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PRELIMINARY GEOLOGY OF THE SAN LUIS PEAK QUADRANGLE AND ADJACENT AREAS SAN JUAN VOLCANIC FIELD, SOUTHWESTERN COLORADO

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ABSTRACT

Rocks exposed in the San Luis Peak 7.5' quadrangle are entirely Oligocene volcanic units of the San Juan field. The quadrangle contains intersecting topographic walls and parts of the resurgently uplifted fills of several calderas of the central San Juan caldera cluster. These include the western flank of the large La Garita caldera that formed at 27.80 Ma in association with eruption of the Fish Canyon Tuff, northeastern parts of Bachelor caldera and fill of related Carpenter Ridge Tuff erupted at 27.60 Ma; a small remnant of the Creede caldera from which the Snowshoe Mountain Tuff erupted at 26.80 Ma, and the southern side of the San Luis caldera complex which subsided recurrently during eruption of four ash-flow sheets (including the Rat Creek and Nelson Mountain Tuffs) between 26.45 and 26.15 Ma. Most of the economically important Creede silver-lead-zinc mining district is contained within the San Luis Peak quadrangle, as is the site for a projected 3-5-km research drillhole into the roots of the epithermal vein system, proposed as part of the U.S. Continental Scientific Drilling Program.

INTRODUCTION

The San Luis Peak (SLP) 7.5' quadrangle is strategically located with respect to several significant geologic problems (Fig. 1). It contains much of the economically important Creede mining district (Steven and Ratte, 1965), intersecting margins of several major ash-flow calderas of the San Juan volcanic field (Steven and Lipman, 1976), and a site of proposed research drilling as part of the U.S. Continental Scientific Drilling Program (CSDP; Bethke and Lipman, 1987). Since the area was last mapped 30 years ago (Steven and Ratte, 1965, 1973), many genetic concepts and analytical methods for interpreting silicic volcanism, caldera evolution, igneous petrology, and geochronology have been developed or significantly refined, and detailed study of this key area has been renewed to provide background for the research-drilling proposal and continuing regional mineral exploration.

The present work involved field mapping during the summers of 1986-87, utilizing color aerial photographs at a scale of approximately 1:16,000 and the newly available 1:24,000 topographic base (geographic names, omitted on the preliminary compilation base, can be obtained from the published topographic map). Interpretation of some geologic features, especially along the southern margin of the quadrangle (Fig. 2), remains based heavily on the previous high-quality mapping by Steven and Ratte (1965, 1973). New surface observations were supplemented by study of approximately 15,000 m of exploration drill core, made available by Homestake Mining Company and Mesa Exploration Partnership. Cited chemical data are from Larsen and Cross (1956), Ratte and Steven (1967), and Sawyer and Lipman (unpubl.). Valuable additional constraints on the geologic relations are provided by other ongoing USGS studies: igneous petrology (D. Sawyer), geochronology (M. Lanphere), paleomagnetism (J. Rosenbaum and R. Reynolds), gravity and aeromagnetic studies (D. Williams), and geoelectrical studies (D. Stanley). Field and laboratory studies of these rocks are still underway, and parts of the quadrangle are incompletely understood, especially some rugged and remote areas north of the continental divide.

This open-file report is being released in advance of a formal publication, in order to aid others working on the CSDP project and involved in mineral exploration. The report includes both specific descriptions of map units in the SLP quad and a broader discussion of the geologic history of the central San Juan caldera cluster. The section "Summary of geologic history" is intended to provide an interpretive framework for understanding the brief lithologic summaries provided in the section "Description of map units." These two sections are intended to be complementary, rather than strictly sequential. More detailed lithologic and petrographic descriptions of most units within the SLP quad and adjacent areas are provided by Ratte and Steven (1967). Revised interpretations of the regional volcanic history builds upon the earlier synthesis by Steven and Lipman (1976), utilizing general concepts of caldera cycles summarized by Smith and Bailey (1968) and Lipman (1984). These overview papers provide an essential framework for the detailed discussion in this paper, that many readers may find useful to consult.

Briefly, many large ash-flow calderas such as those in the San Juan field formed at sites of preceding volcanism that records shallow accumulation of caldera-related magma. Structural boundaries of calderas are single ring faults or composite ring-fault zones that dip vertically to steeply inward. The area and volume of caldera collapse are roughly proportion to the amount of erupted material. Scalloped topographic walls beyond the structural boundaries of most calderas are due to secondary gravitational slumping during subsidence. Large calderas (> 100 km^3 of erupted material) collapse concurrently with eruption, as indicated by thick intracaldera ash-flow fill and interleaved collapse slide breccias. Volumes of intracaldera and outflow tuff tend to be subequal; correlation between them is commonly complicated by contrasts in abundance and size of phenocrysts and lithic fragments, degree of welding, devitrification, alteration, and even chemical composition of magmatic material. Postcollapse volcanism may occur from varied vent geometries within ash-flow calderas; ring-vent eruptions are most common in resurgent calderas, reflecting renewed magmatic pressure. Large intrusions related to resurgence are exposed centrally within some calderas. Resurgence within calderas may result in a symmetrical dome or more geometrically complex forms. In addition to resurgence within single calderas, broader magmatic uplift occurs widely within silicic volcanic fields, reflecting isostatic adjustment to emplacement of associated subvolcanic batholiths. Hydrothermal activity and mineralization accompany all stages of ash-flow magmatism, becoming dominant late during caldera evolution. Much rich mineralization is millions of years later than caldera collapse, where the caldera served primarily as a structural control for late intrusions and associated hydrothermal systems.

The accompanying preliminary geologic map (Figs. 3-4), along with continuing studies in adjacent parts of the volcanic field, provide the basis for reinterpreting the history of the central San Juan caldera cluster, revising stratigraphic nomenclature for the volcanic rocks, evaluating lithologic and structural controls on mineralization, and developing strategies for locating the best site for the proposed CSDP research drillhole. Topographic walls of the major calderas were mapped for the first time, depositional features of the caldera-filling units are interpreted on the basis of recent volcanogenic concepts, and several long-standing regional stratigraphic problems are reevaluated. In particular, we attempt to distinguish the commonly confusingly abrupt compositional, welding, and alteration variations <u>within</u> single ash-flow sheets, versus depositional breaks between such sheets that have more significance in terms of geologic time. In this preliminary report, we emphasize new results, rather than providing comprehensive or uniform treatment of volcanic units and events. All suggested modifications to stratigrphic nomenclature are informal, tentative, and subject to further revision.

SUMMARY OF GEOLOGIC HISTORY

The Oligocene San Juan volcanic field is the largest erosional remnant of a composite volcanic field that covered much of the southern Rocky Mountains in middle Tertiary time (Steven, 1975). The field consists mainly of intermediate-composition lavas and breccias, erupted about 35-30 Ma from scattered central volcanoes (Conejos Formation), overlain by widespread voluminous ash-flow sheets erupted from caldera sources between 30 and 26 Ma. At about 26 Ma, volcanism shifted to a bimodal assemblage dominated by alkalic basalt and silicic rhyolite (Hinsdale Formation), concurrently with inception of regional extension during establishment of the Rio Grande rift zone to the east (Lipman and others, 1970). The SLP quadrangle is located in the northwestern sector of the central San Juan caldera cluster, where eruption of six major tuff sheets (Table 1) was associated with a similar number of caldera subsidences between 28.25 and 26.15 Ma (ages rounded to 0.05 Ma).

The six calderas of the central San Juan cluster formed within a locus of precaldera volcanoes consisting dominantly of andesite-dacite lavas and associated volcaniclastic rocks. This early intermediate-composition assemblage has been previously designated the Conejos Formation in eastern parts of the field and the San Juan Formation in the western field, but no consistent name has been applied to the remnants of these volcanoes that are discontinuously exposed around the margins of the central San Juan caldera cluster (Steven and Lipman, 1976). In various sectors around the central caldera cluster (Fig. 1), rocks that now appear to represent precaldera volcanic edificies of similar age but slightly differing compositions have been previously assigned to varied formations at several inferred stratigraphic horizons, including the Conejos Formation (northeast: Larsen and Cross, 1956); volcanics of Leopard Creek (southeast: Steven and Lipman, 1973); lower rocks assigned to the Huerto Formation (west: Steven, 1967); and Shallow Creek Quartz Latite (northwest: Steven, 1967). Although not exposed in place within the SLP quadrangle, these precaldera rocks are present in landslide breccias, derived from caldera walls, that interfinger with thick ash-flow deposits within the Bachelor caldera (Shallow Creek and Phoenix Park breccia members of the Carpenter Ridge Tuff).

Early ash-flow sheets

The earliest ash flows from the central caldera cluster formed Masonic Park Tuff (not exposed within the SLP quadrangle) at about 28.25 Ma, erupted from the Mount Hope caldera 25 km southeast of Creede. The Masonic Park Tuff and associated caldera in many respects are transitional--in space, time, and petrology--between the earlier Platoro caldera complex, in the southeastern volcanic field, and the central caldera cluster. The Masonic Park Tuff has previously been considered to include two ash-flow sheets, designated as the lower and upper members (Steven and Lipman, 1973), but additional mapping south of Wagon Wheel Gap (Fig. 1) has demonstrated that only one ash-flow sheet is present, complicated by caldera-wall structures (Lipman, unpubl. data).

