic basins owe their origin to reactivation of older Precambrian structures in the buried basement.

Until recently, geologic mapping in the Lake Superior Region was focused in areas known or inferred to contain the important iron and copper deposits for which the region is famed. Recent mapping, mostly published in the last 15 years, has purposely focused on other areas in the region so as to gain better insight into the nature and evolution of previously unknown terranes and their relationship to the known terranes. This mapping has shown (1) that volcanic terranes of Archean and Early Proterozoic age are favorable for the occurrence of massive sulfide and gold deposits, and (2) that the Middle Proterozoic Midcontinent rift system contains potentially valuable resouces of copper, nickel, cobalt, and possibly platinum. This work has aided in the discovery by industry of large tonnages of copper and zinc-bearing massive sulfides in northern Wisconsin. Additional mapping in these terranes is needed to further identify potential ore-bearing rocks and to gain insight into the specific geologic and geochemical factors most favorable for the occurrence of such mineral deposits. General geologic mapping is needed in areas of lesser potential to find possible deposits of strategic and critical minerals.

Pleistocene glaciation in Minnesota. Although much is known about the Pleistocene glacial history and geomorphology of Minnesota, the subsurface stratigraphy and mineralogy are poorly known. Currently an aggressive program by the Minnesota Geological Survey of drilling and analyzing drill-hole data is in progress to determine the stratigraphy and groundwater resources of thick (as much as 200 m thick) glacial deposits. This work in central Minnesota has shown that some of the stratigraphy determined from surface exposures is incorrect, and that the glacial history in this area is more complex than previously thought. A statewide program of shallow drilling and compiling existing water-well drilling data and of geologic mapping of surficial materials is needed to fully understand the glacial history of the region. Pleistocene deposits are the dominant aquifers over much of the state where Paleozoic rocks are not present; the demand for potable water in Pleistocene deposits can be expected to increase.

Late Wisconsin drift of north Wisconsin. The surficial geology in much of northern Wisconsin is poorly understood. Understanding the stratigraphy and mineralogy of the glacial drift, understanding the Pleistocene history, and understanding the mode of deglaciation will require detailed mapping in selected areas. Air-photo reconnaissance mapping indicates a complex late glacial history involving several ice lobes. Ice-contact deposits, largely sand and gravel, appear to cover the majority of land in northeastern and northwestern Wisconsin but are absent in the area covered by a sublobe in north-central Wisconsin. Such extensive ice-contact deposits are atypical of the glaciated U.S. and may indicate an anomalous deglaciation history. Detailed mapping north of the late Wisconsin terminal moraine in each lobe should provide data to understand the late glacial history in the region. Investigating the subsurface glacial geology by a program of shallow drilling and compiling existing well data should accompany surficial mapping to provide information on earlier glaciations, the courses of preglacial drainage, and the potential for ground water resources. Analysis of drift lithology should also be an integral part of the study to aid in distinguishing deposits. The drift covers the Precambrian shield, which is mineralized in many places; thus drift lithology could provide an indicator of potential mineral deposits.

D2. Adirondack Region

General Geology

The Adirondack massif (fig. 4) is a large dome of Middle Proterozoic granulite- and amphibolite-facies metamorphic rocks that were last deformed at about 1 Ga. It constitutes the single largest area of Proterozoic basement rocks in the eastern U.S. Because the rocks of the Adirondack Mountains recrystallized at depths as great as 30 km, they present an unique sample of the deep parts of the continental crust that probably underlies much of the western margin of the Appalachian mountain chain.

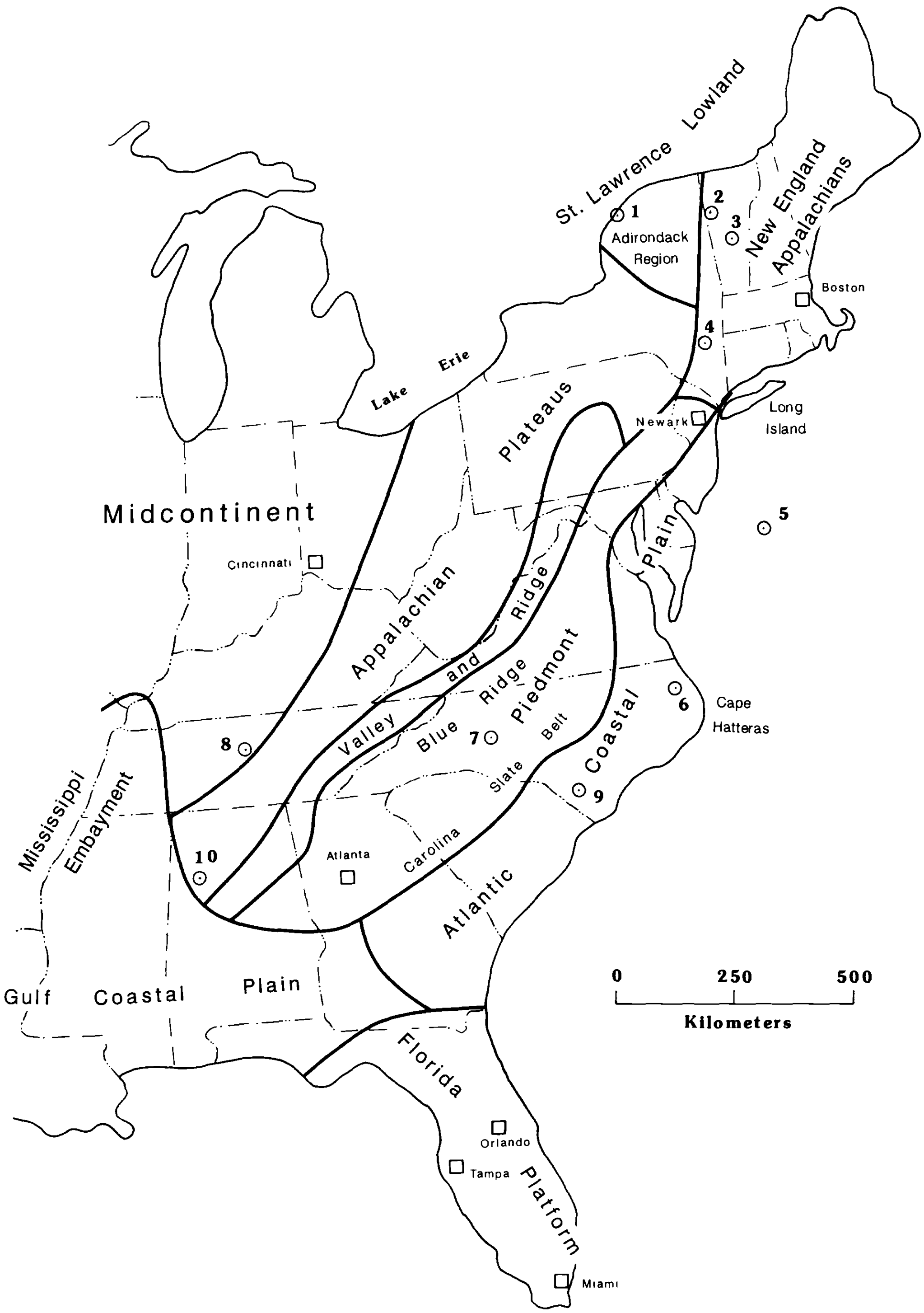


Figure 4. Physiographic provinces of the eastern United states, showing locations of features discussed in the text. Localities identified by number; 1, Alexandria Bay; 2, Lake Champlain; 3, Green Mountains; 4, Hudson River; 5, Baltimore Canyon trough; 6, Albermarle embayment; 7, Statesville; 8, Nashville dome; 9, Cape Fear arch; 10, Black Warrior Basin.

A wide northeast-trending metamorphic and structural front, the Colton-Carthage line, divides the Adirondacks into two terranes. The first, known as the northwest lowlands, consists dominantly of amphibolite-facies metasedimentary rock. The second is known as the granulite terrane and is located in the highlands, where charnockitic gneiss, metaanorthosite, metagabbro, and granite broadly intrude the metasedimentary sequence. Available data suggest that the age of the gneiss and associated granite is greater than 1.1 Ga and perhaps as great as 1.7 Ga. Large bodies of anorthosite, gabbro, and granite intruded highly deformed isoclinally folded gneiss and were subsequently subjected to granulite-facies metamorphism together with their country rocks at about 1 Ga.

Grenville deformation of the massif produced a complex set of fold interference patterns, with a dominant arcuate southwest to northeast structural trend developed relatively late in the structural history. Early nappe structures associated with northwestward-directed tectonic transport, mylonite formation, and strong linear structure may have developed in an early Grenville collisional event that effectively doubled the continental crustal thickness in a fashion analogous to deep crustal structure proposed for the modern Himalayan system.

Multiple glacial tills are known but remain uncorrelated in the Adirondacks. Tills of late Wisconsin age record divergent ice-flow directions during glacial advance and retreat, and ice-marginal deposits in numerous proglacial lakes form the basis of the deglaciation stratigraphy of the Ontario and Hudson-Champlain lobes of the Laurentide ice sheet. Cirques in the high peaks possibly date from multiple glaciations. Small glacial lakes within the Adirondacks and larger lakes in the adjacent Champlain, Mohawk, Black, and St. Lawrence valleys record post-glacial crustal rebound effects.

Geologic Mapping Needs

Tectonic history of deep-seated continental crust. Detailed geologic mapping is needed in the Adirondacks to provide the framework for structural, metamorphic, and petrologic studies directed at the deformation behavior of continental crust under deep-seated conditions. These studies would include mylonitization, chemical redistribution of elements, and origin of tectonically layered continental crust. Detailed mapping to provide a basis for these studies is needed in: (1) the eastern margin of the Adirondacks facing the Green Mountains, and (2) the northwest lowlands at the northern end of the Colton-Carthage line.

Stratigraphy, origin, and age of paragneiss. Major problems exist in the interpretation of the relationship of the paragneiss sequence to a problematic older basement. Locally in the northwest lowlands, granitic gneiss and alaskite are variously interpreted as basement or as intrusive into a cover sequence. Rocks similar to the proposed basement in the Canadian Grenville appear to intrude the paragneisses and are older than 1.1 Ga. Detailed mapping to solve this problem is needed in the northwest lowlands near Alexandria Bay.

Tectonic setting of plutonic activity. Detailed mapping in selected areas would form a basis to study igneous processes of both shallow and deep crustal levels. Recent studies of certain granitic rocks of the Adirondacks suggest that they represent high-level anorogenic granitic-volcanic complexes considered to be 1.4 to 1.2 Ga by analogy to similar rocks exposed in the Midcontinent region. Granitic rocks similar to the problematic rocks of the Adirondacks are present throughout the Appalachian Grenville. Detailed mapping and petrochemistry of these bodies are needed for comparison with Appalachian examples.

Exposures of the anorthosite suite and closely related bordering mangerite offer the opportunity to study the evolution of deep-crustal magmatic activity and the evolution of continental crust through processes of partial melting and bulk transfer. Multi-discipline investigations of the deep structure of continents in other parts of the country, utilizing deep drilling and geophysical techniques, can profit greatly from detailed knowledge gained through geologic mapping of deep-seated terranes, such as the Adirondacks, that are now exposed at the surface.

Cenozoic crustal movement. Doming or redoming of the Adirondack massif may be the result of recent uplift related to abnormal crustal or tectonic conditions. Identification of the actual time and rates of vertical movement requires detailed mapping of Pleistocene lake deposits within and adjacent to the uplift area. The degree to which certain areas express uplift anomalous to that resulting from normal glacioisostatic rebound will identify areas of active tectonism and potential seismic risk.

To address the problems, detailed mapping of small proglacial lakes in the central Adirondacks, and larger lakes in the Black River valley and Mohawk, Champlain, and St. Lawrence lowlands is needed to establish a reliable datum to compare anomalously uplifted lake-water planes. The array of local contours of glacioisostatic crustal warping may then be connected and compared with regional rebound contours of New England and of the Great Lakes basin. Discontinuities within the uplift pattern will identify late Quaternary doming in the Adirondack region not related to rebound.

Late Wisconsin proglacial lakes and the Champlain Sea. The succession of proglacial lakes mentioned in the preceeding section predates the marine transgression of the Champlain Sea in the Champlain - St. Lawrence basin. Radiocarbon dates from wood in Lake Iroquois sediments in the Ontario basin indicate a maximum age of about 12,000 years B.P. for the trangression. However, the oldest dates on marine shells from areas adjacent to the Adirondack region are 12,000 to 12,800 years B.P. The resolution of this problem of absolute ages of the glacial and marine units requires finding new dateable materials that more accurately estimate glacial or marine deposition. It is likely that detailed mapping and sampling of dateable marine materials in shallow coreholes in the marine section or coring upland bogs or other depressions and dating the organic fraction of clastic sediments beneath organic zones would improve the radiocarbon age estimates.

Detailed mapping should be undertaken east of Covey Hill, where detailed maps of ice-marginal lakes and other features might provide a better understanding of the configuration of the Hudson-Champlain ice lobe in the northern part of the Champlain Valley. Deposits associated with this lobe immediately precede the transgression, which is dated in eastern Quebec.

E. COASTAL PLAIN

El. Gulf Coastal Plain

General Geology

The Gulf Coastal Plain is a low-relief surface, partly submerged, that extends from interior parts of the southern U.S. to the continental shelf edge (fig. 4). The subaerial part extends along the Gulf Coast from Mexico to southwestern Georgia and western Florida, where it merges with the Florida platform and Atlantic segments of the Coastal Plain.

The Gulf Coastal Plain is comprised of consolidated and unconsolidated stratified deposits ranging from Jurassic to Holocene that are derived from erosion of igneous, metamorphic, and sedimentary rocks of interior areas. The Mississippi Embayment forms a large reentrant (500 km long) in the middle of the Gulf Coastal Plain that is underlain by mostly unconsolidated clastic sediments (as much as 1,200 m thick) derived from the Appalachian Mountains and western source areas.

Geologic Mapping Needs

Geologic mapping at several scales is needed in the Gulf Coastal Plain. Small-scale (1:250,000) maps are needed to investigate and portray regional features, and larger-scale maps (1:100,000-1:24,000) are needed to depict specific structural features and mineral and energy resources.

In order to produce a three-dimensional stratigraphic (basin) framework in the Gulf Coastal Plain, stratigraphic studies must be tied to deep reference core holes. Because of the generally flat terrain, most of previous mapping has been two-dimensional, in contrast to the largely three-dimensional mapping of similar age basins in the Rocky Mountains and westward. Local seismic reflection profiles and regional electric log correlations are also used as controls to erect a three-dimensional framework for the Gulf Coastal Plain, but surface mapping should be accompanied by deep core holes because of the lower dependability of most E-log correlations. Where cost permits, seismic reflection is also valuable to mapping projects in this region.

Evolution of the north Mississippi embayment. The Mississippi embayment occupies over 260,000 km^2 and is one of the most prominent physiographic features of the North American continent. The late Mesozoic and Cenozoic history of the Midcontinent is preserved in part in the sedimentary rocks of the northern embayment. Detailed mapping of the Cretaceous and younger rocks in the Paducah and Dyersburg 2^o sheets is needed to resolve structural and stratigraphic relationships for this part of the continent. The basal Cretaceous sedimentary rocks, for example, have been mapped as Tuscaloosa Formation (Cretaceous) but differ from sandstone of the type Tuscaloosa in northwestern Alabama.

Geologic mapping is needed to understand the structural history of this region, which includes the seismically active New Madrid region. The crosscutting relations of young sediments to the New Madrid, Rough Creek, Ste. Geneviere, Wabash, and other fault zones have yet to be resolved. Detailed geologic mapping is also needed on the major stratigraphic unconformities, young structures in the area, and detailed sedimentology of the sedimentary fill of the northern embayment. Only recently have compilations of subsurface geology allowed insight into the relations between sedimentary fill and pre-existing crustal structure and land surfaces.

