Geology of the Medicine Lake volcano, California:
An Overview and Field Trip Log

by

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Introduction

The Medicine Lake volcano is the most massive of the fifteen or so major volcanic cones that dominate the Cascade Range. With an estimated volume of 600-750 km3 (Donnelly-Nolan, 1989) it is an important link in a volcanic chain that stretches from northern California to southern British Columbia (Fig. 1; Christiansen, 1982). Because Medicine Lake is a shield volcano that stands 50 km east of the Cascade crest and has a summit elevation of only 2,398 m (7,913 ft), however, it is less well known than the prominent stratovolcanoes that define the range's skyline.

The differences between the Medicine Lake volcano and its better-known neighbors offer important insights into the nature of volcanism in the Cascade Range. For example, the most commonly erupted rocks at the Medicine Lake volcano are basalts, making it more compositionally representative of the Cascades as a whole than are the isolated stratovolcanoes such as Shasta and Rainier (Wood and Baldridge, 1989). The Medicine Lake volcano's development in an extensional environment at edge of the Great Basin also serves to emphasize the important role that regional crustal structures play in localizing volcanism in the Cascades. Finally, because its future eruptions are likely to produce basaltic lava flows and rhyolitic tephra rather than the andesitic pyroclastic flows and mudflows common at other Cascade peaks, the study of the Medicine Lake volcano provides a unique opportunity to develop strategies for dealing with different types of volcanic hazards than are typically encountered in the Cascades. Because future eruptions at Medicine Lake could threaten recreational users and proposed geothermal facilties on and around the mountain (Hoblitt and others, 1987), the volcano continues to be closely monitored by geologists (e.g. Dzurisin and others, 1991).

This paper presents a brief summary of the geology of the Medicine Lake volcano that will serve as an introduction to the features we will be visiting during Saturday's field trip. Much of the information presented here was taken from papers by Anderson (1941) and Donnelly-Nolan (1988 and 1992). The complete list of the references cited is given at end of paper. Definitions of words that are italicized in the text will be found in a glossary that follows the references.

Regional Geologic Setting

Eruptive activity at Medicine Lake and the other Cascade volcanoes is occurring in response to the rise of magma from Earth's mantle as a result of subduction along the

Pacific Northwest coast. The lithospheric plate that carries the North American continent is overriding three small oceanic plates that lie to the west (Fig. 2; Guffanti and Weaver, 1988). As the southernmost of these plates -- the Gorda plate -- slips beneath northern California, it carries water bound into its surface layer deep into the mantle. The descending plate is heated by the surrounding mantle and, at a depth of about 80km, releases its bound water. This water attacks the bonds between Si and O atoms in the mantle rocks above the plate and causes these rocks to partially melt, producing basaltic magmas. These magmas are less dense than the surrounding rocks and rise gradually until they either reach the surface, to erupt as lavas, or cool and solidify underground. To learn more about the details of the subduction process consult the recent article by Stern (1998).

An additional factor that may contribute to the great volume of the Medicine Lake volcano is its location in an extensional setting east of the Cascade crest. Much of the Holocene activity at Medicine Lake has occurred along approximately north-trending fractures that have opened in response to east-west extension of the region (Fink and Pollard, 1983; Donnelly-Nolan, 1988). This fracturing may be related to the large-scale "stretching" of the lithosphere that underlies the Basin and Range province to the east. Basin and Range extension began not long after the North American plate overrode the Farallon Ridge about 27 Ma (Atwater,1970). Whether the stretching of the North American lithosphere is being caused by upwelling of hot mantle rock: (1) along the trace of the old ridge; or (2) through a "slab window" opened by the foundering of the Farallon Plate is still an open question (Fiero, 1986). In either case, however, the development of deep extensional fractures has provided an important pathway for magmas from the Cascade subduction zone to rise into the crust at Medicine Lake.

The rising magmas may also be "taking advantage" of a second zone of crustal weakness because the volcano is located at the intersection of north-trending Basin and Range faults with a northeast-trending fracture system (Fig. 3; Topinka, 1991) that has fed the growth of a basaltic highland between Mt. Shasta and Medicine Lake (Donnelly-Nolan, 1988).

Geologic History of the Medicine Lake Volcanic Center

Volcanic activity in the High Cascade Range began several million years ago, but the growth of the Medicine Lake shield dates back only about a million years. The shield itself overlies a platform of high-alumina basalts that also includes a number of small rhyolite flows and domes. The "pre-shield" basalts have not been dated, but the associated rhyolites yield K-Ar ages between 950 and 430 ka (Mertzman, 1981). Basalts equivalent to those beneath the shield, called the "Warner Basalt" by Anderson (1941), are widespread across the Modoc Plateau and have continued to erupt around the flanks of the Medicine Lake volcano into Holocene time (e.g. Giant Crater and Callahan flows in Fig. 6, below). These "primitive" (unmodified) mantle-derived magmas are thought to be parental to the various lavas that have built the volcano.

The oldest shield-building lavas at Medicine Lake are also undated, but are thought to be about one million years old (Fig. 4; Anderson, 1941). They are basaltic andesites that are characterized by the presence of small olivine crystals and by platy fractures that were developed by mineral alignment during magmatic flow. These lavas were so fluid that the flows which formed the northwest flank of the volcano slope away from the summit at angles of only 3 degrees!

Anderson (1941) has concluded that the 7 by 12 km caldera that occupies the volcano's summit developed during a second phase of shield building as silica-rich andesites drained from an underlying chamber through vents arranged along an elliptical ring fracture (Fig. 4). This second group of andesite lavas lacks olivine crystals and was more viscous than the first, with individual flows having travelled no more than 3-5 km from their vents. Lavas from the rim vents partially filled the subsiding caldera and spilled down the outer flanks of the volcano. The presence of andesitic scoria on the northern, southern, and western rims of the caldera indicates that explosive eruptions built tephra cones at close of this period of activity. Subsequent glaciation has largely obliterated these cones. A more complex sequence of events occurred during the growth of the eastern rim, and included the eruption of the plagioclase-rich Lake Basalt which today forms the eastern and northeastern shores of Medicine Lake.

