National Park Service
U.S. Department of the Interior

Natural Resource Program Center

Whiskeytown National Recreation Area

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2007/008

THIS PAGE & ON THE COVER:
Whiskeytown Lake, Whiskeytown NRA, CA

NPS Photos

Whiskeytown National Recreation Area

Geologic Resource Evaluation Report

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Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
Denver, Colorado 80225

June 2007

U.S. Department of the Interior
Washington, D.C.

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Thornberry- Ehrlich, T. 2007. Whiskeytown National Recreation Area Geologic Resource Evaluation Report. Natural Resource Report NPS/NRPC/GRD/NRR—2007/008. National Park Service, Denver, Colorado.

NPS D- 98, June 2007

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Executive Summary

This report has been developed to accompany the digital geologic map produced by Geologic Resource Evaluation staff for Whiskeytown National Recreation Area. It contains information relevant to resource management and scientific research.

Whiskeytown National Recreation Area is widely known for numerous recreation opportunities, especially related to Whiskeytown Lake, a large reservoir created by the impoundment of Clear Creek behind the Whiskeytown Dam (figure 1).

Whiskeytown is intrinsically connected to the geological processes that established the present- day environment, scenery, and landforms. Humans have modified the landscape in and around Whiskeytown and consequently altered this dynamic geologic system. During the 1849 California Gold Rush, the Klamath Mountains were the focus of miners and prospectors seeking gold, silver, copper and other metals present in placer and massive sulfide deposits. Exploration and mining in the area has continued ever since. While Whiskeytown NRA is one of three National Park Service units open to federal mineral leasing, little leasing has occurred within park boundaries. However, a legacy of mining in the park coupled with active mining outside the park poses significant resource protection issues for present park management.

Igneous and metamorphic rocks dominate the geology at Whiskeytown. Prospectors and miners were attracted to the area by the gold and sulfide deposits associated with igneous intrusions. Remnants of their settlements still dot the landscape at Whiskeytown, preserving the park's historical legacy.

Studying and protecting the geologic and historic features of the park involves more than simple preservation and includes understanding the present landscape geomorphology and the geologic processes that created it. The interactions of rock, water, and surface stability are of paramount importance for park management. The following issues, features, and processes have been identified as geologically important and significant to park management:

- Restoration of roads and mass wasting. The potential for landslide and rockfall exists along most, if not all roads and trails at the park. Slumps and other forms of slope failure are common for some of the weathered igneous and metamorphic rock units. The biotite- rich rocks of the Shasta Bally Batholith weather preferentially and have created slope instability in certain areas of the park. Intense seasonal storms and snowmelt increase slope instability and erosion.

  Additionally, Whiskeytown has an estimated 300 miles of logging and skid roads built on these highly erosive units. These poorly constructed roads increase erosion and can fail catastrophically, resulting in slides and debris flows.
- Mine- related issues. Whiskeytown, which remains open to mineral leasing (oil and gas and solid minerals), has a long history of mining activity demonstrated by over 100 mines within the National Recreation Area and surrounding watersheds. Abandoned mines pose several threats to visitor safety including the risk of falling, bad air, ground collapse, etc. Massive sulfide deposits and sulfide mines are also associated with water quality problems. The exposure of sulfide waste from abandoned mines and tailings has resulted in the creation of sulfuric acid, which alters the chemistry of surface and groundwater. Mercury used in the amalgamation process to extract gold from placer deposits, remains in the waste rock and tailings adding another toxic heavy metal to the water at Whiskeytown.
- Recreation demands. Whiskeytown Lake attracts more than 700,000 visitors per year. Visitors enjoy the lake and lakeshore, the various trails and picnic areas, rock climbing, and hiking the trails of the surrounding mountains. Slope instability and erosion have made it necessary to periodically close trails and roads in the recreation area. Careful monitoring would help to determine risk of landslides along trails and roads. In addition, off- road recreational vehicles are scaling the slopes of Shasta Bally. This affects the park's viewshed and creates noise, dust, and engine exhaust. Resource management concerns include balancing the preservation of the environment with recreational demands of visitors to the area.

Other geologic issues that impact park resource management include: The effects of Whiskeytown Dam, seismicity, and volcanic hazards. Geologic interpretation plays an important role in enhancing visitor understanding of the park. Along with a detailed geologic map, wayside exhibits, and road logs, a guidebook connecting Whiskeytown National Recreation Area to other parks in the Cascade- Klamath- Sierra Nevada region (as well as to the adjacent Shasta- Trinity Units) would be of benefit to visitors. Such a guide would increase visitor appreciation of the geologic history and processes that not only created Whiskeytown, but also created the landscape of the entire region. The accreted terranes in the Klamath Mountains that record some of the growth of the North American continent warrant special attention.

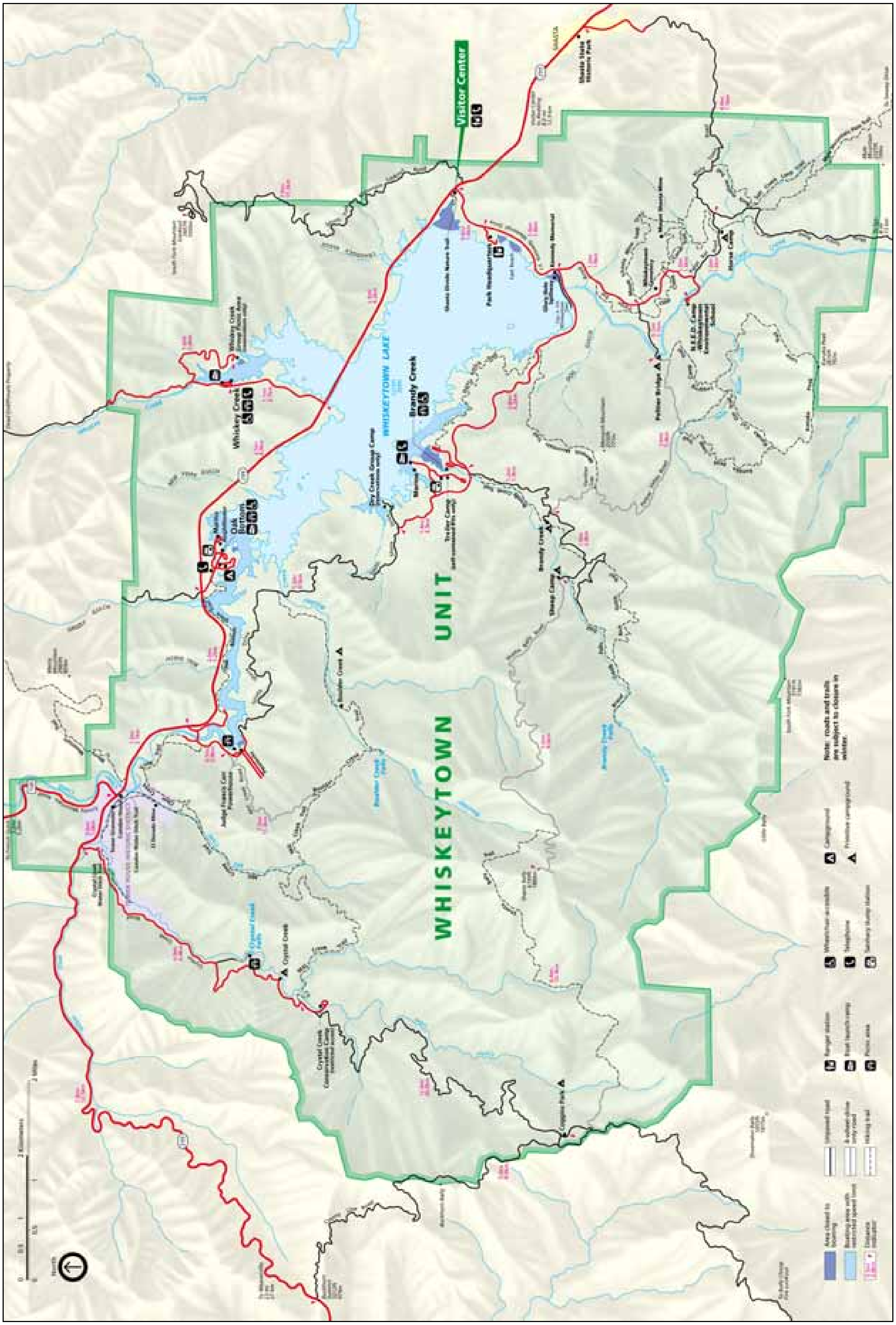

Figure 1. Map of Whiskeytown National Recreation Area

Introduction

The following section briefly describes the regional geologic setting and the National Park Service Geologic Resource Evaluation program.

Purpose of the Geologic Resource Evaluation Program

The Geologic Resource Evaluation (GRE) Program is one of 12 inventories funded under the NPS Natural Resource Challenge designed to enhance baseline information available to park managers. The program carries out the geologic component of the inventory effort from the development of digital geologic maps to providing park staff with a geologic report tailored to a park's specific geologic resource issues. The Geologic Resources Division of the Natural Resource Program Center administers this program. The GRE team relies heavily on partnerships with the U.S. Geological Survey, Colorado State University, state surveys, and others in developing GRE products.

The goal of the GRE Program is to increase understanding of the geologic processes at work in parks and provide sound geologic information for use in park decision making. Sound park stewardship relies on understanding natural resources and their role in the ecosystem. Geology is the foundation of park ecosystems. The compilation and use of natural resource information by park managers is called for in section 204 of the National Parks Omnibus Management Act of 1998 and in NPS- 75, Natural Resources Inventory and Monitoring Guideline.

To realize this goal, the GRE team is systematically working towards providing each of the identified 270 natural area parks with a geologic scoping meeting, a digital geologic map, and a geologic report. These products support the stewardship of park resources and are designed for non- geoscientists. During scoping meetings the GRE team brings together park staff and geologic experts to review available geologic maps and discuss specific geologic issues, features, and processes. Scoping meetings are usually held for individual parks and on occasion for an entire Vital Signs Monitoring Network. The GRE mapping team converts the geologic maps identified for park use at the scoping meeting into digital geologic data in accordance with their innovative Geographic Information Systems (GIS) Data Model. These digital data sets bring an exciting interactive dimension to traditional paper maps by providing geologic data for use in park GIS and facilitating the incorporation of geologic considerations into a wide range of resource management applications. The newest maps come complete with interactive help files. As a companion to the digital geologic maps, the GRE team prepares a park- specific geologic report that aids in use of the maps and provides park managers with an overview of park geology and geologic resource management issues.

For additional information regarding the content of this report and up to date GRE contact information please refer to the Geologic Resource Evaluation web site (http://www2.nature.nps.gov/geology/inventory/).

Geologic Setting

The Klamath Mountains of northeastern California were one of the focal points of the 1849 gold rush. The region is the second most productive gold district in California. Placer gold was first discovered in the regions streams and rivers in 1848, and the lode gold was found in nearby French Gulch in 1852 (Clark 1970). Mining in the French Gulch area continued until 1942. From 1900- 1914, and again in 1930, gold mining activity was at its peak. During the 1970s and 1980s, a resurgence of mining interest for lode gold, copper, silver, zinc, and iron contained in massive sulfide deposits took place (Albers 1965). The name Whiskeytown comes from an early incident involving a team of donkeys that lost their footing on a local trail spilling a load of whiskey into a nearby ravine.

From historical remnants of the early settlers to the present, human interest in the area has continued with the creation of the Whiskeytown Lake and Dam. President John F. Kennedy dedicated Whiskeytown Dam on Clear Creek on September 28, 1963, during his last trip to California. The area was authorized on Nov. 8, 1965 and established as a Natural Recreation Area on October 21, 1972. Together with the Shasta and Trinity units (both managed by the Forest Service, U.S. Department of Agriculture), Whiskeytown is part of the 42,503 acres of Whiskeytown- Shasta- Trinity National Recreation Area (figure 2). This area received more than 750,000 recreation visits in 2006.

The Whiskeytown Unit, with its mountainous backcountry and large, man- made reservoir, offers many recreational opportunities while preserving the historical remains of the 1849 California Gold Rush. Whiskeytown Lake provides 58 km (36 miles) of shoreline and 3,200 surface acres of water at an average elevation of 369 m (1,209 ft). The lake was created by diverting water through tunnels and penstocks, including the Clear Creek Tunnel, from the Trinity River Basin to the Sacramento River Basin (Prokopovich, 1993). The most prominent geologic feature within the recreation area is the peak of Shasta Bally (elevation 1,893 m (6,209 feet).

Whiskeytown National Recreation Area lies in the Klamath Mountains physiographic subprovince of the Pacific Border Province in northern California (figure 3) (CGS, 2002; USGS, 2003). Geomorphologically, this province is considered a northern extension of the Sierra Nevada, but this link is still unclear (CGS, 2002). The boundaries of this province are not well defined. According to Irwin (2003), the Klamath Mountains extend from about 43° north latitude (near the Umqua River in Oregon), south to about 40°15' (North Fork of the Eel River) a distance of approximately 306 km(190 miles).

The province extends roughly 113 km (70 miles) in an east- west direction from the Great Valley west to the Coast Ranges. In northernmost California and southwestern Oregon, the Klamaths are bounded on the east by the Cascade Range, which includes Mount Shasta. The province covers an area of about 30,562 square kilometers (11,800 square miles) (Irwin, 1966).

Following their formation, the Klamath Mountains were cut by several large rivers into separate mountain ranges. In the western Klamaths, an irregular drainage incised on the Klamath peneplain, an uplifted plateau. The uplift is responsible for a series of successive gold- bearing gravel benches in the canyons of the region (CGS, 2002). In California the northern half of the province is drained by the Klamath River and the southern half by the Trinity River (Norris and Webb, 1976). The principal ranges of the Klamath Mountains in California are the Siskiyou Mountains extending northward into Oregon and the Trinity Mountains to the south. Other ranges of the Klamath Mountains include the Salmon, Marble, South Fork and Scott Mountains. The highest point in the Klamaths in Oregon is Mt. Ashland reaching 2,295 m (7,530 ft), near the town of Ashland, Oregon. In California, the highest elevations are Thompson Peak, 2,744 m (9,002 ft) and Mt. Eddy, 2,755 m (9,038 ft). General elevations range from 610 to 1,524 m (2,000 to 5,000 ft) in Oregon and 1,524 to 2,134 m (5,000 to 7,000 ft) in California. The topography is rugged and steep throughout the entire province.

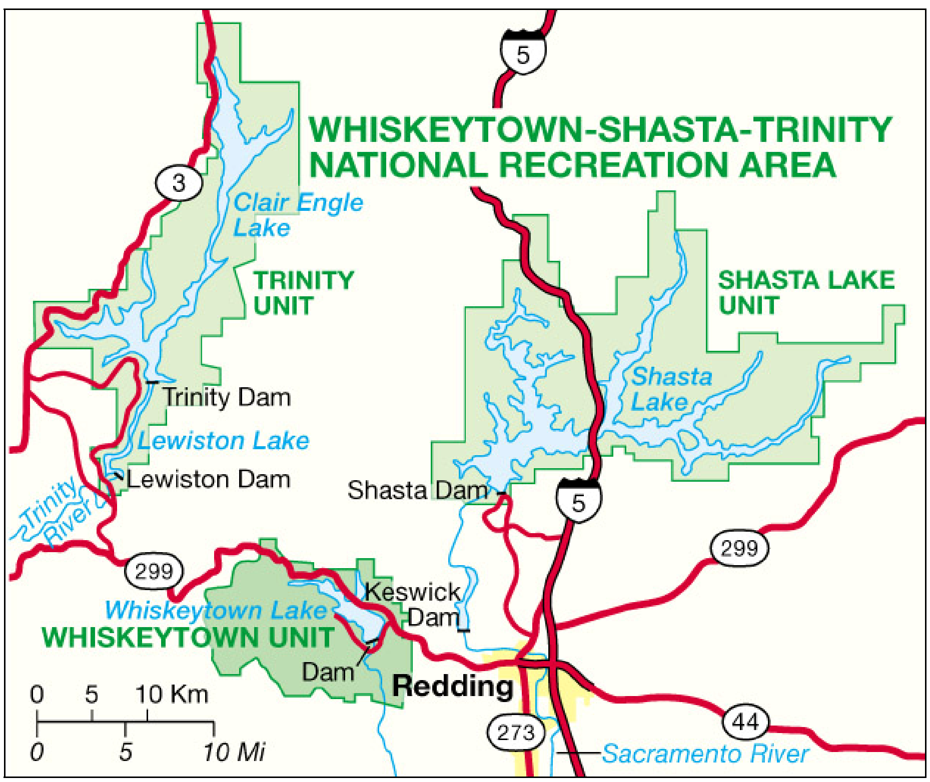

Figure 2. Location of Whiskeytown-Shasta-Trinity National Recreation Area

Figure 3. Location of Whiskeytown National Recreation Area on a physiographic map of California. Red line indicates the rough outline of the Klamath Mountain physiographic province. Note proximity of Whiskeytown to Mt. Shasta, Cascade Ranges and Sierra Nevada. Map is adapted from a U.S. Geological Survey graphic found at the following website: http://wwwflag.wr.usgs.gov/USGSFlag/Data/maps/CaliforniaDEM.html

Geologic Issues

A Geologic Resource Evaluation scoping session was held for Whiskeytown National Recreation Area on March 2- 5, 2004, to discuss geologic resources, address the status of geologic mapping, and assess resource management issues and needs. The following section synthesizes the scoping results, in particular, those issues that may require attention from resource managers.