The next major pyroclastic eruption, of the voluminous Fish Canyon Tuff (3,000 km^3) at 27.80 Ma, caused subsidence of the 30x40-km La Garita caldera. Part of the resurgent dome of this caldera is exposed along the continental divide on the east side of the SLP quadrangle. The resurgent dome consists of intracaldera Fish Canyon Tuff (La Garita Member) more than 1,000 m thick, with no base exposed. The entire volume of Fish Canyon Tuff appears to consist of relatively uniform silicic dacite (66-68% SiO_2 ;40-50%

phenocrysts). Distinctive petrologic features, such as presence of phenocrystic quartz and hornblende, suggest that the phenocrysts grew at relatively high pressure in comparison with other tuff units in the San Juan field (Lipman and others, 1978; Whitney and Stormer 1986), although the quantitative pressure estimates for the Fish Canyon magma are controversial (Grunder and Boden, 1987; Whitney and Stormer, 1987). The west margin of the La Garita caldera lies near the west margin of the SLP quad but is entirely concealed by younger volcanic deposits. A steep gradient in the aeromagnetic high associated with the La Garita resurgent dome (Williams and Abrams, 1987; Bethke and Lipman, 1987, cover), that roughly coincides with the later-formed Creede graben, is thought to mark the location of the concealed structural boundary of the La Garita caldera. All the later ash-flow sheets of the central San Juan cluster were erupted from smaller calderas alined roughly north-south along the western side of the large La Garita caldera, almost as if these were postcollapse ring-fracture volcanoes of the La Garita cycle. Outflow Fish Canyon Tuff is overlain widely by distinctive tabular-plagioclase andesite of the Huerto Formation, but this unit does not crop out in the SLP quadrangle.

Carpenter Ridge Tuff and the Bachelor caldera cycle

Outflow Fish Canyon Tuff and Huerto Formation are widely overlain by the 27.60-Ma Carpenter Ridge Tuff, another large regional ash-flow sheet (1,000 km^3). Eruption of this tuff from the Bachelor caldera produced a laterally and vertically variable intracaldera accumulation that has been the cause of much stratigraphic confusion in the Creede district (Table 2). The outflow Carpenter Ridge Tuff correlates directly with a thick intracaldera accumulation of rhyolitic tuff, designated the Bachelor Mountain Member (Steven and others, 1973). Interfingering with the Bachelor Mountain Member are lithologically and areally distinct lenses of caldera-collapse slide breccia that have previously been assigned several different formation names. Gradationally overlying the Bachelor Mountain, and in part representing a less altered lateral equivalent, is a tuff sequence that grades upward into silicic dacite and previously has been considered a separate ash-flow sheet (Mammoth Mountain Tuff). All these rocks are now reinterpreted as intracaldera parts of the Carpenter Ridge Tuff. Proposed nomenclature for this complex pyroclastic deposit represents a compromise between partly conflicting needs to (1) utilize long-established existing names and stratigraphic concepts, (2) include detailed subdivisions of importance for the mining geology of the Creede district, (3) provide a reasonable framework within which to interpret the processes of pyroclastic volcanism responsible for the deposits, and (4) follow modern guidelines for stratigraphic nomenclature.

Welding and compositional variations

The outflow Carpenter Ridge Tuff consists largely of uniform crystal-poor rhyolite (72-74% SiO_2; 3-5% phenocrysts), locally showing compound welding and cooling zones as it grades upward into silicic dacite (66-68% SiO_2; 25-45% phenocrysts). In places, scoriaceous blobs of more mafic magma (61-63% SiO_2) occur along the relatively abrupt upward transition from rhyolite into silicic dacite (Lipman, 1975, p. 49-53; Whitney and Stormer, in press). Within its source Bachelor caldera, the Carpenter Ridge Tuff is a complex intracaldera assemblage of variably welded, crystallized, and altered compositionally zoned tuff, interleaved with lithologically diverse landslide debris from the caldera walls. These intracaldera deposits ponded to a thickness in excess of

1.5 km, with no basal contact exposed.

The resurgent core of the Bachelor caldera is well exposed in cross section on the north wall of the younger Creede caldera. The fill of the Bachelor caldera consists largely of variably welded rhyolitic tuff, long designated the Bachelor Mountain Rhyolite or Tuff. For nearly a century, the Bachelor Mountain has been divided into the Willow Creek, Campbell Mountain, and Windy Gulch subunits. These were once thought to constitute discrete eruptive deposits of stratigraphic significance (Emmons and Larsen, 1923), but it has since become clear that they are intergradational welding zones within the thick rhyolitic caldera fill of the Bachelor caldera (Steven and Ratte, 1965, p. 24). These zones define a general stratigraphic succession in the interior of the caldera fill, becoming generally less welded upward, but near the caldera margins the welding zones alternate and interfinger complexly. Welding reversals are also conspicuous adjacent to landslide breccia lenses from the caldera wall, which interfinger with the caldera-filling tuffs, although most of these are too thin to show at map scale. In most areas, the mapped boundaries between welding zones appear parallel to primary flow-unit contacts, indicating that the welding zones are mainly related to emplacement temperature and thickness of the flow units. Though these units were previously redefined as formal beds of the Bachelor Mountain Member (Steven and others, 1973), we prefer to use them informally as the Willow Creek, Campbell Mountain, and Windy Gulch zones, both to emphasize their correspondence to the well established welding zones of typical ash-flow sheets (Smith, 1960), and also their lack of a layered or sequential regional stratigraphic significance.

Previously, a distinctive compositionally zoned ash-flow assemblage (66-74% SiO_2; 3-40% phenocrysts) has been interpreted to overlie the Bachelor Mountain Member as a discrete cooling unit; this was mapped as the compositionally zoned Mammoth Mountain Tuff (Steven and Ratte, 1965). Less welded rhyolitic tuffs, initally mapped as the Farmers Creek Rhyolite, were later included within the Mammoth Mountain eruptive cycle (Steven and Ratte, 1973; Steven and Lipman, 1976). The Mammoth Mountain Tuff was described as a mostly densely welded ash-flow sheet of crystal-poor rhyolitic tuff that grades upward into crystal-rich dacite (Ratte and Steven, 1967). In contrast, we find that the mapped contact between phenocryst-poor rhyolites of the Mammoth Mountain and Bachelor Mountain (Carpenter Ridge) lithologies within the Bachelor caldera is principally an alteration boundary within a single welded zone, rather than a primary depositional contact between discrete eruptive events. Changes of color, broadly from tan and light gray-brown to red-brown and purple within these densely welded crystal-poor rhyolitic tuffs, are accompanied by intense potassium metasomatism and alkali exchange (K_2O up to 12%; Na_2O as low as 0.5%). In places in the caldera interior, mapped contacts along this alteration boundary angle gradually across the foliation defined by collapse-pumices textures, also indicating that the boundary is independent of primary depositional horizons. An example is the lateral juxtaposition in upper Nelson Creek, where the compaction foliation dips gently, between unaltered rhyolite (previously mapped as Mammoth Mountain) and K-metasomatized rhyolite (mapped as Campbell Mountain) (Steven and Ratte, 1973).

Accordingly, we include all the phenocryst-poor intracaldera rhyolitic tuffs as welding zones of the Bachelor Mountain Member (intracaldera Carpenter Ridge Tuff), and the name Mammoth Mountain is now used by us as an informal member to designate the phenocryst-rich silicic dacite and dacite high in the compositionally zoned Carpenter Ridge Tuff (Table 2). Within the SLP quadrangle, the silicic dacite of the Mammoth Mountain member is relatively thin, 75 m or less, and is overlain by additional crystal-poor rhyolitic tuff, but the thickness of silicic dacite increases to the southeast, to more than 250 m in the Wagon Wheel Gap area (Ratte and Steven, 1967). The local variably welded rhyolitic tuffs, named the Farmers Creek Rhyolite by Steven and Ratte (1965), are now considered to be lateral depositional equivalents of more welded Bachelor Mountain Member to the northwest.

The overall distribution of the Mammoth Mountain member, the significance of large local variations in its thickness, and the local development of a partial to complete cooling break with underlying rhyolitic Carpenter Ridge Tuff in outflow rocks southwest of the caldera are not yet fully understood. Several aspects of the distribution, along with decreasing amounts of tilt upward through the Mammoth Mountain member in several sections (Steven and Ratte, 1965, 1973), suggest that the Mammoth Mountain may have been deposited during early resurgent doming in the Bachelor caldera, causing ponding of the silicic dacite in the moat between the growing resurgent dome and the topographic wall of the caldera. Local reversals and other complexities in the compositional gradients may be due to fluctuations in discharge rate and duration of the eruptions, permitting varying drawdown levels from the layered or zoned source magma chamber. The most conspicuous cooling breaks are associated with voluminous lithic debris, which may chronicle variations in intensity of the eruptions, as well as acting as heat sinks. More detailed study of the lateral variations in composition, thickness, and welding zones of the outflow Carpenter Ridge Tuff is needed along different trajectories from the eruptive source.

Another part of the intracaldera Carpenter Ridge Tuff, which was previously called rhyolitic intrusive rocks of the Bachelor Mountain Member (Tbi, of Steven and Ratte, 1965, 1973), has been reinterpreted by us (in conjunction with M. Roeber, formerly chief geologist in the Homestake Bulldog Mine) to be rheomorphically remobilized tuff from the Willow Creek zone, rather than truely magmatic intrusions. The densely welded fluidal Willow Creek rocks, characterized by pumice-compaction ratios of 100:1 or more, locally develop irregularly swirly textures, and these in turn grade into rheomorphic rocks that resemble flow-laminated rhyolitic lava. The rheomorphic tuff is locally brecciated and spatially associated with faults of the Creede graben. Some critical relations are particularly well exposed in mine exposures.