The Medicine Lake volcano is known to have produced one pyroclastic flow, but this was during an eruption that post-dated the formation of the caldera. The flow deposited a partially-welded andesitic tuff (Fig. 5) that is found mostly in gullies on the northern and western flanks of the volcano. The absence of the tuff on the caldera rim and its incision by coarse channel deposits led Donnelly-Nolan and Nolan (1986) to conclude that most of hot tephra fell on an ice cap that covered upper part of volcano during a late Pleistocene eruption. The hot tephra melted part of the ice and produced catastrophic floods. The distribution of the tuff implies that its source was in the caldera, but only a single outcrop of it has been found there. The extensive hydrothermal alteration of this outcrop suggests that this body of tuff was deposited near a fumarole where the ice had been melted away. The tuff is estimated to be 160 ka based on its correlation with airfall ashes in Tule Lake sediments (Sarna-Wojcicki, 1991), and it forms an important stratigraphic marker on the volcano.

Holocene eruptive activity at the Medicine Lake volcano has been mostly bimodal, with basalts erupting from flank vents and more silicic lavas (dacites and rhyolites) erupting from vents in or near the summit caldera (Fig. 6; Donnelly-Nolan, 1989). The earliest Holocene eruptions occurred about 10.5 ka, and produced about 5.3 km3 of basaltic lavas that include the Giant Crater flow. A small volume of andesite erupted about 4.3 ka, followed by a series of small basaltic and rhyolitic eruptions that ended 900-1,000 years ago with the eruption of the dacitic and rhyolitic flows and domes of Glass Mountain (Donnelly-Nolan and others, 1990). The most recent series of eruptions has included basalts of the Burnt Lava and Callahan flows, the Medicine dacite flow, and the rhyolites of the Hoffman, Little Glass Mountain, and Glass Mountain events. The total volume of Holocene silicic lavas is small, about 1.5 km3, compared to that of mafic lavas which total perhaps 15 km3 (Donnelly-Nolan, 1988). Although the distribution of Holocene lavas (basalts on flanks and rhyolites near caldera) suggests that a large reservoir of silicic magma may be present beneath the caldera (Eichelberger, 1981), recent geophysical studies have found no evidence to support the existence of such a chamber (Donnelly-Nolan, 1988). Instead, a shallow chamber with a volume of a few tens of cubic kilometers or less has apparently been detected under the east-central part of the caldera (Evans and others, 1986).

Origin of the Lavas in the Medicine Lake Region

Magmas entering the crust from the underlying subduction zone are thought to be predominantly high-alumina basalts that typically contain about 48% SiO2, 18% Al2O3, and 0.07% K2O by weight. They have erupted on and around the volcano from Pleistocene time through about 1,100 years ago (Donnelly-Nolan, 1992). An experimental study of similar magmas at nearby Mt. Shasta (Baker and others, 1994) suggests they originate by small degrees of partial melting (6-10%) of nearly dry upper mantle rocks. Early in history of the Medicine Lake volcanic center these magmas ascended through relatively "cool" crust and underwent little interaction with it.

As the shield-building phase began, however, rising magmas warmed the crust and lowered its density and viscosity. These changes slowed the ascent of later batches of magma and led to the development of small magma chambers within the crust. While residing in these chambers the basaltic magmas were modified compositionally by assimilation of the surrounding crustal rocks and by fractionation of early-crystallizing minerals. Partially-melted granitic xenoliths, similar to Sierran basement rocks that crop out southeast of the volcano, are found in many of the Holocene lavas and appear to have been a common assimilant. Gabbroic xenoliths are also common and sample crystal-rich "cumulates" that were formed as minerals precipitated out of the cooling magmas onto their chamber walls. Assimilation and fractionation, together with mixing of various derivative magmas, can explain the compositional variety seen in the volcano's lavas. The present magmatic system beneath the volcano is envisioned as plexus of basaltic dikes and small chambers filled with andesitic to rhyolitic magmas derived from them, but not a large, long-lived chamber (Fig. 7; Donnelly-Nolan, 1988).

Dry basaltic magma cannot rise directly through a chamber filled with rhyolitic melt because of the lower density of the latter material. Basaltic magmas do occasionally intrude into batches of rhyolite, however, and mix or mingle with them to form dacitic magmas and quenched mafic inclusions that are characteristic of many silicic lavas in the Cascades. A particularly well-documented example of this interaction is preserved in the sequence of dacitic and rhyolitic lavas erupted at Glass Mountain (Fig. 8). According to model developed by Eichelberger (1981) and refined by Donelly-Nolan (1992), basaltic magma with a low (perhaps 3 wt. %) water content rose and spread out beneath the body of rhyolitic magma that had formed below the Glass Mountain area (Fig. 9). Cooling of the basaltic magma against the overlying rhyolitic melt led to vesiculation of the basalt as dissolved water exsolved. The basalt "foam" was less dense than rhyolitic magma and rose into it, mixing to form a dacitic magma and entraining partially-vesiculated and hybridized basalt "blobs". The hotter, water-rich dacitic magma rose to the top of the chamber and began to erupt, forming the first lobe of the Glass Mountain flow. The eruption continued as cooler, drier rhyolitic magma followed the dacite out of the chamber and formed the second lobe of the flow.

Volcanic Hazards Posed by the Medicine Lake Volcanic Center

During its recent history the Medicine Lake volcano has produced both basaltic and rhyolitic lavas. Because of their high eruptive temperatures and low silica contents the basalts are quite fluid and can travel tens of kilometers through tubes to reach areas low on the flanks of the volcano. Higher silica contents make the rhyolitic lavas very viscous so that they retain volatiles (water, carbon dioxide, and hydrogen sulfide) until high vapor pressures are reached. When these magmas approach Earth's surface the trapped volatiles form rapidly expanding bubbles that tear the lava apart in explosive eruptions. Such eruptions are expected to produce ash clouds that will spread airfall tephra tens of kilometers downwind from the vent (Fig. 10; Heiken, 1981). Although large pyroclastic flows are apparently rare at the Medicine Lake volcano, small flows may form where the steep sides of silicic domes or lava flows collapse (Hoblitt and others, 1987).