Restoration of Roads and Mass Wasting

The potential for landslide and rockfall exists along most, if not all roads and trails at Whiskeytown National Recreation Area. These events can cause severe road and trail damage resulting in closures. There are over 483 km (300 miles) of roads, both from logging and mining, covering over 42,000 acres at Whiskeytown National Recreation Area. Many of these roads in the Whiskeytown area are highly prone to downslope movement. This movement can occur slowly as slope creep or catastrophically as a debris flow.

Similarly, slumps and other forms of slope failure are common for weathered igneous and metamorphic rock units in the Klamath Mountains. This region is composed of deeply weathered rock and steep slopes. The Shasta Bally granite, which underlies one- third of the park, has a unique, biotite- rich composition. Minerals such as biotite, muscovite and other micas have planes of inherent weakness within their crystal structure. When these micaceous minerals become hydrated from exposure to surface or near surface conditions, water lubricates these planes of weakness resulting in a sliding movement. These minerals weather preferentially. This property has allowed the Shasta Bally granite to weather deeply, sometimes as much as 200 m (600 ft), creating slope instability in certain areas of the park. On a megascopic scale, this translates into unstable slopes and mass movement. The rocks of the Shasta Bally batholith are rich in micaceous minerals making slopes unstable especially during times of heavy precipitation.

Loosely cemented or unconsolidated rock is especially vulnerable to slope failure. Slope failure and debris flows along many of the roads at Whiskeytown result from erosion associated with seasonal thunderstorms and high rainfall. The Whiskeytown area receives an average annual precipitation of 140 cm (65 in). These heavy precipitation events loosen rock and soil on slopes that lack the stabilizing effect of plant roots. The unconsolidated rock and soil, suddenly saturated with water, can then detach and slide down slope causing a slump or flow. In the winter of 1999, the area received 280 cm (128 in) that triggered three debris flows. Seismic activity may also precipitate mass wasting events. Earthquakes trigger loose rock and debris to fail on moderate to high slopes.

Erosion and weathering processes are exacerbated by road construction, building projects, forest fires, and off- road vehicle use. When fire events remove vegetation and then subsequent roads are hastily built to fight out- of- control fires, erosion is locally accelerated. 70% of down- slope, mass wasting movement occurs within the first year of a fire.

Whiskeytown is a popular setting for recreation. Some areas susceptible to slope failure are also highly visited. For example, the beach area below Brandy Creek Trail is a debris flow creating a potential hazard where visitors may be at risk. Debris flows have been documented on almost all the creeks in the southern reaches of the park. Dating these events is difficult, however, major flows have occurred twice in the last 50 years, the most recent in 1997.

Inventory, Monitoring, Research, and Resource Management Needs

- Reclaim hazardous roads as funding becomes available.
- Locate, characterize, and map the debris flows noting their location and aerial extent.
- Monitor movement along slopes susceptible to slope creep. Focus first on areas where these hazards might affect visitor safety.
- Perform a comprehensive study of the erosion and weathering processes active at Whiskeytown National Recreation Area, taking into account rock formations, slope aspects, location and likelihood of instability.
- Create a rockfall susceptibility map using rock unit versus slope aspect in a GIS; use the map to determine the best locations for future developments and the management of existing developments including trails, buildings, and recreational use areas.

Mine-Related Issues

The Whiskeytown unit of the Whiskeytown- Shasta- Trinity National Recreation Area is open to mineral leasing at the discretion of the Secretary of the Interior, (excluding Whiskeytown Lake, high use recreations areas, and section 34, Twp. 33N, Rge. 7W). The unit does allow recreational gold panning, subject to certain restrictions, but prohibits the use of other means of gold recovery (e.g. use of a suction dredge, a crevice cleaner, screen separator, sluice box, rocker, or any other mechanical or hydraulic device (36CFR7.91d).

The NPS is currently working with the Bureau of Land Management, California Regional Water Quality Control

Board, and Shasta County Department of Resource Management to address concerns regarding heavy metals contamination emanating from abandoned and active mining operations adjacent to the park. Many of the sites of concern are located in the watershed above Whiskeytown Lake, in the vicinity of French Gulch. Arsenic, mercury, acid mine drainage, and other heavy metals contamination of tributaries entering the park results in elevated contaminant levels in lake sediments possibly endangering aquatic wildlife and humans.

Acid Mine Drainage

Whiskeytown National Recreation Area has a long history of mining activity ultimately resulting in over 100 mines within the National Recreation Area and surrounding watersheds. Much of the lode gold extracted from there area was associated with massive sulfide deposits. In addition to gold, copper, iron, zinc, quartz, and silver have been mined in the French Gulch and West Shasta Districts (Albers, 1965).

The exposure of pyrite- bearing (iron sulfide) rock waste, from abandoned mines and tailings, to surface conditions has resulted in the formation of sulfuric acid. The acid is transported in solution by streams and rivers lowering the pH. The low pH of the acidic water also mobilizes heavy metals in the rocks such as lead, arsenic, and cadmium. A pH as low as - 3.5 (a negative pH) was measured at the Iron Mountain Mine, an EPA superfund site in the northeast corner of the park. The acid mine drainage causing these low pH values can damage aquatic habitats, adversely affect birds, fish, and other aquatic organisms. Humans, either by ingestion of contaminated surface water or direct contact may also suffer heavy metal contamination or even acid burns in extreme cases (Scorecard, 2005).

Mercury Contamination

Despite later success with mining lode gold, the largest recovery of gold from the Whiskeytown region has been from placer mining (Clark, 1970). Mercury is used in the process of extracting gold from placer deposits to amalgamate the gold and remove it from the rock. Gold is then separated from the mercury and most of the mercury is reused. However, some mercury remains in the waste rock and tailings and additional mercury is lost in the gold extraction process.

Elemental mercury attaches to both suspended and settled particles in water and moves downstream from placer tailings. Elemental liquid mercury is difficult to immobilize and the process of disturbing and removing contaminated mine tailings could release more entrained mercury into the environment. Mercury has been found in aquatic macroinvertebrates. Mercury tends to concentrate in animal tissue by bioaccumulation. Smaller animals with lower concentrations of mercury are eaten by larger animals in whose tissues, the element concentration increases. Mercury is a neurotoxin, meaning it affects the central nervous system and may cause changes in personality, behavior, trembling, and even dementia (PRF, 2002). Mercury in sufficient quantities can be toxic when consumed by animals and humans (Scorecard, 2005).

Abandoned Mines

Abandoned mines pose a serious threat in addition to contamination issues. There are health and safety issues associated with the mine workings themselves with open shafts and unstable adits. Bad footing is associated with several adits increasing the likelihood of injury for visitors. Mine collapse is a concern at Whiskeytown, as is bad air associated with underground mines. According to the National Park Service Disturbed Lands Restoration Program, there are 39 mine sites and 42 hazardous underground openings at Whiskeytown National Recreation Area (AML, 2001).

Several mines have been closed to visitor access using bat gates, which permit bats and other small fauna to enter, but prevent human intrusion. Other mines are blocked using fences. Another option for closing a mine is using a polyurethane foam which acts as a permanent barrier to the mine entrance. This technique was employed successfully at Theodore Roosevelt National Park in North Dakota. There are likely many mine openings at Whiskeytown, which need to be permanently closed and made safe.

Inventory, Monitoring, Research, and Resource Management Needs

- Accurately map the locations of abandoned mine sites. Over 100 are exist within the park boundaries and surrounding watersheds.
- Characterize each abandoned mine site on- site with regards to size and extent of workings, the amount of exposed waste rock, the degree of weathering and extent of sulfuric acid formation, the potential for mercury (Hg) contamination, proximity to significant water sources, etc.
- Characterize each abandoned mine site with its hazard potential in addition to the status of closure and remediation.
- Monitor the quantity and quality of water outflow from potentially hazardous mines.
- Set up sample sites for monitoring stream sediment and water for mercury contamination, focusing on areas near mine tailings.
- Investigate outside research tests on ways to safely immobilize mercury in situ. Consider ways to implement these techniques.
- Inventory mine sites and create a map with the location and characterization of each site.
- Monitor mine visitation, both human and animal to determine candidate sites for permanent closure.
- Monitor structural integrity of mine workings to determine the risk of collapse.
- Continue efforts to engage the Bureau of Land Management and address the impacts that mines controlled by the Bureau are having on park resources, especially Whiskeytown lake.

Recreation Demands

Whiskeytown Lake, a man- made reservoir, attracts an annual average of more than 700,000 people placing considerable demand on natural resources at the park. Visitors use the lake and the lakeshore for water related activities, hike the various trails, use picnic areas, and climb and hike in the surrounding mountains (figure 4). Hikers are drawn to the many waterfalls throughout the area (figure 5). Whiskeytown offers 45 miles of trails for hiking, mountain biking, and horseback riding. In addition to numerous logging and access roads, the trail system includes a 4x4 drive up to Shasta Bally.

There are three developed campgrounds and several primitive campsites. The campgrounds are located at Oak Bottom, Dry Creek, and Brandy Creek. Another developed site is the Whiskey Creek Group Picnic Area, which offers three- day use picnic areas that can accommodate groups up to 40 people. There are three boat ramps, two on the north and one on the south side of Whiskeytown Lake. The lake itself is ideal for paddling canoes and kayaks, swimming, sailing, scuba diving, water skiing, boating, and fishing. Park visitors negatively impact the park watershed by trampling riparian zones, introducing waste and litter to the area's waterways, and increasing trail traffic which speeds the process of erosion on slopes.

In addition to providing recreational activities, the National Park Service is dedicated to preserve, protect, and restore the natural resources and the existing ecosystem of Whiskeytown National Recreation Area. Preservation of the regional ecosystem requires coordination with the U.S. Forest Service, which manages Shasta and Trinity lakes. Whiskeytown is surrounded by mostly private land and is in close proximity to the city of Redding, CA. As population and development increase in the area, demand for all types of recreation on public lands will increase and place added stress on the integrity of the parks natural resources, accordingly.

Inventory, Monitoring, Research, and Resource Management Needs

- Perform a comprehensive study of the impacts of adjacent development projects and determine potential threats to the ecosystem of the park.
- Initiate a monitoring program to determine recreational impacts to the park with emphasis on water quality, shoreline degradation, slope stability, and habitat condition.
- Cooperate with the U.S. National Forest Service and the Bureau of Reclamation to monitor the effects of recreational use on the entire regional ecosystem.

Effects of Whiskeytown Dam

The presence of the Whiskeytown Dam has a significant effect on the Clear Creek watershed and the ecosystem supported by it. The tributaries of Clear Creek were drowned upon filling the Whiskeytown Lake reservoir. The wetlands and riparian zones associated with the shoreline of the reservoir are sensitive to geomorphological changes and water level changes. Salmonoid habitat is degraded by the reduction of gravel input downstream of the dam. Siltation is present behind the dam in the lake as is erosion of the shoreline locally. The Bureau of Reclamation (BOR) has total control and jurisdiction over the lake and water level and is responsible for the water quality. The National Park Service has little input in the control of the water level and timing of water releases from the reservoir.

Inventory, Monitoring, Research, and Resource Management Needs

- Characterize, map and monitor wetlands along the shoreline of Whiskeytown Lake.
- Work with the BOR to restore salmonoid habitat and slow siltation behind the Whiskeytown Dam.

Seismicity and Volcanic Hazards

Although there are no known major faults in the area, the Lake Shasta region experiences frequent minor tremors. California is a seismic hotspot with the San Andreas fault system running up the western coast of the North American continent. This is one of the most active faults in the United States. Minor earthquakes occur in Whiskeytown nearly every day. These are usually too small to be felt on the surface, but are detected with a seismograph set up in the park by the University of California, Berkeley seismic network. This active seismograph is located at an elevation of 976 m (988 ft) on Pre- Devonian age metavolcanic rocks (Abrahamson et. al, 1984). On November 24th, 1998 the area experienced a magnitude 5.3 earthquake that resulted in moderate damage to structures in the area.

While seismic hazards are not perceived as an imminent threat to Whiskeytown National Recreation Area, awareness of seismic potential is important for resource management. The steep slopes of highly weathered rock are poised to fail as catastrophic landslides along many of the roads, trails, and hillsides at Whiskeytown. Even a moderate seismic event may shake the ground enough to trigger slope failure.

With relatively recent volcanic activity from nearby Lassen Peak (1914), ashfall could impact the resources at Whiskeytown National Recreation Area. The only known historical eruption from Lassen occurred in 1786 with pyroclastic flows and ashfall (Wright and Pierson, 1992). Another large eruption of Mt. Shasta occurred 700 years ago (Foxworthy and Hill, 1982). Mt. Shasta is approximately 42 km (25 miles) north and east of Whiskeytown. Two small fumarole areas on the dome of Mount Shasta are currently emitting gas and steam. There have been several volcanically associated debris flows this century (Wright and Pierson, 1992). The Mt. Shasta volcano has a recurrence eruption interval of about once every 600 years during the last 4,500 years. It has been erupting for the past 100,000 years (Miller, 1980). Future eruptions seem very likely from the mountains 4 main vents at or near the summit, however new vents could occur almost anywhere in the vicinity

(Miller, 1980; Foxworthy and Hill, 1982). Given the distance from Mt. Shasta, in the event of a major volcanic event, the recreation area would likely be affected by ash fall and seismic activity associated with volcanism.

Inventory, Monitoring, and/or Research Needs

- Cooperate with other federal agencies (U.S. Geological Survey, Bureau of Reclamation (BOR), U.S. Forest Service, etc.) and academic institutions (University of California, Berkeley) to determine the risk of near-term, future volcanic eruption from Mount Shasta and surrounding areas.
- Collaborate with other government organizations or educational institutions to perform engineering studies using a strain meter to assess possible slope collapse hazards and the potential for new volcanism.
- Look at rockfall susceptibility with respect to seismic potential and create a map highlighting the areas at risk for seismically induced landsliding.
- Obtain access to regular seismic activity reports in the surrounding areas to measure and monitor activity in the region.

Potential Research Projects

The unique geology of Whiskeytown National Recreation Area has been the focus of human interest for over 150 years. It lends itself to potential scientific research projects including:

- Determine the timing of metamorphic, tectonic and igneous events using cross cutting relationships and age dates in the field.
- Develop more graphics and brochures emphasizing geology, targeting the average enthusiast.
- Perform an inventory of any historical relics found within and around the park.
- Inventory the different rock compositions at macro (outcrop) and micro (thin section) scale. Create a digital coverage of the variability in composition to determine a sequence of events based on chemical genesis.
- Locate, map and characterize rock units rich in micas such as biotite to attempt to predict slope failure. Igneous units such as the Shasta Bally Batholith and the Mule Mountain Stock are obvious targets.

Soils

A soil resource inventory data set for Whiskeytown NRA was completed in 2006 in conjunction with the U.S. Department of Agriculture, Natural Resources Conservation Service, and meets the standards and specifications on the National Park Service Soil Inventory and Monitoring Program. This dataset is intended to serve as the official database for all agency applications regarding soils resources. This digital soil survey is generally the most detailed level of soil geographic data developed by the National Cooperative Soil Survey. The information was prepared by digitizing maps, by compiling information onto a planimetric correct base and digitizing, or by revising digitized maps using remotely sensed and other information. Final SRI products are available for download from the NPS Data Store (http://science.nature.nps.gov/nrdata/index.cfm). Any questions regarding this dataset should be addressed to Pete Biggam, the NPS Natural Resource Program Center Soil Resource Program Manager (pete_biggam@nps.gov).