Caldera-collapse breccias

Four additional named units within the Bachelor caldera are also considered by us to constitute depositional subunits of the caldera-filling Carpenter Ridge Tuff. These are the Phoenix Park and Outlet Tunnel Members of the La Garita Tuff (equivalent to intracaldera Fish Canyon Tuff; Steven and others, 1973), Shallow Creek Quartz Latite, and volcanics of Wagon Wheel Gap (Table 2). All were earlier interpreted as discrete primary eruptive products from local volcanic centers active concurrently with the filling of the Bachelor caldera (Steven and Ratte, 1965; 1973). In contrast, we interpret each of these assemblages as recording repeated landsliding from the adjacent caldera walls, similar to deposits previously recognized in other San Juan calderas (Lipman, 1976). The lithologies present in the landslide deposits vary among caldera sectors, because of differences in the caldera-wall lithologies. Thus, the Phoenix Park and Outlet Tunnel Members of the La Garita Tuff both interfinger with the intracaldera Carpenter Ridge in East Willow Creek. These rocks of Fish Canyon lithology are shattered-brecciated, and locally net-veined by nonwelded crystal-poor rhyolitic tuff that is continuous upward and downward into the adjacent Bachelor Mountain Member of the Carpenter Ridge Tuff. The slide lenses also acted as heat sinks, and welding zonations including local vitrophyre zones formed in the adjacent tuffs of the Bachelor Mountain Member. Steven and Ratte (1965, p. 18) interpreted such vitrophyres as basal vitrophyres of the Phoenix Park Member, but the phenocryst mineralogy and the sequence of welding gradients show that the vitrophyres are composed of rhyolitic tuff of the Bachelor Mountain Member.

In addition to the lenticular landslide breccias, large areas along the Bachelor caldera wall in East Willow Creek are massive breccias of Fish Canyon fragments that grade abruptly eastward into unbroken Fish Canyon Tuff (La Garita Member) along the Bachelor caldera wall. We interpret these rocks as angle-of-repose talus breccia that accumulated along the caldera wall during subsidence. In a few places, blocks of shattered andesite are sufficiently large to map separately from the talus breccias of Fish Canyon lithology; these are thought to be fragments from precaldera andesite-dacite lavas (Conejos Formation), that were locally incorporated in the talus-breccia unit. A fossil-talus origin for some of the La Garita Member (Outlet Tunnel Member) was recognized by Steven and Ratte (1965, p. 17), but the talus breccia has not previously been related to growth of the Bachelor caldera or mapped as a discrete unit of the caldera fill. This unit cannot be interpeted as caldera floor, because nonwelded Carpenter Ridge Tuff is present locally as matrix and interfingering lenses. Such Fish Canyon debris occurs within the Bachelor caldera fill only on its northeast side, adjacent to the high caldera wall cut into the La Garita resurgent dome--the obvious source for the landslide and talus debris. Accordingly, we refer to these deposits as the Phoenix Park breccia member of the Carpenter Ridge Tuff, and further divide them into landslide and talus-breccia units.

In contrast, along the west side of the Bachelor caldera, the dominant caldera-wall lithologies are lavas and associated breccias that once formed the upper parts of precaldera volcanoes. Hornblende-bearing dacite is abundant in this assemblage. Some of these rocks are presently exposed along the west margin of the central caldera cluster (Table Mountain, lower slopes of Bristol Head), west of the SLP quadrangle (Fig. 1). Within western parts of the Bachelor caldera, brecciated landslide masses dominated by hornblende dacite interfinger with tuffs of the Bachelor Mountain Member, but Fish Canyon debris is absent. Accordingly, we refer to these rocks, previously designated Shallow Creek Quartz Latite, as the Shallow Creek breccia member of the Carpenter Ridge Tuff in order to emphasize their dominant textural characteristic and volcanogenic significance in relation to the ash-flow eruptions.

A third lithologically distinctive area of caldera-collapse breccias, associated with the Bachelor caldera but not exposed in the SLP quadrangle, occurs near the Wagon Wheel Gap on the southeast margin of the Bachelor caldera (Fig. 1). These rocks include brecciated masses of aphanitic to sparsely porphyritic andesite as much as several hundred meters across, interspersed with less common masses of brecciated Fish Canyon and Masonic Park Tuffs, and enveloped in variably welded crystal-poor rhyolitic tuff that is indistinguishable from intracaldera Carpenter Ridge Tuff elsewhere. These deposits are overlain by silicic dacite of the Mammoth Mountain member, and accordingly their age is closely bracketed as concurrent with eruption of the rhyolitic Carpenter Ridge. These rocks were previously assigned to the "volcanics of Wagon Wheel Gap" and considered to represent local andesitic-dacitic volcanoes, cut by many small intrusions (Steven and Ratte, 1973; Steven and Lipman, 1973). Most of the "intrusions" are now recognized as megablocks in a tuffaceous matrix. At Wagon Wheel Gap, the dominant sources on the caldera wall for the slide breccias are precaldera andesitic lavas (Conejos Formation), overlain by Masonic Park and Fish Canyon Tuffs.

These slide breccias, deposited within the Bachelor caldera, thus divide into three distinct geographic and lithologic units that can conveniently be correlated with the rocks present on the adjacent caldera wall. Lithologies overlap in few places--andesitic masses within the Phoenix Park breccia member and Fish Canyon blocks within the Wagonwheel Gap breccia Member, but a distinctive rock type dominates in each area. Such slide masses, enclosed by tuff of the Bachelor Mountain Member, have also been confused at times with intrusions where encountered in exploration drill core in the Creede district. Recognition of the caldera-collapse landslide origin of these rocks eliminates the need for several local volcanic and intrusive episodes in the Creede district.

Caldera geometry

A significant regional implication of these stratigraphic and volcanogenic reinterpretations is that the Bachelor caldera is larger and centered farther south than previously mapped. Southern remnants of the Bachelor caldera walls are preserved south of the SLP quadrangle, in the Wagon Wheel Gap and Bristol Head areas (Fig. 1), indicating that the southern caldera wall projects beneath the middle of the younger Creede caldera. The northern margin of the Bachelor caldera is further south than previously interpreted (Steven and Lipman, 1976; Steven and Biewienski, 1977), inasmuch as rocks in the Equity Mine and Bondholder Meadow areas that were been previously interpreted as fill of the Bachelor caldera are reinterpreted as lithologically similar parts of the fill of the San Luis caldera (see later sections).

The core of the Bachelor caldera was broadly uplifted to form a resurgent dome. The crest of the resurgent dome within the Bachelor caldera appears to be eccentrically located north of the center of subsidence (Fig. 1), though detailed geometric interpretation of this dome is difficult, due to truncation by the younger Creede and San Luis calderas and widespread cover by younger volcanic units. Faults that developed along the crest of the Bachelor dome define a keystone graben that has had a complex history of recurrent later movement and provided the dominant structural control for later mineralization. Resurgence may have begun late during the Carpenter Ridge eruptions, because the late silicic dacite tuff of the Mammoth Mountain member appears to have accumulated to greatest thickness in moat areas of the Bachelor caldera and to have wedged out against the crest of the resurgent dome. The moat was further filled by Wason Park Tuff and local volcaniclastic sediments, which thin southwestward against the apparent crest of the dome, on the southwest slopes of Nelson Mountain. The sediments include tuffaceous sandstones, poorly sorted mudflow breccia and conglomerates, and minor finely laminated lake-bed deposits. The sediments are only locally exposed on the surface, on the southwest slopes of Nelson Mountain; they are as much as a few tens of meters thick in exploration drillcore.

Associated lavas

A little-studied lava dome, the rhyolite of Miners Creek, underlies intracaldera tuff of the Bachelor Mountain Member at the southwest corner of the SLP quadrangle. It is unclear whether the rhyolite of Miners Creek is part of the west topographic wall of the Bachelor caldera or possibly a high part of the caldera floor. Broad petrologic similarities suggest that this lava may have been a early leak from the developing Carpenter Ridge magma chamber, in which case it would be part of the caldera floor.

Thick lava flows and domes of silicic dacite and rhyolite were erupted in several places around the margins of the Bachelor caldera after accumulation of outflow Carpenter Ridge Tuff and prior to emplacement of the Wason Park Tuff. Such rocks are widespread on both sides of Wagon Wheel Gap (Steven and Ratte, 1973), and a stratigraphically similar rhyolitic lava on the northwest side of the caldera can be traced into a broad north-trending dike-like feeder in Shallow Creek (Steven, 1967), that is appropriately oriented to have risen along the caldera ring fault. These lavas seem plausibly interpreted as late events of the Bachelor caldera cycle, though they have not been dated directly or studied petrologically in detail. None of these is present within the SLP quad.

Wason Park and Snowshoe Mountain Tuffs, and associated calderas

The Wason Park Tuff, which widely overlies rocks of the Bachelor caldera cycle in the Creede area, was erupted at 27.15 Ma and is locally compositionally zoned from rhyolite to dacite (Krause and others, 1986). The Wason Park was erupted from a poorly understood source, probably represented by the newly recognized South River caldera (Fig. 1; Lipman and Sawyer, unpubl. data). Where the walls of this caldera are locally exposed along the arcuate drainages of upper Red Mountain (South River) and Goose Creeks, and on the north slopes of South River Peak, ash-flow tuffs as young as the Wason Park are abruptly truncated by younger dacitic lavas (Fisher Quartz Latite). These lavas completely bury the interior of the nonresurgent South River caldera; as a result, its eruptive and structural history remain obscure.