If an eruption were to occur in the winter or spring, hot lava or tephra might melt the thick snow pack that covers the area and produce floods and volcanic mudflows (lahars) that could inundate river valleys tens of kilometers downstream from the volcano. Catastrophic flooding has been documented in the past, during the eruption that produced the andesite tuff in late Pleistocene time (Donnelly-Nolan and Nolan, 1986).

Field Trip Log

We will plan to visit seven or eight stops today, as time allows. Please wear hiking boots and bring a lunch, a hat, water, and sunscreen. If you want to collect samples of obsidian at Glass Mountain (stop 5) please bring eye protection (goggles) and gloves. Remember, it is illegal to collect samples within the Lava Beds National Monument.

Depart COS and drive south on I-5 to the junction with highway 89. Turn east on 89 and continue about 20 miles to the junction with forest road 49. This junction is on your left, about one quarter mile east of the Bartle store, and is labelled as the Harris Spring Road. Continue north on 49 about 4 miles to an intersection and turn right, following the sign to Medicine Lake; this is still forest road 49. The road crosses the Warner Basalt, which is mantled by thick red soils that indicate it has undergone extensive weathering since Pliocene time. After 9 miles the road drops onto the younger Medicine Lake basalts and crosses a collapsed lava tube that originates at Giant Crater to the northwest. At 17.6 miles a sign marks a turnoff to Jot Dean ice cave, another lava tube in the Giant Crater flow. 0.8 miles past the Jot Dean road turn left onto a good gravel road (47N11).

Stop 1 -- Chimney Crater: About 0.5 mile past the intersection note Double Hole Crater on the left side of the road. It is one of the vents from which the 10.6 ka Giant Crater basalt flow originated. Continue 1.7 miles further, turn left onto dirt track 49N11H, and park. Climb the agglutinated spatter cones of Chimney Crater (Fig. 11) but, please, do not collect samples from this protected area. These spatter cones erupted a fairly viscous basaltic lava that had been formed by contamination of high-alumina basalt with granitic xenoliths. Remains of these xenoliths can be found in the basalt as voids lined with gray glass. Later phases of the eruption produced less comtaminated basalts which flowed away through lava tubes to the west-southwest.

Return to forest road 49 and turn left. A junction with forest road 97, which descends the eastern flank of the volcano, is reached at 6.2 miles. Continue straight, driving over the southern rim of the caldera another 1.6 miles to the intersection with the paved road to Medicine Lake. Turn left towards the lake and continue 0.3 miles. Turn right onto another paved road that takes you along the north side of the lake past the campgrounds. Continue past the end of the pavement, the ranger station, and the road to Schonchin Spring. After travelling 3.9 miles you will see a dirt track on the right marked with a green arrow. Turn right and drive north 0.3 miles to the first wide parking spot on the left.

<u>Stop 2 -- Extensional fractures</u>: The andesite flow you are standing on is split by a series of northeast-trending extensional fractures that developed over the top of a rhyolite dike that runs between Little Glass Mountain and the Crater Glass flows. The largest crack is located about 100 m northeast of the parking spot, near the edge of the logged-over area. It is about 10 m deep and you will notice that its opposite sides that can be fit back together in an east-west sense (Fig. 12). The upper part of this flow consists of agglutinated spatter and its interior is dense and platy; it was erupted from a glaciated cinder cone just south of the parking spot.

Return to the dirt road and turn right. Drive 0.2 miles west to the base of Little Mount Hoffman and continue straight at the fork in the road. Put your vehicle in low gear and drive 0.6 miles to the lookout at the top. Note: This lookout is no longer used by the Forest Service but is rented out to private groups for overnight stays; please do not disturb the occupants.

<u>Stop 3 -- Little Mount Hoffman:</u> Little Mount Hoffman is an andesitic tephra cone that grew on the western rim of the caldera. The view to the west from its summit (Fig. 13) includes: the Little Glass Mountain rhyolite dome and flow (in the foreground); Pumice Stone Mountain and the tephra-mantled Paint Pot Crater (in the middle distance); and Mount Shasta (on the horizon). The emplacement of the Little Glass Mountain dome was preceded by deposition of a pumiceous airfall tephra (Fig. 10), and accompanied by the emplacement of several smaller domes and flows at the northeast end of the fracture system we examined at stop 2. The view to the east includes the caldera, with Glass Mountain near its eastern rim. Note the USGS seismometer station just west of the summit lookout. It is part of a network used to monitor seismic activity on and around the volcano.

Drive carefully down Little Mount Hoffman and continue 4.7 miles east, along the north shore of Medicine Lake, to the junction with the paved road. Turn left, away from the lake, and continue 0.3 miles to the junction with forest road 49. The outcrops on the right-hand side of this intersection are the plagioclase-rich Lake Basalt. Turn left and drive west on 49, passing the steep front of the Medicine dacite flow and climbing the northern wall of the caldera. After 3 miles pull into the turnout on the left side of the road, just before crossing the north rim.

Stop 4 -- North rim of the Medicine Lake Caldera: Looking south across the caldera, note the late Holocene Medicine dacite flow to your left. It is covered by an outer glassy carapace, and contains xenoliths and quenched inclusions of andesitic magma (Donnelly-Nolan, 1988) that tell of a complex history of assimilation and mixing. Beyond this flow lies Medicine Lake (Fig. 14), which is surrounded on the east by the Lake Basalt and on west by glacial till. The lake has a maximum depth of about 45 m (146 ft) and is kept from draining away by a lining of glacial clay in its bed. The subdued topography of the caldera is due to partial infilling by lavas from its rim vents as well as subsequent glaciation. As originally suggested by Anderson (1941) and generally supported by later field studies, the caldera appears to have subsided in response to the eruption of andesitic lavas from vents along its ring fracture. An outcrop of one of these platy, olivine-free andesites is exposed in the cut just across the road.

Drive 4.5 miles, crossing the northern rim of the caldera, until you reach the intersection with the Cougar Butte Road. Turn right and follow this gravel road for 6.3 miles to an intersection with another gravel road. Turn right and drive south towards the pumice mining area. In about 2 miles the road will intersect a main haul road. Turn left and then, after less than a tenth of a mile, right onto a narrow track that leads to the base of the Glass Mountain rhyolite flow. Park at the base of the mine road that leads up onto the flow.