Ongoing detailed mapping in Illinois is presently focused on the development of the southern Illinois Basin and may be useful for identifying upper Paleozoic structural features to be traced into the embayment fill. The Pliocene-Pleistocene record in the northern embayment has been summarized recently and needs to be integrated with the thicker sections of Pliocene and Pleistocene rocks farther south.

Gulf Coastal Plain - Mississippi embayment transition. Facies transitions from coarse-grained continental siliciclastic to fine-grained marine calcareous sedimentary rocks present fundamental problems for geologic mapping and stratigraphic definition. Regional geologic mapping is needed to provide control for detailed stratigraphic studies along the Tombigbee River from western Alabama into more continental sections in northeastern

Mississippi. The rapid facies transitions between these two areas, from an intercratonic depression to a passive margin, have broad application to our understanding of crustal loading. The mapping will also allow greater understanding of the character and distribution of the oldest marine units. This understanding in turn will help define the time and extent of the Mississippi embayment's development. Furthermore, the comparison of coeval transgressive-regressive sedimentary cycles between this area and the eastern Gulf Coastal Plain margin will allow clearer resolution of eustatic sea-level changes and episodes of cratonic uplift.

This region is one of the last areas of the Gulf Coastal Plain in need of geologic mapping. The sedimentary facies patterns have important implications for the distribution of water resources and the movement of fluids downdip into what are some of the most important hydrocarbon reservoirs in North America. Detailed knowledge of the fault mechanisms and fault geometries are critical to understanding the basin margin architecture and the nature of crustal flexure.

E2. Florida Platform

General Geology

Most of Florida is underlain by carbonate rocks that have a maximum thickness of about 6,000 m in the southern part of the State. The peninsula is the emerged half of a large basement block covered with Coastal Plain sediment. Prior to opening of the Atlantic, Florida was sandwiched among the cratons of North and South America and west Africa. Since the opening of the Atlantic Ocean and Gulf of Mexico, Florida has been the site of extensive carbonate and phosphate deposition and hydrocarbon accumulation during downwarp phases of platform evolution.

Florida is the Nation's top producer of fuller's earth, phosphate, staurolite, titanium minerals, and zircon. It is a large producer of rare-earth metals and uranium, and it has potential for scandium production. Oil and gas, cement, sand and gravel, and crushed stone are also products of the State. Its water needs and groundwater pollution problems currently occupy most of the current budget and manpower of both the Florida Geological Survey and the USGS's efforts in Florida.

Geologic Mapping Needs

Geologic mapping, integrated with subsurface lithologic and paleontologic well data, seismic reflection profiling, and gravity and magnetic surveys, is needed to create three-dimensional maps to address land use and resource problems. No modern geologic maps of Florida at any scale are currently available.

Four high-priority areas in the southwestern part of the State address problems related to petroleum resources in the south Florida basin, water recharge for the Orlando, Tampa, and Miami aquifer systems, and heavy minerals onshore and offshore in the Tampa - St. Petersburg area. Geologic problems on the boundary with the other Coastal Plain provinces, such as the character and regional extent of the Jay field and the transition from Tertiary siliciclastic rocks of central Georgia to a coevel carbonate section in southern Georgia and Florida, also need to be addressed by geologic and geophysical mapping.

E3. Atlantic Coastal Plain

General Geology

The Atlantic Coastal Plain is comprised of consolidated and unconsolidated stratified deposits eroded from igneous, metamorphic, and sedimentary rocks of the Appalachian highlands. Sediment thickness ranges from zero at the western edge of the Coastal Plain to as much as 3,000 m near Cape Hatteras, North Carolina, and 10,000 to 12,000 m in the Baltimore Canyon trough near the edge of the continental shelf. The sediments consist of quartzo-feldspathic sand, gravel, silt, and clay with lesser amounts of glauconite and phosphatic materials. In the southern Atlantic Coastal Plain, substantial volumes of carbonate sediment are also present.

The Coastal Plain of eastern North Carolina and southeastern Virginia encompasses the Albermarle embayment, containing the thickest known (3,000 m) onshore post-Triassic clastic sequence in the Atlantic Coastal Plain. Bounded by the Fort Monroe high to the north and the Cape Fear Arch to the south, the Albermarle embayment is not a typical structural basin but contains a roughly homoclinal sequence of beds that dip seaward at an increasing angle from the Fall Line to the coast. This increase in dip reflects the close proximity and influence of the Baltimore Canyon trough. The embayment is of particular interest because it includes the transition between a siliciclastic sedimentary province in the northern Atlantic Coastal Plain and the more carbonate-rich province (notably in the Paleogene beds) in the southern Atlantic Coastal Plain. In the subsurface, a fairly complete sedimentary section ranges in age from Late Jurassic or Early Cretaceous to late Tertiary and Quaternary.

Geologic Mapping Needs

Albermarle embayment. Geologic mapping in North Carolina and Virginia is needed to develop mineral and groundwater resources, as well as to aid in land-use planning and engineering problems. Specifically, geologic mapping would help determine the regional distribution and character of the Pungo River Formation in which there are active phosphate-mining operations near Aurora, North Carolina. Mapping and drilling would also help determine the variation in thickness of overburden above the phosphate-bearing strata. Other Coastal Plain formations in the same region are sources of limestone for cement manufacture, aggregate for concrete and other construction purposes, and expandable clay. Geologic mapping and groundwater studies are greatly needed here to determine the regional distribution, gradients, and permeability of water-bearing strata and associated confining beds.

The regional transition of major early Mesozoic depositional environments in the Albermarle embayment is represented by rift-basin sediments (continental) in the west that change eastward to marine deposits. Lower to middle Tertiary clastics to the north are equivalents of carbonate and phosphatic deposits in the southern part of the embayment. At the surface, upper Cenozoic deposits resulted from migrating fluvial and deltaic sedimentation along a subsiding marine margin. Geologic mapping with deep drill holes and seismic profiles will provide a data base for interpreting these transitions and their tectonic/eustatic significance. Correlation with the adjacent offshore marine seismic profiles could yield a detailed three-dimensional view of the evolution of the continental margin. Mapping across faulted coastal plain margins and intrabasin fault systems would help to understand the structural framework and seismicity of an area that is currently experiencing expanded urban development.

Central Long Island. The ages of multiple glacial and interglacial deposits in some parts of New England and adjacent areas are poorly known. Detailed surficial geologic maps of these areas are needed to establish reliable correlations among, and absolute ages of, some units. Detailed mapping is required in central Long Island, New York, where the origin, extent, and age of the Manetto Gravel, possibly the oldest glacial deposit in the region, are unknown.

F. Appalachians

General Geology

The Appalachian region includes, from west to east, four distinct geologic provinces: (1) the Appalachian Plateau province, underlain by undeformed to gently folded and faulted sedimentary rocks; (2) the Valley and Ridge province, underlain by similar strata that is strongly folded and thrust faulted; and (3) and (4) the Blue Ridge - Green Mountain province and the Piedmont - New England province, both of which form the eastern part of the region and consist of Precambrian and Paleozoic metamorphic and igneous rocks, locally overlain by Mesozoic rocks. In the following discussion these provinces are treated as a single region and geologic mapping needs are covered by topic.

The region as a whole was once part of a continental mass (Laurentia) ancestral to North America that was locally deformed and metamorphosed about 1 Ga during the Grenville orogeny. This continent rifted about 750-700 Ma, forming a new eastern margin of ancestral North America and a new ocean basin (Iapetus) to the east.

As the Iapetus Ocean basin closed episodically between 600 and 245 Ma, segments of oceanic crust, volcanic island arcs, continental fragments, and large continental masses collided with the eastern margin of the North American craton. Thus foreign terranes of various sizes, each with its own geologic history, were accreted to ancestral North America. This prolonged period of ocean closing and continental accretion was punctuated by at least three major collision episodes. Related metamorphism and magmatism affected different but overlapping areas in the region with different intensities in the Ordovician (Taconic orogeny), Devonian (Acadian orogeny), and Pennsylvanian/Permian (Alleghanian orogeny). The compressive forces accompanying the collisions were generally directed westward and, by folding and thrusting, resulted in crustal shortening that may have exceeded 200 km.

Materials eroded from highlands produced by these Paleozoic orogenies formed a variety of deposits. Cambrian to Permian clastic wedges typically overlie or interfinger westward with deposits formed on the stable, yet periodically submerged, interior of the continent. Stratified rocks deposited in local marine and continental basins within and marginal to the mountain belt and contemporaneous intrusive rocks were deformed by later collisions.

The Appalachian orogen, once continuous with the Caledonide orogen of Europe and Mauritanide orogen of Africa, was broken up by Mesozoic opening of the present Atlantic Ocean. Early stages of that opening about 240-200 Ma produced rift basins that filled with continental sediments (primarily red shale) and igneous rocks (diabase and basalt). Intrusion of granite in New England continued until about 100 Ma.

From Late Jurassic to Pleistocene, the Appalachian region underwent weathering and erosion with little sediment accumulation west of the Fall Line. During the Pleistocene, thin but widespread sediments from multiple glacial and marine transgressions were deposited in the north, and multiple colluvial and fluvial units and a widespread cover of saprolite formed in the south. Interbedded glacial and interglacial marine sediments record three Pleistocene glaciations and intervening nonglacial episodes in coastal New England. Deposits of the latest glaciation include few moraines, discontinuous till, and dominantly glacial lake sediments in the valleys of the northern part of the region.

Geologic Mapping Needs

Transect along the Virginia - North Carolina border. Within the Appalachian region, detailed geologic mapping is needed along a transect across the Piedmont, Blue Ridge, and Valley and Ridge at about the latitude of the North Carolina - Virginia border. More detailed knowledge of this area is needed for compilation of cooperative map projects in the States of North Carolina and Virginia. Some of the oldest rocks in eastern North America are exposed in the Saurtown Mountain anticlinorium, near the center of this area. The recognition of specific terranes that have been previously lumped with other terranes, such as the Milton belt north of Winston-Salem, North Carolina, or the Raleigh-Goochland belt terrane extending from the James River in Virginia to north-central North Carolina, necessitates mapping to define the bounding characteristics, lithologic variability, and extent of individual units, as well as the regional setting of the entire terrane. Smaller areas, such as the Roanoke Rapids complex, are parts of larger terranes--the eastern Slate belt--but require additional detailed mapping to define the nature of this well exposed, extensive volcanic-plutonic belt.

Farther to the west along the Virginia - North Carolina border, areas of the Triassic-Jurassic Durham Basin require detailed mapping to determine the morphology and structure of the layered intrusive complexes and associated structures. Areas bounding geologic terranes are especially important for detailed mapping because these areas may be zones of crustal weakness where both mineralized rocks and recurrent movement along faults could affect fundamental land-use decisions. The area just west of Statesville, North Carolina, for example, is not only poorly known geologically, but is the area of convergence of three major rock belts--the Inner Piedmont, Kings Mountain, and Charlotte belts.

Along the western margin of this high-priority area are a whole series of geologic terranes much in need of detailed mapping. The Martinsville igneous suite and the Ashe-Lynchburg terrane require considerable study to determine the complex sedimentary history of the area in relation to the emplacement of bodies of oceanic crust. Farther to the west, the nature of the Roanoke reentrant, where the structures from the central and southern Appalachians meet, still needs to be mapped in detail, in spite of topical studies and regional structural analysis done in the past.

Proterozoic geology of ancestral North America (Laurentia). Outliers or massifs of Laurentia exposed in the Appalachians are part of the Grenville orogenic belt, which about 1 Ga reached metamorphic conditions as high as granulite facies, characteristic of intermediate and deep crustal levels. Comparable Grenvillian terrane in Canada and the Adirondacks, which has no Appalachian orogenic overprint, reveals increasing evidence of an older heritage dating back as far as 2.2 Ga, with some rocks having affinities to those in older terranes of the adjacent Canadian shield. Most Grenvillian massifs in the Appalachians are poorly understood. Goals are to define the boundaries, to determine the original rock types and stratigraphy, to search for evidence of older crustal heritage, and to reconstruct a Grenvillian history. Geologic mapping supported by petrochemical and structural studies will provide data for interpreting deep crustal information gained by continental drilling, seismic reflection, seismic refraction, and other geophysical methods. The areas most needing detailed mapping are: (1) Green Mountains of Vermont, (2) northern New Jersey - Hudson Highlands of New York, (3) Blue Ridge of central Virginia, (4) central-western North Carolina, and (5) Sauratown Mountains anticlinorium, North Carolina - Virginia.

Late Proterozoic rifting of ancestral North America and opening of Iapetus. Late Proterozoic continental rifting is documented by a bimodal extrusive and intrusive igneous suite and rift-related sedimentary deposits, all metamorphosed, along the Blue Ridge - Green Mountain belt. The history of rifting has not yet been deduced from the sedimentary record and no structural rifts have been identified. All geologic mapping of igneous rocks should be accompanied by petrochemical and isotopic studies.

The following areas or rock units are suggested for detailed mapping: (1) Pinnacle Formation in the core of the Green Mountains anticlinorium, northwestern Vermont; (2) coarse graben-fill deposits of the Taconic allochthons in the Rensselaer Plateau, Rensselaer County, New York; (3) Catoctin Formation, northern end of the Blue Ridge anticlinorium in Maryland and Virginia; and (4) granites of Late Proterozoic age of the Mount Rogers embayment, Grayson County, Virginia, and Burke County, North Carolina.

Accretionary wedges, remnants of ancient ocean crust, and dynamics of Appalachian collision events. Tectonic shuffling (thrust faulting) of the narrow zone of ultramafic lenses extending from Vermont to Alabama is thought to have originated during a collision following the closing of an ocean basin in the Ordovician Taconic orogeny. Detailed geologic mapping of selected sites along the proposed suture is necessary to understand the location, timing, and processes involved in the closure(s).

The following areas are suggested for detailed mapping: (1) the Piedmont of southeastern Pennsylvania; (2) the melange zones of the central and southern Virginia Piedmont; (3) the Ashe-Lynchburg terrane of central Virginia to central North Carolina; and (4) the Inner Piedmont belt in the Morganton-Marion-Rutherfordton area, North Carolina.

Characterization of terranes and their boundaries. Detailed geologic mapping supported by geochemical, isotopic, and geophysical studies is needed to determine the internal character and boundary relations of terranes that may have been added onto ancestral North America during Paleozoic time. This will provide insights into their origins, times of accretion, and movements before, during, and after accretion. Among these terranes are former volcanic islands containing potential for metal sulfide and gold deposits, former oceanic crust that may contain scarce strategic minerals such as chromium, and ancient continental fragments for which mineral deposits might be predicted by correlation along the orogen and across the Atlantic Ocean.

The following areas are suggested for detailed mapping: (1) terranes on opposite sides of the Nonesuch River - Norumbega fault zone in the Liberty area of coastal Maine; (2) the Milford-Dedham zone, southeastern Massachusetts, especially the Milford antiform and Fall River - New Bedford areas on opposite sides of the Narragansett Basin; (3) the Raleigh-Goochland terrane, including the adjacent Carolina slate belt, from about the James River in Virginia to north-central North Carolina; (4) the Milton belt from Winston-Salem, North Carolina, into Virginia; (5) the Carolina slate belt east of Ashboro, North Carolina; and (6) the area west of Statesville, North Carolina.