In the Creede district, Wason Park Tuff is widely overlain by the andesite of Bristol Head. These lava flows were once assigned to the Huerto Formation (Steven and Ratte, 1965; Steven, 1967), but more recently usage of the term Huerto has been restricted to lavas occupying the stratigraphic interval above Fish Canyon and below Carpenter Ridge Tuffs (Steven and Ratte, 1973). Similar andesitic lavas are locally interleaved between most of the more silicic ash-flow sheets of the San Juan field. They represent continued eruption of rocks typical of the dominantly intermediate-composition precaldera volcanic assemblage (Conejos Formation), that constitutes the bulk of the volcanic field. The continued eruption of such andesitic lavas demonstrates that more mafic magma was available throughout the evolution of the central San Juan caldera cluster, probably at greater depth underlying the evolved high-level magma bodies that erupted the ash-flow tuffs (Steven and Lipman, 1976).

The Creede caldera, that formed during eruption of the Snowshoe Mountain Tuff at 26.80 Ma, was until recently confidently interpreted as the youngest in the central caldera cluster (Steven and Lipman, 1976), but new high-precision $^{40/39}$Ar dates appear to indicate that it is older than the San Luis caldera (Lanphere, 1988). The Snowshoe Mountain Tuff, a relatively mafic dacite (62-66% SiO_2; 40-50% phenocrysts), shows some compositional affinities with the Fish Canyon Tuff, in containing sparse quartz and relative potassic sanidine despite its dacitic bulk composition (Matty and Stormer, 1986). Although exposed to a thickness of more than 1.5 km on the resurgent dome within the Creede caldera, outflow Snowshoe Mountain Tuff is only known to be preserved locally to the south and southeast of the Creede caldera. It has nowhere been recognized within the SLP quad or elsewhere to the north, beneath tuffs from the San Luis caldera, where it would be expected on the basis of the radiometric age determinations. Either the Snowshoe Mountain eruptions were relatively low-energy and largely confined to the concurrently subsiding caldera, or some stratigraphic and age complications remain undeciphered.

San Luis caldera complex

The evolution of the San Luis caldera and associated tuffs, which was especially confusing to Steven and Lipman in the mid 1960-70s (1976, p. 22-26), remains the least understood of the four best exposed central San Juan calderas (additional field and laboratory studies are currently underway). This caldera now appears to constitute the composite source of at least four sizeable ash-flow sheets: Rat Creek Tuff, the newly recognized tuff of Cebolla Creek, Nelson Mountain Tuff, and a late unit that is designated the tuff of Cathedral Creek (Table 2). All four sheets contain broadly similar phenocryst assemblages and compositional zonations from rhyolite to dacite (74-65% SiO_2; 5-40% phenocrysts). Outflow portions of these tuff sheets are difficult to correlate from sector to sector beyond the rim of the San Luis caldera; even less certain are the correlations with at least three discrete cooling units of petrographically similar dacite ponded within the caldera and locally separated by local intervening lava flows. Because of the recurrent eruptive and subsidence history in this area, we now refer to the overall volcanic depression as the San Luis caldera complex, while retaining the name San Luis caldera for the last major subsidence structure.

Rat Creek Tuff and associated rocks

The earliest unit of the sequence, the Rat Creek Tuff (26.45 Ma), is restricted in known areal extent largely to the SLP quad; it may be present as far east as Wheeler Monument (Fig. 1) and to the north at Cathedral. The tuff of Cebolla Creek is characterized by dominant phenocrystic hornblende relative to augite, and by a unusual paleomagnetic pole postion; it has not yet been mapped separately from the Rat Creek within the SLP quad, but it is present on the ridge between West Willow and Rat Creeks, along Cebolla Creek to the north, and at Wheeler Monument 8 km southeast of the quadrangle boundary. The tuff of Cebolla Creek is also petrographically similar to the hornblende-bearing Captive Inca lava dome, which possibly is a less explosive phase of the same eruptive event.

Subsidence structures directly related to eruption of these two units have not been positively identified, but several widely spaced features suggest subsidence largely within the area now marked by the San Luis caldera: (1) Both tuff units are relatively limited in areal extent and eruptive volume, and have been identified only within 10-15 km of the San Luis caldera. (2) A thick compositionally zoned tuff unit, tentatively correlated with the Rat Creek, underlies the tuff of Cebolla Creek along the north margin of the San Luis caldera near Cathedral (Fig. 1). This unit wedges out northward against a steep slope that is cut across Fish Canyon Tuff and older units. This slope may be part of a caldera wall related to the Rat Creek eruptions; alternatively, it could be a surviving scallop in the northwest wall of the earlier La Garita caldera. (3) A previous interpretation remains tenable that eruption of the Rat Creek was associated with formation of a depression bounded on its southwest side by a north-facing paleo-slope in upper Miners Creek, on the southwest side of the San Luis caldera just west of the SLP quad (Steven and Lipman, 1976). This depression was filled by thick tuff that ponded as a single cooling unit of compositionally zoned Nelson Mountain Tuff, rather than including thick rhyolitic Rat Creek overlain by dacitic Nelson Mountain Tuff as thought previously. (4) A third probable caldera remnant for the Rat Creek eruptions is in upper East Willow Creek. There, the lowermost intracaldera tuff unit that may be a remnant of caldera-filling dacitic Rat Creek Tuff, and an overlying dacitic lava flow, are both buried along a steep caldera-wall(?) contact by the main intracaldera dacite correlated with the Nelson Mountain Tuff.

Nelson Mountain Tuff

The Nelson Mountain Tuff (26.15 Ma), as mapped in the SLP quad, is the most voluminous outflow-tuff deposit erupted from the San Luis caldera complex. The Nelson Mountain is considered to be the main caldera-filling tuff unit, and constitutes the middle and thickest of the three intracaldera ash-flow units separated by lava flows in the SLP quad. Outflow Nelson Mountain Tuff appears to be a multiple-flow compositionally zoned single ash-flow sheet within the SLP quad, although in the Wheeler Monument area and farther east, units presently assigned to the Nelson Mountain include several discrete cooling units, characterized by variable paleomagnetic pole positions. It is presently unclear whether these additional eastern cooling units represent additional local ash-flow sheets not present to the west, or the splitting of the Nelson Mountain eastward into subunits, defining an overall composite cooling zonation.

Intracaldera Nelson Mountain Tuff is also compositionally zoned from rhyolite upward into thick crystal-rich dacite that constitutes most of the surface exposures. This volumetrically dominant dacite, once called the Equity Quartz Latite (Emmons and Larson, 1923) and here informally designated the Equity facies of the Nelson Mountain Tuff, laps out against truncated outflow Nelson Mountain Tuff along the topographic caldera wall on the north side of Nelson Mountain, and especially clearly along the north side of the mesa between East Willow and Whited Creeks. The total exposed intracaldera tuff is more than 1.5 km with no base exposed in the thickest sections.

Rhyolitic parts of the intracaldera Nelson Mountain are best exposed in the structurally uplifted triangular Equity fault block, where these rocks were previously correlated with the package of rocks now assigned to the Bachelor Mountain Member of the Carpenter Ridge Tuff (Emmons and Larson, 1923; Steven and Ratte, 1965). These two intracaldera assemblages are strikingly similar in lithologic appearance, including presence of fluidally welded rhyolite, similar to the Willow Creek zone of the Bachelor Mountain Member, low in the intracaldera Nelson Mountain section in the Equity block. The critical relation documenting the correlation of the thick rhyolitic tuff in the Equity block with the less voluminous and largely nonwelded lower rhyolitic outflow of the Nelson Mountain is the absence of any cooling break across the compositional transition from rhyolite to dacite. Several small knobs of transitional rhyolite-silicic dacite, exposed along the ridge crest of the Equity block and previously mapped as Mammoth Mountain Tuff (Steven and Ratte, 1973), preserve this compositional gradation. The compositional and welding gradation from rhyolitic to dacitic Nelson Mountain Tuff within a single cooling unit is expecially clear in core from several exploration drillholes in the same general area.

Rhyolitic and transitional rhyolitic-dacitic intracaldera Nelson Mountain Tuff is also locally exposed in several cirque basins north of the continental divide, on San Luis Peak, and in the Bondholder Meadow area just north of the quadrangle boundary. The presence of these small surface exposures is critical in defining the geometry of resurgence structures within the San Luis caldera. Identification of the transitional rhyolite at Bondholder Meadow, previously also mapped as Bachelor Mountain Member of the Carpenter Ridge (Steven and Bieniewski, 1977), has two additional important implications (1) the changed correlation greatly reduces the northward extent of the Bachelor caldera, and (2) the reduced thickness of overlying dacite of the Equity facies, less than 200 m in the Bondholder Meadow area, in contrast to about 1,000 m on geographic San Luis Peak, implies asymmetrical subsidence of the San Luis caldera or some other complex structural response to eruptive events. As a result of recognition that the Mammoth Mountain is an upper part of the Carpenter Ridge Tuff and that the tuffs within the uplifted Equity block are rhyolitic intracaldera Nelson Mountain, the Carpenter Ridge and Nelson Mountain Tuffs now have a striking (and at times confusing!) overall compositional similarity. More detailed mapping of the intracaldera compositional zonations in the interior of the San Luis caldera is needed.