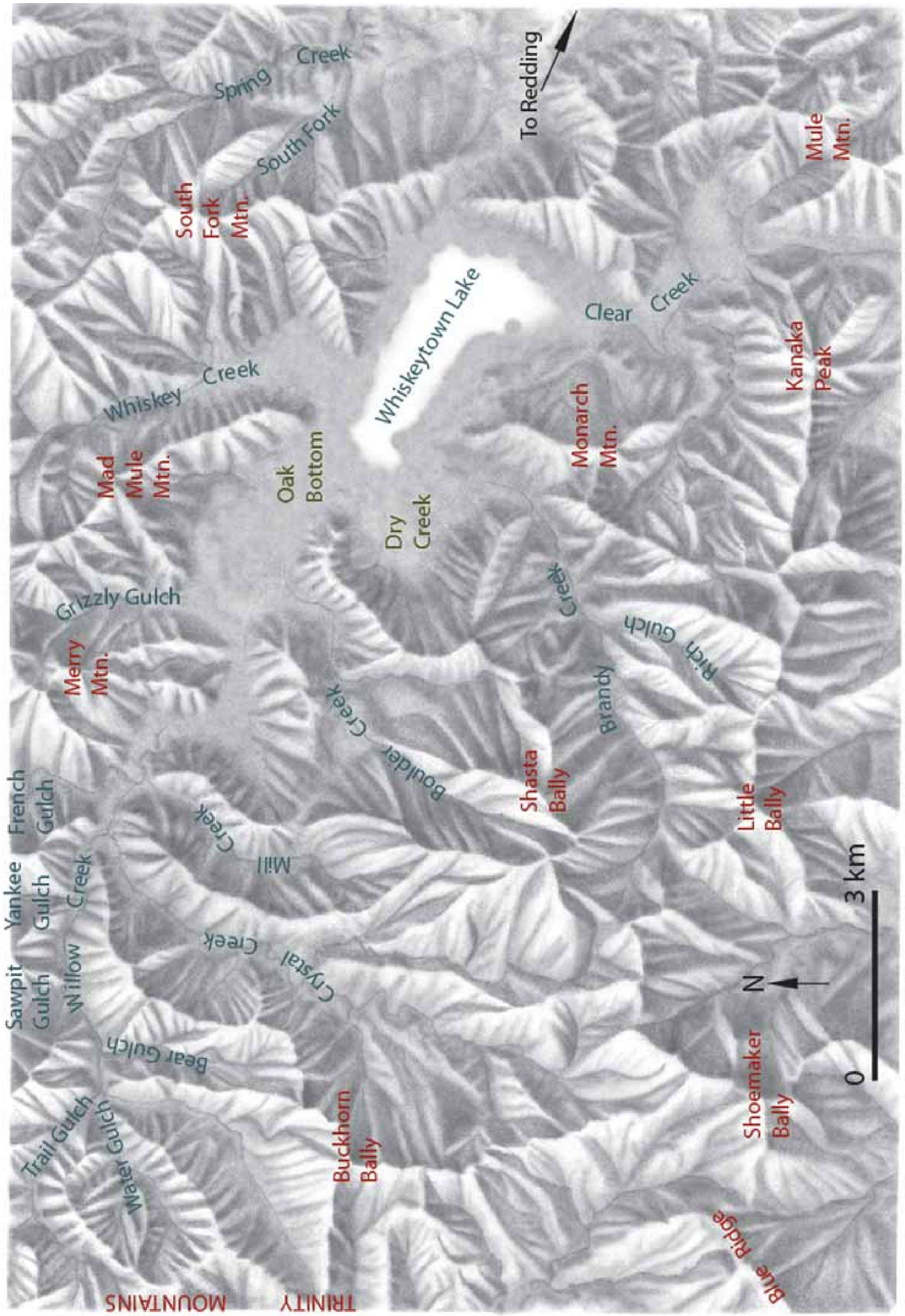

Figure 4. Shaded relief image showing locations of some of mountains, streams, and gulches surrounding Whiskeytown Lake reservoir. Image is courtesy of the National Park Service, graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

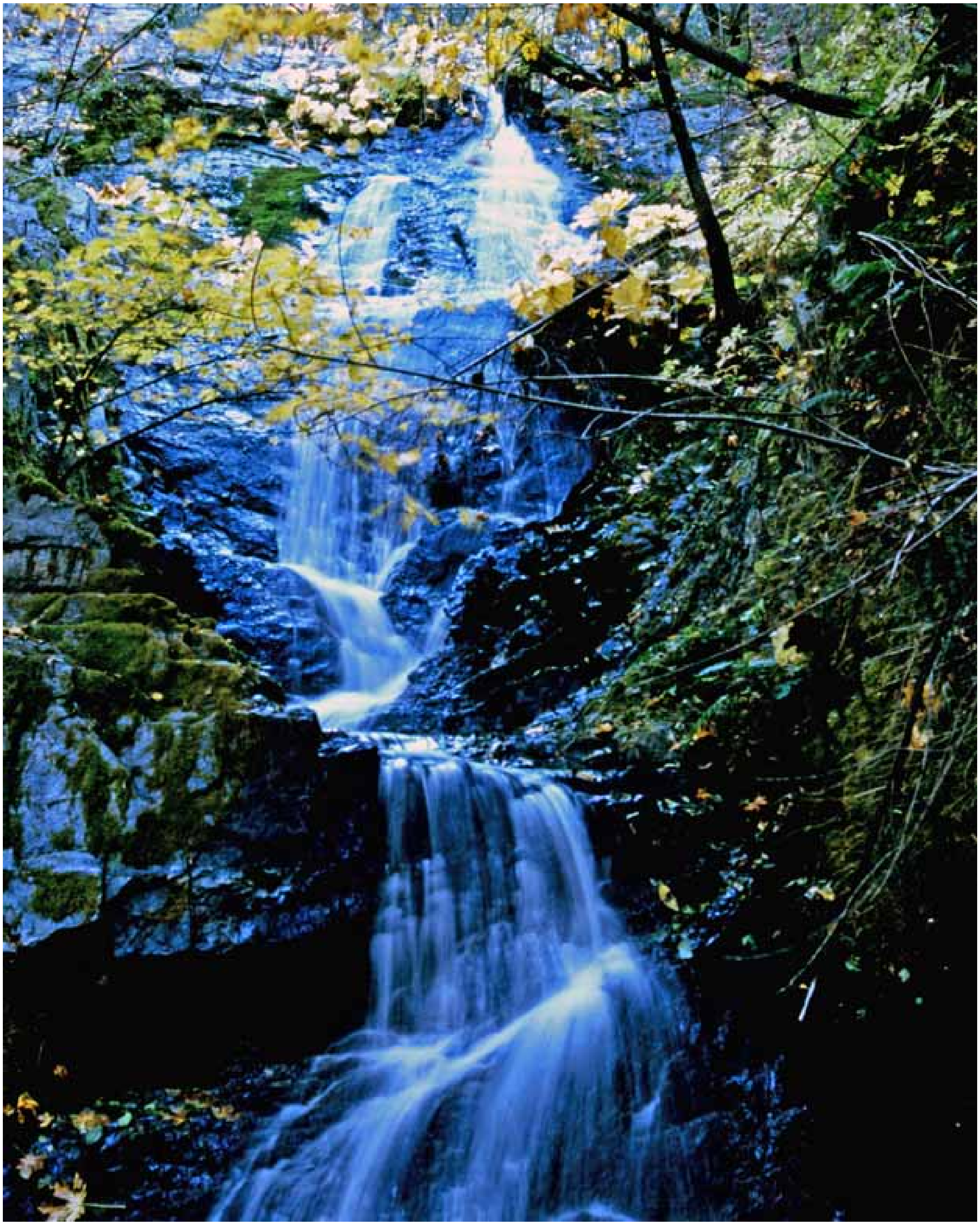

Figure 5. Boulder Creek, one of many small streams flowing off the hill slopes at Whiskeytown National Recreation Area. Photograph courtesy of the National Park Service.

Geologic Features and Processes

This section provides descriptions of the most prominent and distinctive geologic features and processes in Whiskeytown National Recreation Area.

Shasta Bally

The 1,893 m (6,209 ft) high peak of Shasta Bally dominates the skyline at Whiskeytown National Recreation Area (figures 6 and 7). It lends its name to the rock unit that comprises most of the mountain, the Shasta Bally batholith. A batholith is a large igneous intrusion that has more than 100 km2 (40 sq. miles) surface exposure and no known bottom. The Shasta Bally is primarily composed of light- colored quartz diorite ranging to granodiorite (Albers, 1965).

The northwest trending (N45°W) batholith is the dominant feature in the Whiskeytown area. This dominance of the local topographic expression is due to its preferential resistance to erosion in contrast to the surrounding country rock. Its total exposed length is about 48 km (30 miles) and its widest point is about 14 km (9 miles). There are several satellite plutons, identical in composition that crop out around Shasta Bally. One of the largest, the Clear Creek plug, covers more than 2.5 square kilometers (1 square mile). Contacts between the batholith and the surrounding, foliated, gneissic country rocks, are sharp.

The Shasta Bally batholith is an igneous pluton, which intruded the older assemblage of quartz- mica schists, felsic and mafic volcanic rocks, conglomeratic and shaly sedimentary rocks ranging in age from the Precambrian to the Mississippian (Albers, 1965; Irwin, 1999). This intrusive event occurred during the Late Jurassic- Early Cretaceous and was contemporaneous with the Nevadan orogenic event. During this time, plutonism was also occurring in the area that became the Sierra Nevada mountains, southeast of Whiskeytown.

1848 Historical Structures

The rich natural resources of the Whiskeytown area, including precious metals and minerals, have attracted people to this area of California for hundreds, if not thousands of years. Archeological sites in the Lower Clear Creek, and Sulphur Creek Archaeological Districts on Federal Lands of the Whiskeytown area date back to prehistoric aboriginal times, as early as 1,000 B.C. The Tower House District and the French Gulch area are host to a number of historical buildings, cemeteries, and other relics, many of which are listed with the National Register of Historic Places (as of 2007). Within the 200 acres of the Tower House District are 7 buildings, 4 structures relevant to the transportation, agriculture, commerce and industry of the area from 1825- 1874. This information and more on the areas historic features can be found at the following website: (http://www.nationalregisterofhistoricplaces.com). Opportunities for visitors to experience these cultural features include gold panning, interpretive signs, and the Camden House, dating back to the 1850's. The important role geology played in the settlement of this area and historic mining activities should be emphasized. The preservation of these historic features requires knowledge of the geologic processes at work on the landscape. Seismic shaking may undermine historic foundations. Slope processes and erosion may also interfere with the preservation of cultural resources.

Though Whiskeytown National Recreation Area was set aside to preserve a natural area for outdoor activities focusing on the reservoir, careful attention must be paid to the historical context found in the area as well. This context is centered on the geologic resources of the area, which attracted early mining interest and settlement. The preservation and restoration of the historical features present at Whiskeytown will add to the heritage of the gold rush story for this and future generations.

Mining History

Although today there are no active mines in Whiskeytown National Recreation Area, the region once boomed with mining activity. The rivers draining the Klamath Mountains form an irregular drainage pattern that is responsible for the areas successive terraces of sand, gravel, and assorted alluvium deposits. Gold, weathered out from the mountains above, was discovered in these deposits in French Gulch in 1848. This discovery was part of a veritable frenzy that led men to the west in droves during the 1849 California Gold Rush. Wherever gold was found, towns sprang up to service the miners.

When the considerable placer deposits in the Whiskeytown area were exhausted, attention moved toward mining the hillsides for lode gold in massive sulfide deposits and gold- bearing quartz veins. Mining in the area has been active intermittently since 1848 with extraction of copper, zinc, pyrite, gold, and silver (Albers, 1964).

In the quest for gold and other heavy metal deposits of the French Gulch area, more than 40 mines were excavated. Whiskeytown National Recreation Area is located in the Whiskeytown mining district. This district is one of 4 in the area which include the French Gulch-Deadwood, Muletown, and South Fork districts. The mines in the Whiskeytown district include the Eldorado, Gambrinus, Ganim gold- talc, Mad Mule, Mad Ox, Mount Shasta, and Truscott mines. Production of gold from the district is estimated between 68,700 and 71,500 ounces of gold.

The geology associated with the different deposits varies. Contacts between the Bragdon Formation (described below) and intrusive igneous rocks are host to the Mad Mule and Truscott mines. Northwest- trending structures in the Balaklala Rhyolite and Copley Greenstone are the focus of the Mount Shasta and Ganim mines. Veins trending east- west in the Mule Mountain comprise the Mascot, Eiller, and numerous other small deposits (Albers 1965).Veins in the Copley and Balaklala Formations as well as the Mule Mountain stock were much less productive in terms of gold recovered than in the Bragdon Formation contacts more prevalent in other districts.

The Reservoir and Whiskeytown Dam

Whiskeytown Dam recently celebrated 40th anniversary in 2003. It was constructed between 1960 and 1963. In September of 1963, President John F. Kennedy dedicated the dam on what was to be his last trip to California (figure 8). The dam (national ID number CA10204) is owned and operated by the Bureau of Reclamation (BOR). In addition to the main dam, two dikes, called Dike No. 1 and Dike No. 2 (East and West Dikes, respectively), enclose the reservoir.

The dam is located in the Clear Creek drainage basin about 18 km (11 miles) west of the junction with the Sacramento River Valley in the southeastern portion of the Klamath Mountains physiographic province. The basin is bordered on the east by the, relatively low elevation (701 m [2,300 ft])Mule Mountain range. The higher peaks of the Shasta Bally mountains, which grade northward into the Trinity Mountains form the western boundary. The Trinity Mountains separate the Clear Creek drainage from the Trinity River drainage (BOR, 1995). The drainage area for the reservoir is 524.5 square kilometers (202.5 square miles).

The crest elevation of the dam is 374 m (1,228 ft) with the structural height of the dam at 86 m (282 ft). The dam and its associated dikes are composed of zoned earthfill, a mix of rocks, sand, boulders, mud, etc. The dam is constructed on the Balaklala Metarhyolite Formation and the granite of the Mule Mountain Stock.

The reservoir behind Whiskeytown Dam, Whiskeytown Lake, is a major northern California recreation attraction (figure 9). The lake provides 58 km (36 miles) of shoreline and 3,200 surface acres of water. The normal surface elevation of the reservoir is 369 m (1,210 ft) with a hydraulic height of 77 m (252 ft). The dam is not gated. However, the Judge Francis Carr Powerplant on the west end of the lake generates power. The powerplant has two generators with a total capacity of 154,400 kilowatts and has been in service since May, 1963 (BOR, 2003).

Structure

Geologic structures including folds and faults have a strong influence on the topographic expression of an area. In the Shasta Bally area, geologic structures and their lithology control the geomorphology as major faults weather preferentially and resistant granitic rocks remain as high domes and ridges. The dominant geologic structure in the Whiskeytown area is a broad anticline trending north- northeast, plunging to the north in the Bohemotash quadrangle north- northwest of the park. The anticline then plunges slightly to the south across the northeast corner of the Shasta Dam quadrangle and into the Whiskeytown quadrangle. Here igneous rocks of the Mule Mountain stock truncate the anticline. Two minor synclines on either side of the anticline also trend in a generally northerly direction.

The contact between the sedimentary rocks of the Mississippian Bragdon Formation (a primary gold producer) and the underlying igneous intrusives is thought to be a low- angle thrust fault. In areas where contacts are exposed, the Bragdon is highly deformed, faulted, and intruded. Intrusive igneous activity focused along the faulted areas (Albers, 1965). Magma favors preexisting fractures and weaknesses in a rock.

There are numerous faults running through the park, although many are difficult to locate due to the poor exposures and a lack of stratigraphic markers necessary to determine clear offset in the igneous rocks. Most appear to trend northwest to southeast, with secondary faulting trending northeast to southwest. The majority of these faults have little inferred offset.

The Hoadley Fault virtually bisects the park from the northwest end to the southeast corner. It is a normal fault with the downthrown side to the northeast that generally dips 50°- 65° to the northeast. Movement along this fault likely occurred around 140 Ma.

Accreted Terranes

The Klamath Mountains are composed of a series of accreted terranes that attached to the western margin of the North American continent during compressional tectonic events such as orogenies. These rocks range in age from Cambrian to latest Jurassic (Irwin, 1997). The distribution of rocks in the Klamath Mountains is divided into several roughly arcuate, concentric, lithic belts, all of which were lapped onto the continental margin as mixed sedimentary and volcanic rocks during collision with the Pacific and Farallon plates (figure 10).

Faults, linear ultramafic bodies, or granite plutons separate these tectonostratigraphic lithic belts, which contain both volcanic and sedimentary units with associated deep- seated intrusive granites, and near-surface intrusive rocks of Devonian through Cretaceous age (Irwin, 1966). By the early Cretaceous, after at least 8 different major accretionary events, belts of sutured terranes comprised the southern Klamath Mountains. From east to west, these terranes are called: 1) eastern (Paleozoic) Klamath belt (Redding, Trinity, and Yreka subterranes ~399- 380 Ma), 2) central metamorphic terrane (~220 Ma) – Fort Jones terrane (~198- 193 Ma), 3) North Fork terrane (~180 Ma), 4) Eastern Hayfork terrane (~168 Ma), 5) Western Hayfork terrane (~164 Ma), and 6) Rattlesnake Creek terrane (~150 Ma) (figure 10) (Irwin, 1966; 1999). The granites and near- surface intrusives form another series of interstitial belts comprised of bodies of equivalent age that are divided into pre- and post- amalgamation referring to the timing of their emplacement relative to the addition of the major tectonostratigraphic belts. The interstitial belts vary on the degree of metamorphism from unmetamorphosed to amphibolite facies (Danielson and Silberman, 1987).

The eastern Klamath belt is comprised of an essentially homoclinal sequence of layers dipping to the east and terminating with some deformation against ultramafic intrusive rocks. In aggregate the sediments are 12,000 to 15,000 m (40,000 to 50,000 ft) thick and range in age from Ordovician to Jurassic, although the Ordovician and Silurian rocks are limited to exposures in an isolated northernmost part of the belt.

The central metamorphic terrane consists mainly of the Abrams mica schist and the Salmon hornblende schist. It is separated from the eastern Klamath belt by ultramafic igneous rocks and from the western Paleozoic and Triassic belt by faulting with no associate intrusives (Irwin, 1966). The Abrams mica schist is a composite unit which includes metasedimentary rocks occurring both above (Grouse Ridge Formation) and below (Stuart Fork Formation) the Salmon hornblende schist.

The lower rocks are considered fensters in a regional thrust plate formed by Salmon hornblende schist and the Grouse Ridge Formation. The metamorphic history of the area is complex. The regional grade generally ranges from upper greenschist to almandine (garnet)- amphibolite facies with some retrograde metamorphism as well (Davis, 1966).

