National Park Service
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Natural Resource Program Center

Glacier National Park

Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory Digital Geologic Data for Glacier National Park

glac_geology.pdf

Version: 6/24/2013

Geologic Resources Inventory Map Document for Glacier National Park

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Geologic Resources Inventory Map Document

Glacier National Park, Montana

Document to Accompany Digital Geologic-GIS Data

glac_geology.pdf

Version: 6/24/2013

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Glacier National Park, Montana (GLAC).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

National Park Service (NPS) Geologic Resources Inventory (GRI) Program staff have assembled the digital geologic-GIS data that accompanies this document.

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About the NPS Geologic Resources Inventory Program

Background

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the Earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm

Geologic Reports: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

GRI geologic-GIS data is also available online at the NPS Natural Resource Information Reference Search Application: http://nrinfo.nps.gov/Reference.mvc/Search. To find GRI data for a specific park or parks select the appropriate park(s), enter “GRI” as a Search Text term, and then select the Search Button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: http://www.nature.nps.gov/geology/inventory, or contact:

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GRI Digital Maps and Source Map Citations

The GRI digital geologic-GIS map for Glacier National Park, Montana (GLAC):

GRI Digital Geologic Map of Glacier National Park, Montana (*GRI MapCode GLAC*)

U.S. Geological Survey Source Maps:

Carrara, Paul E., 1990, *Surficial Geologic Map of Glacier National Park, Montana*, U.S. Geological Survey. I-1508-D, 1:100000 scale (*GRI Source Map ID 2593*)

Whipple, James W., 1992, *Geologic Map of Glacier National Park, Montana,* U.S. Geological Survey, I-1508-F, 1:100000 scale (*GRI Source Map ID 1171*)

Additional information pertaining to each source map is also presented in the GRI Source Map Information (GLACMAP) table included with the GRI geology-GIS data.

Surficial Map Units List (I-1508-D)

The surficial geologic maps units present in the digital geologic-GIS data produced for Glacier National Park, Montana (GLAC) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qal - Alluvium). Units are generally listed from youngest to oldest, however, listing order adheres to how the source map author grouped surficial units based on how deposits were created (e.g., glacial or mass-wasting). No description for water is provided. Information about each map unit is also presented in the Geologic Unit Information (UNIT) table included with the GRI geology-GIS data.

Geologic Map Units

Cenozoic Era

Quaternary Period

Alluvial Deposits
- Qal - Alluvium
- Qaf - Alluvial-fan deposit
- Qac - Alluvial and colluvial deposit
- Qtg - Terrace deposit

Glaciofluvial Deposits
- Qes - Esker deposit

Glacial Deposits
- Qt1 - Till
- Qt2 - Till
- Qat - Ablation till
- Qt3 - Till

Mass-Wasting Deposits
- Qrg - Rock-glacier deposit
- Qta - Talus deposit
- Qls - Landslide deposit
- Qco - Colluvial deposit
- Qso - Solifluction and related deposit

Frost-Heaved Deposits
- Qfr - Frost rubble
- Qor - Organic deposit

Quaternary and Tertiary

Miscellaneous Deposits
- QTdi - Diamicton

Cenozoic, Mesozoic and Paleozoic Eras

Late Paleogene, Cretaceous Period and Proterozoic

- BR - Bedrock

Bedrock Map Units List (I-1508-F)

The bedrock geologic maps units present in the digital geologic-GIS data produced for Glacier National Park, Montana (GLAC) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Yh _ Helena Formation). Units are generally listed from youngest to oldest. No description for water is provided. Information about each map unit is also presented in the Geologic Unit Information (UNIT) table included with the GRI geology-GIS data.

Geologic Map Units

Cenozoic Era

Quaternary Period

Qal - Alluvium
Qc - Colluvium
Qls - Landslide deposits
Qg - Till

Tertiary Period

Tku - Kishenehn Formation, undivided
Tkp - Kishenehn Formation, Conglomerate Member of Pinchot Creek
Tkcc - Kishenehn Formation, Lacustrine Member of Coal Creek

Mesozoic Era

Cretaceous Period

Km - Marias River Shale
Kb - Blackleaf Formation
Kk - Kootenai Formation
Kbk - Blackleaf and Kootenai Formations, undivided
Ku - Sedimentary Rocks: Undivided
KJm - Mount Pablo Formation, Morrison Formation, and Ellis Group, undivided

Precambrian

Proterozoic

Zd - Diorite, diabase, and gabbro sills and dikes
Ym - McNamara Formation
Ybo - Bonner Quartzite
Yms - Mount Shields Formation
Ysh - Shepard Formation
Ypb - Purcell Lava
Ysn - Snowslip Formation
Yh - Helena Formation
Ye - Empire Formation
Ygl - Grinnell Formation
Yap - Appekunny Formation

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below. Most surficial units are grouped based on groupings (e.g., alluvial deposits) present on the surficial geology (I-1508-D) source map.

Alluvial Deposits

Qal - Alluvium (Holocene and upper Pleistocene)

al - Alluvium (Holocene)
Sand and gravel deposits and minor amounts of silt; in places silt forms thin lenses. Includes channel and overbank deposits in modern floodplain. In narrow mountain valleys locally includes small areas of colluvium. Unit consists mainly of rounded and subrounded clasts of Belt Supergroup rocks; other rock types, chiefly coarse-grained granites, are also present in minor amounts along the North Fork Flathead River. Thickness 1-5 m. (I-1508-D)

Qal - Alluvium (Holocene and upper Pleistocene)
Sand and gravel deposits locally containing thin lenses of silt. Includes channel and overbank deposits in modern floodplains, as well as alluvial-fan and terrace deposits. Unit consists mainly of rounded and subrounded clasts of Belt Supergroup rocks. Thickness 1-10 m (I-1508-F)

Qaf - Alluvial-fan deposit (Holocene and late Pleistocene)

Fan-shaped deposits of fluvial sand and gravel. In places unit contains thin lenses of silt. Unit consists chiefly of rounded and subrounded clasts of Belt Supergroup rocks. Locally includes debris-flow deposits. Thickness 2-50 m. (I-1508-D)

Qac - Alluvial and colluvial deposit (Holocene and late Pleistocene)

Locally derived deposits of silt and sand on Flattop Mountain. Unit locally includes sandy and silty sheetwash deposits. Thickness 0.5-2 m. (I-1508-D)

Qtg - Terrace deposit (late Pleistocene)

Sand and gravel deposits underlying terraces along the North and Middle Forks Flathead River and the mouths of Ole and Park Creeks. Unit consists mainly of rounded and subrounded clasts of Belt Supergroup rocks. Locally contains thin lenses of silt. Terraces range from 3 to 20 m above present stream levels. Thickness 2-10 m. (I-1508-D)

Qc - Colluvium (Holocene and upper Pleistocene)

Locally derived slope deposits consisting of unsorted, angular, gravel-size clasts in a matrix of unsorted sand, silt, and clay. Unit locally includes small areas of till, talus, rock-avalanche, and debris-flow deposits. Commonly 1-5 m thick. (I-1508-F)

Glaciofluvial Deposits

Qes - Esker deposit (late Pleistocene)

Identified in two areas: (1) along north side of Lake McDonald in the Fish Creek campground area, where deposit consists of well-sorted silty sand and gravel composed of Belt Supergroup rocks; (2) in the Railroad Creek area in southeastern corner of park, where deposit consists of sand, silt, and clay derived from the local bedrock. In both areas these deposits form sinuous ridges 0.5-1 km long and about 10-20 m high. (I-1508-D)

Glacial Deposits

Qt1 - Till 1 (late Holocene)

Unsorted subrounded to subangular bouldery rubble, consisting of Belt Supergroup rocks, and minor amounts of sand, silt, and clay. Striated rocks are common. Unit forms steep, rubbly moraines 10-50 m high in front of many of the glaciers and snowfields in the park. Unit is unweathered and supports little vegetation. Many of these moraines were deposited by glacial advances during the mid-19th century (Carrara and McGimsey, 1981, 1988; Carrara, 1987). (I-1508-D)

Qt2 - Till 2 (late Pleistocene)

Unsorted subrounded to subangular bouldery rubble, consisting of Belt Supergroup rocks, and minor amounts of sand, silt, and clay. Unit commonly forms subdued, vegetated moraines 3-10 m high immediately downvalley from t1 deposits. Unit supports thin soil, which in places contains Mazama ash (Osborn, 1985; Carrara, 1987; Carrara and McGimsey, 1988) dated at about 6,845 B. P. (Bacons 1983). Unit is thought to date from about 10,000 B.P. or slightly earlier (Carrara, 1987). (I-1508-D)

Qat - Ablation till (late Pleistocene)

Unsorted subrounded to sub-angular bouldery rubble, consisting mainly of Belt Supergroup rocks, and minor amounts of sand, silt, and clay. Striated rocks are common. This unit, deposited by stagnating mountain glaciers, forms hummocky, poorly drained deposits in valleys tributary to the valley of the North Fork Flathead River. In places this unit overlies t3 deposits, yet it is also older than some t3 deposits that lie upvalley. Thickness exceeds 40 m at some localities. This unit is in places overlain by the Glacier Peak G ash, which has been dated at about 11,200 B.P. (Mehringer and others, 1984). (I-1508-D)

Qt3 - Till 3 (late Pleistocene)

Unsorted subrounded to subangular bouldery rubble, consisting mainly of Belt Supergroup rocks, and minor amounts of sand, silt, and clay. Striated rocks are common. Found on valley floors within mountainous areas where it was deposited as ground moraine by local mountain glaciers; here, its thickness is usually 1-3 m. Also found in the valleys of the North and Middle Forks Flathead River where it was deposited as a thick blanket of ground moraine by the large trunk glaciers that filled these valleys; here, its thickness exceeds 30 m in places. Locally includes small areas of bedrock and colluvium. This unit is in places also overlain by the Glacier Peak G ash. (I-1508-D)

Qg - Till (Holocene and upper Pleistocene)

Unsorted, subrounded to subangular bouldery, rubble, consisting mainly of Belt Supergroup rocks, and lesser amounts of sand, silt, and clay. Striated rocks common. In valleys of the North and Middle Forks Flathead River, unit deposited as a thick (locally >30 m) blanket of ground moraine by large trunk glaciers that filled these valleys. On valley floors in mountainous areas, unit deposited by local mountain glaciers as ground moraine usually 1-3 m thick. In front of many of the glaciers and snowfields in higher regions of park, unit forms moraines 3-50 m high. On Boulder, Cut Bank, and Swiftcurrent Ridges, unit also includes "pre-Wisconsin glacial drift" of Alden (1912), which in places is as much as 60 m thick. Unit also locally includes small areas of bedrock and colluvium. (I-1508-F)

Mass-Wasting Deposits

Qrg - Rock-glacier deposit (Holocene and late Pleistocene)

Lobate masses of unsorted angular blocky rubble; interstices filled with unsorted sand, silt, clay, and ice. Unit occurs at the head of some cirques. Thickness 10-30 m. (I-1508-D)

Qta - Talus deposit (Holocene and late Pleistocene)

Unsorted and mainly unvegetated, angular, bouldery rubble in a matrix of sand, silt, and clay at bases of steep valley walls or cliffs. Some of the larger deposits exceed 30 m in thickness. (I-1508-D)

Qls - Landslide deposit (Holocene and upper Pleistocene)

ls - Landslide deposits (Holocene and late Pleistocene)
Unit includes large rock slumps, slump-earth flows, and rock block slides (Varnes, 1978). The size and the kind of clasts and the grain size of the matrix vary according to the bedrock units involved in the landslide. Rock slumps are common in the eastern side of the park in those areas underlain by Cretaceous sedimentary rocks. Rock block slides, although not common, are present in areas underlain by Belt Supergroup rocks. Rock slumps and slump-earth flows are common in areas in the western side of the park underlain by the soft sedimentary rocks of the late Paleogene Kishenehn Formation. Some of the larger landslides exceed 50 m in thickness and cover several square kilometers. Locally includes small areas of till and colluvium. (I-1508-D)