Paleotectonic environment of Paleozoic basins. Detailed geologic mapping accompanied by sedimentologic and stratigraphic analyses is necessary in order to understand the depositional regime as well as to recognize the effects of gentle tectonism or to correlate geologic structures with the major tectonic episodes. These features in turn control the formation and distribution of coal, oil, and gas resources.

The following areas are suggested for detailed mapping: (1) Silurian-Devonian rocks of the Connecticut Valley basin of eastern Vermont; (2) pre-Silurian rocks of southeastern New York, a major Appalachian recess; and (3) the Ordovician strata of the Nashville Dome, Tennessee.

History and tectonic setting of magmatic belts. By understanding the distribution-composition-volume relations of the igneous rocks of the Appalachian region through time and by comparing them with modern analogues, we may be able to interpret better the tectonic history of the region and have a better framework in which to search for ore deposits. Detailed geologic mapping is needed in selected areas and should be accompanied by petrochemical, isotopic, and geophysical studies.

The following areas are suggested for detailed mapping: (1) the Ordovician volcanic belt of Aroostook and northern Piscataquis Counties, Maine; (2) the Devonian Piscataquis volcanic belt of Piscataquis and Somerset Counties, Maine; (3) granitic plutons in a transect across northern Vermont, New Hampshire, and southeast across the Sebago batholith in Maine to the coast; (4) Middle Ordovician or Silurian(?), largely mafic volcanic rocks of the Barnard Gneiss, eastern Vermont; (5) mafic plutons of western Connecticut; and (6) the Roanoke Rapids complex, from Halifax County, North Carolina, to Brunswick County, Virginia.

Characterization and delineation of fault zones. Fault zones of different ages and types are widespread throughout the Appalachian region. Our knowledge of their ages, magnitudes, and directions of movement is limited. The characterization and delineation of fault zones is essential to understand their regional geologic history and to define earthquake hazards for siting dams, nuclear power plants, and waste-storage facilities. In addition, mineralized fault zones in the region are sources of metal sulfides, gold, uranium, magmatic lithium, and tin.

The following areas are suggested for detailed mapping: (1) the Norumbega fault zone of eastern Maine; (2) the Clinton-Newberry and Bloody Bluff fault zones of eastern Massachusetts; (3) the Spotsylvania fault-lineament, Virginia; (4) any of several fault zones of the Alleghanian-age eastern Piedmont fault system, especially the Nutbush Creek and Hollister fault zones, North Carolina, and Goat Rock fault zone, Alabama-Georgia; (5) the Middleton-Lowndesville fault zone, Georgia - South Carolina; and (6) faults associated with terrane boundaries, thin-skinned thrusting, and Mesozoic extensional basins that are discussed under those headings.

Processes of thin-skinned tectonics. A thin-skinned style of deformation in the Appalachian foreland has been hypothesized for decades and in recent years confirmed by drilling and seismic reflection profiling. Nevertheless, problems remain as to the causal mechanism(s) and variations in style, timing, and sequence of deformational events. These problems can be addressed by detailed mapping of critical areas, particularly if augmented by seismic reflection and other geophysical data. In addition, geologic maps are needed in regions of thin-skinned tectonics as a basis for oil and gas exploration and coal resource studies.

The following areas are suggested for detailed mapping: (1) the Green Pond syncline, New York - New Jersey; (2) the Lackawanna syncline, Pennsylvania; (3) the Juniata culmination of central Pennsylvania; (4) the central Hamburg klippe, southeastern Pennsylvania; and (5) the southeastern end of the Mountain City window and adjacent Blue Ridge, Tennessee - North Carolina.

Fault-bounded Mesozoic extensional basins. Rifting that produced the present North Atlantic Ocean also produced extensional basins of early Mesozoic age in eastern North America. Continental red beds and lake deposits filled these basins during extension about 240 to 200 Ma. Recent seismic reflection profiling, deep drilling for hydrocarbons, and specialized geologic studies have revealed a close association between ancient faults and the zones along which extensional movement has occurred. Reactivation of these ancient faults may account for some of the current seismicity in the region. Geologic mapping is needed to understand the fault history, geologic history, and geometry of these basins, thereby contributing to evaluation of earthquake potential and of potential resources such as uranium, copper, nickel, platinum, cobalt, construction materials, and groundwater.

The following areas are suggested for detailed mapping: (1) faults through the lower Hudson River Valley north to Lake Champlain in Vermont and in the footwall blocks of the Newark basin; (2) areas of border-fan deposits in the Portland Formation of the Hartford basin, Connecticut-Massachusetts, and in the Brunswick Formation near High Bridge and Gladstone, New Jersey; (3) the narrow neck in Pennsylvania connecting the Gettysburg and Newark basins; (4) the southern Gettysburg basin, Pennsylvania; (5) the Renan fault block area of the Danville basin, Virginia, and the northern end of the Durham basin, North Carolina.

Cenozoic crustal movements. Crustal deformation has continued through the Cenozoic in the Appalachians. Evidence for this deformation includes uplifted marine terraces and former glacial-lake shorelines, late Cenozoic movement on ancient faults, and seismicity concentrated along structural boundaries. Vertical isostatic uplift due to glacial unloading since the late Wisconsinan continental glaciation ranges from more than 350 m in northern New England to zero at an uncertain distance south of the glacial margin. Examination of former glacial-lake shorelines indicates that uplift lagged behind ice retreat by as much as 5,000 years and that uplift rates may have been as great as 10 cm/year.

The largest deformation south of the glaciated region appears to be differential uplift between the Blue Ridge and Piedmont that may indicate an eastward tilt. Cenozoic uplift rates can be estimated from various isotopic ages of minerals that record different cooling temperatures. By assuming dynamic equilibrium among uplift, weathering, and erosion, erosion rates can be estimated from ^{10}Be inventories of residual weathering profiles, residual soil characteristics, and chemical weathering rates. Geologic maps are essential in selecting transects for testing the areal variation of these rates. Application of isotopic techniques to minerals and soils requires knowledge of bedrock mineralogy across the Piedmont and Blue Ridge.

The following areas are suggested for detailed mapping: (1) surficial geologic mapping, with particular attention to the elevation of glacial-lake shorelines in (a) the Hudson Valley of New York, (b) the Merrimack Valley in New Hampshire, and (c) along coastal Massachusetts, New Hampshire, and Maine; and (2) bedrock mapping as a precursor for selecting areas to study recent crustal deformation and faulting by comparing Cenozoic uplift rates; areas adjacent to the Baltimore Canyon trough, the Cape Fear arch, and the southeast Georgia embayment are of particular interest.

Quaternary cycles of deposition and erosion. The ages of multiple glacial and interglacial deposits in New England, and fluvial, colluvial, and residual sediments south of the glacial border are poorly known, so that these units cannot be used to confirm climatic cycles indicated by the marine oxygen-isotope record. Detailed surficial geologic maps of the entire upper Cenozoic section, which is as thick as 300 m in the southern New England islands including Long Island, would establish reliable correlations among, and absolute ages of, some of these units. Ages of upper Cenozoic nonglacial sediments to the south can be estimated by integrating soil characteristics and new geochemical techniques with stratigraphic analyses. New studies can provide a comprehensive overview of Cenozoic climatic and tectonic events across the eastern U.S. The older glacial units locally include sand and gravel resources; fine-grained marine units on the coastal islands and thick till units on the mainland are aquicludes and some are used for sanitary landfills.

The following areas are suggested for detailed mapping: (1) coastal islands of the "terminal moraine" belt; (2) the New River and Tennessee River basins and parts of the upper Ohio River basin; and (3) upstream remnants of terraces that are graded to multiple marine interglacial terraces in the tidewater river basins of the Coastal Plain.

Late Wisconsin ice-sheet retreat. Laurentide ice-sheet deglaciation in eastern North America was closely related to calving-bay erosion and ice-surface drawdown in its marine-based areas. A new estimate of the time of deglaciation in New England, 19,500 to 13,000 years B.P., is suggested by correlated ice-margin retreat positions and by sparse carbon-14 dates. Regional ice-margin retreat positions based on detailed maps in southern New England indicate northward acceleration of rate of retreat. In northern New England, reconnaissance maps indicate a greater topographic and marine-drawdown effect on ice-sheet decay, notably in northern Maine where a detached ice cap of unknown configuration has been suggested. Resolving the mode of retreat for ice-sheet margins of divergent glacial lobes or ice-cap borders depends on new detailed surficial geologic maps. Glacial sand and gravel deposited during the retreat are the principal mineral resources of the region as well as the chief source of water for rural towns.

The following areas are suggested for detailed mapping: (1) Long Island, New York; (2) the area of long eskers and suggested ice-cap stagnation deposits in northern Maine, and glacial lake basins in western Maine; (3) glacial lake successions in the upper Connecticut River valley and in tributary basins in New Hampshire and Vermont; (4) the Hudson-Champlain lowland and tributary basins; and (5) areas of marine submergence and dateable deposits of the Champlain Sea and the Presumscot Formation in Vermont and central Maine, respectively.

G. ALASKA

G1. North Slope

General Geology

The North Slope includes parts of the Arctic Coastal Plain and the northern Arctic foothills of the Brooks Range (fig. 5). The northern part of the province has relatively subdued topography mantled by Quaternary sediments; most bedrock is made up of Brookian clastic sediment, which was transported northward from the Brooks Range during Cretaceous and Tertiary time. The strata belong to the Cretaceous Torok Formation, Nanushuk Group, and Colville Group and the Tertiary Sagavanirktok Formation. Fluvial and deltaic sedimentary rocks belonging to the Nanushuk and Colville Groups are

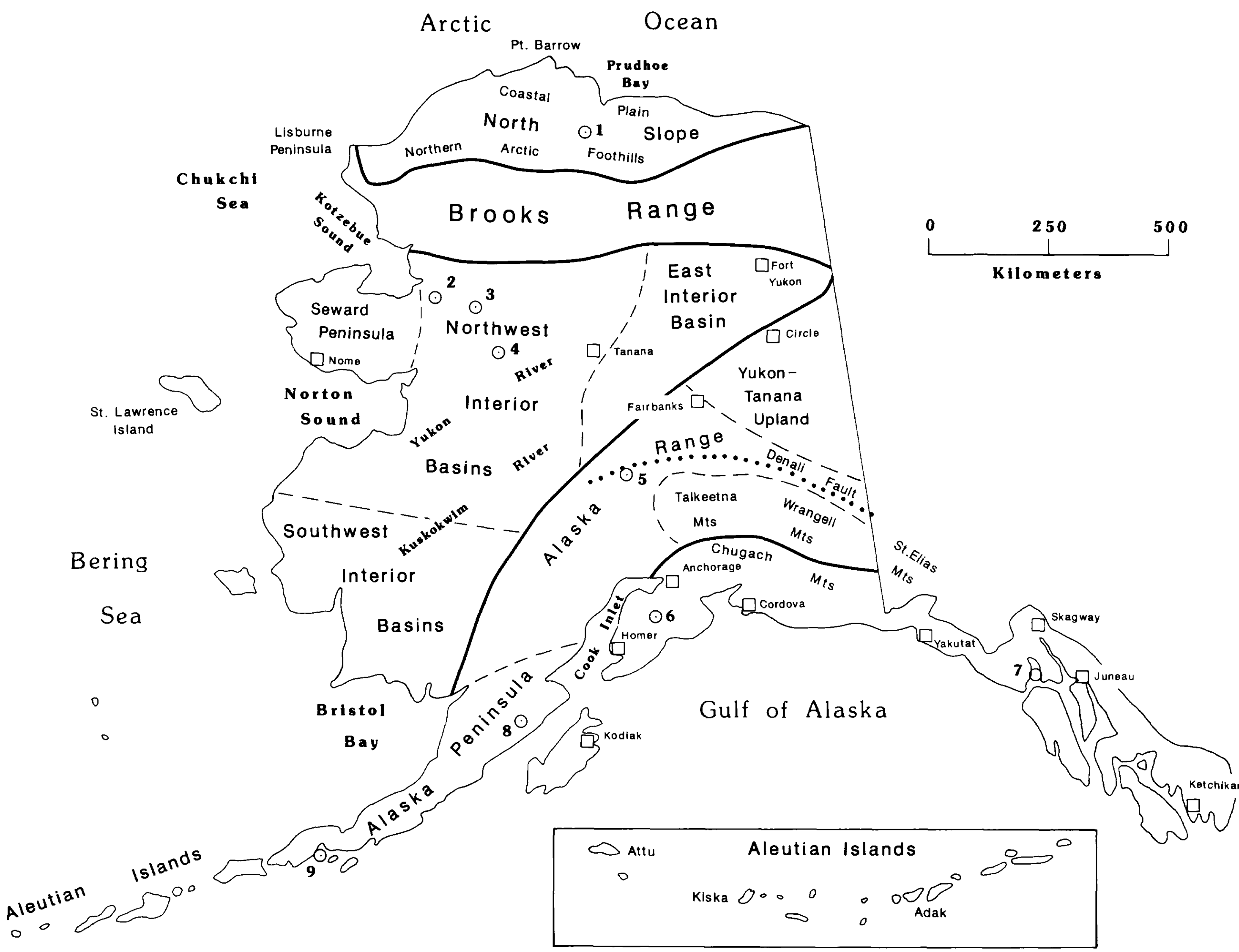


Figure 5. Physiographic provinces of Alaska, showing locations of features discussed in text. Localities identified by numbers; 1, Colville Basin; 2, Buckland River; 3, Koyukuk Valley; 4, Kokrines-Ruby area; 5, Mt. McKinley; 6, Kenai Peninsula; 7, Glacier Bay; 8, Mt. Katmai; 9, Pavlov Bay.

coal-bearing, and they are potentially a source for large quantities of coal. Sparse Triassic and Jurassic sedimentary rocks occur in the western part of the area.

The foothills contain folds and thrust faults formed during Late Cretaceous and younger compression. The strata beneath the Coastal Plain of the eastern North Slope are also complexly deformed, having been strongly shuffled by northward-directed thrust faults that root in or south of the Brooks Range. Some of these thrust faults reach the surface beneath the eastern Coastal Plain, but others extend entirely across it and underlie the Beaufort shelf as well. The age of thrusting beneath the eastern Coastal Plain ranges from at least Eocene to the present. Strata as young as late Quaternary and Holocene age are deformed by faults and folds, and the area is seismically active.

A thick sequence of structurally deformed sedimentary rocks and the presence of oil seeps and tar sands suggest that the eastern North Slope may have a significant potential for petroleum. The presence of subeconomic oil fields near the coast and its proximity to the supergiant oil and gas accumulations near Prudhoe Bay support this view.

The western North Slope was not glaciated during late Cenozoic time, but the central and eastern North Slope were overrun several times by glaciers from the Brooks Range that left moraines and extensive outwash deposits. Surficial deposits of the Brooks Range foothills consist primarily of upper Cenozoic alluvial and colluvial deposits within modern river valleys, and eolian silt and sand. Surficial deposits of the Coastal Plain include marine, alluvial, eolian, and lacustrine deposits of the Gubik Formation. The marine deposits represent at least six and possibly seven or eight late Cenozoic marine transgressions. The fossil faunal and floral contents of these deposits, calculations of temperature history based on rates of amino acid diagenesis in fossil mollusks, the presence of ice-rafted erratics of Canadian provenance in some deposits but not in others, and the present altitudes of the deposits provide potential records of the history of Arctic Ocean sea ice, permafrost, terrestrial paleotemperature variations, crustal stability, continental glaciation in Canada, and Antarctic ice surges. The entire area is underlain by permafrost except where deep lakes are present; ice content of permafrost depends upon the lithology of the surficial deposits and generally decreases with depth.