The terranes west of the central metamorphic terrane consist of phyllitic detrital rocks, radiolarian (fossils) chert, mafic volcanics, and crystalline limestone, which have been intruded by ultramafic and granitic rocks. The grade of metamorphism ranges from low- grade greenschist facies to amphibolite facies. Some fossils have been identified from this belt including Late Pennsylvanian or Early Permian fusulinids and Permian and Triassic ammonites (Irwin, 1966).

The westernmost belts are composed mainly of the Galice Formation and the South Fork Mountain schist. The Galice Formation, dated as Late Jurassic, is composed of a lower metavolcanic unit and an upper metasedimentary unit. The metavolcanic unit is composed mainly of meta- andesite flows and breccias and may be over 2,100 m (7,000 ft) thick. The upper unit is mostly slaty mudstone and foliated greywacke. The South Fork Mountain schist is well- foliated quartz- mica schist extending in a narrow north- south band along western boundary of the Klamath Mountains for about 242 km (150 miles) (Irwin, 1966).

Figure 6. View of Shasta Bally from reservoir shore. Photograph courtesy of the National Park Service.

Figure 7. Shasta Bally summit. Photograph courtesy of the National Park Service.

Figure 8. President John F. Kennedy on September 28, 1963, standing at the podium overlooking Whiskeytown Lake during the dedication of the Whiskeytown Dam. Photograph courtesy of the National Park Service.

Figure 9. View of reservoir in autumn. Photograph courtesy of the National Park Service.

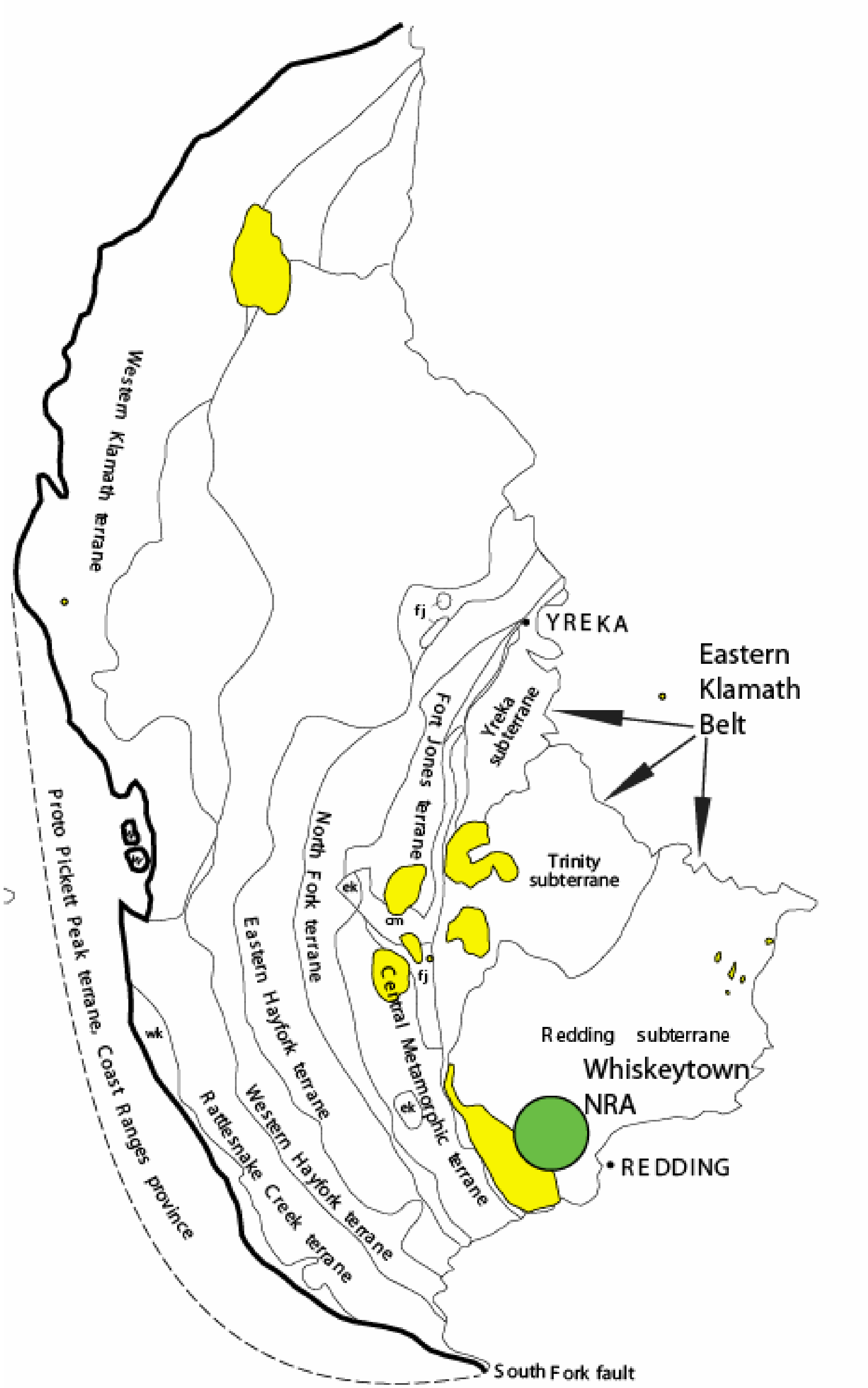

Figure 10. Map of accreted terranes of the Klamath Mountains adapted by Trista L. Thornberry-Ehrlich (Colorado State University) from figure 8 of Irwin (1999). Cretaceous plutons including the Shasta Bally batholith are in yellow. Green circle shows approximate location of Whiskeytown National Recreation Area.

Map Unit Properties

This section provides a description for and identifies many characteristics of the map units that appear on the digital geologic map of Whiskeytown National Recreation Area. The table is highly generalized and is provided for informational purposes only. Ground disturbing activities should not be permitted or denied on the basis of information contained in this table. More detailed unit descriptions can be found in the help files that accompany the digital geologic map or by contacting the NPS Geologic Resources Division.

Though it is intruded and overlain by many rock types, Whiskeytown National Recreation Area is underlain almost entirely by the granite of the Shasta Bally batholith (biotite and hornblende- rich), the granite of the Mule Mountain Stock (sodium- rich), and the Copley Greenstone (metamorphosed volcanic rocks). The Mule Mountain Stock is 400 My old (Irwin, 1999). The Shasta Bally Batholith is Late Jurassic or Early Cretaceous in age. This age was determined because it sharply cuts foliation formed during the Late Jurassic Nevadan orogeny (~144 Ma) within the Copley Greenstone of Devonian(?) age.

The sedimentary rocks in the area include; the Kennett Formation, a Devonian age shale and limestone mix; and the Bragdon Formation, a Mississippian interbedded shale and sandstone. The Devonian age Balaklala Rhyolite grades into the Kennett Formation and is composed of volcanic flows and pyroclastics. There are various other rock units present locally including hornblendite (Jurassic- Cretaceous) as pods associated with the Copley Greenstone, gneiss and amphibolite (Jurassic) that are derived from other rocks and metamorphosed, peridotite, diabase, tuffs, and metagabbro.

Deposited atop these bedrock units are a variety of unconsolidated Quaternary age units. These include soils, landslide material, talus, slope wash, colluvium, terrace and alluvial gravels, silts, sands, and clays. Semiconsolidated and correlative sands and gravels of the Quaternary age Red Bluff Formation also appear locally. Most of these units are the weathered remnants of igneous, metamorphic and sedimentary bedrock units.

The following table presents a view of the stratigraphic column and an itemized list of features for each map unit. This table includes several properties specific to each unit present in the stratigraphic column, including: unit name, map symbol, unit description, resistance to erosion, suitability for development, hazards, paleontologic resources, cultural resource, mineral resources, recreational uses, and global significance.

Map Unit Properties Table

Age	Map Unit Symbol)	Features and Description	Erosion Resistance	Suitability for Development	Hazards	Paleontologic Resources	Cultural Resources	Mineral Occurrence	Recreational Uses	Global Significance
QUATERNARY	Soil, talus & slope wash (Qcl); sand & gravel in stream beds (Qal); sand & gravel (Qg); landslide (Qls); Red Bluff Fm. (Qrb)	Unconsolidated soils, talus and other unsorted slope deposits, sand and gravel in rivers and terraces, landslide deposits, and slope wash. Red Bluff Formation consists of sand, gravel and other older unconsolidated deposits.	Very low	Suitable for most forms of development, unstable on slopes and highly permeable	Slumps, slides, rockfalls if exposed on slope	Modern remains possible	Historical structures and artifacts	Sand, gravel, silt, and clay	Good for trails, picnic areas & campsites; mountain biking	Records geomorphologic processes active today
CRETACEOUS	Chico Formation (Kc)	Conglomerate, shale, and sandstone beds; outcrops only locally.	Moderate to high	Suitable for most forms of development unless highly fractured	Block falls and rock falls if undercut	Loose cementation renders fossils unlikely	Possible tool material and campsites	Flagstones	Good for trails and campsites	Cretaceous sedimentary rocks record tectonic setting
JURASSIC OR CRETACEOUS	Birdseye Porphyry (bp); Hornblendite (hb); Quartz Porphyry (qp); Andesite Porphyry (ap); Felsic dike rocks (ad); Metagabbro (mg); lamprophyre (lp)	Include diorite porphyry, dacite porphyry, andesite porphyry; hornblendite & quartz porphyry present as small pods in outcrop; felsic dikes include aplite appearing as vertical and inclined bodies related to biotite- quartz diorite; metagabbro and lamprophyre outcrop as dikes and irregular bodies; some are associated with Copley Greenstone and most occur only locally, as small irregular bodies and dikes.	Moderate to high	Suitable for development; only very local occurrence	Slides and rockfalls if exposed on steep slopes	None	None documented	Irregular deposits rich in minerals; hornblendite; lamprophyre	Occurs locally	Interesting igneous and metamorphic rocks clustered in one area
JURASSIC OR CRETACEOUS	Shasta Bally Batholith (bqd): Biotite hornblende granodiorite (bhgd)and quartz diorite (bqbd, bqd1) Gneiss and amphibolite (gn) Injected rocks and breccia (in) Peridotite (p)	Batholith dated at 128 Ma to 218 Ma and is of irregular thickness; largely composed of very biotite rich biotite-hornblende granodiorite and quartz diorite with some associated gneiss and amphibolite; quartz diorite about 40% hornblende and biotite. Gneiss and amphibolite derived from Copley, Balaklala and Bragdon formations; injected rocks and chaotic breccias occur locally and peridotite (silica poor, containing olivine) also occurs locally. Sharp contacts with Copley Greenstone.	Low to moderate (biotite- rich portions are less resistant)	Biotite- rich layers should be avoided due to preferential weathering and slope stability problems; sloughing common in this unit.	Sloughing, rockfalls, block falls, slumping and other slope processes pose hazards	None	None documented	Large biotite crystals; injection breccias; peridotite, olivine crystals	Climbing should be discouraged; 4WD vehicle use; trails	Intrusive event records mountain building; contact metamorphism available for study
MISSISSIPPIAN	Bragdon Formation: Upper Unit (Mbu) Lower Unit (Mbl) Shale and siltstone (Mbds) Conglomerate bed (Mbc) Conglomerate, sandstone and grit (Mbdc) Black siliceous shale(Mbd) Phyllite Mbp)	Formation is approximately 1829 m (6000 ft) thick; outcrops in northern region of the park with interbeds of a variety of sedimentary rock types; upper unit contains abundant conglomerate and sandstone with siltstone and shale interbeds; lower unit consists of mostly shale, mudstone, and siltstone with subordinate amounts of tuff and conglomerate; phyllite is derived from Bragdon Formation by contact metamorphism upon intrusion of Shasta Bally batholith.	Moderate to high	Suitable for most forms of development unless highly fractured	Slides and rockfalls if exposed on steep slopes	Fossils probable in shale beds	Historic mining	Contacts rich in gold and precious metals; deposits mostly along faults and joints	Good for most recreation; climbing should be discouraged; mine safety hazard	Part of accreted terrane added to the western margin of North America

Age	Map Unit Symbol)	Features and Description	Erosion Resistance	Suitability for Development	Hazards	Paleontologic Resources	Cultural Resources	Mineral Occurrence	Recreational Uses	Global Significance
DEVONIAN	Mule Mountain Stock: Trondjemite (tag) Siliceous, pseudoporphyritic albite granite (agı) Intrusive breccia (br) Diabase (db)	Dated at approximately 400 Ma on the basis of U- Pb dating and cross- cutting relationships with Bragdon Formation and Shasta Bally Batholith; stock is largely homogenous composed of light- colored sodium- rich granite with some siliceous rich portions and some intrusive breccia and diabase present as dikes.	Moderate	Avoid mica- rich layers which tend to weather as planes of weakness; avoid permeable fractures.	Slides and rockfalls if exposed on steep slopes; biotite- rich layers might weather preferentially	None	Historic mining	E- W trending veins rich in gold & other precious metals; Granite; large mica crystals	Good for most recreation including trails; mine safety hazard	Intrusive rock records plutonism
DEVONIAN	Kennett Fm. (Dk): Limestone (Dkl) Tuffaceous sedimentary rock (Dkt)	0- 122 m (0- 400 ft) thick; outcrops locally outside park boundary; formation contains gray and black cherty shale, most siliceous in composition with limestone dominating the upper beds and tuffaceous (volcanic deposits) sedimentary rocks comprising the lower beds in the formation; some corals, brachiopods in the upper limestone beds.	Moderate to high	Suitable for most forms of development unless highly fractured or dissolved	Slides and rockfalls if exposed on steep slopes	Some corals and brachiopod fossils in limestone beds	None documented	Flagstone	Good for most recreation	Part of accreted terrane added on to the western margin of North America
DEVONIAN	Balaklala Rhyolite: Porphyritic rhyolite (Dbc, Dbm) Nonporphyritic rhyolite (Db) Volcanic breccia (Dbp) Tuff and tuffaceous sedimentary rock (Dbt) Greenstone (Dbg) Greenstone; pyroclastic rock (Dbgp)	0- 1128 m (0- 3700 ft) thick; light- colored generally with flows, pyroclastics and other deposits; porphyritic rhyolite is composed of quartz keratophyre with quartz phenocrysts ranging in size from larger than 4 mm (coarse) to 1- 4 mm (medium); rhyolite with quartz keratophyre and quartz phenocrysts smaller than 1 mm are mapped as nonporphyritic characteristically located in the lower unit of the Balaklala; volcanic breccia includes coarse breccia, tuff breccia, volcanic conglomerate and minor flow breccia; tuff and tuffaceous shale beds are associated with the Balaklala lower beds; greenstones mark the basal layers of the Balaklala, metamorphosed remnants of more basic (less silica- rich) igneous composition; grades upwards into the Kennett Formation.	Moderate to high	Unit can be preferentially weathered creating stability problems; suitable for most forms of development unless highly fractured.	Slides and rockfalls if exposed on steep slopes	None	Historic mining	NW - trending structures host gold and other precious metals; quartz phenocrysts	Good for most recreation; mine safety hazard	Part of accreted terrane added on to the western margin of North America
DEVONIAN	Copley Greenstone: Keratophyre, spilite and meta- andesite (Dc) Pyroclastic rock (Dcp) Tuff, shaly tuff and shale (Dct) Shale, shaly tuff and sandstone (Dcs1)	Unit is at least 1128 m (3700 ft) thick. Keratophyre, spilite and meta- andesite includes some volcanic breccia and agglomerate facies rocks. Volcanic pyroclastic deposits are abundant in this unit. Below these are layers of tuff, shaly tuff and shale, with some sandstone beds further down the column. Greenstone tuff and breccia, and rhyolite tuff are interfingered with gneiss, migmatite, amphibolite and other metamorphic rocks. Unit intertongues with overlying Balaklala Rhyolite.	Moderate to high	Unit can be preferentially weathered creating stability problems; suitable for most forms of development unless highly fractured and undercut on a slope.	Slides and rockfalls if exposed on steep slopes	None	Historic mining	NW - trending structures host gold and other precious metals; garnets in amphibolite; gneiss; migmatite	Good for most recreation; possible mine safety hazard	Part of accreted terrane added on to the western margin of North America
PRE-SILURIAN	Abrams mica schist and Salmon (?)hornblende schist, undifferentiated (Sch)	Abrams mica schist and Salmon (?) hornblende schist are undifferentiated in the map area.	Moderate to high	Mica- rich layers weather preferentially creating local instability.	Block falls, slides, and rockfalls on steep slopes	None	None documented	Large mica crystals	Good for most recreation	Among the oldest rocks in the region

Geologic History

This section highlights the map units (i.e., rocks and unconsolidated deposits) that occur in Whiskeytown National Recreation Area and puts them in a geologic context in terms of the environment in which they were deposited and the timing of geologic events that created the present landscape.

The area surrounding Whiskeytown National Recreation Area is full of mountain ranges and valleys. Unraveling the origin of the Klamath Mountains and associated basins exposes the complex tectonic history surrounding the growth of the western margin of the North American continent. Prior to the early Paleozoic, there was an oceanic basin in the present day location of Whiskeytown National Recreation Area. Here, sediments were deposited from the continental margin to the east and volcanics intruded during extension of the crust. Some of the oldest rocks, of Cambrian age at Whiskeytown reflect this deposition (figure 11).