Qls - Landslide deposits (Holocene and upper Pleistocene)
Includes large slumps, block slides, and earth flows. Slumps are common in east side of park in areas underlain by Cretaceous sedimentary rocks. Block slides are present, although not common, in areas underlain by Belt Supergroup rocks. Block slides and earth flows are common in west side of park in areas underlain by sedimentary rocks of the Kishenehn Formation. Some of the larger landslide deposits in park exceed 50 m in thickness and cover several square kilometers. Unit locally includes small areas of till, rock glaciers, talus and colluvium. (I-1508-F)

Qco - Colluvial deposit (Holocene and late Pleistocene)

Mainly locally derived slope deposits consisting of unsorted angular gravel-size clasts in a matrix of unsorted sand, silt, and clay. Unit locally includes some small areas of bedrock and till as well as talus, rock avalanche, and debris-flow deposits. Commonly l-5 m thick. (I-1508-D)

Qso - Solifluction and related deposit (Holocene and Pleistocene)

Includes solifluction lobes, sorted polygons, and sorted stone stripes. Unit found mainly in unglaciated upland areas. Locally includes other mass-wasting deposits. Thickness 0.5-2 m. (I-1508-D)

Frost-Heaved Deposits

Qfr - Frost rubble (Holocene and Pleistocene)

Unsorted veneer of angular pebbles, cobbles, and boulders derived from the underlying bedrock by frost action. Unit found in unglaciated upland areas. Thickness commonly less than 1 m. (I-1508-D)

Qor - Organic deposit (Holocene and late Pleistocene)

Peat and organic muds. Common in the valley of the North Fork Flathead River. Thickness 2-5 m. (I-1508-D)

Miscellaneous Deposits

QTdi - Diamicton (early Pleistocene or Pliocene?)

Unsorted subrounded to subangular bouldery rubble, consisting of Belt Supergroup rocks, and minor amounts of sand, silt, and clay. Unit occurs beneath Boulder, Cut Bank, and Swiftcurrent Ridges. Striated rocks are common. In places, unit is weakly cemented by calcium carbonate. Locally, unit is as much as 60 m thick. This unit is equivalent to the "pre-Wisconsin glacial drift" of Alden (1912). (I-1508-D)

BR - Bedrock (late Paleogene, Cretaceous and Proterozoic)

Includes: (1) late Paleogene sedimentary rocks of the Kishenehn Formation, consisting of lacustrine and fluvial sediments in west side of park (Constenius, 1981); (2) Cretaceous sedimentary rocks, consisting predominantly of the Upper Cretaceous Marias River Shale, a dark-gray marine mudstone, in east side of park (Mudge and Earhart, 1983); and (3) Proterozoic rocks of the Belt Supergroup, consisting mainly of siltites and argillites and subordinate amounts of igneous rocks that occur as sills, dikes, and flows in central mountainous region of park (McGimsey, 1985; Ross, 1959; Raup and others, 1983; Whipple and others, 1984). In places, unit is mantled by small, thin patches of surficial material. (I-1508-D)

Tku - Kishenehn Formation, undivided (Oligocene and Eocene)

Generally divisible into two parts. Upper part is a sequence of brick-red, red-brown, and vermillion mudstone, sandstone, and conglomerate and interbedded gray, calcareous, sandy pebble and cobble conglomerate. Mudstone beds have yielded fossil gastropods, mammals, and palynomorphs. Maximum thickness about 1,500 m. Lower part consists of light-gray to gray-green sandstone, siltstone, mudstone, lignite, oil shale, marlstone, and sandy pebble and cobble conglomerate. Gastropod fossils prevalent throughout lower part. Maximum thickness at least 3,500 m. (I-1508-F)

Tkp - Kishenehn Formation, Conglomerate member of Pinchot Creek (Eocene)

Brick-red, red-brown, and maroon, intercalated mudstone, sandstone, and conglomerate. Locally, calcareous sandy mudstone and siltstone grade to muddy sandstone; muddy sandstone is composed of varicolored, angular to subrounded, sand- and pebble-size clasts. Pebble and boulder conglomerate beds are gray and sandy and contain abundant mudstone and sandstone matrix material; rounded and subrounded lithic clasts in pebble and boulder conglomerate beds consist entirely of angular to subrounded Belt Supergroup rocks that attain a maximum size of 2.5 m. Vertebrate fossils in some mudstone units. Conglomerate member rests conformably on the lacustrine member of Coal Creek. Maximum estimated thickness 700 m. (I-1508-F)

Tkcc - Kishenehn Formation, Lacustrine member of Coal Creek (Eocene)

Predominantly a light-gray, heterogeneous assemblage of sandstone, siltstone, mudstone, claystone, coal, oil shale, marlstone, and pebble and boulder conglomerate. Lacustrine member is informally divided into three parts, each bounded by gradation contacts. Total thickness about 1,150 m. Upper part consists typically of an interbedded sequence of marlstone, litharenite, siltstone, conglomerate, mudstone, claystone, and coal. Variegated maroon, red-brown, and gray-green color of sandy mudstone beds gives outcrops of upper part a distinctive pink cast, in contrast to the predominantly light-gray to gray color of lower and middle parts of member. Fossil gastropods and Eocene-age mammals common in mudstone beds. Thickness about 100 m. Middle part is interbedded oil shale, marlstone, litharenite, and siltstone, and lesser amounts of lignite, sapropelic coal, tuff, claystone, and mudstone. Gastropod fossils extremely abundant; plants and plant fragments, fish, insects, and mollusks also common in middle part. Fission track analysis of zircon from a tuff bed suggests an Eocene age of 43.5±4.9 Ma (analysis by Charles Naeser, written commun., 1990). Thickness about 500 m. Lower part consists primarily of (1) interbedded carbonaceous siltstone, (2) silty to coarse-grained litharenite that displays climbing-ripple and even, parallel lamination, and (3) light-bluish-gray-weathering oil shale. Lignite, mudstone, claystone, marlstone, conglomerate, and devitrified tuff beds present to a lesser extent. Eocene-age fossil leaves of Macginitea ougustiloba present in beds of litharenite. About 550 m thick. (I-1508-F)

Km - Marias River Shale (Upper Cretaceous)

Dark-gray, marine mudstone and lesser amounts of interbedded sandstone, limestone, and arenaceous shale. Ranges from 365 to 395 m thick (Mudge and Earhart, 1983). (I-1508-F)

Kb - Blackleaf Formation (Upper(?) and Lower Cretaceous)

Gray, marine mudstone and interbedded sandstone. About 260 m thick (Mudge and Earhart, 1983). (I-1508-F)

Kk - Kootenai Formation (Lower Cretaceous)

Gray-green and maroon, non marine mudstone and abundant lenticular beds of poorly sorted, greenish-gray sandstone that are locally crossbedded and contain lenticular interbeds of conglomerate. Brown to brownish-gray limestone and thin to thick lenses of coquina containing pelecypods and gastropods near top of formation. Brown, iron-stained limestone nodules common in mudstone beds. Thickness ranges from 198 to more than 305 m (Mudge and Earhart, 1983). (I-1508-F)

Kbk - Blackleaf and Kootenai Formations, undivided (Upper(?) and Lower Cretaceous)

Unit shown where parts of both formations present but too thin to map separately. (I-1508-F)

Ku - Sedimentary rocks, undivided (Cretaceous)

Lithostratigraphic units not identified or mapped separately. (I-1508-F)

KJm - Mount Pablo Formation, Morrison Formation, and Ellis Group, undivided (Lower Cretaceous and Upper to Middle Jurassic)

Units not mapped separately. See Mudge and Earhart (1983) for detailed descriptions. (I-1508-F)

Zd - Diorite, diabase, and gabbro sills and dikes (Late Proterozoic?)

Dark gray to greenish black, metamorphosed, fine to medium grained, equigranular. Abundant chlorite replaces amphibole and pyroxene; commonly pyritic. Laterally continuous sill in Helena Formation cuts up and down section locally, ranges in thickness from 16 to 90 m, and is commonly flanked by bleached zones of hornfels. Sills (0.5-65 m thick) also occur locally in Grinnell, Empire, and Snowslip Formations. Dikes intrude the Appekunny and Altyn Formations on east side of Glacier National Park and intrude the Purcell Lava and overlying strata near Granite Park (McGimsey, 1985); dikes are 3-6 m thick (Ross, 1959). Sills and dikes closely resemble Late Proterozoic intrusive rocks in west-central Montana reported to be 750±25Ma (potassium-argon age method, Mudge and others, 1968). (I-1508-F)

Ym - McNamara Formation (Middle Proterozoic)

Grayish-green siltite and argillite, commonly inter-laminated as wavy, nonparallel fining-upward couplets. Contains abundant beds of mud-chip breccia; locally, some breccia clasts and thin discontinuous laminae of argillite are silicified. Calcareous and quartzose arenite beds near base. Some calcareous siltite beds also present in lower part. Ripple marks and subaqueous shrinkage cracks common; salt casts rare. Top of formation not exposed; base of formation placed on top of uppermost red feldspathic arenite and siltite of the Bonner Quartzite. Present in southern part of park east of Mount Shields (600 m exposed) and near mouth of Coal Creek (450 m exposed). (I-1508-F)

Ybo - Bonner Quartzite (Middle Proterozoic)

Gray to pale-red, very fine grained to medium-grained feldspathic arenite and lesser amounts of interbedded siltite and dark-red argillite. Rhythmic fining-upward successions as much as 3 m thick. Large-scale channels, crossbedding, and ripple cross-lamination common. Lower contact placed at base of lowermost green feldspathic arenite bed. Exposed east of Mount Shields and near mouth of Coal Creek; thickness 250-280 m. (I-1508-F)

Yms - Mount Shields Formation (Middle Proterozoic)

At type section near Mount Shields in southern part of park, the Mount Shields Formation is informally subdivided into five members designated 1 through 5 in ascending order. Members are not mapped separately but can be recognized throughout exposures in park. Maximum thickness about 850 m. Member 5 is characterized by very thinly laminated, blackish-green argillite and some thin, lenticular beds of arenaceous siltite that are more abundant near top of member. This distinctive succession of blackish-green argillite is locally calcareous and sharply overlain by pale-green, coarse-grained, poorly sorted feldspathic arenite of the Bonner Quartzite; lower contact placed at base of lowermost interval of thinly laminated blackish-green argillite and siltite. Thickness about 9 m. Member4 consists mostly of grayish-green, fining-upward couplets of siltite and argillite and contains carbonate mostly as cement in siltite. Salt casts common, particularly in lower part. Lower contact is placed on top of uppermost noncalcareous, pale-purple siltite and argillite interval of member 3. About 17 m thick at type section but appears to thicken and contain more carbonate beds northward in park. Member 3 is mostly couplets of siltite and argillite. Siltite laminae in couplets successively change color upward from brick red in lower part of member to purplish gray in middle part to dark grayish green near top; argillite laminae in couplets remain dark red to pale purple throughout member. Salt casts and ripple marks are common, but salt casts become less abundant downward as arenite beds increase and argillite beds decrease. Lower part contains pale-purple to brick-red, very fine grained arenite similar to that in member 2 but in equal proportion to siltite and argillite. Base of member 3 is placed on top of uppermost bed of stromatolitic limestone of member 2. Member 3 is thickest (450 m) member of formation throughout park. Member 2 consists mostly of thin, fining-upward successions of brick-red, very fine grained arenite and coarse-grained siltite capped locally by dark-red argillite; member 2 contains more arenite than other members. Ripple cross-lamination and some even, parallel lamination are common in lower part of successions. Pink to cream limestone beds at top of member contain oolites and small stromatolite heads; this zone is recognized throughout northern part of Belt basin (Don Winston, University of Montana, oral commun., 1982). Base of member 2 is placed at base of lowermost succession of brick-red arenite and siltite. About 270 m thick. Member 1 consists of thinly laminated, maroon to pale-purple argillite, brick-red siltite, and some interbedded arenaceous siltite and thin intervals of greenish-gray siltite and argillite. Lower contact placed on top of uppermost sequence of dolomitic siltite of Shepard Formation. Near northern boundary of park, member 1 encloses basaltic lava (shown by black symbol), and because the lava is only about 10.5 m thick and near the base of member 1, it is shown at contact between Mount Shields and underlying Shepard Formation. Member 1 is about 30 m thick. (I-1508-F)