Geologic Mapping Needs

Colville basin. Parts of the Colville basin and Coastal Plain need to be mapped in detail, with geophysical surveys and drill-hole studies incorporated, in order to explain structures and stratigraphic relations in the area. Some of the areas are now being studied to evaluate the petroleum potential of the Arctic National Wildlife Range, but additional detailed lithologic and paleontologic studies tied to careful mapping are needed. The objective of these studies should be to establish an adequate understanding of the bio- and chronostratigraphy and petroleum potential of the outcropping rocks and to establish the relations between these rocks and the numerous thrust faults that disrupt them. Those areas in special need of mapping are in the eastern part of the area, namely the north front and foothills of the Sadlerochit Mountains, Marsh Creek anticline, the Niguanak Ridge area, and the headwaters of the Jago River. These studies will advance our understanding of the petroleum potential of the Coastal Plain and adjacent Beaufort shelf and will allow more detailed and meaningful interpretation of the extensive network of seismic reflection surveys that has been obtained by industry over most of the Coastal Plain.

Dinosaur bones of latest Cretaceous or early Tertiary age have been discovered in cut banks on the lower Colville River. A multidisciplinary study should be made of the exposed beds, including vertebrate and molluscan paleontology, paleobotany, physical stratigraphy, and radiometric dating. If it is confirmed that dinosaurs survived into the Tertiary, this locality would be of primary importance to global climatological models and the impact hypothesis for the worldwide extinction event at the end of the Cretaceous.

Surficial geology. Surficial deposits have been mapped at a scale of 1:250,000 for most of the North Slope. This should be completed to study late Cenozoic marine transgressions, glacial advances from the Brooks Range, gravel resources, ground ice distribution, flooding and mass movement hazards, and conditions and processes important to aid construction and transportation. The Point Lay and Sagavanirktok quadrangles should be mapped.

Where reconnaissance geologic mapping has been completed in and near the oil-producing areas in the eastern part of the province, more detailed mapping (1:125,000 scale) should be done of the Demarcation Point and Barter Island quadrangles. The reconnaissance mapping has only begun to define problems such as the relation between glaciations and glaciomarine or "cold" marine transgressions, the chronology of "normal" marine transgressions, and the relation between eolian sand movement and climatic change. Furthermore, data that can be used to interpret rates of tectonism are just beginning to be acquired. Detailed mapping and stratigraphic studies are necessary to carry this work forward and are essential to provide data for derivative maps and reports on potential permafrost-related engineering problems.

Mapping at intermediate to large scales is needed in critical areas of the North Slope. This research will differentiate various strand-line features, understand better the distribution and character of various permafrost-related periglacial features, and provide important earth-science information to decision makers concerned with engineering and environmental problems.

Overview surficial map. An overview map at a scale of 1:1,000,000, with an accompanying text, is needed to describe the upper Cenozoic surficial deposits and their history on the North Slope. This work would involve making stratigraphic, geochronologic, and paleontologic studies of critical sites throughout the Arctic Coastal Plain and northern foothills to solve problems identified during reconnaissance and large-scale mapping. The overview will allow stratigraphic correlations across this vast area. The accompanying report would include discussions of the depositional, geomorphic, climatic, tectonic, and sea level history of the North Slope, and a description of the special environmental problems of this region that are caused by permafrost, ground ice, and frost action.

G2. Brooks Range

General Geology

The Brooks Range is an uplift of Precambrian through Lower Cretaceous rocks, flanked on the north and south by successor basins of Cretaceous and Tertiary clastic sedimentary rocks. The range was formed during the Late Jurassic and Early Cretaceous Brooks Range orogeny, which was characterized by northward-directed thrust faulting. The Lisburne Peninsula to the west also was deformed by an orogeny in Early to Middle Cretaceous time, during which the rocks were thrust from west to east.

Uplift accompanied and followed the Brooks Range orogeny, and it provided the source area for clastic sediments (Brookian rocks) that were deposited in the foreland Colville basin to the north. Continued north-south compression caused folding and some thrust faulting of the sedimentary rocks in the southern Colville basin, which now form the foothills on the northern flank of the Brooks Range. A basin on the southern side of the Brooks Range also was filled during the Cretaceous and subsequently deformed.

The central Brooks Range consists, from south to north, of the southern range, range crest, range front, and northern Arctic foothills. Metamorphosed pre-Mississippian rocks, ranging from slate and phyllite to schist, underlie the southern range. These rocks are structurally overlain along the range crest by Devonian to Permian sedimentary rocks that have been telescoped and transported northward. The presence of at least two major time-equivalent stratigraphic sequences in the area demonstrates that some of the rocks underwent large northward transport. A system of frontal thrust faults emplaced the rocks of the range crest on complexly deformed Devonian to Lower Cretaceous rocks that underlie the foothills along the range front. The rocks along the range front include broken formations, melanges, and possible olistostromes. The northern Arctic foothills are underlain by Cretaceous sandstone and shale.

In the eastern Brooks Range, the southern range consists of Precambrian to at least Devonian metamorphic and igneous rocks, and the metamorphic belt is divided into a southern "schist belt" and a northern "Skajit belt." South of the schist belt, a southward-dipping thrust fault separates the schist belt from the overlying Angayucham terrane of Devonian to Jurassic mafic volcanic rocks and immature sedimentary rocks. Structurally above the Angayucham terrane on the southern side of the Brooks Range are klippe of ultramafic to mafic plutonic rocks that are probably the lower parts of an ophiolitic sequence, the Misheguk Mountain allochthon. Cretaceous clastic sedimentary rocks derived from the Brooks Range unconformably overlap the schist belt, Angayucham terrane, and Misheguk allochthon, or they are thrust over them. The Skajit belt is structurally separated from overlying allochthonous rocks by a northward-dipping fault. In addition to the schist belt and the Skajit belt, seven major allochthons of Devonian to Cretaceous sedimentary rocks have been interpreted in the western Brooks Range.

Rocks in the eastern Brooks Range can be grossly subdivided into three depositional episodes: Franklinian rocks of metasedimentary and metaigneous origin and Precambrian through Devonian age beneath a widespread pre-Mississippian unconformity; rocks of sedimentary origin and Late Devonian through Early Cretaceous age that include clastic rocks derived from source areas north and east of the Brooks Range; and Brookian clastic strata derived from the Brooks Range. At least five major fault-bounded tectonic units formed during a major south-over-north thrusting in the eastern Brooks Range, with cumulative tectonic shortening on the order of hundred of kilometers. Strata in each tectonic unit are generally significantly different from coeval strata in other tectonic units. The tectonic divisions of the eastern Brooks Range are, in order from structurally lowest to structurally highest: (1) North Slope terrane, correlative with Prudhoe Bay and the rest of the North Slope province; (2) Porcupine terrane containing sedimentary rocks that are coeval with Franklinian and Ellesmerian strata and Tertiary volcanic rocks; (3) Endicott allochthon; (4) the Christian River sequence; and (5) the Christian complex of mafic volcanic rocks and graywacke and a mafic to ultramafic pluton.

Natural resources in the central Brooks Range include coal in the northern Arctic foothills. Oil and gas probably occurs in the northern Arctic foothills, southern Arctic foothills, and possibly in overthrust rocks beneath the Brooks Range. Phosphate and barite occur in the southern Arctic foothills, lead-zinc deposits may occur in some parts of the southern Arctic foothills and Brooks Range, uranium deposits may occur in some parts of the northern Arctic foothills, and placer gold is present in the southern range.

The Brooks Range has a long and complex glacial record that dates back to late Tertiary time. Glaciers flowed north and south through deep troughs to terminate at and beyond both flanks of the range. Northward-flowing glaciers occupied short and steep troughs; they generally terminated in separate tongues confined by massive lateral moraines as high as 350 m. Southward-flowing glaciers coalesced into piedmont lobes that filled valleys beyond the southern flank of the range. Lakes were dammed by advancing glacier ice in some southern valleys, and elongate lakes later formed behind end moraines as the glaciers retreated.

The Brooks Range today is an area of active alpine processes. Mass wasting ranges from episodic landslides, rockfalls, and snow avalanches on steep slopes near valley heads to slower, more continuous, and more widespread flowage of rock, silt, and debris. Aufeis forms along many streams, especially where springs and seeps issue from fractures or solution passages in bedrock or where irregularities at the interface between rock and sediment force water to the surface. Damaging floods can occur on alluvial fans or within confined mountain valleys. Numerous cirque glaciers in the area provide a sensitive record of past climatic changes spanning 5,000 years or more. Rock glaciers are abundant in cirques and along the bases of steep valley walls. In the eastern Brooks Range, immature glacier and valley systems, irregularities in the Quaternary glacial record, local deflections in Pleistocene snowlines, concentrations of earthquake epicenters, and deformed Holocene sediments all indicate that tectonism persisted through late Pleistocene time and probably continues today.

Land use in the region is concentrated along the Dalton Highway and in gold placers of the Koyukuk valley. The highway, with the associated Trans-Alaska pipeline, comprises the principal existing transportation corridor across the Brooks Range. The placer deposits, from which gold has been mined since early in this century, occur along the South and Middle Forks of the Koyukuk River and in a belt that extends from east of Chandalar Lake to west of Wiseman.

Geologic Mapping Needs

Central Brooks Range. Little geologic mapping at scales larger than 1:125,000 has been done in the central Brooks Range. Identifying and evaluating petroleum and other resources cannot be undertaken without accurate cross sections. Collecting detailed structural, stratigraphic, and age information is necessary to construct balanced cross sections across the central Brooks Range, requiring geologic mapping at 1:63,360 scale in selected transect studies across the province. Wherever possible, the transects should be located where well data, seismic reflection data, and other geophysical data are available.

Igneous complexes in the Misheguk Mountain allochthon. Petrologic and isotopic work within the ultramafic and mafic parts of plutons in the Misheguk Mountain allochthon of the western Brooks Range would help to characterize their environment of formation and their age. Also needed are studies of the felsic rocks associated with these bodies and metamorphic aureoles around some of the bodies.

Hub Mountain pluton. The Hub Mountain pluton of the western Brooks Range is surrounded by Precambrian and Paleozoic strata. These are the westernmost exposures of Precambrian rocks in the Brooks Range, but the relations of the rock units are poorly known. There is a possibility of finding evidence of an early Paleozoic or late Precambrian metamorphic and structural event through investigation of this area. This study would be enhanced through comparison with similar Precambrian and lower Paleozoic strata in the northeastern Brooks Range and with the Doonerak fenster in the central Brooks Range.

Mississippian locality near Shishakshinovik Pass. At Shishakshinovik Pass in the western Brooks Range, Mississippian strata of the Kayak Formation and Lisburne Group overlie conglomeratic rocks that probably are correlative with the Kekiktuk Conglomerate and are in direct contact with a granitic pluton. Detailed mapping is needed to determine the relations between the pluton and the conglomeratic rocks and to check the correlation of the conglomerate. Metasedimentary rocks north of the Mississippian strata should be studied to determine whether they are correlative with the Sadlerochit Group.

Zinc-lead-silver deposits in west Brooks Range. The geology near several known or suspected zinc-lead-silver occurrences should be mapped at a large scale to characterize the stratigraphic and structural setting of the deposits. Some occurrences that are fairly well exposed and might yield considerable information include: (1) the Red Dog zinc-lead-silver district, (2) the Ginny Creek zinc occurrence, and (3) the area of the Kivivik Creek zinc-lead-silver geochemical anomalies.

East Brooks Range. There is a need for updated regional mapping to reflect increased understanding of the stratigraphy. Geologic mapping at a scale of 1:63,360 or larger is needed to determine the magnitude of tectonic compression. Mapping poorly explored areas would add the most to regional understanding. In the Table Mountain quadrangle, mapping the different facies of the Endicott and Lisburne Groups will help in a tectonic reconstruction of the eastern Brooks Range and in evaluating metallic mineral resources. In the Coleen quadrangle, lithologic and paleontologic information from the Christian River sequence and the Porcupine terrane would add to regional understanding of the Brooks Range and the geometry and timing of tectonic events in the Interior Basins south of the Brooks Range.

Areas that might justify additional large-scale mapping include: (1) the mafic and ultramafic plutonic body in the Christian complex and its relationship to the surrounding volcanic rocks, and (2) Precambrian through lower Paleozoic rocks in the northern Romanzof Mountains where possible tectonic units of Cambrian and Ordovician rocks that contain coeval but distinct facies occur. In addition, the Bathtub syncline in the southern Demarcation Point quadrangle contains thrust-transported Brookian strata that were deposited far south of the Brookian rocks in the Arctic National Wildlife Range. Comparison between the Bathtub syncline and the North Slope would help characterize facies trends in the Brookian section. Finally, the Bear Mountain stock in the Table Mountain quadrangle needs to be studied for its association with potential tungsten deposits.

Surficial geology. Detailed maps of surficial deposits exist only in a few parts of the Brooks Range, and large areas have not been mapped in reconnaissance. Mapping at 1:250,000 scale should be completed in the western and eastern Brooks Range. In addition to usual applications to resource assessment, mitigation of geologic hazards, and land-use management, the surficial geologic maps would provide data essential for determining rates, mechanisms, and history of late Tertiary through Holocene regional tectonism.

More detailed (1:125,000 scale) mapping is required for deposits and landforms associated with glacial Lake Noatak and its outlets in the western Brooks Range. These maps would show shorelines, shore deposits, outlet channelways, and features created by outburst floods. They should be accompanied by profiles of isostatically deformed shorelines and sections showing lake stratigraphy as exposed in river bluffs. Mapping of selected coastal areas in the western Brooks Range at large to intermediate scale (1:24,000 to 1:125,000) should include eastern Kotzebue Sound, a key area for determining the Quaternary history of the Bering land bridge region, and Cape Krusenstern, where coastal erosion is endangering a unique assemblage of archeologic sites.

Detailed mapping is needed in three areas of particularly intensive present or anticipated land use in the central Brooks Range: (1) the Dalton Highway/trans-Alaska pipeline corridor; (2) the Wiseman mining district, to provide data on erosion history and drainage changes in determining origin and distribution of placer deposits and to aid siting and designing settling basins; and (3) the Gates of the Arctic National Park and Preserve, where maps should be updated and revised.

G3. Interior Basins

General Geology

The Interior Basins province south of the Brooks Range is divided into four parts, the Seward Peninsula in western Alaska, the northwestern Interior Basins in central Alaska, the southwestern Interior Basins in southwestern Alaska, and the eastern Interior Basin south of the eastern Brooks Range. Of these, the Seward Peninsula consists of two terranes: (1) central and eastern and (2) western. The central and eastern Seward Peninsula terrane is composed of Precambrian(?) and lower Paleozoic schist and marble, metamorphosed to blueschist facies in Late Jurassic or Early Cretaceous time. The metamorphic rocks are intruded by three suites of granitic rocks. Cenozoic basins formed on crystalline bedrock contain coal and uranium deposits and plateau basalts. Abundant placer gold is associated with the blueschist-facies metamorphic rocks, along with minor deposits and occurences of lead, zinc, and silver. The western Seward Peninsula terrane is composed of Ordovician to Mississippian limestone, argillaceous limestone, dolostone, and argillite that are cut by Upper Cretaceous tin granite. These rocks probably have a thrust relation to schist of the central Seward Peninsula.

Glaciers of at least four glaciations advanced from the low mountains of the Seward Peninsula toward the coast, where their deposits overlapped marine deposits or were truncated by marine erosion. Beneath these four deposits are an older drift of Iron Creek glaciation and a subjacent marine deposit. Erratics found within and beyond the limits of the Iron Creek drift may be of an even older Pliocene glaciation. The chronology developed on stratigraphic evidence from many localities on Seward Peninsula and in the Bering Strait region is extremely important to students of the migration of early man from Asia to North America across an alternately dry and inundated Bering land bridge.