The Devonian and Mississippian Antler orogeny shoved rocks eastward onto the continental margin along the Roberts Mountains Thrust fault. The thrust carried deep- marine, continental slope and rise deposits over relatively shallow marine carbonate deposits on the margin (Miller et al. 1992). This orogeny was fairly rapid, lasting only about 25 million years. However, it established a compressional regime along the western coast of the United States that lasted until the Mesozoic.

The next tectonic event affecting the Whiskeytown area was the Sonoma orogeny. This orogeny followed the scant deposition of chert- pebble conglomerates, sandstones, and limestones atop the deformed rocks of the Antler orogeny. The Sonoma orogeny involved the thrusting of an allochthonous block containing volcanic sediments atop the continental margin (Silberling and Roberts, 1962; Miller et al. 1992). This occurred during the Late Permian and Early Triassic periods.

The Mesozoic brought a period of expansion to the western margin of the continent. Large batholiths were emplaced along the western margin beneath the magmatic arcs. Entire landmasses, some associated with the western margin and some foreign to the western shore, were sutured onto the western margin from Alaska to California. These sutured landmasses are called displaced terranes (figure 12).

Early Triassic tectonic activity was marked by the accretion of a major Paleozoic island- arc terrane in the northwest Nevada- northern California region. However, Following the Sonoma orogeny a new subduction zone formed. The subduction zone trended north- northwest to south- southeast and dipped eastward beneath the continental margin. Early to Middle Triassic (245- 230 Ma) igneous rocks were emplaced along this subduction zone located east of Whiskeytown National Recreation Area (Saleeby et al. 1992).

The western continental margin was well- established by the Late Triassic (230- 208 Ma). Along the California and Arizona margin, the Late Triassic- Early Jurassic arc occupied an extensional graben sediment- trap system (Saleeby et al. 1992). Evidence of this setting is preserved in the metavolcanic and metasedimentary rocks found along the western margin from California to Washington, and in the displaced terranes of the Klamath Mountains. They overlie rocks with compositions similar to oceanic crust and upper mantle, commonly found in mid- ocean- ridge settings.

Compressional tectonics continued into the Middle Jurassic during the Elko orogeny, which was localized in Nevada, east of Whiskeytown. A north- south island arc extended through what is now central Nevada. During this time, movement of the North American plate changed from a westward direction to a north- northeast direction at a rate of about 45 kilometers per million years (Saleeby et al. 1992). This shift caused California to begin moving towards the northern subtropical latitudes. A significant dextral component of strike- slip faulting affected the relative motion along the plate edge in the Blue Mountains area of central Oregon and northwest Washington. Northwest compressional deformation along the southwest margin also caused transtensional spreading in the western Sierra- Klamath mountains region. Additional accreted terranes were sutured to the margin during the Middle Jurassic.

In the Middle Jurassic a major westward- directed thrusting event occurred in the Klamath Mountains although subduction continued to generate eastward- directed thrusts against the continental margin. Consequently, during this time, the tectonic configuration of the western United States changed to a two- sided tectonic geometry with both eastward- directed and westward- directed thrusts.

Overall, California continued to migrate into northern subtropical latitudes as submarine and subaerial volcanism erupted in the northern and western Sierra Nevada and in northwest Nevada (Saleeby et al. 1992). The volcanic and depositional patterns in northwest Nevada were controlled by a roughly east- west- trending sinistral oblique- slip- fault system. Thrusting from the west disrupted major volcanism during the Middle Jurassic.

Magmatic activity along the western continental margin continued into the Late Jurassic (162- 144 Ma), and led to the emplacement of clusters of smaller and more scattered plutons (Saleeby et al. 1992). Even so, the magmatic activity was widely distributed across the western United States from the Pacific margin in California to the edge of the Paleozoic craton (old continental crust) in Utah (figure 13) (Suppe, 1985). Accompanying the magmatic activity was the Nevadan orogeny, a major deformation event of regional scale.

The Nevadan orogeny was short- lived and may have been the result of colliding terranes along the western Sierra- Klamath belt (Suppe, 1985; Saleeby et al. 1992). In the northwest, the Nevadan orogeny marks the first time that accreted terranes in Washington and Oregon shared similar structures. In the south, the western Sierra Foothills show a complex pattern of shortening, extension, and sinistral strike- slip faulting as part of the Nevadan orogeny. West of the broad magmatic arc, the ocean basin adjacent to the Klamath Mountains was destroyed by eastward subduction and north- northwest obduction. The Great Valley fore- arc basin floor in California, however, survived Nevadan deformation.

Thin- skinned deformation also characterizes the Cretaceous Sevier orogeny (Stewart, 1980). The Sevier orogenic belt is comprised of the the fold and thrust belt of western Utah and an eastern branch that extends through Utah and southern Nevada into southeastern California. The development of the thrust system is a classic example of "stacked- shingle" geometry wherein the structurally highest and oldest fault systems formed in the west and were then carried in piggy- back fashion to the east on sequentially younger and lower thrusts as the basal decollement propagated eastward (Cowan et al, 1992). In eastern Washington and Montana, thrusting occurred from before 100 Ma to 50 Ma. In southeastern California and southern Nevada, thrusting took place over a period of time from before 200 Ma to about 85 Ma.

During thrusting in the eastern part of the region, a belt of Upper Jurassic to Cretaceous granitic plutons was emplaced along the converging plate boundary from southern California to northern Idaho (red bodies in figure 12). The granitic plutons coalesced to form the continuous Sierra Nevada batholith. The Sierra Nevada batholith intruded the margin of North America after the Late Jurassic Nevadan orogeny and before about 80 Ma. Individual plutons within the batholithic belt vary widely in size and shape and the Sierra Nevada batholith has probably been displaced as a block about 200 km (120 mi) westward in response to Cenozoic extension in the Basin and Range province to the east.

The western United States (Cordillera) divided into two distinct tectonic regimes during this time: an eastern regime and a western regime. The eastern regime consisted of the Sevier, Idaho- Wyoming, and Montana fold and thrust systems. The Sierran batholithic belt (described above), the Great Valley Group and the Franciscan Complex constituted the western regime.

The Great Valley formed an elongate basin west of and parallel to the Sierra Nevada batholith and southeast of the Klamath Mountains in California. Jurassic oceanic crust floored the basin, which was flanked on the west by an outer- arc high that existed in Late Jurassic to Early Cretaceous time (Cowan et al. 1992). Sediments accumulated in the basin from Late Jurassic to Paleogene time. Within the sediments is evidence for a profound change in the tectonic setting of California in response to the Nevadan orogeny. Stratigraphic relationships suggest that the Nevadan orogeny was more than a simple accretionary event. The Nevadan orogeny coincides with the extinction of the Late Jurassic magmatic arc and the inception of a new forearc basin and magmatic arc represented by the Great Valley group and Sierra Nevada batholith, respectively.

The Franciscan Complex also lay west of the Sierra Nevada batholithic belt. The Franciscan Complex is a chaotic assemblage of upper Mesozoic and lower Tertiary clastic sedimentary rocks, basalt, chert, and metamorphic rocks deformed by a number of imbricate thrusts. The timing and association these thrust faults is not fully understood (Cowan et al. 1992). Exposures of the sequence are present in the Coast Ranges east of the San Andreas fault and west of the Great Valley and Klamath Mountains. The Franciscan is considered a subduction complex.

The Sevier orogeny evolved into the Late Cretaceous - Early Tertiary Laramide orogeny. Instead of thin- skinned thrusts involving the upper layers of sedimentary rock, the Laramide orogeny involved deep thrusts that carried basement rocks from the subsurface and stacked them atop younger rocks. Both the Sevier and Laramide orogenies involved subduction of the Farallon plate (preceding the Pacific plate) beneath the western margin of North America. The east- dipping, oceanic Farallon plate subducted at a steep angle during the Sevier Orogeny (figure 14).

Near the end of the Cretaceous, the subducting Farallon plate may have changed its angle of dip from steep to relatively flat (Dickinson and Snyder, 1978; Livaccari, 1991; Fillmore, 2000). Subducting at a flatter angle, likely caused the oceanic plate to stop melting thus cutting off the source for volcanic activity and generating tremendous shear stresses between the two slabs. Stresses at the base of the thick continental crust were transmitted upward in the form of compression which thrust great wedges of basement rock skyward forming the Laramide Rocky Mountains.

Following the Laramide orogenic events the Cordilleran deformation transitioned from compression to extension and strike- slip tectonics. This transition occurred in different places at different times and was probably related to impingement of the North American plate on the western margin, development of the San Andreas fault system, and the opening of the Gulf of California beginning in the Oligocene (Bally et al. 1989; Christiansen et al. 1992). The change in plate motions and stress regimes may have been related to the development of the Basin and Range Province at this time (Balley et al. 1989).

As the crust extended around 15 Ma, the surface broke into the basin- and- range topography seen today in western Utah, parts of California, Nevada, Arizona, and the Rio Grande Rift in New Mexico (figure 15). The Basin and Range province of the western United States is an excellent example of horst- and- graben topography wherein fault blocks forming valleys (grabens) have dropped relative to the adjacent uplifted blocks (horsts) forming mountain ranges on steeply dipping normal faults. These fault planes flatten at depth and merge with a regional decollement surface (Wernicke, 1992).

Transform faulting along the subduction zone on the western margin continued to reconfigure the Coast Ranges of California west of Whiskeytown during the Middle Tertiary. The western Santa Monica Mountains moved westward with respect to the Peninsular Ranges and the San Gabriel fault became the main strand of the San Andreas system across the western Transverse Ranges. East of the subduction zone, the Cascades Arc extended southward along the California- Nevada border and by about 20 Ma, the arc was continuous to as far south as the latitude of Las Vegas, some 500 km (310 miles) from the Klamath Mountains (red area on figure 15).

From about 17- 14 Ma, the Western Cascades- Oregon Coast Range- Klamath Mountain block rotated clockwise by as much as 16° (Christiansen et al. 1992). Tremendous outpourings of flood basalts, between about 17 and 14 Ma, accompanied crustal extension east of the Cascade Arc in eastern Washington and eastern Oregon.

Basins in California were filled by sediment as shown by bathyal (deep water)organisms to neritic (shallow water) or nonmarine organisms deposited near the end of the Miocene as the San Andreas fault system was superimposed over part of the continental- margin subduction zone (Atwater, 1970; Christiansen et al. 1992).

Central California basins, such as the Sacramento and San Joaquin Valleys, that had persisted as bathyal depocenters (deep water depositional basins) were tectonically inverted in the Pliocene to Pleistocene period of combined compression and oblique tension and began to collect nonmarine sediments.

Volcanism in the Cascade Arc along the western coast of the United States continues to the present day (figure 16). The Quaternary Period is subdivided into two epochs: 1) the Pleistocene Epoch, about 1.6 Ma to 10,000 years before present (B.P.), and 2) the younger Holocene Epoch that extends from 10,000 years B.P. to the present. The Pleistocene Epoch is known as the Ice Age and is marked by multiple episodes of continental and alpine glaciation. Great continental glaciers, thousands of feet thick, advanced and retreated over approximately 100,000- year cycles. Huge volumes of water were stored in the continental glaciers during glacial periods so that global sea level dropped as much as 91 m (300 ft) (Fillmore, 2000).In at least 5 major pulses, local alpine glaciers carved the peaks of the Sierra Nevada and Klamath Mountain ranges. Evidence of this glaciation includes glacial cirques, deposits, and striations. Ice and snow bodies still exist in the Trinity Mountains, Mt. Shasta, and the Lassen Volcano area, west, north, and east of Whiskeytown National Recreation Area, respectively (Basagic, 2006). Glacial deposits were not specified on the map of Whiskeytown National Recreation Area.

The Holocene, is the age of humans and human impact on the global ecosystem is complex. With the retreat of the glaciers and the end of widespread glaciation about 12,000 years ago, the climate has continued to warm and global sea level has risen. Geologically, the physiographic provinces of the western United States have not changed much during the Holocene. Although, volcanoes periodically erupt in the Cascade Mountains and earthquakes signal the continued movement of the San Andreas Fault system.

The peaks of Shasta Bally and surrounding landscape at Whiskeytown National Recreation Area stand as a monument to the expression of deep time, that time that surpasses human understanding and serves as a reminder that Earth is not static but subject to change.

Eon	Era	Period	Epoch	Ma		Life Forms	N. American Tectonics
Phanerozoic (Phaneros = "evident"; zoic = "life")	Cenozoic	Quaternary	Recent, or Holocene	0.01	Age of Mammals	Modern man	Cascade volcanoes
			Pleistocene	1.8		Extinction of large mammals and birds	Worldwide glaciation
		Tertiary	Pliocene	5.3		Large carnivores	Uplift of Sierra Nevada
			Miocene	23.0		Whales and apes	Linking of N. & S. America
			Oligocene	33.9			Basin-and-Range Extension
			Eocene	55.8			
			Paleocene	65.5		Early primates	Laramide orogeny ends (West)
	Mesozoic	Cretaceous		145.5	Age of Dinosaurs	**Mass extinctions** Placental mammals Early flowering plants	Laramide orogeny (West) Sevier orogeny (West) Nevadan orogeny (West)
		Jurassic		199.6		First mammals Flying reptiles	Elko orogeny (West) Breakup of Pangea begins
		Triassic		251		First dinosaurs	Sonoma orogeny (West)
	Paleozoic	Permian		299	Age of Amphibians	**Mass extinctions** Coal-forming forests diminish	Super continent Pangea intact Ouachita orogeny (South) Alleghenian (Appalachian) orogeny (East) Ancestral Rocky Mts. (West)
		Pennsylvanian		318.1		Coal-forming swamps Sharks abundant Variety of insects	
		Mississippian		359.2		First amphibians First reptiles	Antler orogeny (West)
		Devonian		416	Fishes	**Mass extinctions** First forests (evergreens)	Acadian orogeny (East-NE)
		Silurian		443.7		First land plants	
		Ordovician		488.3	Marine Invertebrates	**Mass extinctions** First primitive fish Trilobite maximum Rise of corals	Taconic orogeny (NE)
		Cambrian		542		Early shelled organisms	Avalonian orogeny (NE) Extensive oceans cover most of N.America
Proterozoic ("Early life")		Precambrian		2500		1st multicelled organisms Jellyfish fossil (670Ma)	Formation of early supercontinent First iron deposits Abundant carbonate rocks
Archean ("Ancient")				~3600		Early bacteria & algae	Oldest known Earth rocks (~3.93 billion years ago)
Hadean ("Beneath the Earth")				4600		Origin of life?	Oldest moon rocks (4-4.6 billion years ago) Earth's crust being formed
						Formation of the Earth	

Figure 11: Geologic time scale; adapted from the U.S. Geological Survey and International Commission on Stratigraphy. Red lines indicate major unconformities between eras. Included are major events in life history and tectonic events occurring on the North American continent. Absolute ages shown are in millions of years.

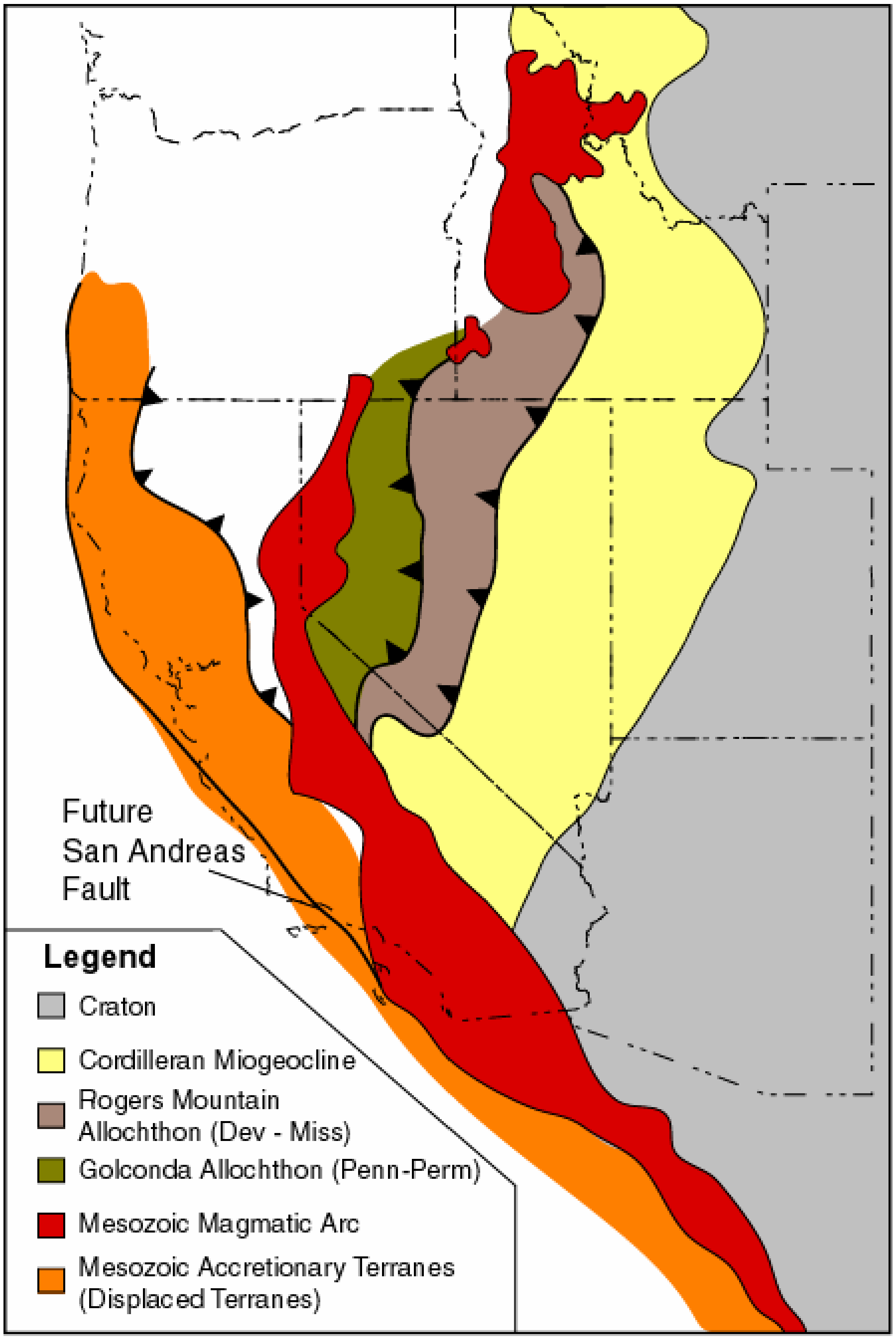

Figure 12. Location of tectonic features during the early Mesozoic Era (Triassic to Late Jurassic). Note the northeast-southwest trend of the Paleozoic features and how their southwest margin has been truncated by the Mesozoic magmatic arc and accreted terranes. Solid triangles mark the emplacement of major thrust belts with the triangles on the upper, hanging block of strata. Modified from Suppe, 1985.