Ysh - Shepard Formation (Middle Proterozoic)

Typically consists of yellowish-gray to greenish-gray dolomitic and pyritic siltite and argillite and a few thin beds of coarse-grained calcarenite, quartz arenite, limestone, and dolomite. A succession of very thinly laminated, olive-green argillite beds about 53 m thick occurs in lower part of formation near Mount Shields at southern edge of park but is not present near U.S.-Canada boundary. Thin beds of stromatolitic limestone are common in southern exposures but are rare in northern parts of park. Lamination is generally wavy, nonparallel and composed of fining-upward couplets. Fluid-escape structures, shrinkage cracks, ripple marks, miniature molar-tooth structures, and mud-chip breccias are common. Because of the carbonate and pyrite content of strata, most exposures weather tan to dusky orange. Lower contact placed at base of lowermost bed of dolomitic siltite or dolomite. Thickness about 400 m in southern part of park; thins northward to 165 m at Hole-in-the-Wall and westward to 210 m in Apgar Mountains. (I-1508-F)

Ypb - Purcell Lava (Middle Proterozoic)

Grayish-green to dark-greenish-gray mafic lava flow(s) (which can be subdivided into three facies) and a hypabyssal sill. In the park, the Purcell occurs within strata of the upper part of the Snowslip Formation as defined here. Because of map scale and position of lava in the uppermost part of the Snowslip, the Purcell is shown on map at contact between the Snowslip and Shepard Formation in northern part of park. Maximum total thickness of the Purcell is 92 m in northernmost exposure at Hole-in-the Wall; thins southward to 19 m at Granite Park and pinches out at Huckleberry Mountain. Upper facies of subaerially emplaced pahoehoe ranges in thickness from 0 to 54 m, is a compound flow sequence of multiple flow units (0.1-6 m thick), and overlies a lower pillow-lava facies; ropy flow structures are common on upper flow surfaces. Lower pillow-lava facies is 9-15 m thick and consists of interconnected pillows, which range in diameter from 20 cm 2 m, and associated hyaloclastite breccia. Locally, a third facies of vent rock is confined to north-central exposures in park; it forms a lens-shaped, chaotic breccia (maximum thickness 10 m) containing randomly distributed, angular to subrounded, equidimensional cognate blocks (5-35 cm) and lapilli intermixed with accidental, deformed and undeformed blocks of Snowslip strata (as much as 2 m long) in a devitrified, oxidized matrix. Vent facies is within pillow-lava facies and is overlain by pahoehoe flow units. A hypabyssal diabase sill, spatially correlative with vent facies but interpreted to be from a younger igneous event (McGimsey, 1985), is 18-21 m thick and generally enclosed by the Snowslip Formation about 5 m below base of pillow-lava facies. (I-1508-F)

Ysn - Snowslip Formation (Middle Proterozoic)

At type section at Snowslip Mountain in southern part of park, the Snowslip is informally subdivided into six members designated 1 through 6 in ascending order (Whipple and Johnson, 1988). Members are not mapped separately but can be recognized in exposures throughout park. Contact with underlying Helena Formation is sharp, apparently disconformable, and placed at base of first occurrence of red lithic arenite that overlies gray limestone or dolomite of the Helena. The Snowslip ranges from about 360 m thick (including 95 m of Purcell Lava) at reference section on west wall of Hole-in-the-Wall cirque (Whipple and Johnson, 1988) to 635 m thick in Apgar Mountains (including 32.5 m of Purcell Lava); thickness about 490 m at type section. Member 6 consists of interbedded noncalcareous, grayish-green and pale-maroon, fine-grained arenite, siltite, and minor argillite at type section. In northern part of park, member 6 conformably encloses the Purcell Lava and consists mostly of grayish-green siltite and argillite beneath the lava and alternating beds of pale-maroon and grayish-green, very fine grained arenite, siltite, and argillite above the lava. Where the Purcell is present, thin, discontinuous beds of pink and gray stromatolitic limestone occur in lower part of member 6. Base of member is placed on top of uppermost red, fining-upward succession of arenite and argillite of member 5. Thickness ranges from 8 to 130 m. Member 5 is composed of rhythmic, fining-upward successions as much as 5 m thick, but typically 2-3 m thick, of very fine grained to medium-grained, white to pink quartz arenite and subfeldspathic arenite, fining upward to siltite in middle of succession and dark-red argillite at top. Base of each succession is erosional and forms a sharp contact with dark-red argillite at top of underlying succession. Sedimentary structures include abundant ripple marks, desiccation cracks, mud-chip breccias, and fluid-escape structures. Lower contact is placed at base of lowermost fining-upward succession that rests on calcareous strata of member 4. Thickness ranges from 35 to 145 m. Member 4 is predominantly wavy, nonparallel- laminated, grayish-green and yellowish-gray calcareous siltite and argillite. A few interbeds of very fine grained arenite and several thin, conspicuous beds of pink stromatolitic limestone are present, particularly in lower part of member. Lower contact is placed at base of lowermost sequence of calcareous grayish-green strata. Thickness ranges from about 85 to 140 m. Member 3 is similar to member 5 but the rhythmic, fining-upward successions from arenite to argillite are not as regular as in member 5. For example, a succession could have arenite at base and argillite at top, but no siltite in middle, or a succession could be all siltite, coarse grained at base and very fine grained at top. Successions are as much as 3 m thick. At type section, rhythmic successions show a more regular change in grain size, grading from arenite to argillite and are thicker than elsewhere in park Thickness ranges from about 15 to 65 m. Member 2 is nearly identical to member 4; it includes a few interbeds of arenite and several thin beds of pink stromatolitic limestone, particularly in lower part of member. Thickness ranges from about 70 to 150 m. Member 1 is characterized by alternating pale-maroon and grayish-green sequences of calcareous siltite, argillite, and oolitic arenite. Arenite grains are fine to very coarse, moderately to poorly sorted, subrounded to rounded; arenite beds are thin and commonly cross-laminated. Siltite and argillite laminae are commonly arranged as wavy, nonparallel, fining-upward couplets that contain abundant mud-chip intraclasts, subaqueous shrinkage cracks, and fluid-escape structures. Thickness ranges from 25 to 90 m. (I-1508-F)

Yh - Helena Formation (Middle Proterozoic)

Generally subdivisible into three parts at most exposures in park. Lower contact of the Helena is placed on top of a 1.8-m-thick interval of green argillite of the Empire Formation. Thickness ranges from 750 m in most of park to a maximum of about 1,030 m in southwestern part. The following description is from a measured section along Going-to-the-Sun Road between Logan Pass and The Loop on west side of park. Upper part consists primarily of interbedded stromatolitic limestone, dolomite, oolitic limestone, and quartz arenite. At base of upper part, an interval of stromatolitic limestone about 30 m thick, known as the Conophyton zone (Rezak, 1957), is composed of Baicalia-Conophyton stromatolite cycles (Horodyski, 1983, p. 407). Massive character of Conophyton zone (shown by blue symbol) causes it to stand in relief in most exposures of the Helena Formation in park. A 40-m-thick diorite sill (unit Zd) intrudes the Helena in this part of measured section just above Conophyton zone. This sill, which is present throughout park, changes stratigraphic position from near the base of the Helena in southeastern part of park to the lower part of the Snowslip in northernmost part of park. Upper part is 235 m thick at measured section. Middle part is predominantly dolomitic molar-tooth beds, some as much as 30 m thick. A few thin beds of quartz arenite and stromatolitic limestone are present in the middle part of the Helena. Thickness 360 m at measured section. Lower part consists of thick, smoky-gray limestone beds near top, thin beds of horizontally laminated and molar-tooth dolomite in middle, and interbedded quartz arenite and thin-bedded dolomite near base. Thickness 180 m at measured section. (I-1508-F)

Yhcs - Helena Formation, conophyton stromatolite zone (Middle Proterozoic)

See unit Yh (Helena Formation). (I-1508-F)

Ye - Empire Formation (Middle Proterozoic)

Consists primarily of argillite, siltite, and lesser amounts of arenite and dolomite. Upper part is composed primarily of olive-green and a few purplish-red argillite and siltite beds that range in thickness from a few centimeters to 1.5 m. Thin dolomite beds are present near middle of the Empire and increase in number and thickness upward. Lower part of the Empire is composed largely of white to buff quartz arenite beds that range in thickness from 13 cm to 3.5 m and contain minor carbonate cement and pyrite; most arenite is well sorted, however, within some beds grain size ranges from fine to coarse. Locally, arenite beds have well-developed crossbedding, load structures, and asymmetrical ripple marks. Arenite beds decrease in number and thickness from bottom to top of the Empire. Lower contact is placed at base of lowermost bed of white quartz arenite that overlies the uppermost sequence of red argillite of the Grinnell Formation. Thickness ranges from 158 m on Scalplock Mountain to 122 m near Grinnell Glacier. (I-1508-F)

Ygl - Grinnell Formation (Middle Proterozoic)

Mostly quartz arenite on east side of park and interlaminated siltite and argillite on west side. Contact between the Grinnell and underlying Appekunny Formation is placed where red argillite and siltite of the Grinnell change to green argillite of the Appekunny. Thickness ranges from 530 to 790 m. In southeasternmost part of park, the Grinnell averages 60 percent quartz arenite, and its upper part is nearly 100 percent quartz arenite or quartz conglomerate. Quartz arenite beds in eastern exposures are typically white, medium to coarse grained, lenticular, ripple marked, and prominently crossbedded, and, in general, become more common upward in the Grinnell. Basal scours and red argillite chips, pellets, and cobbles are common. Red or purplish-red laminated siltite, silty argillite, and argillite are commonly interbedded; lamination ranges from even parallel to wavy nonparallel and locally includes ripple cross-lamination; mud cracks and fluid-escape structures commonly disrupt bedding in these red beds. Greenish-gray siltite and argillite are locally present in the upper and lower transition zones with adjacent formations. Interbedded quartz arenite and red argillite in the eastern exposures changes northwestward to a lithofacies that contains less quartz arenite and instead is composed mainly of pale, grayish-green and grayish-purple siltite and argillite. In northwestern part of park, the Grinnell can be subdivided into two parts. Upper part is 425 m thick and is similar to the lower part except that it contains more lenses of rippled, white quartz arenite (locally as much as 20 percent of the section). Lower part is 365 m thick and is predominantly interbedded blocky siltite and evenly laminated argillite that contains a few thin lenses of ripple-marked, white quartz arenite. Bedding is disrupted by abundant shrinkage cracks, fluid-escape structures, and interlayers of mud-chip breccia. (I-1508-F)

Yap - Appekunny Formation (Middle Proterozoic)