The northwestern Interior Basins are underlain by seven pre-middle Cretaceous lithotectonic terranes that were assembled by Early Cretaceous time and subsequently were overlapped by Upper Cretaceous terrigenous sedimentary rocks. All of these rocks were subjected to widespread magmatism in Late

Cretaceous and Cenozoic time. Plateau basalt of late Cenozoic age occurs along the Bering and Chukchi coasts. All pre-Upper Cretaceous rocks in the area are tightly folded and broken by closely spaced high-angle faults. Uppermost Cretaceous to lowest Tertiary rocks are broadly warped, and younger ones are essentially undisturbed. The area is transected by three east- and northeast-striking fault systems, the Kobuk, Kaltag, and Nixon Fork-Iditarod. All three systems are believed to have had large-scale strike-slip movement but this is well-documented only for the Kaltag system.

Loess probably is the most widely distributed sediment of Quaternary age in the northwestern Interior Basins, where it forms a mantle that is locally more than 60 m thick and covers most areas below elevations of 300-450 m. The loess was blown from the vegetation-free flood plains of braided glacial rivers. A large part of the loess has been washed into valley bottoms to form thick silt deposits rich in organic matter, locally called muck. The loess can be of great economic importance because it forms the principal agricultural soils of Alaska. Because of its high ice content, the loess and muck present serious ground-settlement problems when their thermal regime is disturbed by construction activities and the ground ice is allowed to melt. Coarser deposits such as sand and gravel occur as outwash and fluvial terraces bordering the Alaska and Brooks Ranges. The two largest areas of active dunes in Alaska are in the Koyukuk and Kobuk valleys. Large lakes existed in the middle Koyukuk River valley in middle and late Pleistocene time. Older stages of these lakes were ponded by glaciers pushing south from the Brooks Range; younger stages resulted from glacial-isostatic deformation. The valleys of the Kuskokwim and Yukon-Koyukuk lowlands are filled by thick fluvial, lacustrine, and eolian sediments of Quaternary age. The delta of the Yukon and Kuskokwim Rivers contains alternating marine and freshwater beds. The subprovince was largely devoid of glaciers in the Pleistocene, but altiplanation terraces are common on higher summits, and periglacial processes operated throughout the uplands.

The bedrock of the southwestern Interior Basins is divisible into four broad units: (1) a complex assemblage of pre-middle Cretaceous terranes; (2) a thick, widely distributed unit of middle Cretaceous clastic sedimentary rocks; (3) scattered Upper Cretaceous to lower Tertiary volcanic and plutonic complexes; and (4) scattered Pliocene to Pleistocene volcanic fields. Pre-middle Cretaceous deformation may represent convergence between several pre-middle Cretaceous terranes. Three major systems of northeast-striking faults traverse the region; their movement histories are poorly known but probably included sporadic lateral and(or) vertical motions from Cretaceous to Holocene time. Much of the present landscape probably was controlled by Neogene motion along these fault systems.

Surficial deposits of the southwestern Interior Basins include fluvial deposits of the Kuskokwim River and glacial deposits. The history of fluvial deposition of the Kuskokwim River is related to glacial advances in the nearby Alaska Range. Placer gold has been mined in the upland areas in a broad belt that extends across the region from northeast to southwest; the Nyac area has been especially productive. The Goodnews Bay area possesses the largest known placer resources of platinum-group minerals in the U.S., having produced more than 540,000 ounces of platinum-group minerals from 1934 to 1976.

The oldest rock units in the eastern Interior Basin province are Devonian and older metasedimentary and meta-igneous rocks as high as greenshist grade; minor isolated rocks of probable Precambrian age; a discontinuous belt of serpentinite, ultramafic, and mafic rocks of uncertain affinity; and rare amphibolite-facies metamorphic rocks. Younger rock units include upper

Paleozoic and lower Mesozoic basalt, gabbro, and sedimentary rocks of low metamorphic grade. A thick, rarely fossiliferous upper Mesozoic flysch sequence forms a northeast-trending belt near the south-central boundary of the region, and small isolated exposures of coeval sedimentary rocks occur in the eastern part of the region; all of these rocks are greatly deformed but essentially unmetamorphosed. Tertiary clastic and coal-bearing rocks form small, scattered outcrops in the central part of the region and are probably widespread beneath the extensive surficial cover, particularly in the Yukon Flats lowland basin. Some granitic plutons of Cretaceous and Tertiary ages are a source for gold and minor amounts of cassiterite in placer deposits, chiefly in the Livengood and Tanana quadrangles. Tertiary to Quaternary mafic and felsic extrusive and hypabyssal rocks occur in scattered exposures. The major geologic and structural features of the region are: (1) the Ruby terrane, a geanticline in the western areas with a core of igneous and mylonitic matamorphic rocks of uncertain origin; (2) the Tozitna terrane, in the central and northeastern areas, of upper Paleozoic and pre-Cretaceous Mesozoic mafic, volcaniclastic, and sedimentary rocks with radiolarian chert that overlie the Devonian and older rocks, probably in a thrust-fault relationship; (3) a belt of Precambrian(?) to Cretaceous, fault-bounded packages of sedimentary and volcanic rocks whose setting and origins are variously interpreted; (4) a part of the Alaskan segment of the northern Coldilleran fold and thrust belt; (5) a series of subparallel, northeast-striking, right-lateral transcurrent faults that in part may be splays of the Kaltag and Tintina fault systems; (6) the serpentinite belt in the Tana, Livengood, and Circle quadrangles that may mark an ancient suture zone; and (7) a Tertiary basin underlying the Yukon Flats in the east-central area.

The eastern Interior Basin area was largely unglaciated. The lowlands are underlain by fluvial deposits ranging from high-level gravel terraces, probably of late Tertiary age, to valley-fill terraces and floodplain deposits of Quaternary age and by enormous alluvial fans bordering the glaciated mountains. Sand dunes border the alluvial fans fronting the Brooks Range; are extensive Quaternary loess deposits occur between the dunes. The loess, reworked and mixed with organic material to form perennially frozen muck, fills many valleys in the uplands, concealing placer deposits; the main gold placers are the Tanana, Tofty-Eureka-Manley Hot Springs, Rampart, and Livengood areas. Lacustrine deposits are thick beneath sand dunes and alluvium at Fort Yukon, suggesting a widespread occurrence beneath the Yukon Flats. Just how the Yukon Flats lake deposits are related to the terraced spillway in the Porcupine River Valley, formed by the dumping of glacial lake Old Crow and other Pleistocene ice-dammed lakes in Yukon Territory, remains to be determined.

Geologic Mapping Needs

Seward Peninsula. An Ordovician submarine sedimentary and volcaniclastic protolith of metamorphic rocks in the central Seward Peninsula requires large-scale mapping to resolve: (1) the early Paleozoic geologic and tectonic history of the northernmost section of the North American Cordillera; (2) the nature of crustal blocks and granitic rocks (the Bendeleben, Kigluaik, and Darby Mountain Ranges would be the areas to map to address this problem); (3) the possible presence of submarine exhalative ore deposits in the western Bendeleben Range, northern Darby Range, and north-central Seward Peninsula; and (4) the structural setting and age of gold-bearing veins in the Nome gold district. The York Mountains of western Seward Peninsula would benefit from large-scale mapping, accompanied by comprehensive microfossil sampling with particular attention to structures that deform the Paleozoic rocks.

The following surficial mapping in the Seward Peninsula is recommended: (1) Reconnaissance mapping should be completed on the peninsula and 1:63,360-scale mapping should be done in important settlements, along transportation corridors, and in the larger mining areas such as the Nome coastal plain. (2) Additional investigations of the western part of the northern coast of St. Lawrence Island should be made to confirm the presence of the Nome River (penultimate glaciation) drift supposedly deposited by glaciers from Siberia, to consider the reasons for the much greater extent of ice from that source than from Seward Peninsula, and to examine evidence for two or more local glaciations at Northeast Cape and other mountains. (3) Individual glacial sequences in the York and Kigluaik Mountains need to be correlated by detailed mapping of moraines. (4) Further studies are needed of the York marine terrace to help answer questions about the history of emergence of the Bering land bridge and tectonic activity in the Port Clarence rift zone. (5) Searching for new onshore submarine and fossil beach placers is needed along the southern coast of Seward Peninsula. (6) Engineering geologic mapping and groundwater/permafrost maps would be useful for water supply, sewage disposal, construction, and other projects in villages and along transportation routes.

Norton Sound - Yukon. The first priority for mapping in the northwestern Interior Basins is for completing 1:250,000-scale mapping in the south-central part of the area. Fundamental questions that need to be resolved include: (1) the southwestern extent of the Ruby geanticline, (2) the location of the boundary between the Nixon Fork and Ruby terranes, (3) the direction and amount of displacement on the Nixon Fork-Iditarod fault system, (4) the extent and lithology of Late Cretaceous-early Tertiary volcanism, and (5) the depositional environment of the Cretaceous sedimentary rocks in the Yukon-Koyukuk and Kuskokwim basins. The 1:250,000-scale quadrangles to be completed are Norton Bay, Nulato, Ruby, Unalakleet, Ophir, Holy Cross, and Iditarod.

North Kuskokwim Mountains. Mapping of several 1:63,360-scale quadrangles in the Nixon Fork terrane of the northern Kuskokwim Mountains (north of the Kuskoswim River) is needed to extend knowledge of the biostratigraphy and carbonate petrography of thick lower Paleozoic platform carbonates and to gain a better understanding of their relations with an underlying Precambrian metamorphic assemblage. The Nixon Fork terrane represents a displaced fragment of an early Paleozoic continental margin but its paleogeographic affinities and tectonic history are uncertain. Recent mineral investigations show that carbonate rocks there have a high potential for strata-bound and skarn-type precious metal and base metal ore deposits.

Kokrines Hills - Kaiyuh Mountains. Mapping of selected 1:63,360-scale quadrangles in the Ruby geanticline can provide information on the composition, tectonic history, and interrelations of the Ruby, Tozinta, and Angayucham terranes. More information is needed about protolith ages, internal structure, and metamorphic petrology of the greenschist-blueschist metamorphic assemblages of the Ruby terrane and about the source and direction of tectonic transport of the allochthonous bodies of oceanic crustal rocks comprising the Tozitna and Angayucham terranes. The recent discovery of a major polymetal ore body in the Ruby terrane of the Kaiyuh Mountains adds economic importance to this mapping.

Waring Mountains - Buckland River. The depositional environment of the Cretaceous sedimentary fill in the northwestern part of the Yukon-Koyukuk basin is poorly known. Selected 1:63,360-scale mapping along the basin margins in the Waring Mountains and Buckland River drainage will improve our knowledge of such factors as provenance, direction of sediment transport, and environment of deposition. This information will not only improve our understanding of the depositional history but will provide further insight into the late Mesozoic tectonic history of northwestern Alaska and of the potential petroleum basins of the Chukchi Sea shelf.

Surficial geology of northwest Interior Basins. The surficial geology of the northwestern Interior Basins may be the least mapped of any area of comparable size within the United States. Complete coverage at reconnaissance scale (1:125,000 to 1:250,000) is necessary to provide a framework for land-use decisions and to identify critical areas where more detailed mapping is warranted. Such critical areas include: (1) existing and potential transportation corridors, where detailed information is needed on geologic hazards, foundation conditions, and construction materials; (2) faults that offset Quaternary sediments and therefore are potentially still active; and (3) basins occupied by Quaternary lakes, where abandoned strandlines and sediment fillings should provide a rich record of glacial, isostatic, and climatic history.

Southwest Interior Basins. Major research problems include: (1) origin and assembly of pre-middle Cretaceous terranes; (2) depositional, deformational and diagenetic histories of middle Cretaceous sedimentary rocks; (3) age, petrology, and setting of Late Cretaceous and Cenozoic magmatism; (4) movement histories (including Holocene activity) of major high-angle fault systems; and (5) evolution of Neogene landscapes, especially those of the lowlands of the Yukon-Kuskokwim delta and the Nushagak-Kvichak lowland.

Middle Cretaceous clastic rocks hold important clues to the assembly and possible strike-slip dispersion of some terranes. However, the biostratigraphy, petrography, sedimentology, and paleocurrent patterns of the middle Cretaceous strata need to be known before even rudimentary basin analysis can begin.

Upper Cretaceous magmatic rocks in this region are part of a belt that extends to the northeast and southwest. Preliminary geochemical and isotopic studies suggest that this belt was a subduction-related continental magmatic arc. However, both oceanic plate reconstructions and land-based paleomagnetic studies indicate that this belt has rotated clockwise about 45 degrees subsequent to or synchronous with eruption. Better mapping of these volcanic fields is needed to improve age and stratigraphic control for the following reasons: (1) to allow more paleomagnetic studies to document the timing of motion along major fault systems, (2) to allow petrologic modeling, and (3) to use isotopic data as tracers of underlying crustal types. The timing of faulting, the petrologic evolution, and the underlying crustal types are all important factors in evaluating the potential for mineral resources commonly associated with these volcanic fields.

Documenting movement histories on the major high-angle fault systems is important for mineral-resource potential and evaluating earthquake hazard potential. Studies along the Togiak fault would probably be most fruitful because it traverses several areas of Upper Cretaceous and Cenozoic rocks that are offset.

The chemistry and geologic setting of Plio-Pleistocene alkaline volcanic rocks suggest that they are related to extensional tectonics behind the modern Alaskan-Aleutian volcanic arc system. The volcanic rocks are particularly useful for dating Neogene fault movements and the development of Neogene landscapes. Abundant mantle inclusions are of interest for broader regional studies of mantle beneath western Alaska.

In addition to the mapping requirements listed above, four topical projects have mapping needs: (1) the Russian Mission area of the lower Yukon River region, where geologic mapping would characterize two terranes, a Mesozoic volcanic sequence and an upper Paleozoic assemblage; (2) the Thumb Mountain area Precambrian metamorphic terrane, which underwent a 1.8 Ga high-grade metamorphic event and a later (130 Ma) low-grade metamorphic overprint; (3) the Tikchik Lakes area upper Paleozoic assemblage; and (4) Plio-Pleistocene basalt on Nunivak Island needs detailed geologic mapping to provide understanding of the petrology and evolution of the province.

Yukon River valley. Modern, large-scale (1:63,360) geologic maps are available for only five percent of the eastern Interior Basin. Some of the geologic problems in the area are: (1) nature of the contact and history of interaction between the Ruby geanticline and Koyukuk basin; (2) origin and internal history of the Ruby igneous and metamorphic complex; (3) degree of similarity and original continuity between the Ruby geanticline rocks and those in the southern Brooks Ranges and Yukon-Tanana Upland; (4) continuity and age(s) of Ordovician and lower Paleozoic chert in the Livengood and Kantishna River quadrangles; (5) origin of the Tozitna "suspect" terrane and(or) Rampart Group sequence; (6) the way in which a postulated 450 km of strike-slip displacement on the Tintina fault is dispersed in central Alaska; (7) origin, stratigraphy, and ages of flysch in the south-central part of the region; (8) possible displacement of pre-Cretaceous blocks in the Livengood quadrangle from the Cordilleran belt of eastern Alaska and Yukon Territory; and (9) oil and gas potential of the Alaska segment of the northern Cordilleran fold and thrust belt and the Yukon Flats Tertiary basin.