A late upper unit of dacitic Nelson Mountain lithology is exposed within the SLP quad only along the continental divide in upper East Willow Creek, but occurs widely to the north. This unit, here designated the tuff of Cathedral Creek, has previously been mapped elsewhere as the tuff of Cochetopa Creek (Steven and Bieniewski, 1977) and interpreted as having been erupted from the Cochetopa Park caldera (Steven and Lipman, 1976). Though study of these rocks is still in progress, several features suggest that at least large parts of them were erupted as a late phase from the San Luis caldera complex: (1) ponding to a thickness of several hundred meters within the caldera complex, (2) presence of lithic lag breccias and surge crossbedding at the base of the unit in and near the San Luis caldera--features indicative of proximity to source, (3) stratigraphic position--interleaved with postcaldera lavas of the San Luis caldera, (4) involvement in resurgent doming of the San Luis caldera, and (5) similar mineralogy, paleomagnetic pole position, and $^{40/39}$Ar age as the underlying Nelson Mountain Tuff.

Lenses of landslide breccia, inferred to have slid from oversteepened walls during caldera subsidence, are interleaved with the intracaldera Nelson Mountain Tuff, especially the lower rhyolitic unit. Although cropping out at the surface only in a few small exposures--on the west slope of the Equity block and in upper East Willow Creek, horizons of landslide breccia were encountered repeatedly in mineral exploration drilling in upper West Willow Creek. Two breccia types are present. One consists of monolithologic fragments of Fish Canyon Tuff, presumably derived from the northeast caldera wall that cuts the La Garita resurgent dome. The other contains mainly fragments of porphyritic dacite, in places with some andesite blocks; these are thought to have been derived from the west wall of the San Luis caldera, where precaldera lavas (Conejos Formation) stood high.

Caldera-related lava flows

Several lava flows and domes around the south margin of the San Luis caldera complex appear to represent early phases of this caldera cycle. One is the dacite of McKenzie Mountain, which previously was interpreted as a late lava flow of Fisher Quartz Latite, filling a valley carved in Rat Creek and Nelson Mountain Tuffs on the wall of the Creede caldera (Steven and Ratte, 1965; Steven and Eaton, 1975). In contrast, we have found that this lava dome rests conformably on the Wason Park Tuff and andesite of Bristol Head, is truncated by the topographic wall of the San Luis caldera in geographic Rat Creek, and that both Rat Creek and Nelson Mountain Tuffs lap out against it. Locally, laccolithic intrusive parts of this lava dome have tilted and uplifted adjacent rocks, such as an east-dipping slab of Wason Park Tuff west of Rat Creek. New $^{40/39}$Ar ages also indicate that the McKenzie Mountain dome, at 26.40 Ma, is more appropriately considered an early phase of the the San Luis caldera complex (26.45-26.15 Ma) than a late part of the Creede cycle

(26.80-26.70 Ma).

Intermittent filling of the subsided core within the San Luis caldera complex is documented by several lava flows that interleave with the thick welded intracaldera tuffs--a relation seemingly unlike that found in any other central San Juan caldera. These include a local dacite flow in upper East Willow Creek, that overlies a lower intracaldera dacite unit tentatively correlated with outflow Rat Creek Tuff. This small inferred remnant of a subsidence structure related to Rat Creek eruptions is abruptly truncated along a steep slope by the main body of younger caldera-filling Equity facies of the Nelson Mountain. Another lava flow in upper East Willow Creek overlies the Equity facies tuffs and in turn is overlain by a locally preserved late dacite tuff of similar petrology; this unit is tentatively correlated with the tuff of Cathedral Creek which occupies a similar stratigraphic position in the northern caldera moat (Steven and Biewienski, 1977)

Additional lava flows, that overlie all the tuff units, form an arcuate belt around the southern side of the caldera, burying and obscuring features of the caldera walls. We were unable to recognize the previouly reported distinction (Steven and Bieniewski, 1977) between the volcanics of Stewart Peak (tilted by resurgent doming) and volcanics of Baldy Cinco (untilted); accordingly, we map all these lavas in the SLP quad as "volcanics of Stewart Peak." Some rocks previously mapped as Stewart Peak on the east side of the caldera are flat-lying, and others to the west previously mapped as Baldy Cinco appear tilted due to resurgence. In many areas such distinctions, based on structural attitude, are uncertain because of primary dips of as much as 30-40^{o} mapped on flanks of the postcaldera volcanic edifices. In addition most of the lavas mapped in the Creede 15' quad by Steven and Ratte as "quartz latite of Baldy Cinco" are andesite (58.5-61.7% SiO_2; 7 analyses). North of the SLP quad, thick rhyolitic lava domes, present low in the caldera fill, are mapped separately by us as the rhyolite of Mineral Mountain (Table 2). All the tuffs and lavas associated with the San Luis caldera complex appear to have erupted within the interval 26.40-25.70 Ma (Lanphere, 1988, and written commun., 1988).

Intracaldera sedimentary deposits are known only locally in a few places within the San Luis caldera; two of these are in the SLP quad, in a small tributary cirque basin of upper East Willow Creek and poorly exposed similar sediments just south of San Luis Pass. These fluvial and lake-bed sediments are similar to those found farther north in the caldera. They overlie the main Equity dacite facies and underlie lava flows of the Stewart Peak assemblage, but stratigraphic details are obscured by heavy surficial cover. They appear to have accumulated in local depositional basins, and are at maximum only a few tens of meters thick.

Caldera geometry

The geometry of the southern topographic wall of the San Luis caldera is especially well displayed in the SLP quad, where surface exposures are augmented by extensive mineral exploration drillhole data. The topographic wall is an irregularly northward-dipping slope, characterized by generally gentle slopes (5-15^{o}). These slopes, in combination with the present rugged topography, result in a highly irregular map trace of the caldera wall. A paleo-ridge underlain by the Captive Inca lava dome projects northwestward about 3 km into the caldera complex, and the southward embayment in Rat Creek to the west may be a remnant from early subsidence during eruption of the Rat Creek Tuff. The Rat Creek embayment is filled by unfaulted Nelson Mountain Tuff (Steven and Lipman, 1976). Another large lobate embayment is present in the Deerhorn Creek area, where the northward slope is mostly in the range 5-10°. In contrast, the east caldera wall, against Fish Canyon Tuff in the La Garita Mountains, has an average slope of 30°. An even steeper slope of as much as 70° characterizes the plaster of the Equity facies against the lower dacitic intracaldera unit of possible Rat Creek affinity at the head of Whited Creek.

The San Luis caldera was resurgently uplifted as a complex asymmetric trap-door block, that is still incompletely understood. Faults with large displacements bound the southern and western sides of the structurally highest block (containing geographic San Luis Peak), but displacements diminish gradually to an unbroken hinge zone near the northern margin of the caldera. Some of the resurgent uplift and associated faulting appears to predate eruption of the volcanics of Stewart Peak, as indicated by varied thicknesses of intracaldera Equity dacite tuff and overlying moat-filling volcanics of Stewart Peak in upper Cochetopa Creek. Detailed interpretation of the resurgent structures of the San Luis caldera is impeded by the obscure character of compaction foliation in much of the dacitic Equity facies, and also by the lack of mappable stratigraphic horizons within sections of dacite as much as 1000 m thick.

Separate fault-bounded uplift of the triangular Equity block is presumably related to a shallow underlying intrusion. The east-west trend of the Equity fault is regionally anomalous. This structure forms a boundary between flat-lying caldera fill to the south and asymmetrically uplifted fill to the north, but it could not be traced confidently westward across the northern Amethyst fault or eastward into Whited Creek. A smaller but geometrically similar fault-bounded triangular uplift, north of San Luis Peak, is only 0.5 km east of exposed granitic rocks thought to be part of the main resurgent intrusion in the core of the caldera.

Structure

Normal faults are the dominant structural features of the SLP quad. Most of these are related to evolution of the Oligocene calderas: caldera-subsidence ring faults, and extensional structures related to resurgent uplift. No caldera ring faults are exposed, but such structures are inferred to exist concealed at depth, between the topographic wall and resurgent domes of all the calderas, based on analogies with other more eroded calderas in the San Juan field and elsewhere in the world (Lipman, 1984).

The dominant feature is the north-northwest-trending Creede graben, which was initially established as the keystone graben along the crest of the resurgent dome of the Bachelor caldera. The Creede graben appears to overlie and follow the trend of the buried western ring fault of the La Garita caldera, as indicated by its position over the west margin of a large positive aeromagnetic anomaly associated with the structural core of this caldera (Williams and Abrams, 1987). Initiation of the Creede graben during resurgence of the Bachelor caldera (ancestral Amethyst fault of Steven and Ratte, 1965) is documented by its location at the crest of the Bachelor resurgent dome, and by the preferential concentration of rheomorphic tuff along the graben faults, indicating movement while the tuff filling the Bachelor caldera was still sufficiently hot to sustain plastic flow.

The complex later history of movement and reactivation along faults of the Creede graben has been carefully documented by Steven and Ratte (1965). Major offsets involve all the younger tuff sheets, including Wason Park and Nelson Mountain Tuffs, and movement continued during the time of vein mineralization at 25.10 Ma. A few additional features based on our mapping are noteworthy.

The northern continuation of the Creede graben, in the SLP quadrangle, has been difficult to constrain because of heavy surficial cover and lack of stratigraphic markers in the thick Equity dacite facies, but the north-northwest trends of drainages and alinement of aeromagnetitic anomalies, as far as the north margin of the San Luis caldera (Williams and Abrams, 1987; Bethke and Lipman, 1987, cover), suggest that these structures have more continuity than previously mapped.