At Apikuni Mountain in northeastern part of park, the Appekunny is informally subdivided into five members designated 1 through 5 in ascending order; members are not mapped separately. On west side of park only parts of members 5, 4, and 3 are present and are mapped along with the disconformably underlying Prichard Formation as unit Yapp. On east side of park, the Appekunny disconformably overlies the Altyn Formation (see fig. 1); the contact between the two is placed on top of the uppermost dolomite bed of the Allyn and locally shows as much as 2 m of erosional relief. Thickness on east side of park ranges from 530 to 690 m. Member thicknesses are from measured section near Apikuni Mountain. Member 5 consists of bright-green argillite and lesser amounts of siltite. Lamination is wavy, nonparallel, lining-upward couplets. Mud-chip breccias, fluid-escape structures, and dolomite-filled subaqueous shrinkage cracks common. About 60 m thick. Member 4 contrasts sharply with member 5 and is poorly exposed because outcrops are mostly cleaved and easily weathered. Member consists of thin to very thin laminae of olive siltite and thin lenticular beds of rusty-brown arenite. Commonly stained by iron and manganese oxides. Notably cleaved, folded, and faulted near thrust faults. Lower contact placed at base of lowermost sequence of thinly laminated siltite. About 135 m thick. Member 3 is characterized by interlaminated and interbedded grayish-green siltite, yellowish-brown arenite, and lesser amounts of grayish-green argillite; subaqueous shrinkage cracks, load structures, and mud-chip breccia common. Lamination is wavy nonparallel; arenite beds typically contain pyrite. Lower contact placed at base of lowermost bed of pyritic arenite, where pyritic arenite and overlying beds are wavy laminated and contain numerous shallow-water sedimentary structures. About 165 m thick. Member 2 consists mostly of interlaminated siltite and some argillite. Thin arenite beds, 2.5-7.5 cm thick, common in lower part. Bed lamination is even parallel to nonparallel and curved nonparallel; some beds show broad, low-angle hummocky cross-lamination and small-scale, scour-and-fill structures. Lower contact is placed on top of uppermost maroon sequence of member 1 and generally coincides with an increase in thickness of siltite laminae in member 2. In areas where maroon beds are absent, contact between members 1 and 2 may be indistinguishable. About 165 m thick. Member 1 closely resembles member 2 except for the presence of maroon beds and consists of alternating successions of pale-maroon and grayish-green siltite and minor argillite. Laminae are generally thinner in member 1 than in member 2. A quartz arenite interval forms a key marker about 55 m above base of member 1. This interval thins gradually northward from about 25 m at Elk Mountain (at south end of park) to 15 m at Bear Mountain (near U.S.-Canada boundary). About 135 m thick (I-1508-F)

Yapa - Appekunny and Altyn Formations, undivided (Middle Proterozoic)

Undivided in areas adjacent to southern part of Lewis thrust fault where map scale and complex structure preclude differentiation. (I-1508-F)

Yapp - Appekunny and Prichard Formation, undivided (Middle Proterozoic)

Present only on west side of park where unit is divisible into three parts, but parts are not differentiated on map. Upper part is the Appekunny Formation; middle and lower parts are subdivisions of the Prichard Formation. Base not exposed. Minimum thickness ranges from 1,608 to 2,165 m. Upper part of map unit is partial sections of members 5, 4, or 3, or of all three members of the Appekunny that appear to rest disconformably on the Prichard. Upper part ranges in thickness from 63 m in west-central part of park where it consists only of member 5, to about 500 m near the U.S.-Canada boundary where it consists of members 5, 4, and 3. Middle part of map unit is the upper part of the Prichard and consists of wavy, nonparallel laminae of greenish-gray to medium-gray calcareous siltite. Locally, middle part contains thin lenticular beds of white quartz arenite and discontinuous beds of fragmental limestone or breccia and stromatolitic limestone. Equivalent to the transition zone of the Prichard as described by Cressman (1989). Thickness ranges from 245 to 365 m. Lower part of map unit is characterized by thin, even, parallel laminae of rusty-weathering, blackish-gray argillite and light-gray siltite that contain disseminated pyrite and pyrrhotite. Some small-scale cross-lamination is present in siltite laminae. Carbonate occurs locally near top of lower part as cement in thin siltite laminae and as pods and nodules of black manganiferous limestone. About 1,300 m thick. (I-1508-F)

Ya - Altyn Formation (Middle Proterozoic)

Occurs only on east side of park; completely exposed at Yellow Moutain and northward in northeastern part of park. In exposures south of Yellow Mountain, base is not exposed and formation is truncated by Lewis thrust fault. In Yellow Mountain area the Altyn can be informally subdivided into three members designated 1 through 3 in ascending order (Jardine, 1985); members not mapped separately. Locally where map scale permits, the Altyn and an eastern facies are differentiated and mapped separately. At Yellow Mountain, the Altyn ranges in thickness from 238 to 255 m. Member 3 is interbedded and interlaminated, light-gray to brownish-yellow dolomite, dolarenite, and arenite. Dolomite beds are 2-20 cm thick; arenite beds are medium to coarse grained and commonly crossbedded, some herringbone lamination. Stromatolites and styolites common. Thickness 55-62 m. Member 2 is massive, medium- to thick-bedded, white to gray dolomite. Some medium- to coarse-grained poorly sorted arenite beds in upper part. Stromatolites and dark-orange dolomite blebs occur locally in lower part. Contains black asphaltic veinlets near Lewis thrust fault. Thickness 58-68 m. Member 1 is yellow- to orange-weathering, dark- gray to black dolomite in thin to thick (2 m) beds, and thin, lenticular interbeds of fine-grained arenite. Stromatolites common in lower part. About 125 m thick. (I-1508-F)

Yae - Altyn Formation, Eastern facies (Middle Proterozoic)

Similar to main body of Altyn except middle member (member 2) is mostly thick beds of brownish-weathering, coarse-grained quartzite (Hill and Mountjoy, 1984). Low-angle cross-lamination common. Minor interbedded argillaceous gray dolomite. Partially exposed in thrust-fault plates in Divide Mountain area. (I-1508-F)

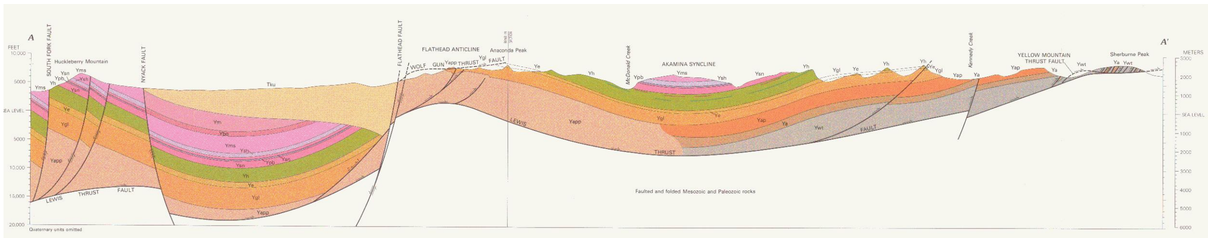
Ywt - Waterton Formation (Middle Proterozoic)

Present only in northeastern part of park, where base is not exposed and Waterton is truncated by Lewis thrust fault. In Yellow Mountain area, Waterton is informally subdivided into five members designated 1 through 5 in ascending order (Jardine, 1985); members not mapped separately. At Yellow Mountain, Waterton ranges in thickness from 170 to 229 m; becomes thicker northward as Lewis thrust fault cuts downsection. Member 5 consists of silty dolomite, dolomitic siltite, and dolomitic sandstone. Most strata are rusty reddish brown, some are maroon, orange, and green. Bed thickness usually thin to medium but sometimes thick. Crossbedding and stromatolites are common locally. Thickness ranges from 22 to 46 m. Member 4 is orangish-yellow and light-brown, fine-grained dolomite. Usually medium bedded but some thin or thick beds. Thickness 18-28 m. Member 3 is dark-gray and bluish-gray limestone and minor light-tan dolomite. Bedding is generally thin to medium, thickens downward, and has a striped appearance because of discontinuous 1- to 3-cm-thick mottled dolomite layers within 7- to 10-cm-thick limestone and limestone breccia beds. Breccia composed of rip-up clasts of fine-grained dolomite. Stromatolites, thin cherty layers, pisolites, and soft-sediment deformation are present. Thickness ranges from 15 to 30 m. Member 2 consists of yellowish-gray and light-gray, fine-grained, medium- to thin-bedded dolomite. A 1-m-thick dolomite bed contains chert nodules 5-10 m from top. Thickness 15-25 m. Member 1 is mostly dolomite that contains chert nodules and cherty beds. Color is generally tan to gray with a light-yellow tint, but locally some beds are grayish brown and yellowish white. Most beds are 0.3-1 m thick. Bedding is usually weakly defined by discontinuous, black calcareous beds, 2-4 cm thick, that are commonly dolomitic and have a concretionary form. Chert nodules, chert "blebs," and siliceous laminae are common. Chert is black when fresh and weathers rusty orange. Chert nodules are usually less than 5 cm in diameter. Stromatolites as much as 30 cm in diameter are common and sometimes have cherty tops and bottoms. Small-scale crossbedding is present locally. Asphaltic material fills veinlets adjacent to Lewis thrust fault. Member is truncated by Lewis thrust fault but is at least 100 m thick. (I-1508-F)

Geologic Cross Sections

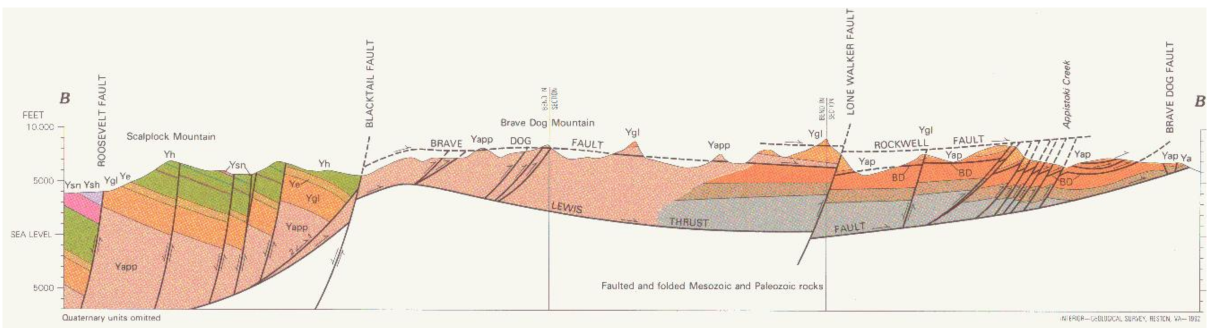
The geologic cross sections present in the GRI digital geologic-GIS data produced for Glacier National Park, Montana (GLAC) are presented below.

Cross Section A-A'



Extracted from: I-1508-F

Cross Section B-B'



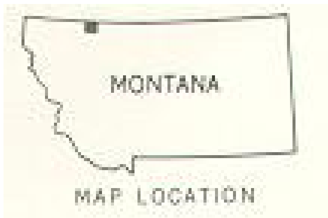
Extracted from: I-1508-F

GRI Source Map Citations

Surficial Geology Source Map (I-1508-D)

Carrara, Paul E., 1990, *Surficial Geologic Map of Glacier National Park, Montana*, U.S. Geological Survey. I-1508-D, 1:100000 scale (*GRI Source Map ID 2593*)