The eastern interior basin provides a link between the major geologic elements of central and northern Alaska and those of northwestern Canada. An extensive intermediate- and large-scale geologic mapping program, coordinated with appropriate topical studies, is required. The following are examples of investigations that should be undertaken: (1) complete intermediate- and(or) large-scale mapping in the Tanana quadrangle, the Ray Mountains area, and the Rampart-Manley area to provide structural and stratigraphic information and data on the sources of economic gold and tin placers; (2) complete large-scale mapping and paleontologic and stratigraphic studies in the Livengood B-6 and B-5 quadrangles to provide lithotectonic data for interpreting the Paleozoic sequence and the Mesozoic flysch unit and to provide data on source and controls for gold mineralization; (3) complete intermediate-scale mapping and paleontologic studies in the central and western parts of the Kantishna River quadrangle to provide correlation information for a carbonate sequence and to establish better the age and setting of a chert belt now dated only as early Paleozoic; (4) topical studies and large-scale mapping of the serpentinite belt in the Tanana, Livengood, and northwest Circle quadrangles to better define the age, origin, and tectonic significance of these rocks and appraise resource potential for chromite; (5) large-scale mapping and paleontologic and structural topical studies of the Livengood C-1 and D-1 (1:63,360 scale) quadrangles to define the ages and structures included in the lower Paleozoic and Precambrian(?) sequence of the White Mountains - Cache Mountain area, determine the contact between the Paleozoic sequence and Mesozoic flysch unit, resolve the age and tectonic setting of the carbonate sequence, and evaluate the mineral-resource potential of the Cache Mountain granitic pluton; (6) intermediate-scale mapping to elaborate on the bedrock units and structures in the Beaver quadrangle to link east-central Alaska and the Koyukuk basin and southern Brooks Range, interpret the isolated block of upper Paleozoic - lower Mesozoic Rampart Group of Tozitna terrane rocks and its structural relation to adjacent Devonian(?) clastic and lower Paleozoic schistose rocks, and evaluate resource potential for gold, tungsten, and possibly other metallic minerals peripheral to large granitic bodies; and (7) intermediate- and large-scale mapping, combined with structural, stratigraphic, and paleontologic topical studies, of the Paleozoic and Mesozoic rocks along the northern and northeastern margins of the Yukon Flats basin (Chandalar, Christian, Coleen, and Black River quadrangles), where complex structures and diverse sedimentary, metamorphic, and igneous rock units constitute a critical link between the Brooks Range region and the Cordilleran fold and thrust belt of Canada.

The expected results of these studies include the following: (1) determine better age controls for several major sedimentary rock units, (2) identify major faults and structural elements, (3) collect lithotectonic data to correlate sedimentary and mafic rock units of the Rampart-Group-Tozitna terrane with similar units farther southwest in the interior regions, (4) evaluate gneissic granite and schist complexes, (5) support paleogeologic reconstructions, and (6) collect information to make mineral and energy resource and land-use evaluations.

Surficial geology of the east Interior Basin. Basic mapping needs in the eastern Interior Basin include 1:63,360-scale surficial mapping and derivative studies along transportation corridors, notably the Elliott and Dalton Highways, and along any other proposed overland transportation routes. It is also necessary in the Livengood, Rampart, Eureka-Tofty-Manley Hot Springs mining districts, and in the Chandalar area. Further mapping of the Kantishna C-5 and C-6 quadrangles at a scale of 1:63,360 is needed to define the lacustrine deposits and to determine their age and relation to sand dunes.

Mapping at reconnaissance scale (1:125,000 to 1:250,000) is needed in the northern Yukon Flats to link upper Quaternary alluvium to the respective moraines in the southern Brooks Range and to establish relations between the high-level gravel and the silt underlying Yukon Flats. Glaciation of the Hodzana Highland should be related to terraces at Yukon Flats, the glacial limit along the southern Brooks Range east of the Chandalar River needs definition, and the relation of the fan deposits in northern Yukon Flats to outwash terraces in front of the moraines should be studied.

G4. Aleutian Islands/Alaska Range

General Geology

The Aleutian Islands/Alaska Range province consists of four regions, discussed below from west to east: Aleutian Islands/Alaska Peninsula, Alaska Range, Talkeetna Mountains/Wrangell Mountains, and Yukon-Tanana upland. The first of these, the Aleutian Island/Alaska Peninsula area, is an active middle Tertiary to Holocene volcanic arc superimposed on a Mesozoic magmatic arc of thick, mainly marine forearc sedimentary rocks and nonmarine lower Tertiary sedimentary and volcanic rocks. The entire area is part of an allochthonous terrane that was accreted to Alaska in early Mesozoic time and is referred to as the Peninsular Terrane. The terrane is bisected by the high-angle Bruin Bay fault, which extends along the western side of Cook Inlet for about 600 km. Earthquakes common throughout the region are caused mainly by the underthrusting of the Pacific plate beneath the volcanic arch bordering the Aleutian Trench. The Shumagin seismic gap occurs near the southwestern end of the Alaska Peninsula. Deposits of gold, silver, copper, lead, zinc, and molybdenum are associated with upper Tertiary hypabyssal intrusions in the province, and coal deposits of Late Cretaceous and early Tertiary age and minor amounts of oil and gas are present.

Most of the landforms in the western part of the Aleutian Islands/Alaska Peninsula area were formed by Quaternary glaciers. Deposits are late Wisconsin in age, but at least four major glaciations occurred. The highest mountains of the region are volcanic and most support glaciers.

The Alaska Range exposes a wide variety of bedrock units and also contains the Denali fault, interpreted by some workers as a major right-lateral strike-slip fault, possibly derived from an older accretionary suture. Along its east part, the Denali fault generally forms a major geologic boundary between accreted ocean-affinity tectonostratigraphic terranes to the south, and accreted continental-affinity terranes to the north. Extensive portions of older wallrocks in the core of the west-central Alaska Range are intruded by the upper Mesozoic to lower Tertiary Aleutian - Alaska Range batholith. Each terrane is characterized by a distinctive stratigraphy, structure, metamorphism, geologic history, and suite(s) of mineral deposits, and each terrane is bounded by major faults or sutures. Because of the lack of detailed geologic mapping and attendant specialized studies, considerable debate is occurring over the number, size, and origin of this collage of accreted terranes. Complex right-lateral Cenozoic movement along the Denali fault and Cenozoic movement along thrusts dipping into the range both north and south of the Denali fault have resulted in an intricate and complex pattern of Cenozoic and older rock units in the eastern Alaska Range. Data indicate small amounts of movement along the Denali fault in the Quaternary and large amounts of movement in the Tertiary and Cretaceous. The uplift of the Alaska Range is possibly a result of right-lateral movement along the Denali fault and locally associated thrusts dipping into the core of the range. Overall, the Cenozoic movement along major faults and older sutures in southern Alaska appears to be the result of northwest-southeast convergence of the Pacific and North American plates along the Aleutian megathrust in the northern Gulf of Alaska. Substantial lode-deposit exploration during the last decade has resulted in discovery of a belt of volcanogenic massive sulfide deposits in the southern margin of the Yukon-Tanana terrane north of the Denali fault, a series of more discontinuous island-arc-related mineral deposits and occurrences south of the Denali fault, and a series of widely scattered Mesozoic and lower Tertiary porphyry copper deposits north and south of the Denali fault.

The Alaska Range, containing the highest peak in North America (Mount McKinley, 6,226 m), forms a great glacially sculptured arcuate mountain wall. Glaciers are more extensive on the southern side of the Range, reflecting the southerly moisture source. Large braided streams flow in deep valleys in the mountains, many heading in glaciers, and large lakes occupy glaciated valleys. The Alaska Range shows the effects of repeated Pleistocene glaciations, with abundant moraines and glacial lakes in the mountain valleys. Outwash gravel plains and river terraces extend along the principal rivers. Windblown sand and silt mantle much of the lower elevations on the northern side of the range and dunes are locally present.

The Talkeetna Mountains/Wrangell Mountains area is part of the accretionary continental margin of western North America, consisting of many allochthonous and geologically disparate tectonostratigraphic terranes. These terranes, mostly of undetermined geographic origin, were accreted to the ancient North American continent in middle Cretaceous time. The largest and most significant terrane in the subregion is the Talkeetna superterrane, which developed, prior to its emplacement in Alaska, by the amalgamation of the

Wrangellia terrane (upper Paleozoic and Triassic marine and non-marine volcanic anc volcanoclastic rocks), and the Peninsular terrane (Jurassic and Cretaceous marine sedimentary and volcanic rocks and Jurassic granitic rocks). The northern half of the Talkeetna Mountains is underlain by flysch-like rocks of Early Cretaceous age that were deposited in an oceanic basin. Post-accretionary rocks of the subregion include subordinate marine sedimentary rocks of Late Cretaceous age, extensive Tertiary plutonic rocks, Tertiary non-marine sedimentary rocks, and subaerially deposited volcanic rocks. Volcanic rocks of Tertiary age occur in both the Talkeetna and Wrangell Mountains, but those of Quaternary age are largely limited to the Wrangell Mountains, where one volcano is still active.

The Talkeetna and Wrangell Mountains are major mountain masses from which glaciers moved radially into adjacent lowlands. At least two levels of glacial lakes in the Copper River basin were formed by glacier dams at the margins of the basin.

East-central Alaska is divided into two parts by the Tintina fault zone, a major northeast-striking system of transcurrent faults. Metamorphic rocks south of the fault zone are thrust faulted and complexly folded. Protoliths were largely Paleozoic sedimentary and igneous rocks. The metamorphic rocks were intruded by granitic plutons that range in age from Late Triassic to Tertiary. Unmetamorphosed felsic and mafic volcanic rocks of Cretaceous and Tertiary age are especially abundant in the southern part of the area. Serpentinized ultramafic rocks with associated gabbro and diabase, and sedimentary rocks including chert, are part of a dismembered ophiolite that was thrust over the metamorphic terrane. Placer gold is the principal metallic resource and occurrences of porphyry copper, tin, and tungsten are known. Other metals of possible significance south of the fault include molybdenum, antimony, platinum, chromium, and nickel. Asbestos deposits are known.

North of the Tintina fault system, the rocks are mostly sedimentary and range in age from Precambrian through Mesozoic. Most Paleozoic rocks are considered to have been deposited along a continental margin and then folded and faulted. It is now recognized that the northern Cordilleran fold and thrust belt extends into this area and that the area is a link between the Canadian Cordillera and the Brooks Range orogen. Some structures may be suitable for the accumulation of hydrocarbons.

East-central Alaska has dune fields along the Tanana River and extensive thick loess deposits generally below 1,000 m elevation that have proven helpful for developing the non-glacial Quaternary chronology. Above 1,000 m elevation, the rounded hills and steep-walled valleys are generally free of thick loess deposits and are subject to mass wasting due to intensive frost action, particularly above timberline. The Yukon-Tanana upland and the Canadian boundary are type localities for the study of periglacial features because both regions were glaciated only in the higher, more craggy peaks. The glaciation of the higher mountain groups included one pre-Pleistocene and four Pleistocene glaciations.

Geologic Mapping Needs

Aleutian Islands and Alaska Peninsula. Reconnaissance mapping of the Port Moller, Stepovak Bay, Mount Katmai, Afognak, Naknek, and Cold Bay quadrangles is needed, with supplemental mapping at 1:63,360 scale of important mineralized areas, such as Unga and Popof Islands east of the Alaska Peninsula and Pyramid Peak and Painter Creek on the Alaska Peninsula. Supplemental mapping at 1:63,360 scale for mineral resources and volcano-hazards evaluation are also needed for most of the Aleutian Islands, with detailed mapping of known mineralized areas on Unalaska Island. This mapping also would focus on the geothermal potential of the volcanic structures as a possible source of power. Mapping at a scale of 1:63,360 is needed in some areas of complex sedimentary rocks on the Alaska Peninsula such as Port Moller - Bear Lake, Chignik, and Katmai areas to determine the depositional environment and structure and to assess the hydrocarbon potential. This mapping also would determine the potential for development of the coal deposits at Herendeen Bay and at Chignik.

Surficial geology of the Alaska Peninsula. Detailed mapping and pebble counts in moraines are needed to determine if the continental shelf along the Pacific Ocean was a major contributor to the deposits, rather than the Alaska Peninsula mountains. The best area for this work is west of Pavlof Bay, where evidence for an offshore source is indicated. Detailed investigations in the Pavlof Bay area also should include an intensive search for radiocarbon samples. Detailed work also is needed in the Cold Bay area to correlate rocks with areas farther north. Permafrost is just one of many engineering problems; it is locally present in the northern part of the peninsula near populated areas at King Salmon, Naknek, Katmai National Park, and a number of small villages. Detailed mapping of surficial deposits at a scale of 1:63,360 is needed to provide the basis for applied engineering studies. The high mountains and numerous glaciers of the northern Alaska Peninsula pose a threat for local catastrophic debris flows and floods during and after volcanic eruptions; these areas thus need to be studied in detail. Gold has been discovered in beach sand along Beaver Bay, across Unga Strait from Unga Island; the most likely source for this is the gold-producing area on Unga Island. Detailed mapping and sampling is needed along the eastern side of the Alaska Peninsula near Beaver Bay to determine if other beaches contain gold, and to determine the source area for the gold.

North Wrangell and Nutzotin Mountains. The northern part of the Wrangell and Nutzotin Mountains has been mapped at 1:250,000 scale, with local areas mapped at 1:63,360. This area is geologically complex and contains excellent exposures of Wrangellia terrane, including large areas of the Upper Jurassic and Lower Cretaceous flysch of the Gravina-Nutzotin belt. Locally extensive Jurassic and Cretaceous plutons intrude Wrangellia with local extensive Cu-Mo porphyry deposits and gold skarns. Mapping is recommended at 1:63,360 scale for the rugged core of the northeastern Wrangell and Nutzotin Mountains. This mapping will result in basic knowledge on the distribution, nature, and origin of this type section of the Wrangellia terrane and on important skarn and porphyry mineral deposits associated with the Jurassic and Cretaceous plutons.

Parts of the east Alaska Range. Small parts of the eastern Alaska Range have been mapped at 1:63,360 scale, but more detailed mapping of this part of the Alaska Range is needed. The following three specific areas are recommended for mapping at a scale of 1:24,000: (1) south of the Denali fault and along the north-dipping Broxson Gulch thrust and related faults such as the Ann Creek and Rainy Creek thrusts for an east-west strike length of about 60 km and north-south width of about 13 km; (2) south of the Denali fault and along the north-dipping McCallum Creek - Slate Creek thrust for an east-west strike length of about 50 km and north-south width of about 13 km; and (3) north of the Denali fault along the south-dipping Hines Creek fault and adjacent McGinnis Glacier and Trident Glacier faults. This mapping will provide information on the nature and age of Tertiary and Quaternary movements along these faults and will help define the relation of these thrusts to the Denali fault. Mapping of the Broxson Gulch mining district, which contains

Cu-Pb-Zn-Au-Ag skarn, volcanic porphyry, and massive sulfide deposits, is also needed.

Detailed mapping of various mineral deposits in the following two belts is recommended at 1:12,000 or 1:24,000 scale: (1) north of the Denali fault and along a zone of Devonian volcanogenic massive sulfide deposits from the Miyaoka deposit in the west to the Roberts deposit to the east (northwestern Mount Hayes quadrangle); and (2) north of the Denali fault and along a similar zone of Devonian volcanogenic massive sulfide deposits (east-central Mount Hayes quadrangle), locally named the "Delta district" by geologists who discovered these deposits in the early 1970's. Mapping, sampling, and isotopic and geochemical studies will yield basic information on the distribution, size, grade, extent, and origin of these important and extensive Cu-Pb-Zn-Ag-Au volcanogenic massive sulfide deposits.

Parts of the central Alaska Range. Parts of the central Alaska Range have been mapped at 1:250,000 and 1:63,360 scales, but large-scale mapping is recommended for the rugged core area along and adjacent to the Denali fault; this area is about 100 km east-west and about 30 km north-south. This mapping will improve our knowledge of the nature, distribution, and age of the major bedrock units, contacts, and major faults. This information will be important to studies of Cenozoic movement along the Denali and adjacent faults, of earthquake occurrence, and of lode mineral deposits.