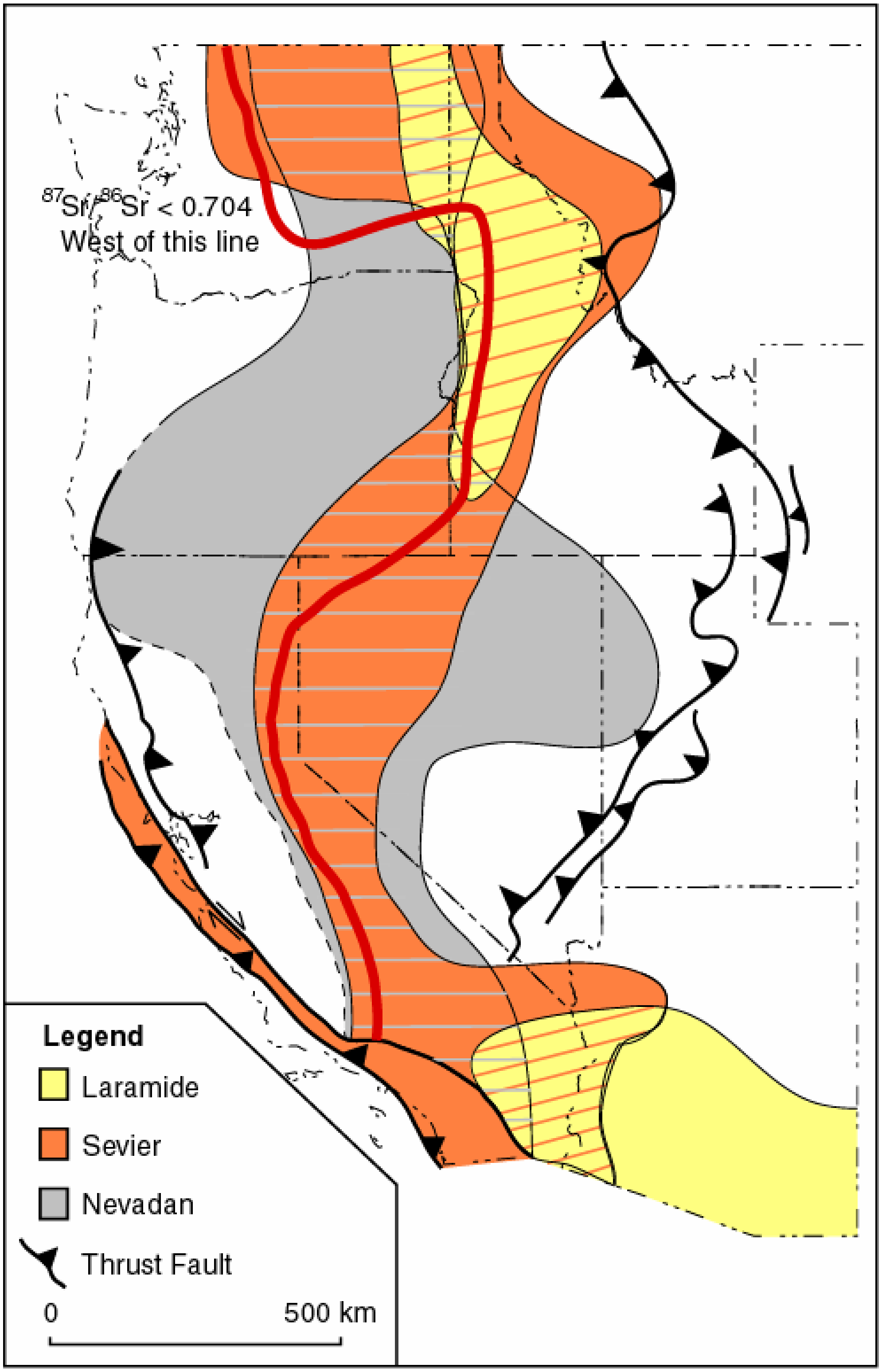

Figure 13. Location of magmatism in the western United States during the Nevadan (160-125 Ma), Sevier (105-75 Ma), and Laramide (50-75 Ma) orogenies. The red line ($^{87}Sr/^{86}Sr$ = 0.704) marks the western edge of the Precambrian Continental crust. Modified from Suppe, 1985.

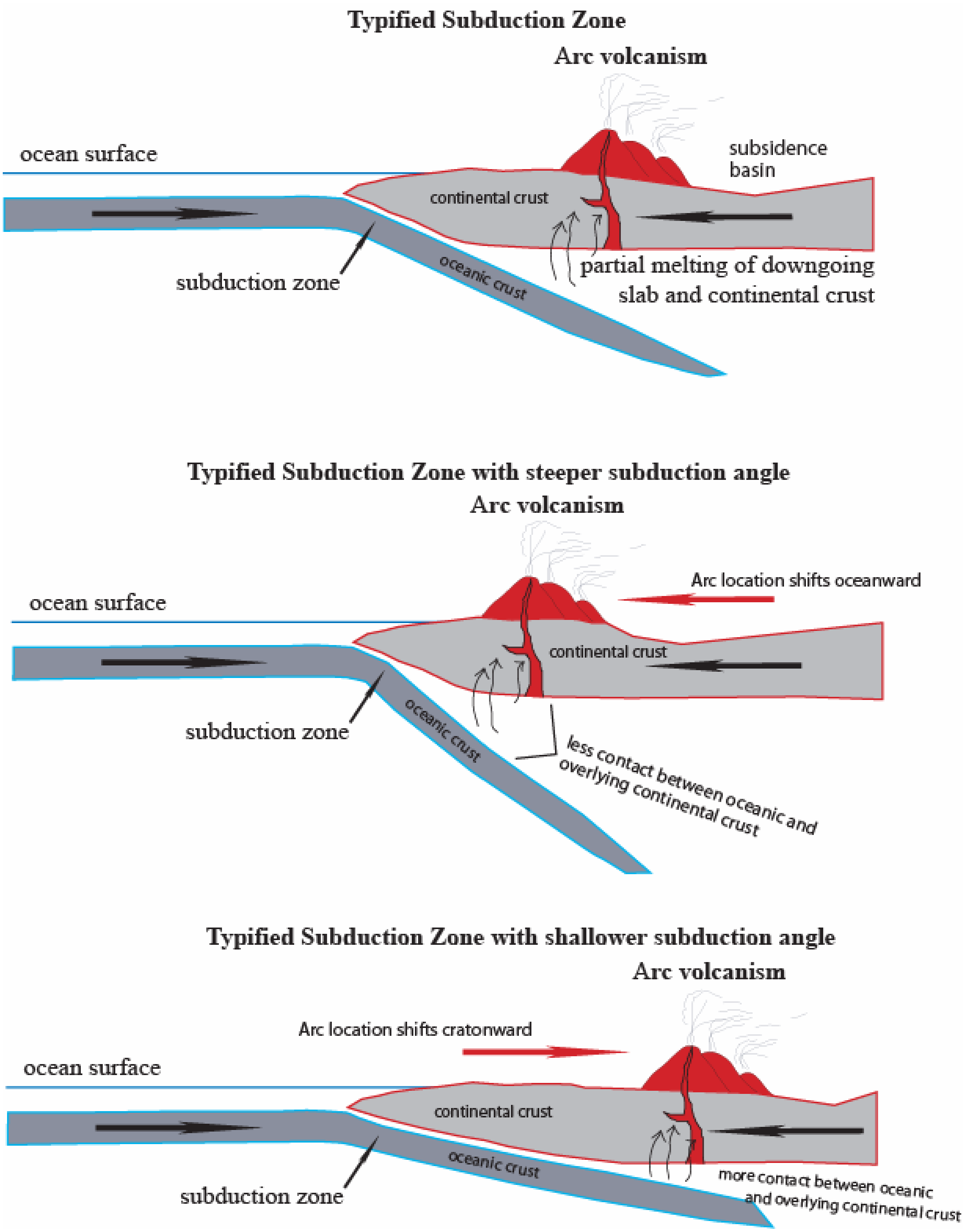

Figure 14. Graphic shows the effects of changing subduction angle on arc volcanism and mountain building. Graphic is by Trista L. Thornberry-Ehrlich (Colorado State University)

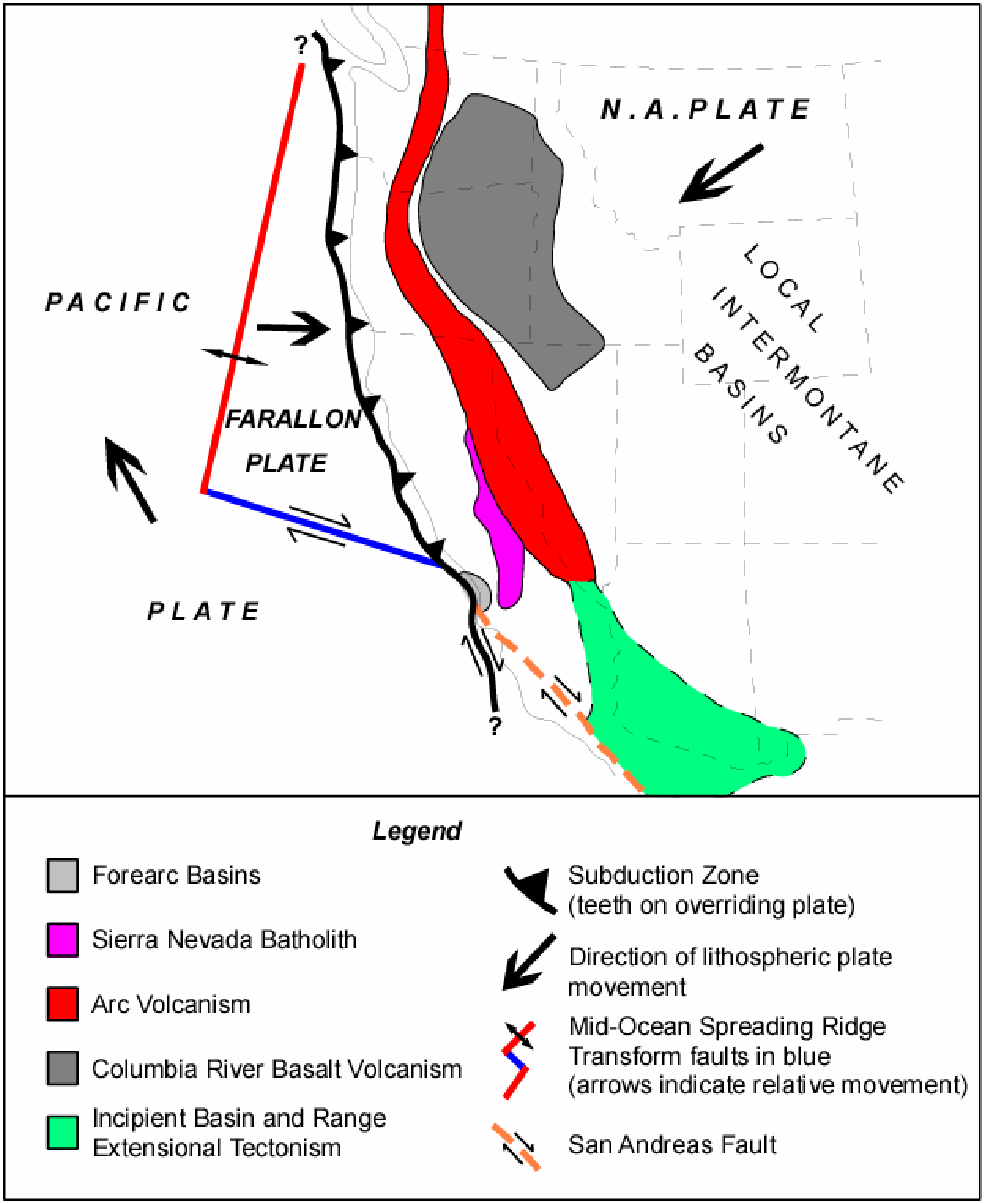

Figure 15. Paleotectonic map of western United States approximately 15 Ma in the Miocene Epoch. Initiation of basin-and-range faulting and the San Andres fault system takes place about this time. Modified from Dickinson, 1979.

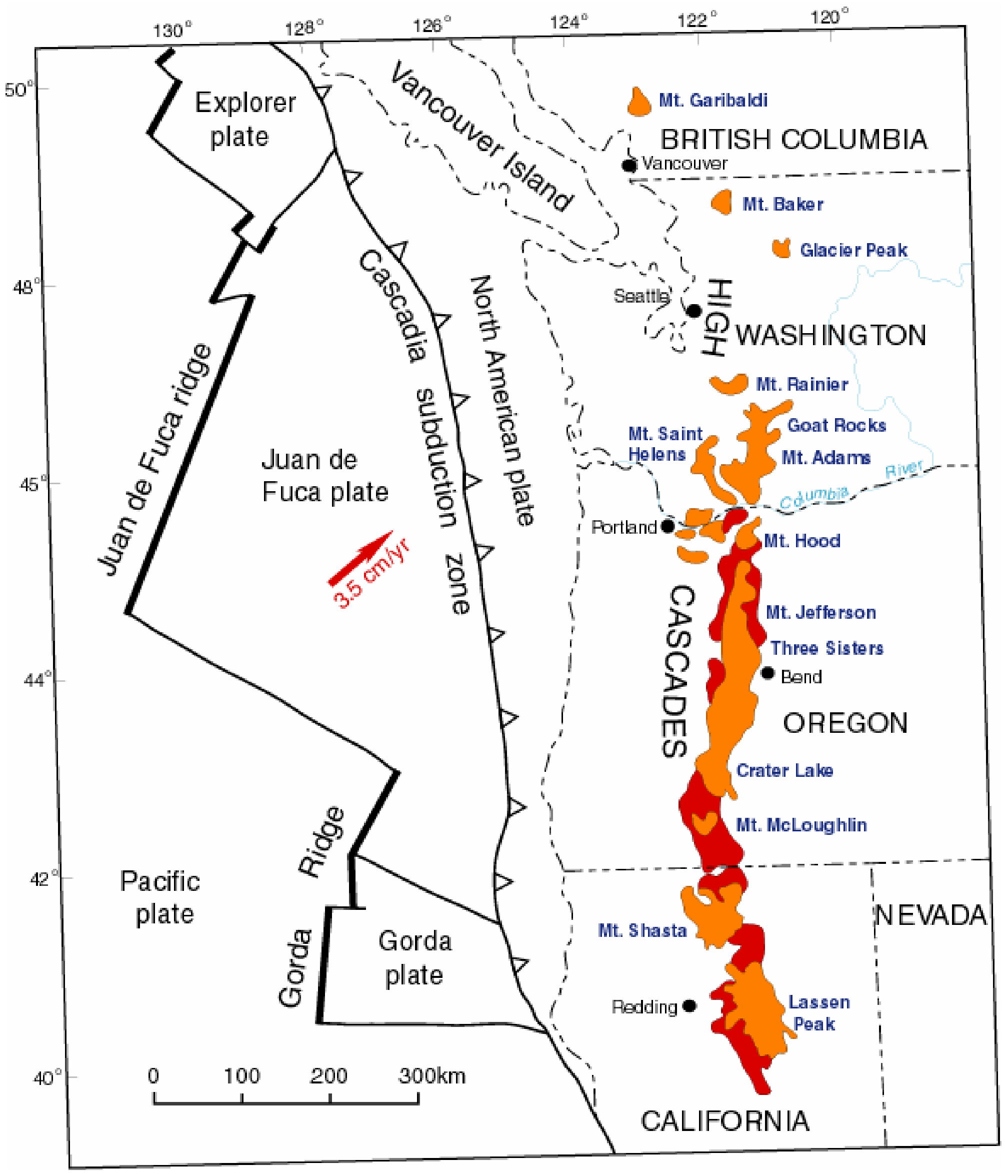

Figure 16. Map of late Miocene and younger magmatic systems in the Cascade Mountains. Light coloring indicates volcanic rocks of 7 to 2 Ma age; dark coloring indicates volcanic rocks of 2 to 0 Ma age. The arrow indicates relative convergence between the Juan de Fucca and North American Plates. Modified from Christiansen et al. (1992).