Location Map



Extracted from: I-1508-D

Index Map of the Glacier National Park Region

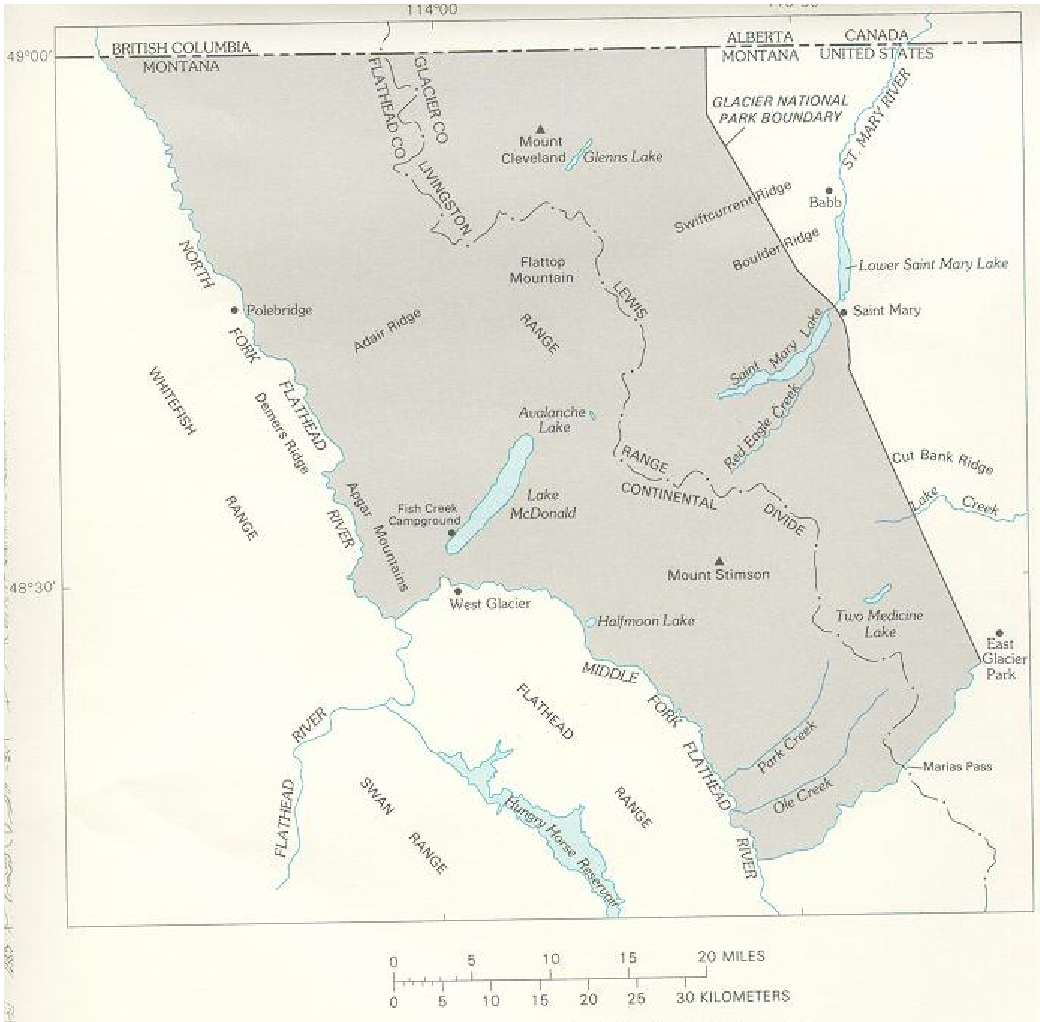
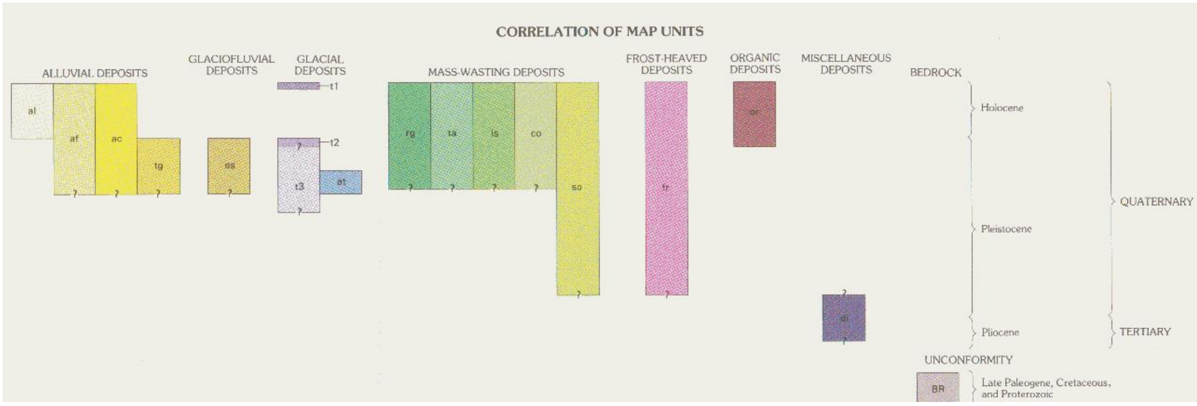


Figure 1.—Index map of the Glacier National Park region.

Extracted from: I-1508-D

Correlation of Units



Extracted from: I-1508-D

Ice Limit Map

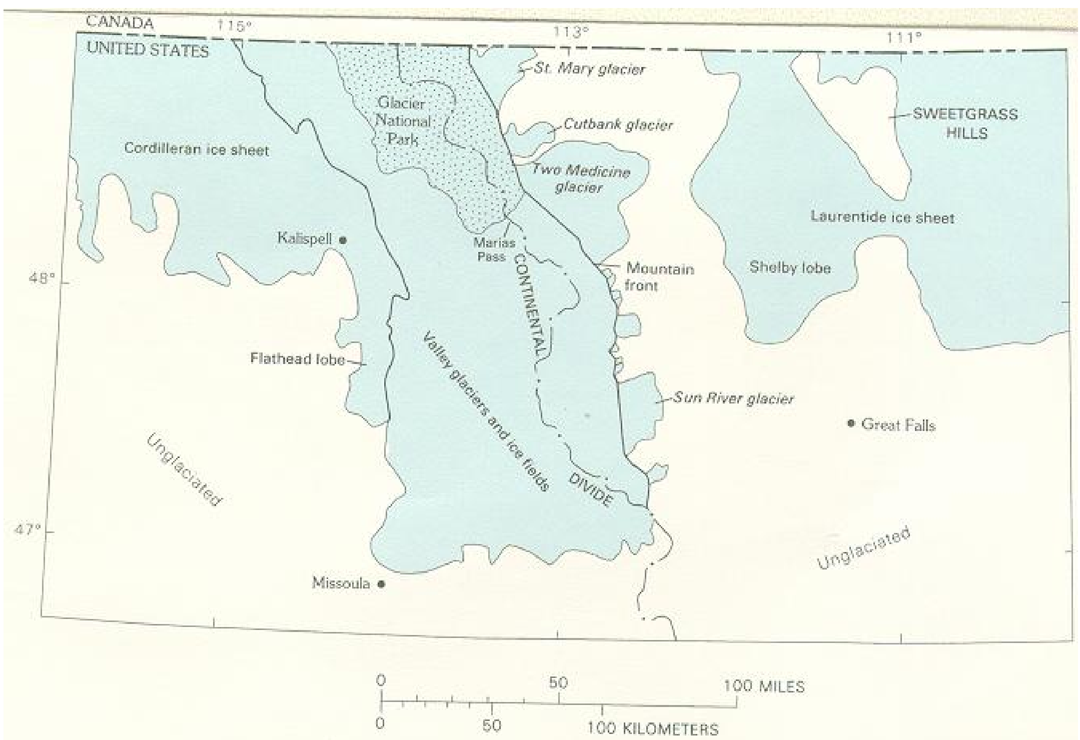


Figure 2.—Map of the Glacier National Park region showing ice limits about 20,000 years ago. After Alden (1932, 1953), Calhoun (1906), Colton and others (1961), Mickelson and others (1983), Waitt and Thorson (1983), and Richmond (1986).

Extracted from: I-1508-D

Table 1. Radiocarbon Ages

Table 1.—*Radiocarbon ages in the Glacier National Park region*

^{14}C age	Laboratory No.	Material dated
780±70	W-5169	Wood[1].
8,730±80	W-5041	Pine fragments[2].
9,510±350	W-5571	Pine fragments[2].
9,650±250	W-5575	Gyttja containing conifer fragments[2].
9,680±110	W-5182	Peat[3].
9,850±260	W-5577	Gyttja containing willow fragments[3].
9,910±100	W-5191	Pine fragments[2].
9,920±120	W-5187	Peat and pine fragments[2].
10,090±130	W-5185	Gyttja[3].
10,630±250	W-5348	Spruce or larch fragments[2].
11,150±90	W-5043	Organic material[3] (<0.125 mm).

[1]Material found at base of landslide.
[2]Minimum date of reforestation following deglaciation.
[3]Minimum date of organic sedimentation following deglaciation.

Extracted from: I-1508-D

Discussion of Geology and Geography

Glacier National Park, in northwestern Montana adjacent to the Canadian border, encompasses about 4,000 km2 of Flathead and Glacier Counties (fig. 1). The park contains three physiographically distinct areas: (1) the valleys of the North and Middle Forks Flathead River on the west, (2) the central mountainous region, and (3) the plains on the east. Bedrock in the park ranges in age from late Paleogene to Proterozoic (Ross, 1959; Raup and others, 1983) and is in many places mantled by surficial deposits of Quaternary age.

On the west, the heavily forested valleys of the North and Middle Forks Flathead River trend northwest to southeast; valley floors range in altitude from about 975 to 1,280 m. These valleys have been downdropped on the east and are underlain by 5,000 m of upper Paleogene sedimentary rocks of the Kishenehn Formation, consisting of lacustrine and fluvial sediments (Constenius, 1981). In some places, these rocks have failed, resulting in large landslides, such as the one in the Halfmoon Lake area. In other areas, these rocks are covered by till of late Pleistocene age as much as 30 m thick. Depressions within this till contain numerous bogs filled with peats, organic muds, and volcanic ashes.

The central part of Glacier National Park is dominated by two rugged mountain ranges that trend northwest to southeast and contain numerous small glaciers and snowfields. The Livingston Range, on the west, extends for 40 km from the Canadian border south to the Lake McDonald region. The Lewis Range, on the east, extends for 85 km from the border south through the park to Marias Pass. Large areas of these ranges lie above timberline (about 2,000 m) and many of the peaks in these ranges exceed 2,800 m in altitude. Mount Cleveland (3,191 m), in the Lewis Range, is the highest peak in the park. Relief in these ranges is rugged and many of the valley floors are as much as 1,500 m below their surrounding summits. The Continental Divide follows the crest of the Lewis Range northward to a position about 16 km south of the border, then shifts westward and follows the crest of the Livingston Range north into Canada.

These mountain ranges are underlain by Proterozoic sedimentary rocks of the Belt Supergroup, ranging in age from about 800 Ma to 1,600 Ma (Raup and others, 1983). The rocks consist of a sequence of argillites, siltites, and carbonates that have a maximum stratigraphic thickness of 5,200 m (Whipple and others, 1984). Because these rocks have been affected only by low-grade metamorphism, many of their original sedimentary features (ripple marks, mud cracks, salt casts, and fossil algal stromatolites) are well preserved. In places these rocks have been intruded by diabasic and gabbroic sills and dikes. The upper part of the section contains mafic lava flows 10-60 m thick (McGimsey, 1985). This entire sequence of rocks was thrust eastward over Cretaceous sedimentary rocks along the Lewis thrust fault during the Paleocene (Raup and others, 1983), and today forms a broad syncline whose axis closely parallels the Continental Divide (Ross, 1959).

Numerous surficial deposits mantle these mountain ranges. A large rock block slide is present immediately west of Avalanche Lake and several are present in the area north of Glenns Lake. Steep valley sides, whose forest is scarred in places by snow avalanche tracks, are mantled by colluvium. Talus cones and sheets are common at the base of steep slopes and cliffs. Till mantles the floors of many of the mountain valleys. In the higher regions of these two ranges, two sets of moraines can be found in front of the present-day glaciers and snowfields (Osborn, 1985; Carrara, 1987; Carrara and McGimsey, 1988). High, unglaciated upland surfaces locally have a thin cover of stone stripes, sorted polygons, and solifluction deposits.

East of the mountain front is the western margin of the Montana plains. This area consists of low, rounded hills mantled in places by a veneer of glacial till. Altitudes range from about 1,370 to 2,000 m. This area is underlain by sedimentary rocks of mainly the Upper Cretaceous Marias River Shale, which is a dark-gray marine mudstone (Mudge and Earhart, 1983). In places immediately east of the mountain front, Pleistocene valley glaciers emerging from the Lewis Range gouged deep, steep-sided valley walls in these soft rocks. After deglaciation, many of these rocks failed and formed massive landslides.