Healy B-6 quadrangle. The Healy B-6 quadrangle straddles the Denali fault and contains excellent exposures of Tertiary and older bedrock units juxtaposed by the fault. Patches of lower Tertiary sedimentary and volcanic rocks south of the fault are lithologically similar to the lower Tertiary Cantwell Formation, which occurs north of the Denali fault. However, available paleobotanical data provisionally suggest that the lower Tertiary sedimentary rocks south of the Denali fault are slightly younger than the Cantwell Formation. Also, limestone clasts in the sedimentary rocks south of the fault are similar to Devonian limestone cropping out north of the fault. More definitive age and fossil determinations are needed for the Devonian limestone. Large-scale mapping of the Healy B-6 quadrangle is recommended to help resolve these problems and help decipher the Tertiary movement history of the Denali fault.

West Alaska Range. Large parts of the western Alaska Range have been geologically mapped at 1:250,000 scale and a few areas have been mapped at 1:63,360 scale. Large-scale mapping of the core of this part of the range is recommended to determine the nature, distribution, and age of major bedrock units, contact, major faults, and mineral deposits and occurrences. This basic information will be important to studies of Cenozoic movement along the Denali and adjacent faults, of earthquake occurrence, and of lode mineral deposits.

Roof pendants in the Aleutian - Alaska Range batholith. Mapping is recommended for the Lake Clark B-2, B-3, B-4, and B-5 quadrangles, which contain excellent exposures of the Aleutian - Alaska Range batholith. This pluton intruded crustal rocks that are now preserved as roof pendants. Mapping the roof pendants and adjacent parts of the batholith will provide insight into the pre-batholith geology and on the nature, distribution, and origin of the batholith. The provenance and metamorphic and tectonic histories of the rocks should be determined and compared with the Chilikadrotna Greenstone of Late Silurian age in the middle of the Lake Clark quadrangle and with the Kakhonak complex of Mesozoic and possibly late Paleozoic age in the Iliamna quadrangle.

Kahiltna terrane in west and central Alaska Range. The northwestern part of the Lake Clark and parts of the Lime Hills, Iliamna, McGrath, Mount McKinley, Healy, and Talkeetna Mountains quadrangles are underlain by the Upper Jurassic and Lower Cretaceous flysch of the Kahiltna terrane. Northeast-striking lineaments, some of them known faults, divide the flysch into elongate areas, some of which may have been brought together by accretionary tectonic processes. Knowledge of the distribution, petrology, and provenance of the flysch detritus in various areas will provide clues to the geology of source areas and may indicate whether the flysch was deposited in one or several basins. Megafossils are scarce in the flysch, but recent advances in micropaleontology, particularly dinoflagellata, may provide new data for establishing the ages of various sections. Recent studies have also shown that vitrinites may be useful for determining metamorphic and deformational histories of such rocks. Most of this area is mapped only in reconnaissance at 1:250,000 scale. Selection of specific areas for mapping at 1:63,360 or 1:48,000 scale, sampling, and measurement of stratigraphic sections would provide data for determining the provenance, origin, deformation, and accretionary history of this vast area of flysch.

Surficial geology of the Alaska Range. The surficial geology of parts of the southern Alaska Range is unmapped or poorly mapped. Complete coverage at reconnaissance scale (1:250,000) is necessary to provide a regional geologic framework to tie together existing maps and to identify specific localities critical to understanding Quaternary tectonic, climatic, and glacial history. More detailed mapping is required in placer-mine areas, along transportation corridors, near communities, and near known or suspected Holocene faults. Intermediate- to large-scale maps of these areas are necessary for understanding the origin and distribution of placer deposits, delineating geologic hazards and foundation conditions in areas of intensive land use, determining amount and quality of construction materials, and assessing potential seismic hazards.

Talkeetna and Wrangell Mountains. All 1:250,000-scale sheets in the Talkeetna and Wrangell Mountains are mapped except the Gulkana quadrangle, which is currently being mapped. Supplemental mapping of parts of the Talkeetna Mountains A-3, A-4, B-3, and B-4 quadrangles at 1:63,360 scale is needed to study the age, areal extent, and contact relations of charnockitic rocks. The area also contains a poorly known lower Tertiary volcanic complex.

Supplemental mapping along the Talkeetna thrust fault in the Talkeetna Mountains C-3, C-4, C-5, and D-3 quadrangles at 1:63,360-scale would provide detailed structural information on the thrust. This would aid interpretation of the methods and mechanisms of emplacement of the Talkeetna superterrane. The mapping would also help to evaluate the earthquake hazard for the proposed Devil's Canyon hydroelectric power plant.

Detailed mapping and sampling of a belt of charnockitic rocks in the McCarthy B-5 and B-6 and Valdez B-1 quadrangles of the Talkeetna Mountains would provide information on these rocks, aiding understanding of the tectonic evolution of southern Alaska. Detailed geological, geochemical, and geophysical investigations in the Willow Creek district of the southwestern Talkeetna Mountains are needed to check the possibility that gold reserves continue to depth in the ore-bearing dike systems.

Surficial geology of the Talkeetna and Wrangell Mountains. The Talkeetna and Wrangell Mountains are currently being settled along a road net that is expanding outward from the Glenn and Richardson Highways, and a renaissance of placer gold mining is taking place. Even though the region is relatively well known, 1:63,360-scale maps of surficial deposits should be prepared of the

Nabesna A-6, B-5, B-6, and C-6 quadrangles, and glacial engineering-geologic maps should be prepared for the southwestern part of the quadrangle at a scale of 1:125,000. Quaternary mapping at 1:125,000 and 1:250,000 scales is needed in the Talkeetna Mountains. Furthermore, 1:63,360-scale quadrangles are needed because of the reservoir and damsites of the Susitna project, and because the glacial and glaciolacustrine history of the region needs to be understood. Spectacular landslides in the Talkeetna Mountains A-2, A-3, and B-2 quadrangles need to be studied. Reconnaissance mapping of the central Talkeetna Mountains at a scale of 1:125,000 is needed for possible transportation routes and the late glacial history. Additional mapping in the Gulkana C-4 through C-6 and D-4 through D-6 quadrangles is needed to tie together work in the Denali Highway area with the glaciolacustrine history of the region to the south, so as to define the extent of a Pleistocene lake and to study the older glaciations of the Gulkana Hills. Similarly, work is needed in the Gulkana B-1, C-1, D-1, and D-2 quadrangles to examine the glacial invasion of the Alaska Range foothills. Highway engineering-geologic maps at a scale of 1:63,360 should be completed along the Glenn Highway between Matanuska Glacier and Eagle River (Anchorage D-3 to D-7 and C-7). Reconnaissance mapping of the Gulkana A-1 quadrangle should be done at a scale of 1:125,000 to complete the Gulkana sheet.

East-central Alaska. Mapping (1:63,360 scale) of selected areas of Cretaceous and Tertiary granitic plutons, particularly in the western Eagle quadrangle, is needed to understand the distribution and formation of such mineral resources as molybdenum, tin, and tungsten. Mapping is also needed in the Fortymile gold mining district in the Eagle quadrangle to understand the complex structural history and sources of placer gold.

Although the Tintina fault system appears to be a fundamental crustal suture, it has not been mapped in detail. There are few data on the distribution of major splays, amounts of offset, and types and times of movements. Most areas in the Alaska part of the Tintina fault system require mapping at a scale of 1:63,360. The stratigraphy of the rocks north of the Tintina fault is poorly known. Unraveling the complex stratigraphy and structure requires mapping of the better exposed parts of the area at 1:63,360 scale, with updated mapping of the remainder at 1:250,000. All of the quadrangles that occur in the eastern parts of the Charley River and Black River quadrangles along the U.S.-Canadian border require mapping at 1:63,360 scale. The Cordilleran fold and thrust belt is an important oil and gas producer in Canada, and the Alaskan segment of the belt north of the Tintina fault has been investigated recently by geologists of energy companies. At least one area within the Alaskan segment is known to have had a thermal history favorable for petroleum generation. Better understanding of the geologic framework of the belt in Alaska, based on detailed and intermediate-scale mapping, is necessary. An understanding of the relation of this belt to other major elements of Alaskan geology bears on important geologic problems and concepts of paleogeographic reconstruction critical to developing regional mineral and petroleum exploration models for Alaska.

Surficial geology of east-central Alaska. A reconnaissance geologic study is needed along the Steese Highway as far north as Circle and along the Taylor Highway. If the maps are to be used for major road rebuilding, a scale of 1:63,360 may be preferable to a reconnaissance scale of 1:125,000. Distribution, thickness, and gold content of high-level gravel deposits, which range in age from probable late Tertiary to early Pleistocene, and studies of Tertiary and Cretaceous sedimentary rocks for fossil placers, are needed in the Circle district. Placer studies should also seek out the bedrock sources of the gold.

It has not yet been possible to clearly relate the glacial sequence through outwash deposits to the non-glacial sequence of alluvium and loess/dune sand, or to identify episodes of periglacial activity and tie them to cycles of glacial advance. Mapping should concentrate on locations throughout the subregion where these elements can be tied together in a series of key sections to be used for intraregional correlations. The higher parts of the upland are fertile areas for topical research on periglacial forms and on past and present periglacial processes; this research requires large-scale geologic mapping.

G5. Southeast Alaska

General Geology

The Southeast Alaska province consists of two major parts, the Chugach Mountains/nearby islands and the southeastern Alaska panhandle. Of these, the Chugach Mountains are made up, from south to north, of all or parts of four terranes: (1) The Yakutat terrane, which is presently being accreted to the southern Alaska continental margin along the Chugach - St. Elias and Fairweather fault systems, consists of upper Mesozoic flysch and melange in the eastern part and probably upper Paleocene to lower Eocene oceanic crust in the west. Overlying the basement is a variably deformed, thick, dominantly clastic, lower Eocene through Quaternary sequence containing coal and petroleum deposits. (2) The Prince William terrane, between the Chugach - St. Elias and Contact fault systems, consists of a highly deformed, slightly to moderately metamorphosed Paleocene and Eocene deep-sea fan complex, oceanic volcanic rocks, and pelagic sedimentary rocks cut by Eocene plutons, and it includes massive copper sulfide, gold, and base metal deposits. (3) The Chugach terrane, between the Contact and Border Ranges fault systems, consists of at least three subterranes: (a) accreted Upper Cretaceous flysch and oceanic basaltic rocks, (b) accreted and subducted(?) Upper Jurassic to Lower Cretaceous sheared melange, and (c) subducted Lower(?) Jurassic or older blueschist/greenschist. Rocks in the terrane are variably metamorphosed from greenshcist to amphibolite facies and are intruded by 50 Ma plutons and dikes containing widespread lode gold deposits. (4) The Wrangellia and Peninsular terranes lie along the northern margin of the Chugach terrane along the Border Ranges fault system. This terrane consists primarily of upper Paleozoic intraoceanic andesitic arc rocks containing associated mafic and ultramafic plutonic rocks and superposed intrusive and extrusive magmatic rocks of the Jurassic Talkeetna arc. Layered mafic and ultramafic rocks that may represent the roots of upper Paleozoic and Mesozoic magmatic arcs contain deposits of chromite and may have potential for other types of cumulate deposits.

The heavily glaciated coastal part of the Chugach Mountains rise abruptly from the Gulf of Alaska and to the east are separated from the coast by a narrow belt of elevated continental shelf. The shelf is covered by piedmont glaciers and Holocene glacial, glaciofluvial, and marine deposits and is backed by successively older rock units bounded by faults parallel to the shore. Deltas fronting the heads of fjords are loci of local waves generated by earthquake-induced failure of unstable delta faces. The inland margin of the Chugach Mountains is a fault boundary separating the Kenai lowland and Anchorage - Matanuska - Copper River area of Tertiary rocks. The region is earthquake prone. Mineral resources are sand and gravel, chromium, gold, copper, coal, and petroleum. Gold in beach placers is still being mined in the Turnagain Arm - Kenai Peninsula area. The eastern 80 percent of Kodiak Island during late Pleistocene time contained local valley glaciers and perhaps at one time an ice cap that fronted in the sea. In the western part, outwash plains front moraines and glaciolacustrine deposits that formed upvalley from them.

The "panhandle" part of Southeast Alaska has exceedingly complex geology that includes strata from the Cambrian(?) through part of the Tertiary with several significant gaps. Important events in Southeast Alaska geology include at least ten major episodes of plutonism from Silurian through late Tertiary. Metamorphic events accompany each plutonic episode, and at least two other metamorphic events do not appear to be related to plutonism. Several major deformations correspond to plutonic and metamorphic events. The area is known to contain Holocene volcanic rocks and large-displacement transcurrent faults. All of this complex geology represents pre-, syn-, and post-collision effects of the accretion of three or more terranes. Mineral deposits range from Ordovician volcanogenic massive sulfides to Tertiary gold-quartz veins.

The regional geology of the panhandle part of Southeast Alaska is best described as a central terrane (Alexander terrane) containing mostly sedimentary and volcanic rocks that range from Cambrian(?) through Late Triassic, flanked on the west by Cretaceous flysch and melange (Chugach terrane) that sutured to the Alexander terrane in Late Cretaceous time, and flanked on the east by Cretaceous and lower Tertiary rocks of the coast plutonic-metamorphic complex (CPMC). At most latitudes, the Alexander terrane is separated from the CPMC by a highly deformed flysch and volcanic rock sequence (the Gravina belt) that rests stratigraphically on the Alexander terrane and is involved in the metamorphism that characterizes the CPMC. The Chugach terrane has some granitic plutons of 50 Ma and younger; the Alexander terrane is locally intruded by plutons of several ages; and the Gravina belt and Coast complex are intruded by different suites of granitic rocks of Late Cretaceous through late Tertiary age.

Most surficial deposits of the panhandle were deposited during the last major glaciation. Succeeding deposits are high-level marine diamicton bottom deposits and related delta deposits that are as much as 200 m above present sea level, indicating the large altitudinal changes between land and sea over the past 13,000 years. The eustatic, isostatic, or tectonic origins of sea level changes are thus important to identify. The panhandle is one of the poorest known glaciated areas in the world.

Geologic Mapping Needs

Chugach Mountains. Geologic mapping at 1:250,000 scale is needed in the Yakutat, Mount St. Elias, western Skagway (outside Glacier Bay National Park), Bearing Glacier, eastern Kenai, eastern Seldovia, and Kodiak quadrangles. Large-scale mapping is needed in critical areas to address problems related to mineral deposits, geologic hazards, the tectonic evolution of terranes, and the nature of major tectonic boundaries between terranes.

Five areas are of particular interest: (1) Yakutat D-2, D-3, D-4 quadrangles, where it is possible to span the active transform boundary between the Yakutat terrane and the more stable part of North America and to obtain detailed information on an upper Mesozoic melange and flysch complex in an area of outstanding exposure. The data would help make land-use decisions in the Russell Ford Wilderness Area and evaluate the seismic potential of the Fairweather fault. (2) Mount St. Elias A-7 and A-8 quadrangles, which contain the oldest exposures in the Gulf of Alaska Tertiary province containing abundant petroleum seeps and extensive coal beds. Although the area is within the St. Elias - Wrangell National Park and therefore not open to petroleum exploration, this area provides the best opportunity to determine the source of petroleum and the structure of the Tertiary basin. This knowledge would have application to regional models. (3) Cordova B-1 and B-2 quadrangles, where study is possible of a major boundary between the Yakutat block and Prince William terrane. Understanding the bedrock geology would have implications for petroleum exploration beneath the overthrust belt and for coal resources in the Paleogene sequence. (4) Cordova D-7 and D-8 quadrangles, where the structural style of the thrust boundary between the Prince William and Chugach terranes can be studied to guide future prospecting for massive copper sulfide and lode gold deposits. (5) Seldovia C-3, C-4, and B-5 quadrangles, where the structure along the Border Ranges fault zone, the relation of chromite-bearing mafic and ultramafic rocks to that boundary, and the nature, timing, and history of accretion of the deep-sea assemblages can be studied.