Stop 5 -- Glass Mountain: We have been driving through pumice produced by the explosive, early phase of rhyolitic volcanism at Glass Mountain and several other small vents along the same fracture system. Walk up the mine road and examine the rhyolite pumice (white) and obsidian (black) that form the surface of the youngest lobe of the Glass Mountain flow. Note that the melt which was quenched to produce these rocks was crystal free. Walk back down the mine road and a short distance east to the snout of the dacite flow that forms the oldest lobe of Glass Mountain. This dacite is the lava that was formed when basaltic magma mixed and mingled with a shallow body of rhyolitic magma, and triggered the first phase of the Glass Mountain eruption. Mingled "blobs" of a mixed basalt/rhyolite magma can easily be seen in the dacite.

Drive back out of the pumice mining area and turn left onto Cougar Butte Road. After 0.3 miles turn right onto another gravel road and follow it northwest for 5.5 miles until you intersect forest road 49 (paved). If you cross road 49 and continue straight ahead on the dirt road that leads to the northwest, a 3.1 mile drive would bring you to the approximately 1,100 year old Callahan basalt flow and its vent, Cinder Butte. Instead, turn right onto forest road 49 and follow it for 1.6 miles to Mammoth Crater.

Stop 6 -- Mammoth Crater: Park in the turnout on the left-hand side of the road and walk up the short paved trail to view this pit crater formed by the draining of a lava-filled basin. Mammoth Crater was the source of a series of basalt flows that cover about two-thirds of the Lava Beds National Monument (Donnelly-Nolan and Champion, 1987). The first flows erupted from this vent were crustally-contaminated basaltic andesites. Later, however, more fluid high-alumina basalts poured out and flowed as far as 25 km through great tube systems to form some of the largest "caves" in the Monument including Skull and Mushpot Caves.

Continue 2.6 miles north on road 49 to its intersection with the paved road through Lava Beds National Monument. Turn left and drive north through the Monument. To your right is Schonchin Butte, an andesitic tephra cone from which there are great views of the Monument and the Medicine Lake highlands to the south. A bit further along, the road crosses the rugged aa surface of the Devils Homestead basalt, which erupted from spatter vents at Fleener Chimneys. Ahead and to the left is the Gillem Bluff fault scarp; this fault served as a conduit for the Devils Homestead basalt. About 5 miles from where you entered this road you will reach an intersection with a road signed "Not maintained for public use." Turn left onto this road and proceed 0.4-0.5 miles to the first road on the right. Turn right onto this less well-used track and proceed 0.2 miles, staying left at a Y-junction marked by a group of junipers. Park on the road next to a shallow gulley on the left side.

Stop 7 -- Andesitic ash-flow tuff: Walk down into the gulley to see outcrops of the andesitic ash-flow tuff that was erupted from the caldera about 160 ka. This locality was below the snow line when the eruption occurred, and the pyroclastic flow that swept across this area deposited a layer of tephra that was hot enough to partially fuse back together despite being only about 2 m thick. Note the clasts of black, glassy andesite preserved in the tuff. This is our final field trip stop unless we decide to visit the Prisoners Rock tuff cone.

Return to the main road and head north out of the Monument towards highway 161. Turn left onto 161 and drive west to the junction with highway 97. Turn left onto highway 97 and return to Weed via Doris and Grass Lake.

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Glossary

Andesite: Volcanic rock with a low to intermediate silica content (about 54 to 63 wt. %); typically has a fine gray to black groundmass that contains coarser crystals of plagioclase, augite, and hypersthene.

Assimilation: Process in which a magma engulfs blocks of a foreign rock, heating and reacting with them chemically and incorporating their components into itself.

Basalt: Volcanic rock with a low silica content (about 47 to 54 wt. %); typically has a fine black groundmass that contains coarser crystals of plagioclase, olivine, and augite.

Caldera: Circular or elliptical depression formed when the block of crust that overlies a shallow magma chamber subsides after the chamber has been partially emptied by an eruption.

Dacite: Volcanic rock with an intermediate to high silica content (about 63 to 70 wt. %); typically has a fine gray groundmass that contains coarser crystals of plagioclase, quartz, hornblende, and hypersthene.

Dome: Volcano formed when a batch of viscous magma (typically dacite or rhyolite) rises to the surface and piles up in a mound on top of the vent. Domes are typically 1 to 5km in diameter.

Fractionation: A progressive change in the composition of a magma over time that is the result of the separation of two or more chemically-dissimilar materials. In most magmas, it is the growth and removal of mineral crystals enriched in elements such as Fe, Mg, and Ca that drives this process.

Fumarole: A hydrothermal vent that produces mostly steam; solftaras are similar, but discharge more sufur-rich vapors.

Holocene: Interval of time between approximately 11 ka and the present during which the Earth has been relatively warm and free of large continental ice sheets.

Hydrothermal: Literally, "hot water"; hydrothermal systems in volcanic areas are typically fed by rain or snow melt that percolates down into the Earth, is heated by hot rock or magma at a shallow depth, and rises back to the surface.

ka: Thousands of years.

Lithospheric plate: Slab of Earth's outer surface that consists of the crust (continental or oceanic) and the cool, rigid upper mantle that underlies it. Plates are typically 100 to 150 km thick and move about relative to one another on a warmer, softer layer of the mantle beneath them.

Ma: Millions of years.

Magma: Partially-molten rock; typically a mixture of melt, mineral crystals, and gas bubbles.

Mudflow: Dense suspension of fine volcanic rock fragments in water that moves down slopes under the influence of gravity. The density of these flows allows them to easily carry large blocks of rock at speeds of up to 50kph.

Olivine: Magnesium-iron silicate mineral that typically forms small, green to yellow crystals that have a curved, glass-like fracture.

Plagioclase: Sodium-calcium aluminosilicate mineral that typically forms gray to white rectangular crystals with a pronounced cleavage marked by fine, straight striations.