During the height of the last major glaciation, about 20,000 years ago, much of northwestern Montana, including the Glacier National Park region, was covered by glacial ice (fig. 2). To the west, the southern margin of the Cordilleran ice sheet stretched from the Puget Sound area of Washington to N western Montana. This large ice sheet was formed by the coalescence of valley glaciers in the mountains of British Columbia and flowed south overriding low mountain ranges in Washington, Idaho, and Montana. Lobes from this ice sheet flowed into various river valleys south of the main ice mass. The easternmost lobe of this ice sheet, the Flathead lobe, flowed south into the Flathead Lake region (Alden, 1953; Waitt and Thorson, 1983; Richmond, 1986).

On the plains of Montana east of Glacier National Park lay the southwestern lobe of the Laurentide ice sheet. This ice sheet covered most of Canada, and its southern margin stretched from Montana east to the Atlantic Ocean. The southwestern lobe of this ice sheet, the Shelby lobe, advanced south from Canada across the Montana plains into this region (Alden, 1932; Mickelson and others, 1983).

Between these two large ice sheets, in the mountains along the Continental Divide, valley glaciers and icefields developed (Alden, 1953; Richmond, 1986). The present-day Glacier National Park region was covered by hundreds of meters of glacial ice so that only the higher peaks protruded as nunataks above this ice cover. On the western side of the Continental Divide, glaciers flowed from valleys along the western flank of the Livingston Range and the eastern flank of the Whitefish Range. Many of these glaciers were 10-20 km long and several hundreds of meters thick. These glaciers merged with a large trunk glacier flowing southeast down the valley of the North Fork Flathead River. This trunk glacier, which headed in the mountains of British Columbia, filled the valley of the North Fork with at least 1,000 m of ice. Evidence for such an ice thickness is given by striations and erratics along the crest of the Apgar Mountains and Demers Ridge (Alden, 1953), and by sinuous meltwater channels, which trend northwest-southeast, on the interfluves on the west flank of the Livingston Range, such as Adair Ridge. This ice drained to the southwest, overrode the Apgar Mountains, and merged with the Flathead lobe of the Cordilleran ice sheet.

From the Lake McDonald area south, the Lake McDonald glacier, which drained the Flattop Mountain area, and glaciers flowing from valleys along the western flank of the Lewis Range in the park and from valleys along the eastern flank of the Flathead Range merged with a large trunk glacier that occupied the valley of the Middle Fork Flathead River. This large trunk glacier, which headed in the Lewis and Clark Range about 100 km to the southeast in the present-day Great Bear Wilderness, formed a local ice field in the area west of Manias Pass. Some of this ice flowed to the northwest and joined the large trunk glacier flowing south in the valley of the North Fork Flathead River and eventually merged with the Flathead lobe of the Cordilleran ice sheet. Other ice from this glacier flowed east across the Continental Divide and was a major source of ice for the former Two Medicine glacier.

East of the Continental Divide in the Glacier National Park region, some glaciers advanced beyond the mountain front and formed large piedmont glaciers on the adjoining plains. The largest of these piedmont glaciers was the Two Medicine glacier. Mountain glaciers along a 60-km length of the mountain front merged to form this glacier, including glaciers from the Two Medicine Valley and ice from the icefield west of the Continental Divide in the Manias Pass area. This piedmont lobe had a maximum width of about 50 km, extended about 55 km east of the mountain front, and deposited a veneer of hummocky till over a 2,000-km2 area (Calhoun, 1906; Alden, 1932).

To the north in Glacier National Park, glaciers occupied the valleys of Lake and Cut Bank Creeks. These glaciers flowed east and merged on the plains to form a small piedmont lobe that extended beyond the mountain front about 15 km (Calhoun, 1906; Alden, 1932). Farther north, a large glacier flowed down Saint Mary Valley, beyond the mountain front and into Canada where its terminal deposits lie beneath till of a subsequent advance of the Laurentide ice sheet (Calhoun, 1906; Alden, 1932; Horberg, 1954). In the vicinity of Lower Saint Mary Lake this glacier was about 370 m thick (Alden, 1932). This large glacier was fed by other glaciers flowing from the valleys of Divide, Red Eagle, Boulder, Swiftcurrent, Kennedy, and Otatso Creeks in Glacier National Park. In the interior of the park, the valleys of the Belly and Waterton Rivers were filled with large glaciers, about 400 m thick, that flowed north into Canada. Volcanic ashes erupted from volcanoes in the Cascade Range of the Pacific Northwest have been identified in postglacial deposits in the Glacier National Park region. Glacier Peak G ash, erupted from Glacier Peak in Washington State, has been identified in postglacial deposits at nine sites in the map area. This ash was erupted about 11,200 B.P. (Mehringer and others, 1984). At two of these sites, this ash is underlain by an ash erupted from Mount St. Helens (Jy) in Washington State. The Mount St. Helens Jy ash is thought to date from about 11,400 B.P. (Carrara and others, 1986).

Because the Glacier Peak G and Mount St. Helens Jy ashes were both erupted in the late Pleistocene, when the Glacier National Park region was undergoing extensive deglaciation, the presence of these ashes at a site provides information concerning the extent and timing of deglaciation. Also, at sites where these ashes were found with associated pollen and plant and insect macrofossils, information concerning revegetation and environmental conditions has also been obtained (Carrara and others, 1986). The location of sites containing the Glacier Peak G and Mount St. Helens Jy ashes in the Glacier National Park region indicates that between 11,200 and 11,400 B.P. deglaciation was at least 90 percent complete. By this time remaining glaciers, if any, were confined to local mountain valleys (Carrara, 1986). In addition, data from Banff and Jasper National Parks, Alberta, indicate that by 10,000 B.P. late Wisconsin glaciers had receded to positions close to those of present-day glaciers (Luckman and Osborn, 1979). A similar amount of deglaciation at that time is inferred for the Glacier National Park region. Hence, by 10,000 B.P. any remaining glaciers were probably confined to those same cirques and well-shaded niches that contain present-day glaciers and snowfields.

The Mazama ash, which erupted from Mt. Mazama, the present site of Crater Lake, Oregon, about 6,845 B.P. (Bacon, 1983), was also deposited in the Glacier National Park region. This ash commonly occurs in bogs as well as in the soil overlying glacial and periglacial deposits in the higher regions of the park. The Mazama ash is a useful time-stratigraphic marker and provides a minimum date for many of the deposits in the higher regions of the park that could not be radiocarbon dated because of a lack of associated organic material (Osborn, 1985; Carrara, 1987; Carrara and McGimsey, 1988). In addition, a number of radiocarbon ages have been obtained from organic material recovered from bogs and exposures along stream banks in the Glacier National Park region (table 1). Radiocarbon ages on the lowestmost organic material at these sites provide minimum dates for the beginning of organic sedimentation as well as minimum dates of deglaciation. Radiocarbon ages on wood fragments from some of these sites provide minimum dates of reforestation. Because Glacier National Park was extensively covered by glacial ice about 20,000 years ago, most of the surficial deposits shown on this map were deposited during or after the late Pleistocene regional deglaciation. Only those deposits in areas not covered by glacial ice during the last glaciation may date from earlier periods.

Extracted from: I-1508-D

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Extracted from: I-1508-D

Bedrock Geology Source Map (I-1508-F)

Whipple, James W., 1992, *Geologic Map of Glacier National Park, Montana,* U.S. Geological Survey, I-1508-F, 1:100000 scale (*GRI Source Map ID 1171*)

Location Map

Extracted from: I-1508-F

Correlation of Units

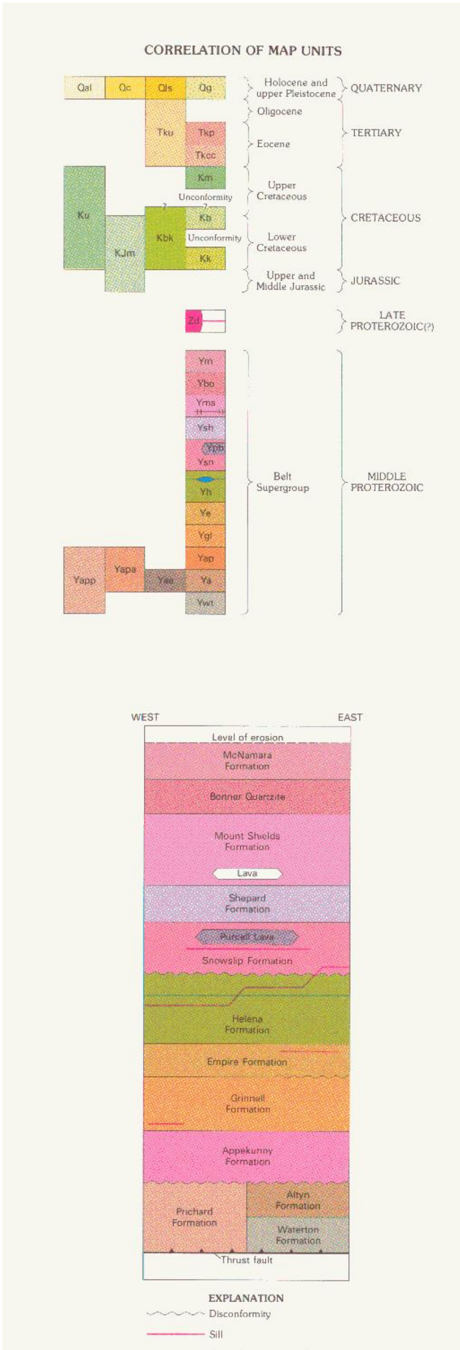


Figure 1. Chart showing stratigraphy and nomenclature of Middle Proterozoic Belt Supergroup map units on east and west sides of Glacier National Park.