Within the SLP quadrangle, the North Amethyst fault trends toward San Luis Pass, where any offset is obscured by surficial cover and lack of diagnostic marker horizons in the intracaldera dacitic Equity facies of the Nelson Mountain Tuff. At the head of West Willow Creek, the gradation from deeper welded to upper nonwelded zones in the Equity facies, which is nearly level across the valley at 11,800 feet, hinges upward on the east side toward the pass, indicating increasing monoclinal flexing or faulting northward. A possible northwesterly continuation of the Amythyst structure is an up-to-the-east fault, concealed beneath surficial deposits in upper Cascade Creek. This structure juxtaposes typical dacite of the Equity facies west of the creek with lower transitional rhyolite/dacite tuff of the Equity facies containing rhyolitic pumices east of the creek. Several northeast-trending strands of the North Amethyst fault also cross the continental divide, into the head of Spring Creek, and have associated pyritically altered rock. Large structures related to resurgent uplift of the San Luis caldera must be present in upper Spring Creek, as indicated by differing tilts within the caldera-filling dacite and by offsets of the dacite-rhyolite transition. These structures are largely covered by surficial deposits and are poorly understood, but they potentially provide links between the strong mineralization of the Creede district to the south, and the more limited known mineralization in the Bondholder Meadow area to the north.

Additional large faults within the San Luis caldera are associated with trap-door resurgent uplift of a northwest-trending block several kilometers across containing San Luis Peak. This block is characterized by steep northwestward dips (35-75^{o}) of compaction foliation within the Equity dacite facies of the intracaldera Nelson Mountain Tuff, in contrast with the generally gentle dips of this unit elsewhere within the caldera, and by the uplift of lower rhyolite and transitional rhyolite-silicic dacite units of the Nelson Mountain. Faults bounding the uplifted block are widely concealed by glacial debris and talus, and several critical localities have not yet been examined.

Although we thus identify some structures not previously shown on published maps, the major strands of the economically important North Amysthest fault, as interpreted by us utilizing new subsurface information, are virtually identical to those mapped by Steven and Ratte (1965, 1973). Some other structures previously shown within the SLP quadrangle area are more equivocal; these include the northern continuation of the Bulldog fault, western and eastern extents of the Equity fault, and evidence for many small concealed faults. Some of these offsets were largely based on features that we alternatively interpret as depositional truncations along the intersecting topographic walls of the La Garita, Bachelor, and San Luis caldera walls. For example, in upper West Willow Creek, the northern continuation of the Bulldog Mountain fault as mapped by Steven and Ratte (1973) is exposed in only one place--a spur ridge west of the Equity mine. Here, the contact is clearly a steep depositional plaster along the caldera wall, rather than a fault: a vitrophyre is present along the base of the dacitic tuff, and compaction foliation in the tuff steepens from nearly horizontal, to about 40^{o} adjacent to the caldera-wall contact. Another example, is the structure on the ridge between East Willow and Whited Creeks, where Steven and Ratte (1965, 1973) show several faults to account for complexities in the distribution of units; in contrast, we map these features as depositional wedgeouts of units within the San Luis caldera against the topographic wall. Also, the steep dips and differing elevations among outcrops of Wason Park Tuff west of Rat Creek, shown by Steven and Ratte (1973) as due to concealed faults, are at least in part due to deformation adjacent to lacolithic intrusive phases of the McKenzie Mountain lava dome.

Because the thickness of volcanic units can vary greatly in short distances in a caldera environment, small structures can readily be missed from surface exposures, especially where surficial deposits are widespread. Therefore, even though some faults in the SLP quad are not as large or continuous as previously mapped, the potential remains for the existance of additional small structures of possible significance for mineralized rock. In the Creede district, many of the most productive veins have been on minor structures.

Igneous activity and mineralization

Mineralization within the central caldera cluster, mainly in the Creede district, was localized by caldera structures but was about 1 Ma younger than any associated volcanic deposits (Bethke and others, 1976; M. Lanphere, written commun., 1987). No sizeable shallow granitic intrusions are exposed within the Bachelor caldera, but by analogy with more deeply eroded calderas elsewhere (Lipman, 1984), such bodies are inferred to be present within a few kilometers of the surface to provide heat sources for the hydrothermal systems responsible for the mineralization.

Several small granitic bodies intrude the uplifted core of the San Luis caldera and probably are high points on a larger resurgent intrusion. These are associated with conspicuous pyritic and argillically altered rocks, in places along faults and well-defined fractures, but no significantly mineralized rock has been found to date.

DESCRIPTION OF MAP UNITS

[*, Preliminary usage of new or redefined name, based on in-progress studies; formal changes in stratigraphic nomenclature not proposed at this time]

Units are listed in order, following correlation of map units diagram (Fig. 4). Volcanic rock names are in accord with the IUGS classification system (Le Bas and others, 1986), except that silicic dacite (equivalent to quartz latite of previous workers) is separated as an important petrologic type. Quartz latite is retained in continuity with historic usage for formally named units. The volcanic rocks constitute a high-K subalkaline suite similar to those of other Tertiary volcanic fields in the southern Rocky Mountains, but the modifiers required by some classification schemes have been dropped for brevity: thus, a unit is called andesite, rather than trachyandesite or high-K andesite. Names, divided on the basis of % SiO_2, are: <52, basalt; 52-57, basaltic andesite; 57-62, andesite; 62-66, dacite; 66-70, silicic dacite (quartz latite); 70-75, rhyolite. >75, silicic rhyolite (compositions recalculated to 100% volatile-free).

Ages for igneous rocks are $^{40/39}$Ar plateau determinations on biotite phenocrysts by M. Lanphere (1988, and written commun.), except where otherwise noted.

SURFICIAL DEPOSITS

HOLOCENE DEPOSITS

Qal Alluvium--Silt, sand, gravel, and peaty material in valley bottoms. Locally includes small deposits of colluvium and talus (Qc, Qt) at margins of valley bottoms

Qc Colluvium--Poorly sorted silt- to boulder-sized material on slopes and in steep valleys. Locally includes small alluvial, talus, landslide, and glacial moraine deposits

Qt Talus--Angular rock fragments as much as 1 m in diameter forming talus cones, talus aprons, and scree slopes. Locally well sorted. Grades into colluvium (Qc) as sand and silt content increases

HOLOCENE AND PLEISTOCENE DEPOSITS

Ql Landslide deposits--Lobate accumulations of poorly sorted soil and rock debris on slopes marked by hummocky topography and downslope-facing scarps. Derived from bedrock and glacial deposits. Includes small earthflow, block-slump, and block-slide deposits

Qr Rock glacier--Glacier-shaped deposit of angular rock fragments, generally lacking fine-grained material on upper surface

PLEISTOCENE DEPOSITS

Qm Moraine and till--Terminal and lateral moraines, and thick valley-bottom till. Poorly sorted and generally unstratified clay, silt, and sand containing erratic boulders; characterized by hummocky or ridgey topography. Some till has been mapped with colluvium (Qc)

OLIGOCENE ROCKS OF THE SAN LUIS CALDERA

POSTCALDERA ROCKS

Ti Resurgent intrusions--Equigranular to porphyritic fine- to medium-grained hypabyssal granitic rocks, intrusive into intracaldera Nelson Mountain Tuff on west and northwest slopes of San Luis Peak

Volcanics of Stewart Peak--lava flows and associated volcaniclastic rocks, filling moat area of caldera. Gray porphyritic lavas containing 5-25% phenocrysts of plagioclase, augite and/or hornblende; sparse biotite occurs in more silicic rocks. Andesitic compositions (58-61% SiO_2) are most common. Boundaries between some dacite flows are obscure; individual flows may be as much as 200 m thick; andesitic flows tend to be thinner (10-50 m). Several individual flows and domes (north of Nelson Mountain; west of San Luis Pass) are incomplete mixes of nearly aphyric dark-gray andesite and more porphyritic light-gray dacite. Contacts are shown between some major flows within unit. Lower flows locally interleave with intracaldera dacite welded tuffs within the San Luis caldera. No consistent differences were recognized between previously mapped volcanics of Stewart Peak and quartz latite of Baldy Cinco (Steven and Bieniewski, 1977). Thickness, 0-500 m. $^{40/39}Ar$ and K-Ar ages, 26.9 on a lava flow and 25.7 Ma on an intrusion into the lavas

Tsa Andesite lava flows--Dark-gray rocks, mostly containing less than

10% small phenocrysts, mainly of plagioclase and augite

Tsd Dacite lava flows--Gray rocks, mostly containing more than 10% phenocrysts of plagioclase, augite, and biotite; some flows contain hornblende in place of augite

Tsac Andesitic volcaniclastic rocks--Mainly mudflow deposits flanking andesitic volcanic piles

Tsdc Dacitic volcaniclastic rocks--Mudflow deposits and coarse breccias derived from coarsely porphyritic dacite lava domes

Tsi Porphyritic dikes and plugs--Hypabyssal intrusions of various sizes and shapes; dacitic compositions are most common, especially in larger bodies

Tcc? TUFF OF CATHEDRAL CREEK(?)*--Late intracaldera silicic dacite to dacite ash-flow sheet of gray to tan welded tuff, locally having a black basal vitrophyre; 25-35% phenocrysts of plagioclase, biotite, and augite. Stratigraphically highest unit of ash-flow fill of San Luis caldera, overlying volcanics of Stewart Peak at head of East Willow Creek and interfingering with these rocks in Spring Creek north of quadrangle boundary. Provisional informal name; probably correlative with upper caldera-filling tuff at Crethedral Creek, north of quadrangle, and with Cochetopa Park Tuff of Steven and Lipman, 1976). Thickness, 0-100 m