Pleistocene: Interval of time between 1.8Ma and approximately 11ka during which landmasses at high elevations and latitudes were subjected repeated glacial advances and retreats (the "Ice Ages").

Pyroclastic flow: Hot, dense suspension of lava fragments, volcanic gases, and entrained air that may travel at speeds of up to 100kph down the slopes of a volcano.

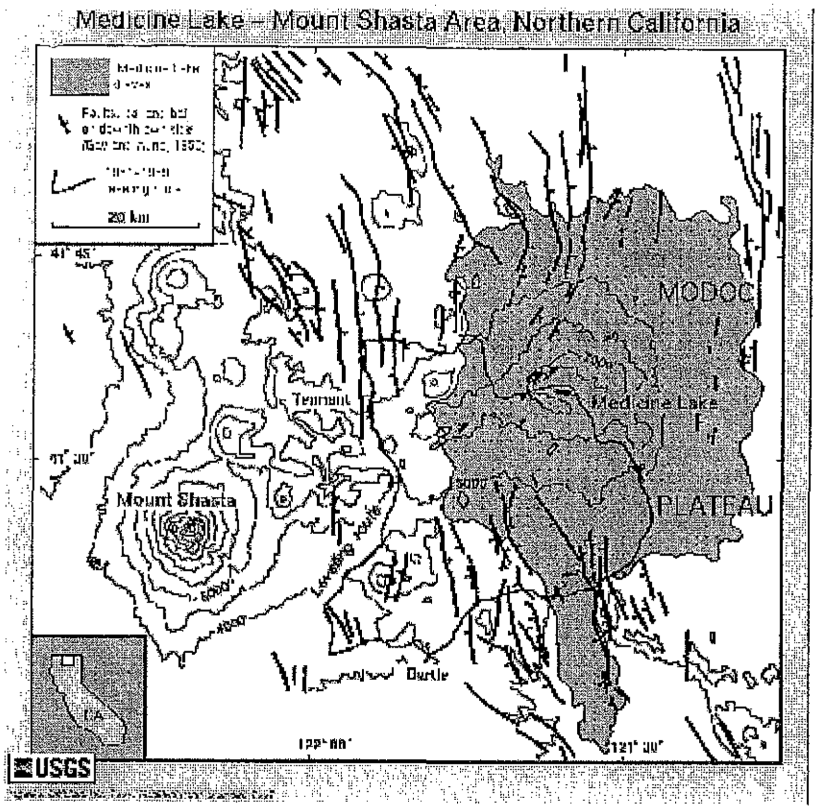
Rhyolite: Volcanic rock with a high silica content (about 70 to 76 wt. %); typically has a fine, light gray to pink groundmass that contains coarser crystals of plagioclase, quartz, and sanidine, and biotite.

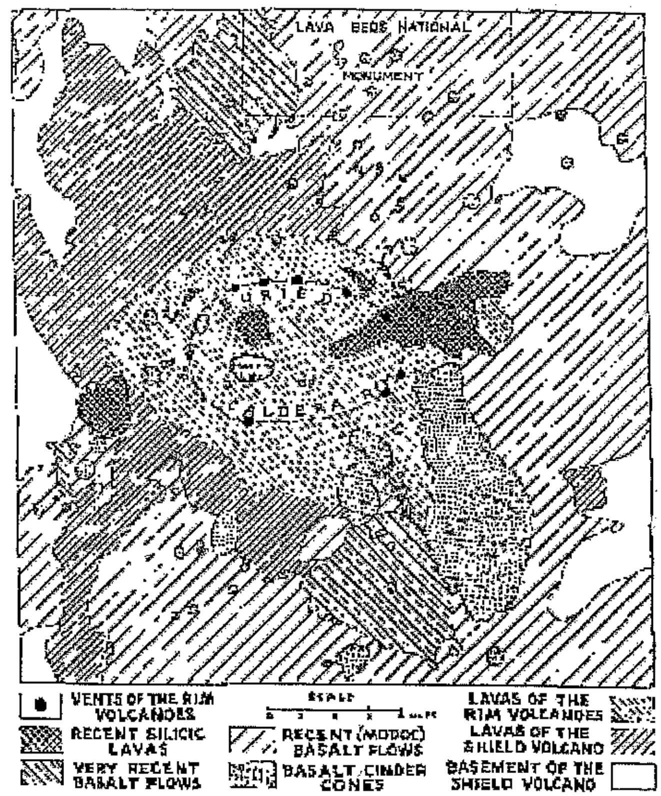
Shield volcano: Volcanoes with low slopes that are composed of hundreds of thin flows of low viscosity basaltic or basaltic andesite lava erupted from a central vent or fissure.