Extracted from: I-1508-F

Structural Features Map

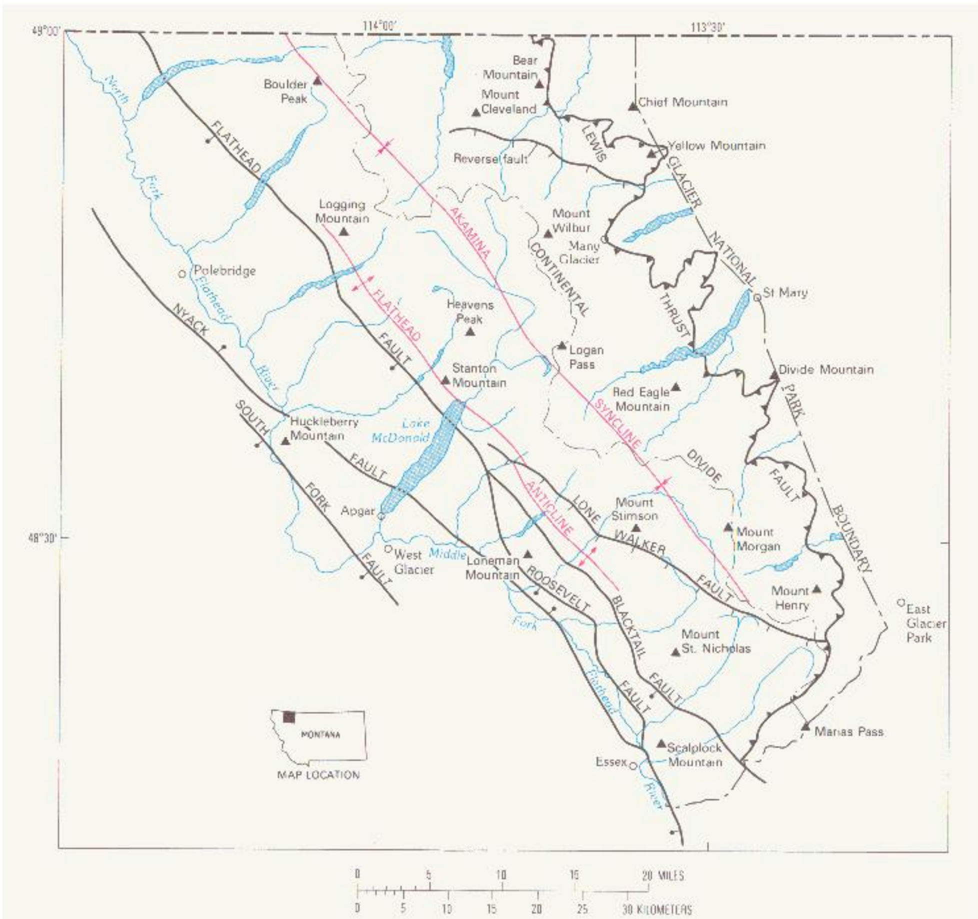
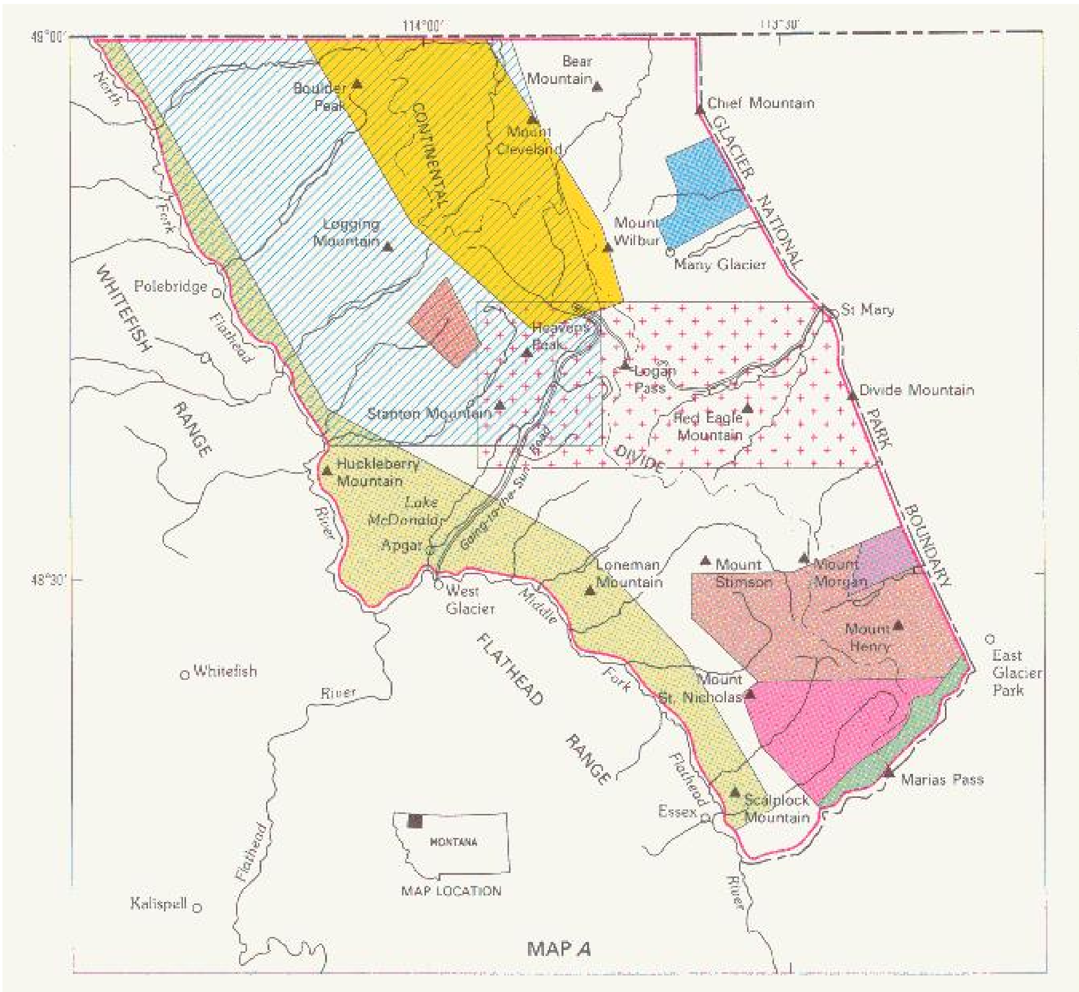


Figure 2. Principal structural features of Glacier National Park.

Extracted from: I-1508-F

Index of Mapping

Index of Mapping (A)



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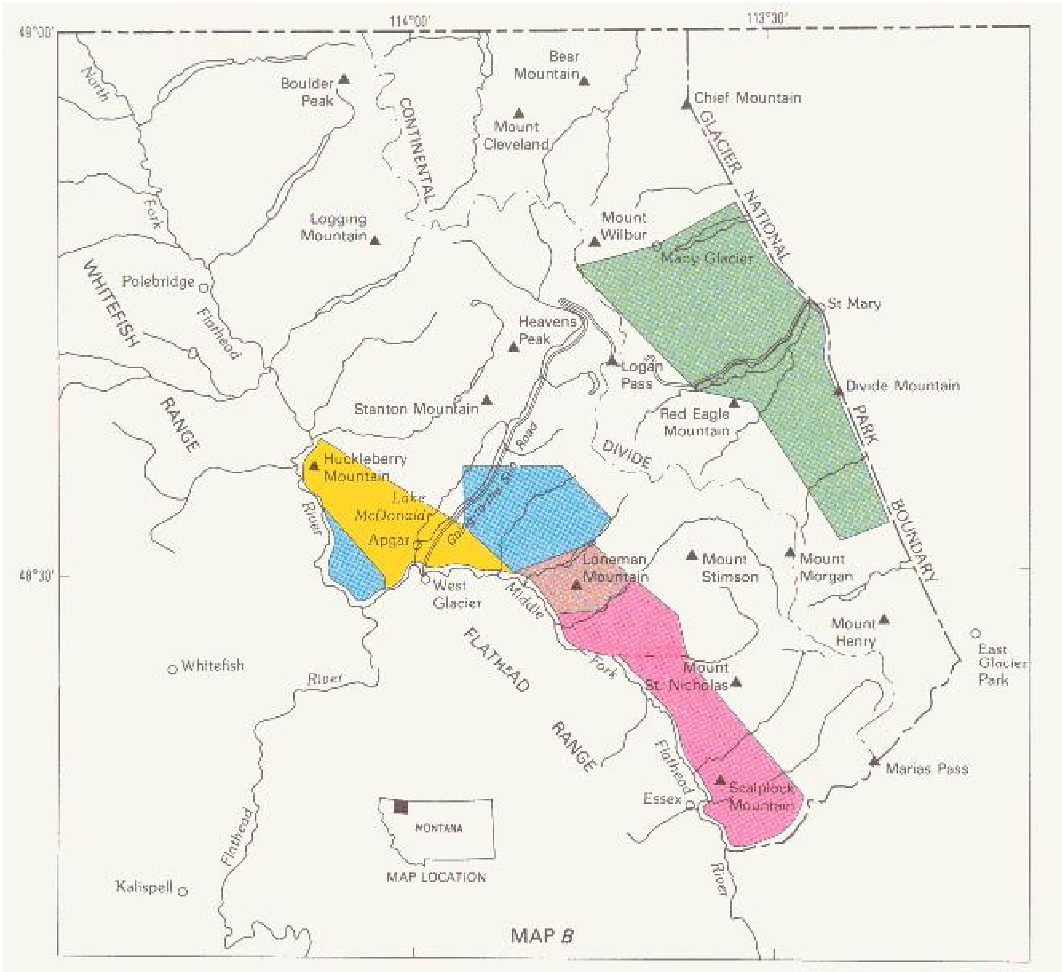

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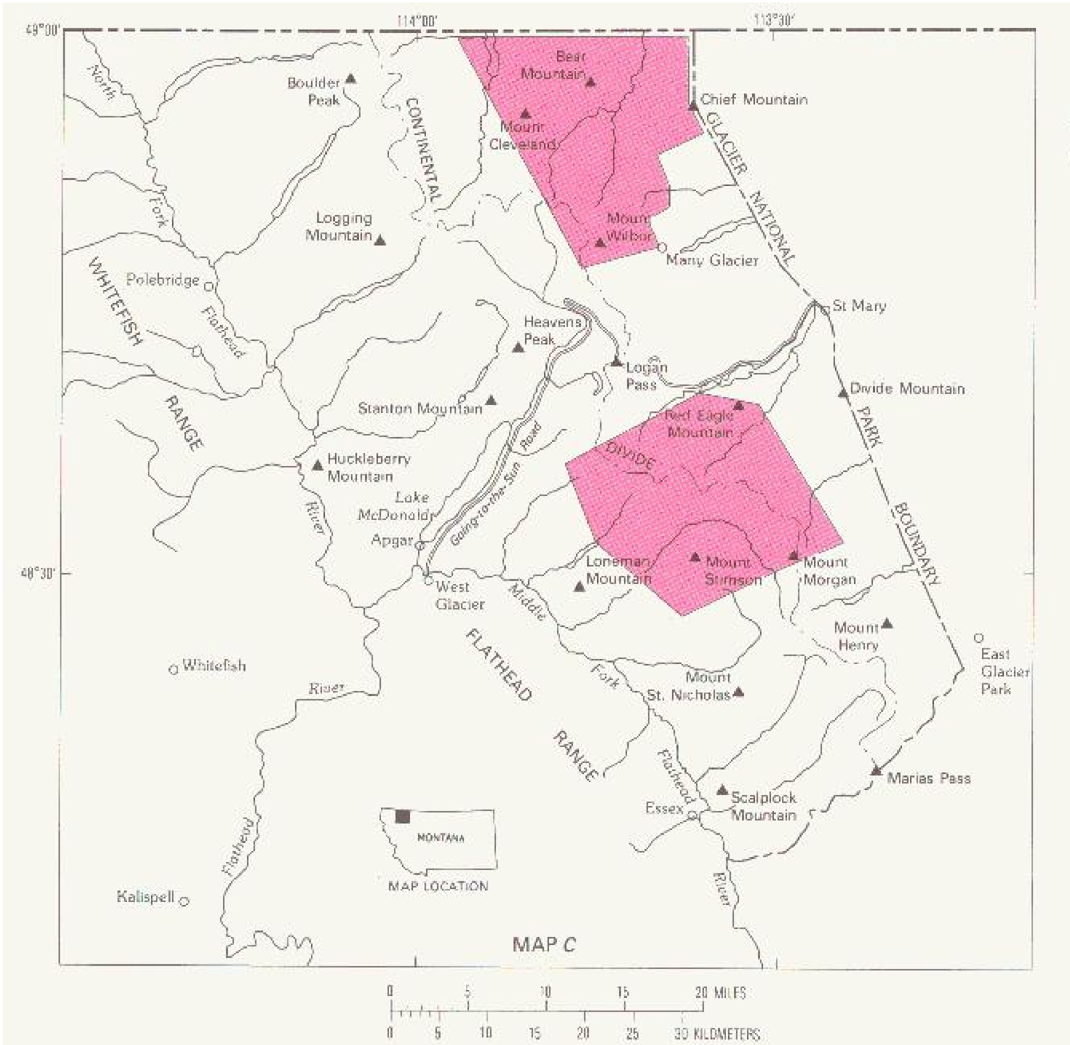

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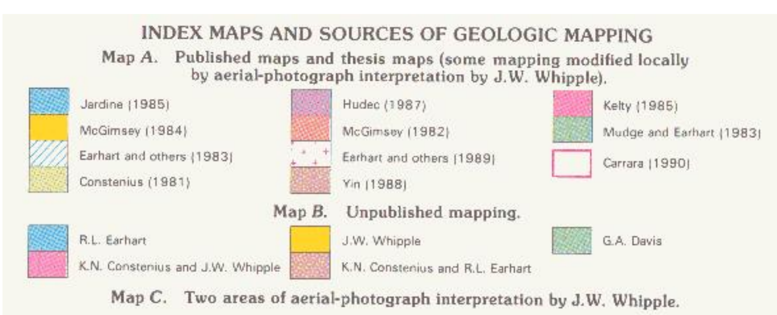
Index of Mapping Legend



Extracted from: [I-1508-D]

Stratigraphic Descriptions

Names used for bedrock units shown on the geologic map of the park differ from accepted nomenclature in some cases. For Middle Proterozoic Belt Supergroup map units (fig. 1) nomenclature is the same as that proposed by Mudge (1977) except for the lower part of the stratigraphic sequence. For this part of the Belt Supergroup, we propose to reinstate the names Grinnell and Appekunny Formations, introduce the Waterton Formation into the east side of the park, and recognize the Prichard Formation on the west side of the park. Tertiary rocks are assigned the name Kishenehn Formation as proposed by Constenius (1981) and are subdivided into informal members where recognized and mappable.