Glossary

allochthonous. Formed far from its present place.
alluvium. Stream- deposited sediment that is generally rounded, sorted, and stratified.
ash (volcanic). Fine pyroclastic material ejected from a volcano (also see tuff).
basement. The undifferentiated rocks, commonly igneous and metamorphic, that underlie the rocks of interest.
basin (structural). A doubly- plunging syncline in which rocks dip inward from all sides (also see dome).
basin (sedimentary). Any depression, from continental to local scales, into which sediments are deposited.
batholith. A massive, discordant pluton, greater than 100 km^2, (39.6 mi^2) often formed from multiple intrusions.
bathyal depocenter. Pertaining to an area of maximum deposition in an ocean environment between 200 and 4,000 m of depth.
bed. The smallest sedimentary strata unit, commonly ranging in thickness from one centimeter to a meter or two and distinguishable from beds above.
block (fault). A crustal unit bounded by faults, either completely or in part.
breccia. A coarse- grained, generally unsorted, sedimentary rock consisting of cemented angular clasts.
caldera. A large bowl- or cone- shaped summit depression in a volcano formed by explosion or collapse
clastic. Rock or sediment made of fragments or pre-existing rocks.
conglomerate. A coarse- grained sedimentary rock with clasts larger than 2 mm in a fine- grained matrix.
continental crust. The type of crustal rocks underlying the continents and continental shelves; having a thickness of 25- 60 km (16- 37 mi) and a density of approximately 2.7 grams per cubic centimeter.
continental rise. Gently sloping region from the foot of the continental slope to the abyssal plain.
continental shelf. The shallowly- submerged portion of a continental margin extending from the shoreline to the continental slope with water depths of less than 200 m (656 ft).
continental slope. The relative steep slope from the outer edge of the continental shelf down to the more gently sloping ocean depths of the continental rise or abyssal plain.
craton. The relatively old and geologically stable interior of a continent (also see continental shield).
cross-bedding. Uniform to highly- varied sets of inclined sedimentary beds deposited by wind or water that indicate distinctive flow conditions.
crust. The outermost compositional shell of Earth, 10- 40 km (6- 25 mi) thick, consisting predominantly of relatively low- density silicate minerals (also see oceanic crust and continental crust).
debris flow. A rapid and often sudden flow or slide of rock and soil material involving a wide range of types and sizes.
decollement. Detachment structure of strata owing to deformation associated with folding and overthrusting, resulting in independent styles of deformation in the rocks above and below.
deformation. A general term for the process of faulting, folding, shearing, extension, or compression of rocks as a result of various Earth forces.
dike. A tabular, discordant igneous intrusion.
dip. The angle between a structural surface and a horizontal reference plane measured normal to their line of intersection.
dome. A doubly plunging anticline that dips radially in all directions.
extrusive. Of or pertaining to the eruption of igneous material onto the surface of Earth.
facies (metamorphic). The pressure- temperature regime that results in a particular, distinctive metamorphic mineralogy (i.e., a suite of index minerals).
facies (sedimentary). The depositional or environmental conditions reflected in the sedimentary structures, textures, mineralogy, fossils, etc. of a sedimentary rock.
fault. A subplanar break in rock along which relative movement occurs between the two sides.
fenster. A window formed as an area of erosion in an overthrust sheet in which the rocks beneath the overthrust are exposed.
formation. Fundamental rock- stratigraphic unit that is mappable and lithologically distinct from adjoining strata and has definable upper and lower contacts.
fusulinid. Any foraminifer belonging to the suborder Fusulinina, family Fusulinidae, characterized by a multichambered calcareous test, commonly resembling the shape of a grain of wheat. Used as an index fossil from the Ordovician through the Triassic.
graben. A down- dropped structural block bounded by steeply- dipping, normal faults (also see horst).
homoclinal. A structural condition in which rock strata dip uniformly in one direction.
horst. An uplifted structural block bounded by high-angle normal faults.
intrusion. A body of igneous rock that invades older rock. The invading rock may be a plastic solid or magma that pushes its way into the older rock.
island arc. A line or arc of volcanic islands formed over and parallel to a subduction zone.

joint. A semi- planar break in rock without relative movement of rocks on either side of the fracture surface.

landslide. Any process or landform resulting from rapid mass movement under relatively dry conditions (cf.: debris flow).

lava. Magma that has been extruded out onto Earth's surface, both molten and solidified.

mafic. A rock, magma, or mineral rich in magnesium and iron.

magma. Molten rock generated within Earth that is the parent of igneous rocks.

mantle. The zone of Earth's interior between crust and core.

member. A lithostratigraphic unit with definable contacts that subdivides a formation.

metamorphism. Literally, "change in form". Metamorphism occurs in rocks with mineral alteration, genesis, and/or recrystallization from increased heat and pressure.

migmatite. Literally, "mixed rock" with both igneous and metamorphic characteristics due to partial melting during metamorphism.

normal fault. A dip- slip fault in which the hanging wall moves down relative to the footwall.

obduction. The process by which the crust is thickened by thrust faulting at a convergent margin.

oceanic crust. Earth's crust formed at spreading ridges that underlies the ocean basins. Oceanic crust is 6- 7 km (3- 4 mi) thick and generally of basaltic composition.

orogeny. A mountain- building event, particularly a well-recognized event in the geological past (e.g. the Laramide orogeny).

overthrust. A nondescript and not recommended term for a large- scale, low- angle, thrust fault.

peneplain. A geomorphic term for a broad area of low topographic relief resulting from long- term, extensive erosion.

pluton. A body of intrusive igneous rock.

scarp. A steep cliff or topographic step resulting from vertical displacement on a fault or by mass movement.

slump. A generally large, coherent mass movement with a concave- up failure surface and subsequent backward rotation relative to the slope.

stock. An igneous intrusion exposed less than 40 square miles at the surface.

strike. The compass direction of the line of intersection that an inclined surface makes with a horizontal plane.

strike-slip fault. A fault with measurable offset where the relative movement is parallel to the strike of the fault.

subduction zone. A convergent plate boundary where oceanic lithosphere descends beneath a continental or oceanic plate and is carried down into the mantle.

suture. The linear zone where two continental landmasses become joined due to obduction.

tectonic. Relating to large- scale movement and deformation of Earth's crust.

terraces (stream). Step- like benches surrounding the present floodplain of a stream due to dissection of previous flood plain(s), stream bed(s), and/or valley floor(s).

terrane. A region or group of rocks with similar geology, age, or structural style.

thrust fault. A contractional, dip- slip fault with a shallowly dipping fault surface ($<45^\circ$) where the hanging wall moves up and over relative to the footwall.

transform fault. A type of strike- slip fault along which the displacement suddenly stops or changes form.

transtensional. Deformation of the crust in oblique zones of ocean spreading consisting of stepped transform faults.

tuff. Generally fine- grained, igneous rock formed of consolidated volcanic ash.

uplift. A structurally high area in the crust, produced by movement that raises the rocks.

weathering. The set of physical, chemical, and biological processes by which rock is broken down in place.

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Appendix A: Geologic Map Graphics

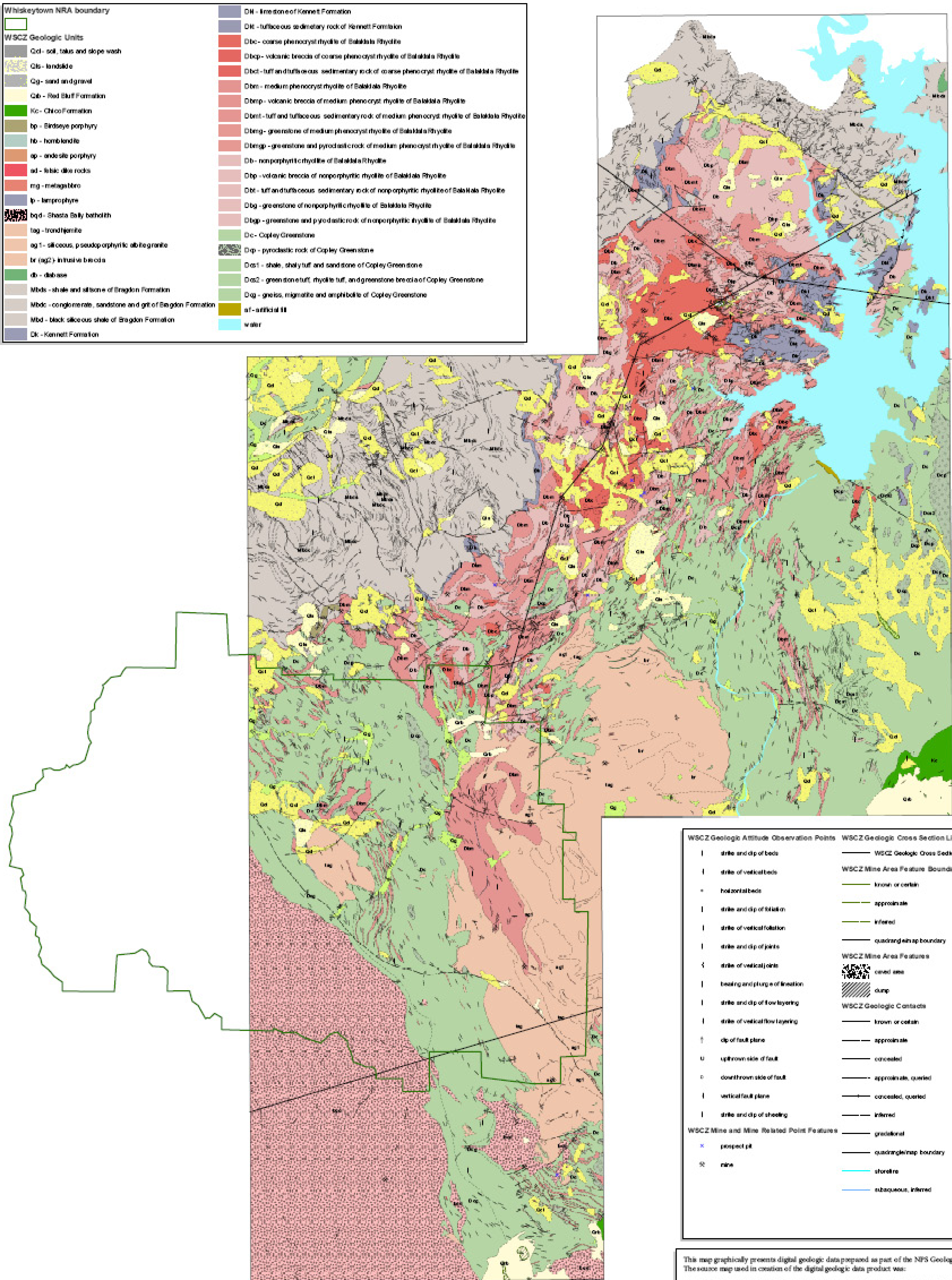
The following pages provides a preview or "snapshot" of the geologic maps for Whiskeytown National Recreation Area. For poster size PDFs of this map or for digital geologic map data, please see the included CD or visit the GRE publications webpage: http://www2.nature.nps.gov/geology/inventory/gre_publications

Geologic Map of Whiskeytown, CA

Whiskeytown NRA boundary

WSCZ Geologic Units

- Qal - soil, talus and slope wash
- Qls - landslide
- Qg - sand and gravel
- Qrb - Red Bluff Formation
- Kc - Chico Formation
- bp - Birdseye porphyry
- hb - hornblendite
- ap - andesite porphyry
- ad - felsic dike rocks
- mg - metagabbro
- lp - lamprophyre
- bqd - Shasta Bally batholith
- tag - trondhjemite
- ag1 - siliceous, pseudoporphyritic albite granite
- br (ag2) - intrusive breccia
- db - diabase
- Mbds - shale and siltstone of Bragdon Formation
- Mbdc - conglomerate, sandstone and grit of Bragdon Formation
- Mbd - black siliceous shale of Bragdon Formation
- Dk - Kennett Formation
- Dkl - limestone of Kennett Formation
- Dkt - tuffaceous sedimetary rock of Kennett Formation
- Dbc - coarse phenocryst rhyolite of Balaklala Rhyolite
- Dbcp - volcanic breccia of coarse phenocryst rhyolite of Balaklala Rhyolite
- Dbct - tuff and tuffaceous sedimentary rock of coarse phenocryst rhyolite of Balaklala Rhyolite
- Dbm - medium phenocryst rhyolite of Balaklala Rhyolite
- Dbmp - volcanic breccia of medium phenocryst rhyolite of Balaklala Rhyolite
- Dbmt - tuff and tuffaceous sedimentary rock of medium phenocryst rhyolite of Balaklala Rhyolite
- Dbmg - greenstone of medium phenocryst rhyolite of Balaklala Rhyolite
- Dbmgp - greenstone and pyroclastic rock of medium phenocryst rhyolite of Balaklala Rhyolite
- Db - nonporphyritic rhyolite of Balaklala Rhyolite
- Dbp - volcanic breccia of nonporphyritic rhyolite of Balaklala Rhyolite
- Dbt - tuff and tuffaceous sedimentary rock of nonporphyritic rhyolite of Balaklala Rhyolite
- Dbg - greenstone of nonporphyritic rhyolite of Balaklala Rhyolite
- Dbgp - greenstone and pyroclastic rock of nonporphyritic rhyolite of Balaklala Rhyolite
- Dc - Copley Greenstone
- Dcp - pyroclastic rock of Copley Greenstone
- Dcs1 - shale, shaly tuff and sandstone of Copley Greenstone
- Dcs2 - greenstone tuff, rhyolite tuff, and greenstone breccia of Copley Greenstone
- Dcg - gneiss, migmatite and amphibolite of Copley Greenstone
- af - artificial fill
- water



WSCZ Geologic Attitude Observation Points

- strike and dip of beds
- strike of vertical beds
- horizontal beds
- strike and dip of foliation
- strike of vertical foliation
- strike and dip of joints
- strike of vertical joints
- bearing and plunge of lineation
- strike and dip of flow layering
- strike of vertical flow layering
- dip of fault plane
- upthrown side of fault
- downthrown side of fault
- vertical fault plane
- strike and dip of sheeting

WSCZ Mine and Mine Related Point Features

- prospect pit
- mine

WSCZ Geologic Cross Section Lines

- WSCZ Geologic Cross Section Lines

WSCZ Mine Area Feature Boundaries

- known or certain
- approximate
- inferred
- quadrangle/map boundary

WSCZ Mine Area Features

- caved area
- dump

WSCZ Geologic Contacts

- known or certain
- approximate
- concealed
- approximate, queried
- concealed, queried
- inferred
- gradational
- quadrangle/map boundary
- shoreline
- subaqueous, inferred

WSCZ Faults

- thrust fault, known or certain
- thrust fault, approximate
- normal fault, known or certain
- normal fault, approximate
- normal fault, concealed
- normal fault, approximate and queried
- normal fault, concealed and queried
- normal fault, subaqueous
- unknown offset/displacement, known or certain
- unknown offset, approximate
- unknown offset, concealed
- unknown offset, approximate and queried
- unknown offset, concealed and queried
- unknown offset, inferred
- right-lateral, unknown offset/displacement, approximate
- vertical fault, known or certain
- vertical fault, approximate
- vertical fault, concealed
- vertical fault, approximate and queried
- vertical fault, concealed and queried
- vertical fault, subaqueous

0 2.5 5 10 Kilometers

0 1.5 3 6 Miles

Produced by Geologic Resources Division

This map graphically presents digital geologic data prepared as part of the NPS Geologic Resources Division's Geologic Resource Evaluation Program. The source map used in creation of the digital geologic data product was:

Albers, J.P., Kinkel, A.R., Jr., Drake A.A., Irwin, W.P., 1964, Geology of the French Gulch Quadrangle Shasta and Trinity Counties, California: U.S. Geological Survey, Geological Survey Bulletin, 1141-J scale 1:62,500.

Albers, J.P., Kinkel, A.R., Jr., Hall, W.E., 1956, Geologic Map of the West Shasta Copper-Zinc Deposits, Shasta County, California: U.S. Geological Survey, Professional Paper, 285 PLATE 1 scale 1:24,000.