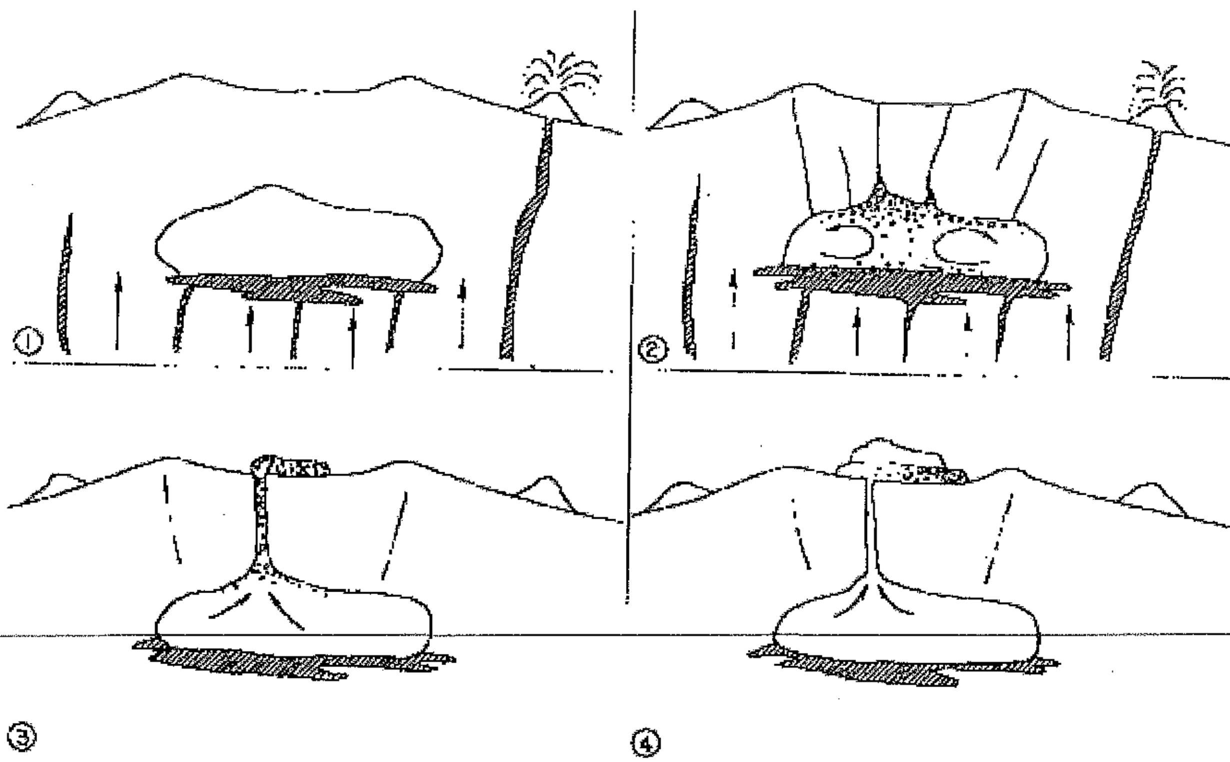
Stratovolcano: Volcanic cone, typically on the order of 20 to 30km in diameter, that is composed of alternating layers of of lava and pyroclastic debris.

Subduction: Process in which a plate of oceanic lithosphere is overridden by another plate at a convergent boundary and passes down into the mantle.

Tephra: Pyroclastic ("fire broken") material of a wide range of sizes -- from fine dust to large blocks -- ejected explosively from a volcano.


Medicine Lake – Mount Shasta Area, Northern California
20 km
41°45'
41°30'
MODOC
PLATEAU
Medicine Lake
Tennant
Mount Shasta
Bartle
5000'
6000'
122°00'
121°30'
USGS


LAVA BEDS NATIONAL
MONUMENT
VENTS OF THE RIM VOLCANOES
RECENT SILICIC LAVAS
VERY RECENT BASALT FLOWS
SCALE
RECENT (MODOC) BASALT FLOWS
BASALT CINDER CONES
LAVAS OF THE RIM VOLCANOES
LAVAS OF THE SHIELD VOLCANO
BASEMENT OF THE SHIELD VOLCANO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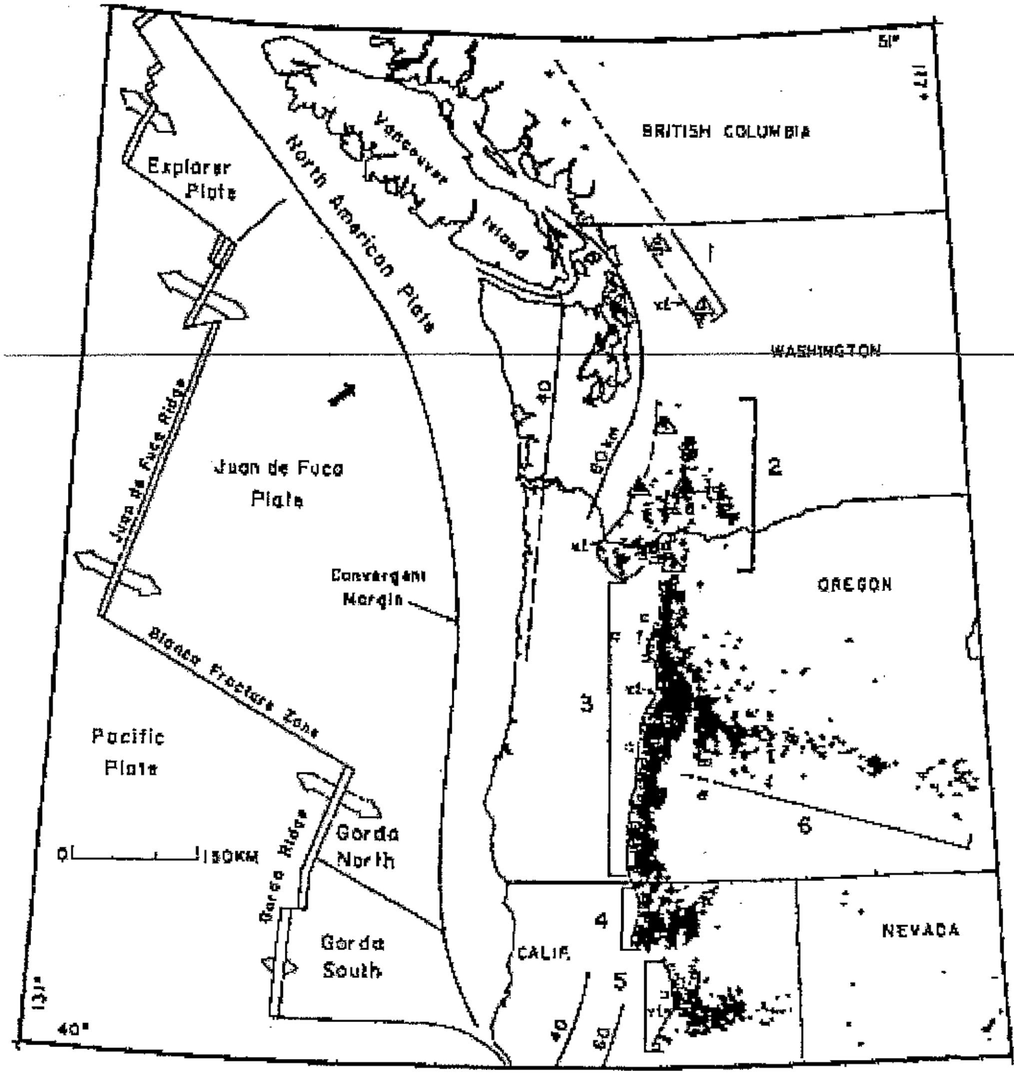