Tss Intracaldera sedimentary rocks of San Luis caldera--Pale yellow to tan fine-grained volcaniclastic rocks. Includes finely laminated lacustrine sediments, tuffaceous sandy fluvial beds, and local bedded travertine hot-spring deposits. Mostly poorly exposed as float in landslides and in small gullies. Thickness, 0-50 m

NELSON MOUNTAIN TUFF--Regional ash-flow sheet and thick intracaldera fill; grades upward in composition from rhyolite to dacite (73-63% SiO_2). Map subunits are primarily compositional and welding zones, rather than strictly sequential stratigraphic units. Normal magnetic polarity. $^{40/39}Ar$ age at geographic Nelson Mountain, 26.15+/-0.08 Ma

Tndn Silicic dacite and dacite, nonwelded or weakly welded zone--Upper part of Nelson Mountain Tuff, both within and outside the San Luis Peak caldera. Yellow-tan to gray, porous, vapor-phase crystallized to glassy. Grades into more welded Nelson Mountain Tuff (Tnd). Crystal rich; phenocrysts similar to welded dacite (Tnd). Thickness, 10-50 m

Tnd Silicic dacite and dacite, welded zone--Dense dark-gray devitrified upper part of the main Nelson Mountain ash-flow sheet. Contains 20-35% phenocrysts of plagioclase, biotite, and augite; sanidine and quartz are sparsely present. Dashed lines indicate locally conspicuous welding boundaries. Grades downward into rhyolite or transitional rhyolite-silicic dacite tuff (Tnr, Tnrd). Within caldera on south slopes of San Luis Peak and slopes east of upper Cascade Creek, includes zone as much as several hundred meters thick, that is transitional into silicic dacite and characterized by presence of scattered rhyolitic pumice fragments. Thickness, 20-50 m in outflow sheet, but as much as 1,200 m within caldera

Tnrd Transitional rhyolite-silicic dacite, welded zone--Forms brownish-gray main cliff-forming welded part of outflow Nelson Mountain

Tuff sheet (68-72% SiO_2). Contains 10-20% phenocrysts of plagioclase, sanidine, biotite, and sparse augite and quartz. Contains pumice lenses of both crystal-poor rhyolite and crystal-rich dacite. Grades downward into rhyolite (Tnr). Thickness, 20-50 m outside caldera; not mapped separately everywhere within caldera

Tnr Rhyolite, welded zone--Light gray and tan, to light reddish brown welded tuff; characterized by pumice flattening ratios <10:1. Phenocrysts (3-5%) of sanidine, plagioclase, biotite, and sparse augite. Locally intensely argillically altered. Exposed mainly on uplifted block north of the Equity fault, where Steven and Ratte (1973) previously correlated it with lithologically similar Campbell Mountain zone (Tcbc) of the Bachelor caldera fill. Grades into less welded and fluidally welded rhyolites (Tnrn, Tnrf). Thickness, 0-100 m

Tnrf Rhyolite, fluidally welded zone--Light-gray phenocryst-poor densely welded tuff. Characterized by pumice flattening ratios >10:1, commonly 100:1. Locally lineate. Exposed only on uplifted block north of the Equity fault, where Steven and Ratte (1973) previously correlated it with lithologically similar Willow Creek zone of the Bachelor caldera fill (Tcbw). Phenocrysts similar to welded rhyolite (Tnr). Thickness, greater than 300 m; base not exposed

Tnrn Rhyolite, nonwelded or weakly welded zone--Gray porous pumiceous tuff. Originally glassy; now everywhere argillized or zeolitized. Phenocrysts similar to welded rhyolite (Tnr). Thickness, 10-50 m

Intracaldera landslide breccia lenses--Local landslide deposits, derived from oversteepened caldera walls during eruption-related subsidence

Tnld Breccia lenses, dominantly of dacitic lavas--Fragments of porphyritic dacite as much as several tens of meters in diameter in a matrix of comminuted rock fragments. Probably derived from the McKenzie Moutain lava dome, the Captive Inca lava dome, and related precaldera lavas along the southwestern margin of the San Luis caldera. Thickness, 0-100 m

Tnlf Breccia lenses, dominantly of Fish Canyon Tuff--fragments of intracaldera Fish Canyon Tuff (La Garita Member) as much as several tens of meters in diameter in a matrix of finely comminuted Fish Canyon Tuff. Derived from La Garita Mountains along east caldera wall. Thickness, 0-100 m.

Td LOCAL DACITE LAVA FLOW--Interleaved betweeen intracaldera Rat Creek Tuff (Trd?) and Nelson Mountain Tuff (Tnd) in upper East Willow Creek. Contains about 20% phenocrysts of plagioclase, biotite, and augite. Thickness 0-75 m

RAT CREEK TUFF--Compositionally zoned ash-flow sheet (65-70% SiO_2) of relatively modest volume, generally poorly exposed beneath Nelson Mountain Tuff. Map subunits are primarily welding and compositional zones, rather than strictly sequential stratigraphic units. Remanent magnetic polarity: normal. Thickness, 0-100 m. Mean of $^{40/39}$Ar ages in Rat Creek and on southest slope of Nelson Mountain, 26.45+/-0.065 Ma

Trdn Silicic dacite and dacite, nonwelded to weakly welded zone--Locally preserved upper part of the Rat Creek Tuff: yellow-tan to gray, porous, vapor-phase crystallized. Grades downward into welded silicic dacite and dacite (Trd) Phenocrysts same as in welded dacite (Trd)

Trd Silicic dacite and dacite, welded zone--Light-brown devitrified upper part of Rat Creek Tuff. Typically contains 20-40% phenocrysts of plagioclase, biotite, augite, and sparse sanidine. Commonly characterized by glassy black flattened pumices in brownish devitrified matrix where partly welded at base of zone, resulting in a colorful "halloween" texture. Grades downward into rhyolitic tuff (Trr). Exposures labelled Trd?, at head of East Willow Creek and adjacent areas were identified mainly by stratigraphic position below local dacite lava flow (Td). Includes a hornblende-bearing sanidine-poor dacitic tuff, on ridge between West Willow and Rat Creeks, that is probably an unmapped separate cooling unit, correlative with tuff of Cebolla Creek north of San Luis caldera and at Wheeler Mounument

Trr Rhyolite, mostly nonwelded--Light-gray to yellow glassy pumiceous tuff where nonwelded or weakly welded, commonly containing several percent centimeter-size fragments of andesitic to rhyolitic rocks. Glassy, ranging to zeolitic or argillically altered tuff. Grades upward into silicic dacite (Trd). Typically contains 5-15% phenocrysts of sanidine, plagioclase, biotite, and sparse augite

Trl Lithic-rich zone in rhyolite tuff--Zone characterized by abundant fragments of andesitic to rhyolitic lava fragments, 5-20 cm in diameter; mainly exposed as float on south side of Nelson Mountain

PRECALDERA AND SYNCALDERA LAVA FLOWS

Dacite of McKenzie Mountain*--Tan to brown flow-layered lava dome (64-65% SiO_2), containing 20-30% phenocrysts of plagioclase, biotite, and augite. Formerly considered by Steven and Ratte (1973) to be a late lava flow of Fisher Quartz Latite on wall of Creede caldera, but unconformably overlain by Rat Creek and Nelson Mountain Tuffs. It probably is an early lava related to the San Luis caldera. Remanent magnetic polarity, normal. $^{40}Ar/^{39}Ar$ age, 26.40+/-0.13 Ma. Thickness, 0-200 m

Tmd Lava flow--Flow layered and largely devitrified interior of lava dome

Tmb Flow breccia--Basal and upper carapace breccia of lava dome, mostly originally glassy but now partly altered to clays and zeolites

Tmi Dikes and vent neck--Steeply flow-layered rocks, marked by structural discontinuity with main body of lava dome

Silicic dacite of Captive Inca mine*--Tan to brown lava dome and associated volcaniclastic rocks (69-70% SiO_2). Contains 15-25% phenocrysts of plagioclase, biotite, and hornblende. Previously mapped by Steven and Ratte (1973) as "Rat Creek volcano" along West Willow Creek. Thickness 0-200 m

Tcd Lava flow--Flow-layered and largely devitrified interior of lava dome

Tcdb Flow breccia--Basal and upper carapace breccia of lava dome, mostly originally glassy, but now partly altered to clays and zeolites. Thickness, 0-30 m

Tcdi Vent neck--Steeply flow layered zone, in which glassy and devitrified zones alternate on centimenter to meter scale

Tcs Volcaniclastic sedimentary rocks--Mainly conglomeratic mudflows, derived from the Captive Inca lava dome. Thickness 0-20 m

OLIGOCENE ROCKS OF THE CREEDE CALDERA

Tc CREEDE FORMATION--Volcanic sandstone and conglomerate filling a paleovalley on north wall of Creede caldera. Thickness, 0-50 m

OLIGOCENE ROCKS UNRELATED TO IDENTIFIED CALDERAS

Tab ANDESITE OF BRISTOL HEAD--Lava flows and associated breccias of aphyric to sparsely porphyritic gray andesite (58-59% SiO_2). Thickness, 0-125 m

WASON PARK TUFF--Ash-flow sheet of rhyolite, locally grading upward into silicic dacite (68-74% SiO_2), containing 10-30 percent phenocrysts (plagioclase, sanidine, biotite, and augite). Phenocryst content increases (and silica decreases) upward to top of densely welded zone, then decreases in winnowed less welded upper part. $^{40/39}Ar$ age, 27.17+/-0.12 Ma. Remanent magnetic polarity: reverse. As much as 200 m thick

Twn Nonwelded or weakly welded zone--Upper light-gray vapor-phase crystallized tuff. Grades downward into welded tuff (Tw). Mapped where more than about 20 m thick.