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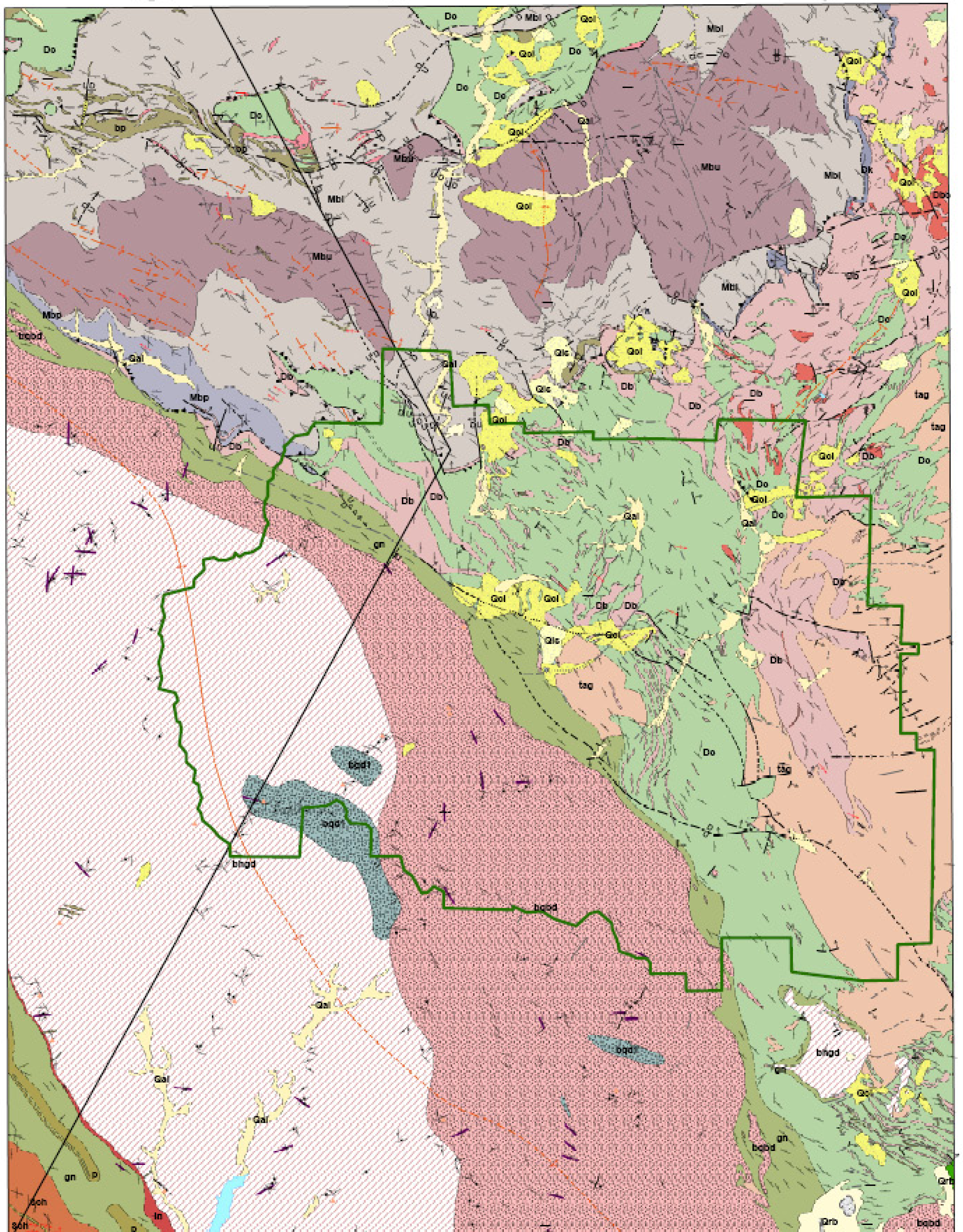
June 2007

Geologic Map of Whiskeytown NRA, CA



French Gulch Quadrangle

Whiskeytown NRA boundary

FREG Geologic Cross Section Lines
- FREG Geologic Cross Section Lines

FREG Geologic Attitude Observation Points
- strike and dip of beds
- strike of vertical beds
- strike and dip of joints
- strike of vertical joints
- bearing and plunge of lineation
- strike and dip of cleavage
- bearing and plunge of minor anticline
- bearing and plunge of minor syncline
- strike and dip of flow layering
- strike of vertical flow layering
- dip of fault plane
- upthrown side of fault
- downthrown side of fault
- vertical fault plane
- dip of contact
- anticline
- syncline
- plunge of fold axis
- strike and dip of inclined dike
- strike of vertical dike
- strike and dip of sheeting
- strike of vertical sheeting
- strike and dip of schistosity
- strike of vertical shistosity

FREG Geologic Sample Localities
- mineralogical/chemical sample

FREG Mine Area Feature Boundaries
- approximate
- quadrangle boundary

FREG Mine Area Features
- tailings

FREG Folds
- anticline, known or certain
- anticline, approximate
- syncline, known or certain
- syncline, approximate
- syncline, concealed

FREG Faults
- thrust fault, known or certain
- thrust fault, approximate
- thrust fault, concealed
- thrust fault, queried
- reverse fault, known or certain
- reverse fault, approximate
- reverse fault, concealed
- normal fault, known or certain
- normal fault, approximate
- normal fault, concealed
- normal fault, queried
- unknown offset/displacement, known or certain
- unknown offset/displacement, approximate
- unknown offset/displacement, concealed
- unknown offset/displacement, queried
- high-angle fault, known or certain
- high-angle fault, approximate
- vertical fault, known or certain
- vertical fault, approximate
- vertical fault, queried

FREG Linear Intrusives (Dikes)
- ad - Felsic dike rocks

FREG Geologic Contacts
- known or certain
- approximate
- concealed
- queried
- inferred
- gradational
- quadrangle boundary
- shoreline

FREG Geologic Units
- Qsl - soil, talus and slope wash
- Qal - sand and gravel in stream beds
- Qls - landslide
- Qrb - Red Bluff Formation
- Kc - Chico Formation
- bp - Birdseye porphyry
- hb - hornblendite
- qp - quartz porphyry
- mg - metagabbro
- bhgd - biotite hornblende gnodiotite and quartz diorite of Shasta Bally batholith
- bqbd - coarse biotite granodiorite and quartz diorite of Shasta Bally bahtolith
- bqd1 - fine biotite granodiorite and quartz diorite of Shasta Bally batholith
- gn - gneiss and amphibolite derived from Copley, Balaklala, and Bragdon formations
- in - injected rocks and breccia
- p - peridotite
- tag - trondhjemite
- br (ag2)- intrusive breccia
- Mbu - upper unit of Bragdon Formation
- Mbl - lower unit of Bragdon Formation
- Mbc - conglomerate bed in lower unit of Bragdon Formation
- Mbp - phyllite derived from Bragdon formation by contact metamorphism of Shasta Bally batholith
- Dk - Kennett Formation
- Dbc - coarse phenocryst rhyolite of Balaklala Rhyolite
- Db - nonporphyritic rhyolite of Balaklala Rhyolite
- Dbt - tuff and tuffaceous sedimentary rock of nonporphyritic rhyolite of Balaklala Rhyolite
- Dc - Copley Greenstone
- Dct - tuff, shaly tuff, and shale of Copley Greenstone
- Sch - Abrams mica schist and Salmon hornblende schist, undifferentiated
- water

0 2.5 5 10 Kilometers

0 1.25 2.5 5 Miles

This map graphically presents digital geologic data prepared as part of the NPS Geologic Resources Division's Geologic Resource Evaluation Program. The source map used in creation of the digital geologic data product was:

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Appendix B: Scoping Summary

The following excerpts are from the GRE scoping summary for Whiskeytown National Recreation Area. The scoping meeting occurred on March 2- 5, 2004; therefore, the contact information and Web addresses referred to herein may be outdated. Please contact the Geologic Resources Division for current information.

Executive Summary

A Geologic Resource Evaluation scoping meeting for Whiskeytown National Recreation Area was held in Ashland, Oregon, March 2, 2004. The scoping meeting participants identified the following geologic resources management issues.

- Restoration of roads from logging and mining activities is needed to stabilize slopes and prevent further erosion and sedimentation.
- Acid mine drainage from abandoned gold and copper mines is lowering the pH in some streams and introducing heavy metals into the environment
- Mercury contamination from past placer mining has introduced free mercury into streams and drainages

Introduction

The National Park Service held a Geologic Resource Evaluation scoping meeting for Whiskeytown National Recreation Area on the campus of Southern Oregon University on Tuesday, March 2, 2004. The purpose of the meeting was to discuss the status of geologic mapping in the NRA, the associated bibliography, and the geologic issues in the park. The products to be derived from the scoping meeting are: (1) Digitized geologic maps covering the NRA; (2) An updated and verified bibliography; (3) Scoping summary (this report); and (4) A Geologic Resource Evaluation Report which brings together all of these products.

Whiskeytown National Recreation Area was established on October 21, 1972, as one unit of the Whiskeytown-Shasta- Trinity National Recreation Area. The Shasta and Trinity units are managed by the Forest Service, U.S. Department of Agriculture. The NRA covers about 42,503 acres including 3200 acres of Whiskeytown Lake at a maximum surface elevation of 1,209 feet. The reservoir has 32 miles of shoreline and was created by diverting water from the Trinity River Basin. The Whiskeytown Dam impounds water from Clear Creek.

Whiskeytown NRA lies entirely within the French Gulch 15- minute quadrangle (1:62,500). This has subsequently been divided into four 7½' quadrangles: Whiskeytown, French Gulch, Shasta Bally and Igo. Albers, et. al. published the geology of the French Gulch 1:62,000 quadrangle in 1964. Kinkel, et. al., published the "Geologic Map of West Shasta Copper- Zinc District" in 1956 at a scale of 1:24,000. This map covers the east two-thirds of the park. Both of these maps have been digitized. Lyndon, 1972, published a geologic map of Shasta County at a scale of 1:250,000.

Resource Management Issues

1. Restoration of roads.
Whiskey NRA has over 300 miles of logging and mining roads covering over 42,000 acres. In an area of deeply weathered rock on steep slopes with high rainfall, the erosion of these roads has created slope failure and debris flows. Weathering of the granodiorite of the Shasta Bally batholith frees the considerable biotite mica. The hydration of the biotite creates glide planes in the crystal structure allowing the mica particles to slide past one another. On the megascopic scale, this translates to this material sliding down slope, especially in periods of high rainfall. A similar situation exists in shales which comprise some of the Copley Greenstone.

Road construction as well as fires remove the stabilizing vegetation and expose slopes to further hydration and erosion. The result is that these roads have created areas highly prone to down slope movement. This may occur as slow creep or as catastrophic slope failure and debris flows. 70% of down slope movement occurs within the first year after a fire, both from the fire roads and from the denuding of the slopes from fire.

Some of the areas prone to slope failure are also areas of high visitation. For example, the beach area below Brandy Creek Trail, a popular recreation spot, is susceptible to debris flow and may put visitors as risk. Debris flows have occurred on almost all the creeks in the southern half of the park. Although there is difficulty in dating past debris flows, it is possible and major debris flows have occurred twice in the last 50 years, the last in 1997. There is a need to study and monitor debris flows as well as to map their locations and aerial extent. Also, there is a need to measure soil moisture and to research slope hydrology, although many of these areas are remote and inaccessible.

2. Acid mine drainage
The Klamath Mountains are the second most productive gold producing province in California. Placer gold was first discovered in 1848, and lode gold was discovered in the French Gulch area in 1852 (Clark, 1970). Gold mining in the French Gulch area continued until 1942, with peak activity from 1900 to 1914 and again in the 1930s.

There was a resurgence of gold exploration in the 1970s and 80s. Much of the lode gold came from massive sulfide deposits. Copper, iron, zinc, and silver along with considerable pyrite have been also been mined in the French Gulch and West Shasta Districts (Albers, 1965). Today there are over 100 abandoned mines in the NRA.

The result has been acid mine drainage from the oxidation of the pyrite (iron sulfide) to sulfuric acid and transportation of acid solution into streams and rivers. The sources are from the abandoned mines and from the tailings that were produced and then left from the mining and milling of these pyritic ores. This low pH acidic water also mobilizes heavy metals such as lead, cadmium, and arsenic. At the Iron Mountain Mine, an EPA Superfund site in the northeast corner of the park, the water is so acidic that a negative pH (- 3.5) has been measured.

There is a need for accurate maps showing the location of abandoned mine sites. Each of these abandoned mines needs on- site characterization. Additional monitoring of water outflow from the mines is also a priority.

3. Mercury contamination
The largest recovery of gold from the Whiskeytown area has been from placer mining (Clark, 1970). As part of the gold recovery process from placer deposits, mercury is used to amalgamate the gold and remove it from the surrounding rock. The gold is then separated from the mercury and most of the mercury can be reused. However, some mercury remains in the waste rock and tailings and additional mercury is lost in the recovery process.

Although placer tailings are one of the likely sources of mercury, the process of removing the tailings and disturbing entrained mercury, could release more mercury into the environment. Nevertheless, mercury has been found in aquatic macroinvertebrates. Additional sampling and monitoring of stream sediment and water is needed.

4. Other Issues
Abandoned mines: Apart from acid mine drainage and mercury contamination, abandoned mines also present health and safety issues associated with the workings. Open shafts and adits can be hazardous to visitors terms of falling, collapsed workings, and bad air. Some mines have been closed using bat gates to allow access for bats and some have fences to keep visitors out. There are likely many more mines that need permanent closures using polyurethane foam (PUF). These mine sites must be inventoried and characterized before closures can proceed.

Groundwater: Most groundwater is high in iron and aluminum due to the mineralogy of the country rock. Some septic tanks are located too close to water wells, raising the potential for contamination. These well are closely monitored.

Surface water: Salmonid habitat below the dam on Clear Creek has been degraded by the Whiskeytown Dam reducing gravel input downstream. Likewise, there has been siltation behind the dam in the lake. There is some shoreline erosion on Whiskeytown Lake. However, the Bureau of Reclamation (BOR) has jurisdiction over the lake and controls the water level. The NPS has little input in the control of the water level and timing of the release of water from the lake. The BOR also has responsibility for the water quality of the lake.

Wetlands: There are some wetlands along the shoreline of Whiskeytown Lake. There may be a need to characterize and monitor these areas, especially as they respond to changes in lake levels.

Seismic activity: Although there are minor earthquakes in Whiskeytown, there are no major active faults. There are frequent minor earthquakes around Lake Shasta. A seismograph has been set up in the area as part of the University of California, Berkley network.

Volcanic hazards: Ashfall from a major eruption of Mt. Lassen could impact the park.

List of Scoping Meeting attendees with contact information

NAME	AFFILIATION	PHONE	E-MAIL
Tim Connors	NPS, Geologic Resources Division	(303) 969- 2093	Tim_Connors@nps.gov
Sid Covington	NPS, Geologic Resources Division	(303) 969- 2154	Sid_Covington@nps.gov
Anne Poole	NPS, Geologic Resources Division	(303) 987- 6954	Anne_Poole@nps.gov
Pete Biggam	NPS, Natural Resources Information Division	(303).987- 6948	Pete_Biggam@nps.gov
Chris Currens	USGS, Biological Resources Division	(707) 825- 5189	CCurrens@usgs.gov
Marsha Davis	NPS, Columbia Cascades Support Office	(206) 220- 4262	Marsha_Davis@nps.gov
Brian Rasmussen	NPS, Whiskeytown NRA		Brian_Rasmussen@nps.gov
Daniel Sarr	NPS, Klamath Network		Daniel_Sarr@nps.gov
Bob Truitt	NPS, Klamath Network		Bob_Truitt@nps.gov
Hanna Waterstat	NPS, Klamath Network		Hannah_Waterstat@nps.gov

Whiskeytown National Recreation Area

Geologic Resource Evaluation Report

Natural Resource Report NPS/NRPC/GRD/NRR—2007/008
NPS D-98, June 2007

National Park Service

Director • Mary A. Bomar

Natural Resource Stewardship and Science

Associate Director • Michael A. Soukup

Natural Resource Program Center

The Natural Resource Program Center (NRPC) is the core of the NPS Natural Resource Stewardship and Science Directorate. The Center Director is located in Fort Collins, with staff located principally in Lakewood and Fort Collins, Colorado and in Washington, D.C. The NRPC has five divisions: Air Resources Division, Biological Resource Management Division, Environmental Quality Division, Geologic Resources Division, and Water Resources Division. NRPC also includes three offices: The Office of Education and Outreach, the Office of Inventory, Monitoring and Evaluation, and the Office of Natural Resource Information Systems. In addition, Natural Resource Web Management and Partnership Coordination are cross- cutting disciplines under the Center Director. The multidisciplinary staff of NRPC is dedicated to resolving park resource management challenges originating in and outside units of the national park system.

Geologic Resources Division

Chief • David B. Shaver
Planning Evaluation and Permits Branch Chief • Carol McCoy

Credits

Author • Trista Thornberry- Ehrlich
Editing • Brian Rasmussen, Sid Covington, and Melanie Ransmeier
Digital Map Production • Stephanie O'Meara, Trista Thornberry- Ehrlich, and Victor deWolfe
Map Layout Design • Georgia Hybels

National Park Service
U.S. Department of the Interior

Geologic Resources Division
Natural Resource Program Center
P.O. Box 25287
Denver, CO 80225

http://www.nature.nps.gov/geology/inventory/
(303) 969-2090