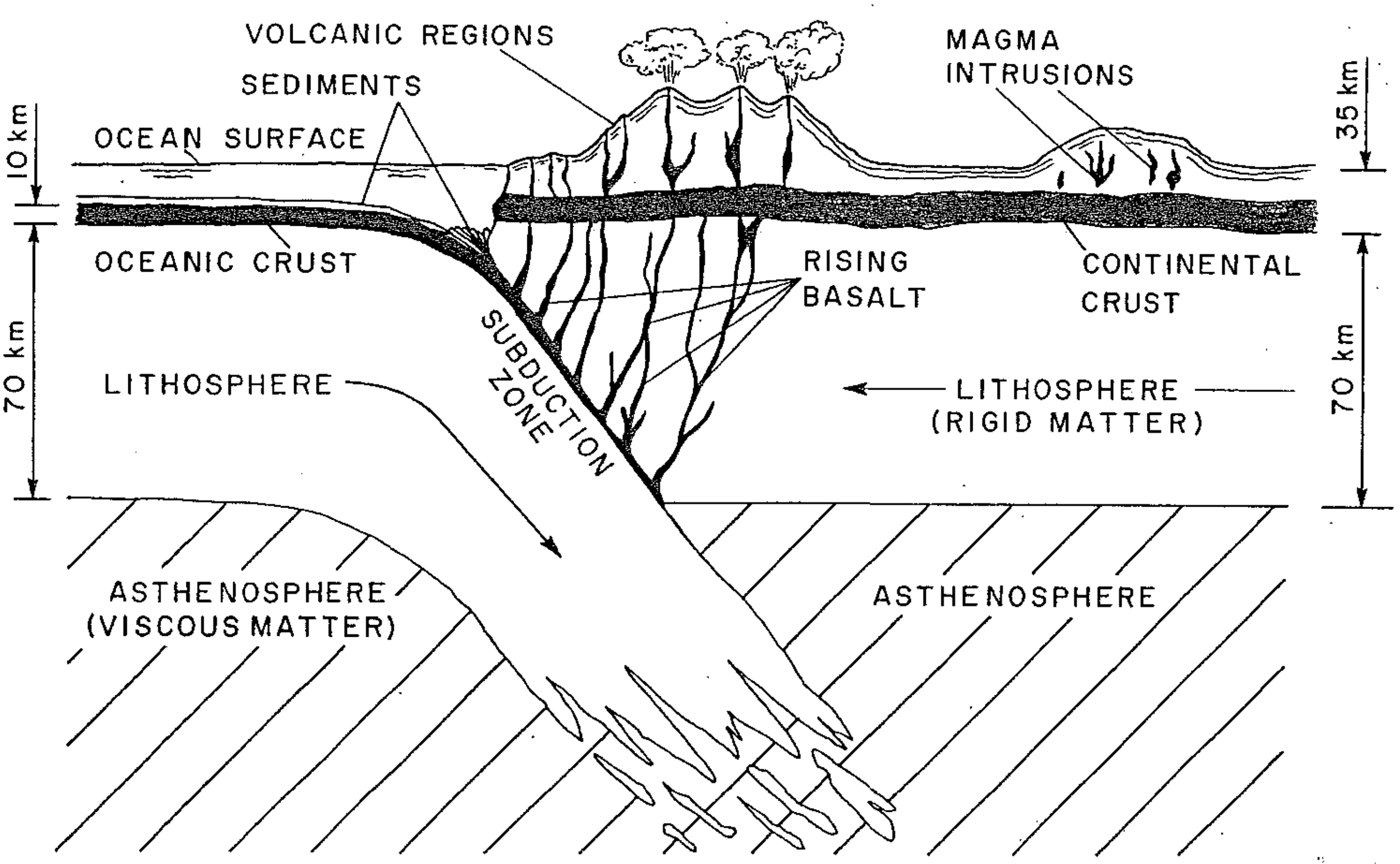

FIGURE 1.2—Subduction zone. Diving plate forms zone of partial melting, giving rise to molten basalt. Young regions are highly volcanic; other regions may contain magma intrusions.