Surficial geology of Chugach Mountains and nearby islands. Research tasks include identifying former positions of the glaciers and evaluating past changes in shorelines caused by tectonic, isostatic, and eustatic forces. Data suggest that a tectonic uplift event may be overdue in the seismic gap between the Prince William sound and Yakutat earthquakes. Mapping should be continued at 1:125,000 scale to evaluate outwash and fan/delta deposits as potential landslide risks, to evaluate the local glacial history in the fjord region, and to collect data on marine terraces and their ages between Prince William Sound and Icy Cape. Detailed glacial chronology studies and mapping at scales of 1:63,360 to 1:125,000 should be extended southward from Anchorage to previously mapped parts of the Kenai Peninsula. Similar scale mapping is needed between Anchorage and Milepost 100 of the Glenn Highway near Matanuska Glacier. Mapping at a scale of 1:63,360 is needed (1) from Cordova up the Copper River to Chitina and along the Tasnuna River to Thompson Pass in support of the proposed Copper River Highway; and (2) to support new road construction and development on Kenai Peninsula near Palmer, and along the Richardson Highway.

Pleistocene deposits require mapping at a scale of 1:63,360 or larger near the city of Kodiak, where the steep sea coast is locally unstable and in many places is the site of active landslides. The Pleistocene history of west Kodiak island needs study to develop a glacial chronology for the island.

Volcanic-plutonic rocks of the panhandle. These rocks, including the Pleistocene and Holocene volcanic rocks on Kruzof Island and elsewhere and the volcanic-plutonic complexes of the CPMC and the Alexander terrane, require large-scale mapping to understand the recent and current crustal evolution in this segment of the northeastern Pacific rim tectonic province, to understand transcurrent fault regimes, and to understand host rocks for molybdenum and other metallic mineral deposits. Studies of the young volcanic rocks will apply to volcanic hazard evaluation.

Coast plutonic-metamorphic complex. Several areas within the complex require large- to intermediate-scale mapping to understand plutonic events and differential uplift. These studies would aid regional metallogeny and mineral resource considerations, as would studies of metamorphism for understanding of the origin of deposits in the Juneau gold belt. The geologic mapping should be supplemented by geophysical and geochemical mapping in some areas.

Gravina belt sedimentation and volcanism. Rocks in the Gravina belt have been metamorphosed and deformed in the western part of the coast plutonic-metamorphic complex. Inasmuch as they are a key link between the Alexander terrane and the complex, their tectono-depositional environment should be investigated by large-scale mapping. Improved understanding of the Gravina belt rocks would in turn influence interpretation of gold deposits in the western part of the complex.

Chugach terrane. The Chugach terrane requires study of the depositional processes and structural evolution of the melange facies of the complex. Large-scale mapping would focus on sedimentation, syn- and post-depositional processes, and effects of the tectonic environment on sedimentation and the development of sedimentary facies. Studies of post-depositional structures will contribute to our understanding of the overall deformational regime that influenced the localization of the Chaichagof District - type gold deposits.

Alexander terrane stratigraphy and plutonism. The stratigraphy of the middle and upper parts of the Alexander terrane is not well known because the facies changes are extremely complicated, involving both sedimentary rocks and volcanic rocks. The volcanic rocks are key to determining crustal evolution of the terrane and they host large volcanogenic massive sulfide deposits. Large alkalic granitic plutons require study for information on the pre-transport and pre-accretionary crustal history of the terrane and because they are potential hosts for uranium deposits. Large-scale mapping is needed for adequate interpretation of these problems.

Surficial geology of the panhandle. Mapping surficial deposits of the southeastern Alaska panhandle requires inventorying the known locations of high-level, post-glacial marine and deltaic deposits and updating studies east of 141^{o} W long. Data from this inventory may permit correlating shorelines from one island or mainland locality to another with the aim of detecting tectonically warped shorelines. Initial plotting and study would be at a scale of 1:63,360, as would local mapping of study areas, and a final compilation would be at scales of either 1:125,000 or 1:250,000. The history of Holocene glacial advance and retreat and its effect of sedimentation in the fjords requires selected 1:63,360-scale mapping. Surficial mapping also is needed along all potential highway routes and in many communities to evaluate the rockfall, landslide, and avalanche hazards, including the wave in Lituya Bay that reached 530 m above sea level. In some areas Quaternary strata containing dated organic horizons can be used to determine past earthquake displacements.

Hawaii

General Geology

Hawaii is comprised of eight principal islands, extending west-northwest across 650 km of the north-central Pacific Ocean (fig. 6) plus several smaller uninhabited islands to the northwest. These volcanic islands, with a total land area of 16,700 km^2, are progressively younger to the east, ranging in age of latest principal volcanism from about 8 Ma on Niihau to the present (1986) on Hawaii. Because of this gradation in age, the islands also differ in physiography, from the deeply eroded terrain and highly weathered rocks of Kauai to the largely undissected shield volcanoes and relatively unweathered lava flows of Hawaii.

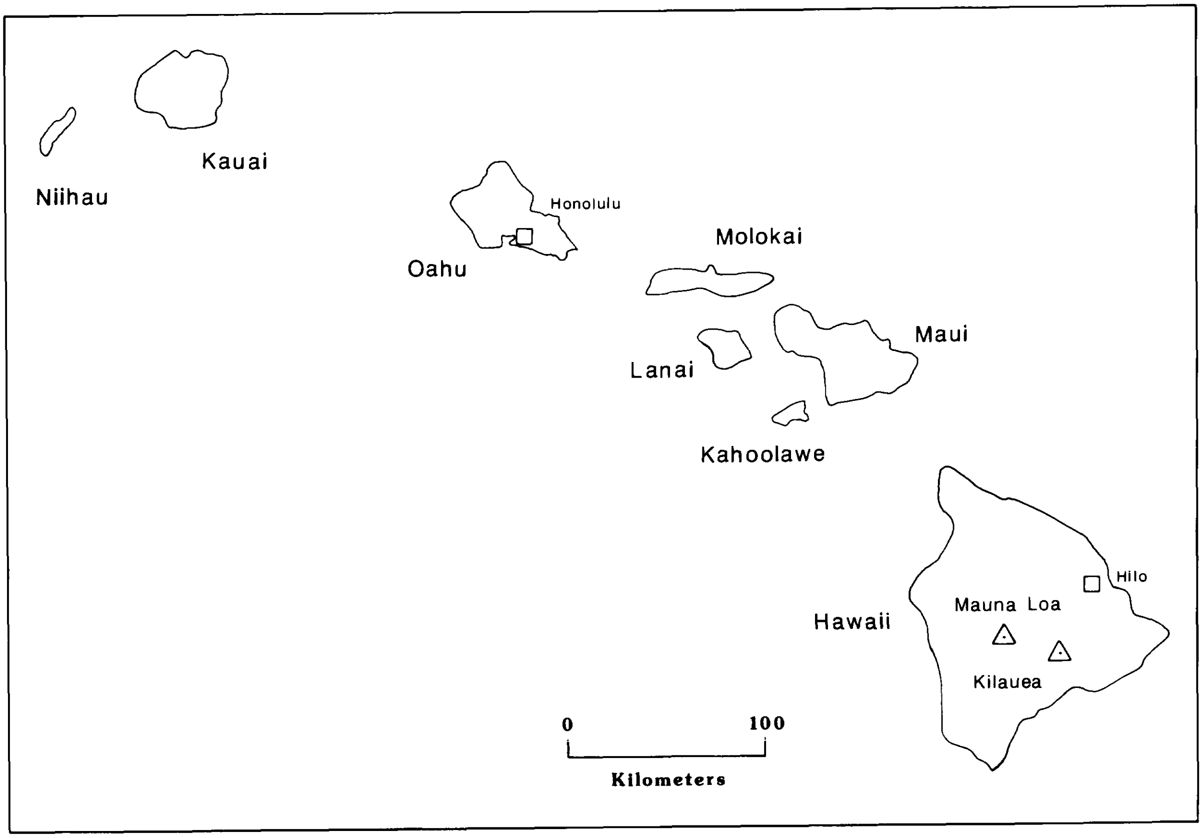


Figure 6. Principal Hawaiian Islands, showing locations of features discussed in the text.

The Hawaiian Islands occur on the Pacific plate, which is moving west-northwestward at a rate of several centimeters per year toward Asia. The widely accepted "hot spot" theory maintains that the islands formed by partial melting of the Earth's mantle above a fixed heat source beneath the plate as it moved westward during Tertiary and Quaternary time. This results in the locus of most active volcanism and island-building on the eastern end of the chain, and explains the increase in island age westward, farthest from the melting source.

Most rocks exposed on the islands are volcanic, but uplifted reefs, consolidated calcareous dunes, and alluvium also occur. The volcanic history of the islands can be characterized by a sequence of eruptive stages that produced lava of distinct chemical compositions and mineralogy. The subaerial history began with frequent large-volume eruptions of SiO_2-rich tholeiitic basalt that constructed classic shield volcanoes like Kilauea and Mauna Loa. During this stage and the subsequent alkalic post-shield stage, calderas formed and were filled with younger lava. The alkalic post-shield stage produced a thin cap of alkalic basalt and associated differentiated lava including hawaiite, mugearite, benmoreite, and trachyte, which covered the tholeiitic shield. After several million years of erosion, alkalic rejuvenated-stage lava erupted from isolated vents. An individual volcano may become extinct before the sequence is complete.

The elongate shape of all Hawaiian volcanoes suggests initial control by eruptive fissure zones. Such rift zones characterize the active Hawaiian volcanoes on Hawaii and Maui and control the loci of many seismic events. All Hawaiian volcanoes have also probably been characterized by centralized eruptive vents at some time in their development. These central vent areas are unstable, in that withdrawal of underlying magma may result in localized collapse and the formation of central calderas, typical of Hawaii's younger volcanoes. Calderas are loci of complex, multiple collapse and dike injection events, and they are well-exposed in the eroded cores of older volcanoes. With increasing age, the distribution of eruptive vents becomes more complex and less influenced by central conduits or linear rift zones; isolated cinder cones are scattered over much of the volcanoes' surfaces.

Oceanic volcanoes such as those of Hawaii commonly develop oversteepened slopes as they grow. These slopes may become gravitationally unstable, especially during times of glacially-lowered sea level. Resultant large landslides have catastrophically modified the shapes of many of Hawaii's volcanoes in the past. Active normal faults characterize Hawaii's younger volcanoes and allow more gradual adjustment of gravitational stresses within the volcanoes' flanks.

Although no minerals of commercial importance are found in Hawaii, the soils and rocks themselves are of great economic importance, and studies of soils and rock construction materials are important to Hawaii's economy. Manganese nodules, found in deep water surrounding Hawaii, may in the future be of great economic importance.

Geologic Mapping Needs

Most of the geologic mapping in the Hawaiian islands was completed prior to recognizing the chemical characteristics of the lava erupted during different volcanic stages. New mapping, coupled with geochemical studies and detailed dating of volcanic units, is essential to understanding the processes that lead to the succession of volcanic stages. The duration of the volcanic stages and intervening erosional periods is only poorly known and would be better constrained with mapping and dating of mapped units.

The transitions between stages, particularly between the tholeiitic shield and alkalic post-shield stage, are poorly understood and important to understanding the processes of magma generation beneath Hawaii. The orientations of the rift zones, size and shapes of calderas, and locations and orientations of faults have not been mapped in detail. The relations between these structural features and the various volcanic stages are only poorly known.

Regional mapping at 1:100,000 scale and detailed mapping of selected areas at 1:24,000 scale will provide the fundamental data base for determining eruption frequencies and style during the different volcanic stages that in turn are the bases for assessing volcanic hazards. Volcanic eruptions take place frequently on the island of Hawaii, and they have also occurred on Maui (ca. 1790). On both these islands, residential and resort development is in progress or is planned on historic lava flows and on areas that will certainly be affected by future eruptions. To minimize development in hazardous areas, civic officials, planners, investors, and developers need to be provided with better assessments of volcanic hazards.

Groundwater supplies were originally developed in large part to meet agricultural needs, but the rapidly expanding population of Hawaii (especially since Statehood) and the development of large resort facilities have increased the need for additional water supply. Much of this water can be provided by additional "Maui-type" wells into the Ghyben-Herzberg basal fresh water lenses beneath the higher islands, but geologic structure must be known to economically develop these wells as well as to find additional groundwater sources impounded by impermeable dikes of ash layers. The need to locate additional sources of impounded water is especially acute on Oahu, where Hawaii's population is concentrated.

Expanding power consumption in Hawaii and a desire to obtain independence from imported energy sources has motivated a great interest in exploitation of geothermal resources. Exploration for geothermal deposits in Hawaii requires knowledge of volcanic structure and magmatic systems, which is provided by both geophysical research and geologic mapping. Mapping of eruptive centers is required to indicate past heat sources and mapping of surface geology gives important information on subsurface reservoir-containing rocks.

Geologic mapping is required to identify areas of structural weakness subject to earthquake activity and areas of potential land failure. Mapping of surficial ash deposits is required to identify areas of potential seismic amplification. These needs are most critical in areas where expanding population has created development in mountainous areas, as on Oahu.

Geologic maps are a basic resource for engineering studies of substrate stability and construction activities in Hawaii. The locations of suitable rock for quarrying operations can be best determined on detailed geologic maps.

The distribution of soil types is directly related to the types of underlying rock, especially on the younger eastern islands. Ash deposits are most suitable for agricultural activities and should be depicted on geologic maps. A'a lava flows are more suitable than pahoehoe flows for most agricultural purposes; these flow types can be distinguished on detailed geologic maps.

CONCLUSIONS

The purpose of this report is to identify the important National problems that need to be resolved by geologic mapping. The emphasis in the report is on solving basic scientific questions. It is from such investigations that scientists create the data base that for many years will form the basis for solving a wide variety of societal as well as scientific problems. In the years ahead, earth-science users in the country will need increasingly detailed and sophisticated knowledge of the geologic framework of the United States, requiring significant geologic mapping for basic data acquisition. Furthermore, increased earth-science knowledge will pay such practical dividends as decreasing dependence on foreign sources of mineral and energy resources, finding water resources, lessening the impact of geologic hazards as the population increases, research on disposal of toxic and nuclear wastes and other environmental-impact concerns, making more knowledgeable land-use decisions, and increasing the geoscience data base to solve other future short-term problems in society. To systematically acquire these earth-science data requires a coordinated plan on the National level. Thus, the greater aim of this report is to help guide this National geologic mapping program.

In this report, we have attempted to identify the major areas in the country containing earth-science problems that geologic and related mapping investigations can play a major role in solving. We have not attempted to set priorities on the various topics or areas where geologic mapping is to be undertaken. This task is to be done later by various committees involving scientists from the National Academy of Sciences, the USGS, professional organizations, numerous academic institutions, State geological surveys, and industry.

Although we have confined our list of areas to be studied to onshore parts of the United States, many problems of National concern lie in areas off the coast of the U.S., such as the Exclusive Economic Zone. These are not included here because they involve geologic mapping of a nontraditional sort. Furthermore, some scientific problems can be solved and concepts learned by studying the rocks of other countries, especially those elsewhere in North America, in cooperation with foreign geoscientists.