GRINNELL AND APPEKUNNY FORMATIONS

For units sequentially underlying the Empire Formation in the Ravalli Group, we prefer reinstating the names Grinnell and Appekunny Formations in the park after the usage of Ross (1959) as opposed to the currently accepted names of Spokane and Greyson Formations, respectively, that were assigned to these formations by Mudge (1977). Whereas the Grinnell and Appekunny Formations may be in part time-stratigraphic equivalents of the Spokane and Greyson Formations, they are not exactly the same units and differ lithologically. The Grinnell Formation contains abundant beds of white quartz arenite, particularly in its upper part, and the total arenite content of the formation is locally as much as 60 percent. The arenite is interpreted to have been derived from an eastern source terrain. The approximately correlative Spokane Formation is mostly interlaminated siltite and argillite and contains only limited amounts of very fine grained subfeldspathic arenite. The Appekunny has five lithologically distinct members that include thick beds of quartz arenite, hummocky cross-stratified siltite, and mudcracked argillite. The Greyson does not have any of these lithofacies and is composed mostly of thinly laminated siltite and dark-greenish-black argillite.

Because of the differences in lithofacies between the Grinnell and Spokane Formations and between the Appekunny and Greyson Formations, we concur with Connor and others (1984) that the rock units were deposited in separate depositional settings and probably have separate provenances. The Grinnell and Appekunny Formations are restricted to Glacier National Park and adjacent areas; the Spokane and Greyson Formations are confined to the west-central part of Montana, generally referred to as the Helena embayment.

WATERTON FORMATION

The Waterton Formation is introduced in the park for that stratigraphic unit underlying the Altyn Formation after the usage of Douglas (1952) as modified from Daly (1912); it is the lowermost unit of the Belt Supergroup on the east side of the park. The name Waterton originates from its application to strata below the Altyn Formation in and around the Waterton Townsite immediately north of Glacier National Park in Alberta, Canada. A more detailed discussion of its stratigraphy can be found in Hill and Mountjoy (1984). In the park, only part of the Waterton is present and that part is in faulted sections near Yellow Mountain and north along the trace of the Lewis thrust fault. Five informal members are recognized and described but are not shown separately on the geologic map because of map scale and structural complexities.

PRICHARD FORMATION

The Prichard Formation is recognized only on the west side of the park where it is the lowermost stratigraphic unit and is overlain disconformably by the Appekunny Formation. Because the overlying Appekunny Formation is very thin in this part of the park (less than 125 m in most places), the Prichard and the Appekunny are described separately but shown together as one map unit (unit Yapp). The Prichard Formation has not previously been recognized this far east in exposures of the Belt Supergroup. In the park, the Prichard is subdivided into an upper part and a lower part; the parts are described but not shown separately on the map.

KISHENEHN FORMATION

The Kishenehn Formation in the Middle Fork Flathead River drainage is informally subdivided into the conglomerate member of Pinchot Creek and the lacustrine member of Coal Creek after the usage of Constenius and Dyni (1983). Elsewhere in the park these members have not been recognized, and the Kishenehn is only informally subdivided into an upper part and a lower part, which are not shown separately on the map.

Structure Report

The principal geologic structures of Glacier National Park trend about N. 40° W. (fig. 2) and consist from west to east of a Tertiary-filled graben bounded by the Flathead and Nyack faults in the Middle and North Fork Flathead River drainages flanking the west side of the park a fold and thrust belt on the western edge of the Livingston and Lewis Ranges, a broad, open syncline in the central part of the park called the Akamina syncline, and a spectacular thrust belt on the eastern edge of the Livingston and Lewis Ranges featuring the Lewis thrust fault. Associated with these major features are many smaller scale structures, of which only a few are discussed here. The details of the geometry and kinematics of the principal structures as well as those of the smaller scale structures are discussed in separate publications (see, for example, Yin and others, 1989) on the structural geology of Glacier National Park.

Faults are the most conspicuous structural feature on the geologic map. Of them, the thrust faults, and particularly the Lewis thrust fault, are recognized worldwide as classic geologic structures because of their excellent exposure in the cliff faces on the south and east sides of Glacier National Park. The Lewis thrust fault is considered to be the easternmost and structurally lowermost thrust fault that transported Middle Proterozoic strata of the Belt Supergroup over sedimentary rocks of Cretaceous age. Hudec and Davis (1989) suggested that the Lewis: "may be a composite of multiple thrust surfaces that were not all active at the same time." The Lewis is estimated to have had at least 40-60 km of lateral displacement (Dahlstrom, 1970; Gordy and others, 1977) on a gently southwest-dipping detachment surface (less than 20°) that is interpreted to be broadly folded and locally displaced by normal faults (see cross sections A-A' and *B-B').* The transport direction of the Lewis allochthon is generally northeast and it ranges from N. 40°±10° E. to N. 70°±10° E. (Davis and Jardine, 1984; Hudec and Davis, 1989). Locally at Marias Pass, kinematic indicators suggest southward-directed movement (Kelty, 1985).

Within the Lewis allochthon, two imbricate thrust belts, one on the western edge of the Livingston and Lewis Ranges and one on the eastern edge, appear to have formed over ramps in the Lewis detachment surface and form part of several duplex structures as much as 300 m thick (Davis and others, 1989). In general, the duplexes contain panels of intensely faulted and deformed Belt strata that are floored by the Lewis thrust and roofed by local thrust faults. Roof faults such as the Yellow Mountain thrust (cross section A-A') and Brave Dog and Rockwell thrusts (cross section *B-B')* are interpreted to have formed after imbrication (Davis and Jardine, 1984), or were preexisting structures (Yin and others, 1989) and were not formed contemporaneously with structures contained in the duplexes.

The northwest-southeast-trending Tertiary-filled graben on the west side of the park is bounded on the northeast by the Flathead fault, a large-displacement, listric normal fault, and on the southwest by the Nyack fault, a steeply east-dipping to overturned normal fault that is antithetic to the Flathead (Constenius, 1988). Tertiary sediments were deposited in an asymmetrical graben synchronously with movements on the Flathead fault, which resulted in a wedge of Tertiary strata that dips and thickens to the east toward the Flathead fault. The Flathead fault has at least 2,440 m of stratigraphic displacement. The listric Flathead is interpreted to offset the Lewis thrust fault at depth as proposed by Childers (1963) and to sole into a detachment below the Lewis, which is a slightly different interpretation than reported by others more recently (Constenius, 1988; Dahlstrom, 1970). Southeast of Lake McDonald, the Flathead splits into the Roosevelt and Blacktail faults. The Roosevelt fault becomes the northeast-bounding fault of the Tertiary graben and the Blacktail is considered to be the southern extension of the Flathead because of its similarity in dip (about 40° southwest) and greater displacement compared to the Roosevelt. The Blacktail fault appears to cut the Lewis thrust fault at the southern limit of the park and its normal movement is interpreted to be younger than the latest movement on the Lewis at this point, as shown in cross section *B-B'.* The east-dipping panel of Belt rocks between the Roosevelt and Blacktail faults shows increasing dips toward the Blacktail fault, which is considered to be an indication of rollover caused by normal movement on the listric fault plane of the Blacktail.

The South Fork fault is another west-dipping listric normal fault that has at least 2,135 m of stratigraphic displacement, but it is interpreted to sole into the Lewis detachment surface rather than offset it. This fault divides the Apgar Mountains on the west edge of the park and continues northwest and southeast into the Whitefish and Flathead Ranges.

Broad regional folds warp the central part of the park and the Lewis allochthon into a northwest-plunging syncline (which is the southern extension of the Akamina syncline in the Clark Range of Canada) and an anticline flanking the Flathead fault called the Flathead anticline. Belt rocks are gently folded about the axis of the Akamina syncline, but they are tightly folded and faulted within the Flathead anticline. Both folds are interpreted to have warped the Lewis thrust fault, however the anticlinal fold might be associated with ramping of the Lewis.

Two conspicuous, steeply dipping reverse faults that transect the northern and southern parts of the map area trend N. 60°-70° W., about 20°-30° more west of north than the regional structural trends. The southernmost of these faults, which is named the Lone Walker fault, has a displacement that ranges from 30 to 500 m (Yin, 1988). Crosscutting relations suggest that these structures are probably two of the youngest faults in the park.

Cross sections A-A' and B-B' show structural and stratigraphic relations of rock units in the Lewis allochthon in the northern and southern parts of the park, respectively. Folded and faulted Paleozoic and Mesozoic rock units are interpreted to be below the Lewis thrust fault, however we prefer not to speculate on their detail at this time. Quaternary mar are not shown on the cross sections because the surficial deposits are too thin to show scale of 1:100,000. A cross section through the central part of the park has been published as U. S. Geological Survey Miscellaneous Investigations Series Map I-1508-B (Earha others, 1989).

Different fault symbols are used on the map so that the reader will not misinterpret location or existence of these structures. In several places on the map, faults are she end abruptly with no apparent extension or reason for the termination. In most cases termination of the fault is marked by a query that indicates an uncertain location or presence. In other cases, the fault is assumed to terminate where displacement is small and is transferred to local small-scale folds and faults. Where faults extend beneath Quaternary map units, the projection may not be shown by a dotted line. Where the trace of the thrust fault is concealed and nearly coincident with the contact between Quaternary Proterozoic map units, a special map symbol is used to show that Proterozoic rocks a thrust over Quaternary units.

Extracted from: I-1508-F

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Author's Note

In 1979, a cooperative project between the U.S. National Park Service and the U.S. Geological Survey (USGS) to study the geology of Glacier National Park was initiated. During the next 7 years, several USGS geologists and university students and professors employed by the USGS mapped and studied parts of the park. This map is a compilation of that work, and it represents the most modern and complete interpretation of the geology of the park. Several geologists contributed to the geologic map of Glacier National Park; they are: Paul E. Carrara, Jon J. Connor, Kurt N. Constenius, Gregory A. Davis, Robert L. Earhart, Michael R. Hudec, Eric A. Jardine, Thomas K. Kelty, Debra H. McGimsey, Robert G. McGimsey, Omer B. Raup, Richard E. Van Loenen, James W. Whipple, and An Yin. The "Indexes to Geologic Mapping" show areas mapped by each contributor and remaining areas mapped by aerial-photograph interpretation. Detailed geologic mapping at a scale of 1:24,000 had to be generalized for this

1:100,000-scale compilation, and only major stratigraphic units and structural features are represented. This is particularly true of much of the east side of the park, which was mapped by Gregory A. Davis and his students at the University of Southern California. Over 1,000 35-mm color slides, taken from a helicopter, were used for mapping areas by aerial-photograph interpretation. The aerial-photograph interpretation was supplemented by map data from Ross (1959) and reconnaissance ground traverses.

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This document was developed and completed by Stephanie O'Meara (Colorado State University) from and earlier GRI Help document produced by Stephanie O'Meara, Robert Thompson (GRD student intern), and Victor deWolfe and (Colorado State University) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory(GRI) Program.

The information contained here was compiled to accompany the digital geologic-GIS map(s) and other digital data for Glacier National Park, Montana (GLAC) developed by Stephanie O'Meara and Dave Green (Colorado State University), Matt Schaefer and Rachel Johnson (GRD student interns), Melissa Copfer and Josiah Engblom (Colorado State University student interns) and Victor deWolfe. Format migration and Google Earth product by Stephanie O'Meara.

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