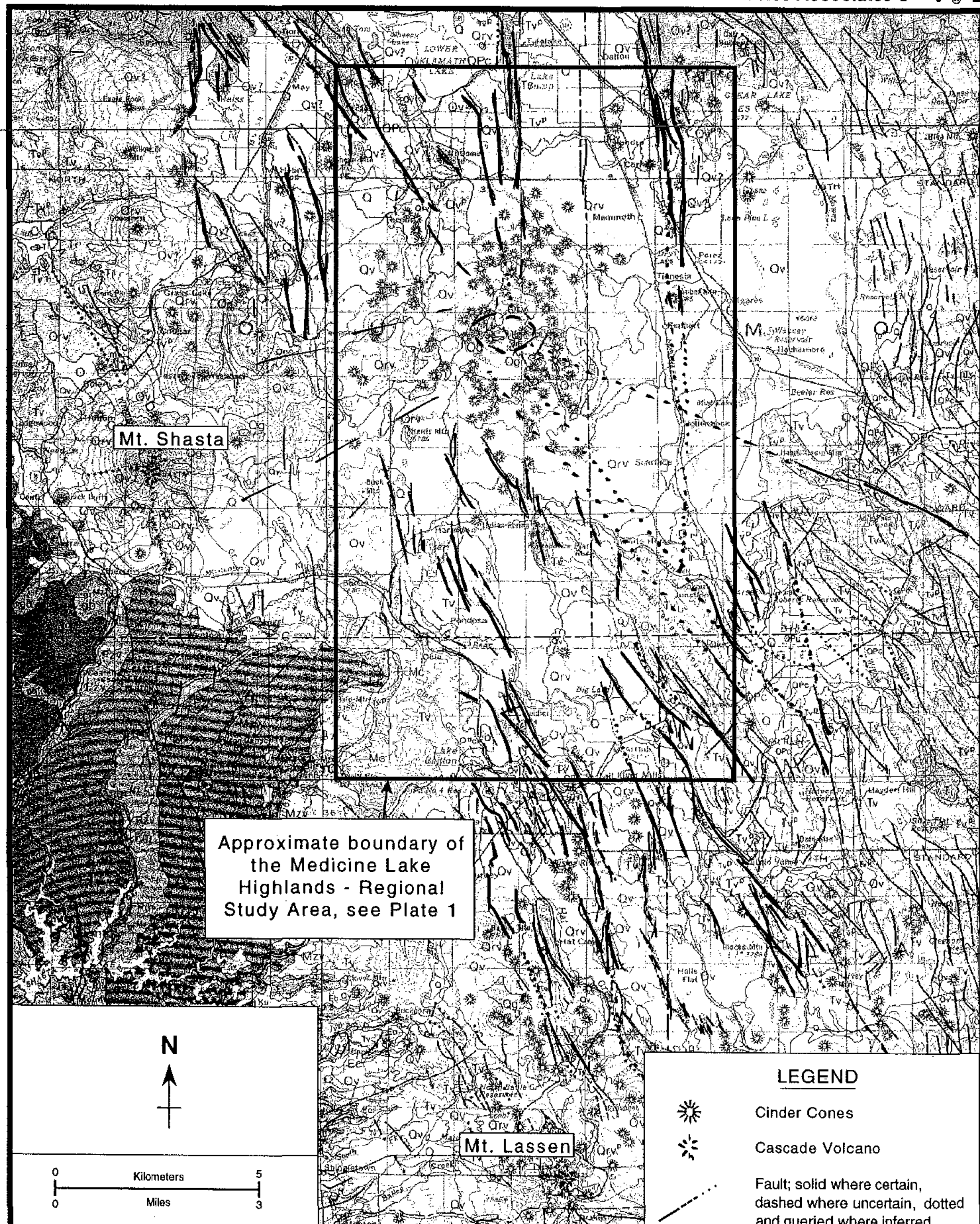

Figure 4b Generalized Geologic Map for the Study Area (modified after Jennings et. al., 1973; and Heiken, 1978)

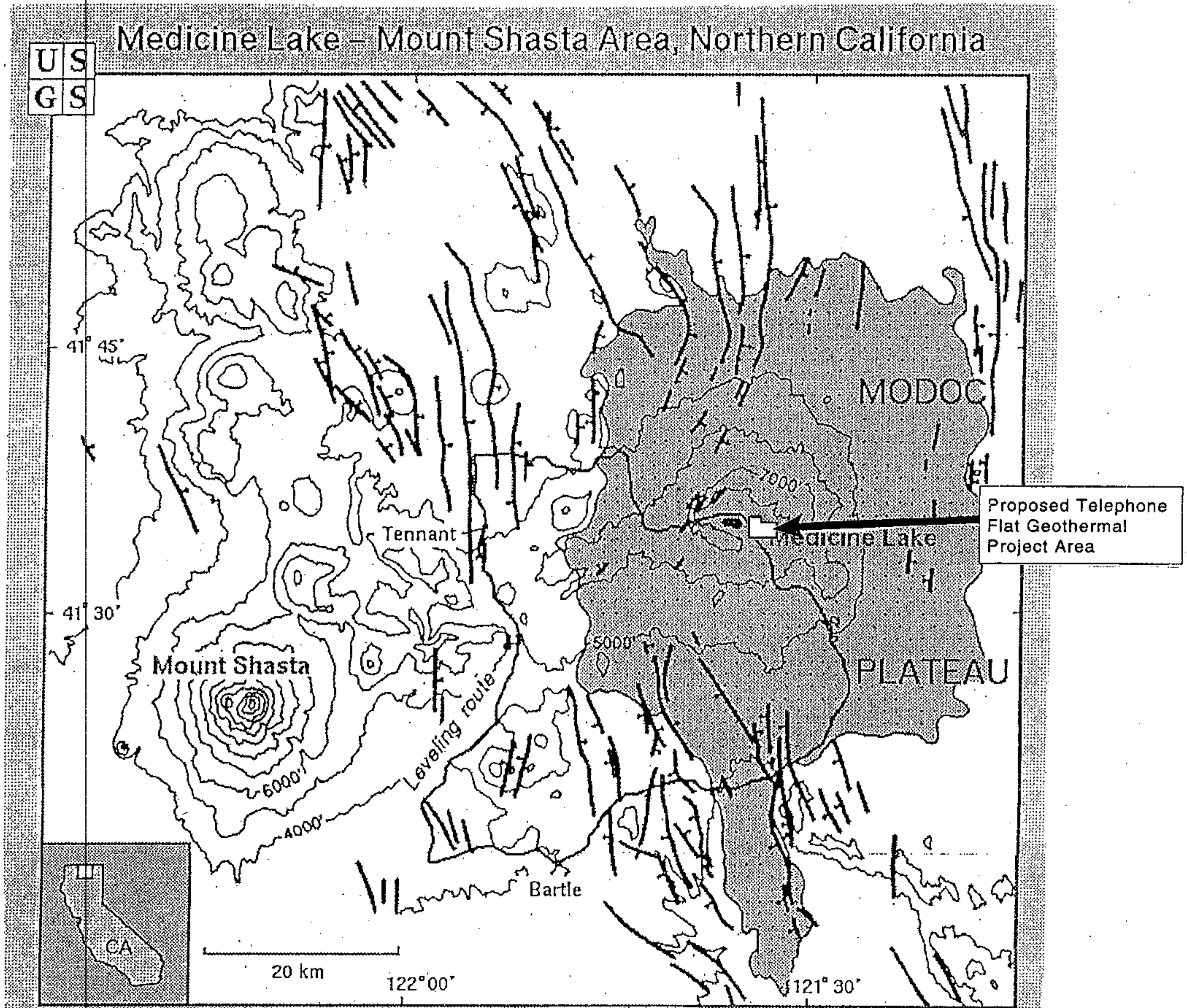

Figure 5. Geologic Structural Map for the Medicine Lake Highlands (stippled pattern) Mount Shasta Area (from Dzurisin et al., 1991)