Tw Welded zone--Red-brown devitrified interior of cooling unit, characterized by white collapsed pumice lenses as much as 0.3 m long, consisting of intergrown alkali feldspar and tridymite. Locally includes black basal vitrophyre as much as 15 m thick

OLIGOCENE ROCKS OF THE BACHELOR CALDERA

Tbs INTRACALDERA SEDIMENTARY ROCKS--Pale yellow to tan fine-grained volcaniclastic rocks. Includes finely laminated lacustrine sediments, tuffaceous sandy deltaic beds, and local tuffaceous breccias of probable mudflow origin. Poorly exposed, mostly as float, on southwest slopes of Nelson Mountain; present in exploration drill core in west Willow Creek area. 0-50 m thick

Tcr CARPENTER RIDGE TUFF--Widespread ash-flow sheet, containing complex compositional and welding zonation (65-74% SiO_2), especially within Bachelor caldera. Volumetrically dominant rhyolite, containing 3-5% phenocrysts, grades locally upward to silicic dacite and dacite containing as much as 45% phenocrysts. Remanent magnetic polarity: reverse

Mammoth Mountain member*--Phenocryst-rich (10-40%) welded silicic dacitic to dacitic ash-flow tuff. Gradationally overlies rhyolitic Campbell Mountain zone of Bachelor Mountain Member (Tcbc) within caldera except where separated by Phoenix Park breccia member, but separated by partial to complete cooling break in outflow deposits, especially southwest of caldera. Previously interpreted as a separate ash-flow sheet, the Mammoth

Mountain Tuff (Steven and Ratte, 1973). Thickness within quadrangle, 0-100 m, but as much as 250 m thick along Blue Creek within southeastern moat of Bachelor caldera. $^{40/39}$ total-fusion age, 27.32+/-0.18 Ma

Tcmn — Silicic dacite-dacite unit, nonwelded to weakly welded--Light gray vapor-phase-crystallized tuff and zeolitized nonwelded tuff at top of ash-flow sheet that was originally glassy. Grades down into welded dacite zone (Tcm); phenocrysts same as in welded dacite zone (Tcm)

Tcm — Silicic dacite - dacite unit, welded zone--Tan to brown devitrified tuff, containing 10-45 % phenocrysts of plagioclase, sanidine, biotite, and augite. Grades downward into welded rhyolitic Campbell Mountain zone of Bachelor Mountain Member (Tcbc)

Outflow rhyolitic member (not present in San Luis Peak quadrangle)--Dominantly phenocryst-poor tan rhyolite, characterized by black basal vitrophyre and central lithophysal zone. Distinctive mafic scoria and accidental volcanic lithics are common in upper part, especially along cooling break between rhyolite and dacite of the Mammoth Mountain member in outflow deposits (Lipman, 1975; Whitney and Stormer, in press), but have not been identified within caldera. $^{40/39}$Ar age, 27.61+/-0.21 Ma

Intracaldera rhyolitic tuff assemblage--Ash-flow accumulation more than 1 km thick, with no base exposed, characterized by texturally diverse welding and crystallization zones. Interfingers complexly with landslide and talus breccia deposits derived by gravitational slumping from caldera walls during subsidence

Phoenix Park breccia member*--Breccia masses dominantly of Fish Canyon Tuff, in matrix of finely comminuted Fish Canyon Tuff. Derived from La Garita Mountains along northeast caldera wall. Previously mapped as late ash-flow sheets of Fish Canyon type, that intertongued with Bachelor Mountain Member (Steven and Ratte, 1965)

Tcpl — Landslide-breccia unit--Several sheets of landslide breccia, interfingering with upper part of Bachelor Mountain Member of Carpenter Ridge Tuff (Tcb) in East Willow Creek; one sheet overlies Mammoth Mountain member (Tcm). Enclosing tuffs become less welded and locally vitrophyric against slide breccias. Thickness of individual sheets, 0-50 m

Tcpt — Talus-breccia unit--Monolithologic breccia consisting of fragments of Fish Canyon Tuff. Basal depositional contact, against northeast caldera wall, is obscure transition between transported talus blocks and undisturbed in-place welded Fish Canyon Tuff. Previously mapped as part of intracaldera Fish Canyon Tuff (La Garita Member) by Steven and Ratte °1973). Local vague bedding and alined blocks define angle-of-repose depositional slopes. In places, net-veined by nonwelded rhyolitic ash of Carpenter Ridge Tuff. Thickness, 0-300 m

Tcpa — Andesite-block unit--Local mappable blocks and masses of aphyric to sparsely porphyritic andesite. Probably derived from precaldera volcanoes on northwest caldera wall

Tcs — Shallow Creek breccia member*--Landslide breccia lenses, dominantly of porphyritic dacite. Derived from precaldera volcanoes exposed on west wall of caldera. Previously mapped as lava flows interfingering with the Bachelor Mountain Member (Steven and Ratte, 1965) Thickness within quadrangle, 0-50 m; farther southwest, as much as 500 m thick

Tcw Wagon Wheel Gap breccia member* (not exposed at surface in SLP quadrangle--Consists dominantly of blocks, commonly 1-100 m in diameter, of sparsely porphyritic precaldera andesite-dacite, derived mainly from southeastern caldera wall. Blocks of Fish Canyon and Masonic Park Tuff are locally conspicuous. Matrix of nonwelded rhyolitic Carpenter Ridge Tuff, that was originally glassy but now argillized and zeolitized, is locally conspicuous. Previously mapped as a primary volcanic accumulation of lava flows, tuffs, and breccias (Steven and Ratte, 1973).

Bachelor Mountain Member--Variably welded intracaldera rhyolitic Carpenter Ridge Tuff; widely characterized by alkali-exchange alteration involving potassium metasomatism (shown by stipple pattern. In extreme cases, K_2O is >12% and Na_2O <0.5%; unaltered alkali contents are about 5% and 4%, respectively. Least-altered rhyolitic tuff previously mapped as rhyolitic part of Mammoth Moutain Tuff (Steven and Ratte, 1973)

Tcbr Rheomorphic tuff unit* (Not present in surface exposures of SLP quad)--Flow-layered rheomorphic rhyolitic tuff, typically characterized by steep dips and locally brecciated rock due to rapid deformation. Caused by plastic flowage of intensely welded and remobilized Willow Creek zone (Tcbw) while still hot. Commonly localized along early faults associated with resurgent doming of Bachelor caldera. Locally gradational with fluidally welded rhyolite of the Willow Creek zone (Tcbw), but diapirs project into Campbell Mountain zone. Previously mapped as flow-layered intrusions (Steven and Ratte, 1973)

Tcbg Windy Gulch zone--Gray porous slightly to nonwelded tuff; consists of pumiceous and locally lithic-rich rhyolitic tuff. Mostly originally glass or vapor-phase crystallized; now variably zeolitized, argillized, and modified by potassium metasomatism. Thickness variable, 10-50 m, at top of Bachelor Mountain Member. Grades into welded rhyolite of the Campbell Mountain zone (Tcbc). Present adjacent to landslide-breccia deposits deep in unit, but mostly too thin to show on map. Also present above Mammoth Mountain member, east of E. Willow Creek, where compositional zonation becomes more phenocryst poor and silicic upward.

Tcbc Campbell Mountain zone--Welded phenocryst-poor rhyolitic tuff. Tan to gray brown where least altered (formerly included with rhyolitic Mammoth Mountain Tuff of Steven and Ratte, 1973), and red-brown to purplish-gray where affected by potassium metasomatism (Tcbck). Grades into fluidally welded rhyolite of the Willow Creek zone (Tcbw)

Tcbw Willow Creek zone--Light-gray zone of fluidally welded rhyolitic tuff, characterized by pumice-flattening ratios >10:1, and commonly 100:1. In places, lineate due to drawn-out pumices. Flow foliation locally swirly; grades into rheomorphic tuff unit (Tcbr). Base not exposed except at wedgeout against rhyolite of Miners Creek (Tmc)

PRECALDERA LAVAS

Tmc Rhyolite of Miners Creek--Local lava dome of sparsely porphyritic flow-layered rhyolite (74% SiO_2). About 5% phenocrysts of plagioclase, sanidine, and biotite. May constitute part of Bachelor caldera floor and represent eruption premonitory to petrologically similar Carpenter Ridge Tuff. More than 300 m thick; base not exposed

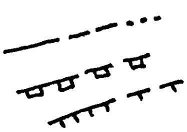
OLIGOCENE ROCKS OF THE LA GARITA CALDERA

Tfc FISH CANYON TUFF--Regional ash-flow sheet, dominantly of densely welded red-brown to dark-gray silicic dacitic ash-flow sheet (66-68% SiO_2) containing 40-50 percent phenocrysts (mainly plagioclase, sanidine, biotite, and hornblende). Sparse resorbed quartz, accessory sphene, and hornblende without augite are distinctive phenocrysts. $^{40/39}Ar$ age, 27.80 Ma. Remanent magnetic polarity: normal. Exposed as fill on resurgent dome within La Garita caldera (La Garita Member), as much as 1 km thick, with top eroded and no base exposed.

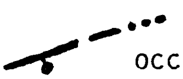
MAP SYMBOLS

Contact--Dashed where approximately located; dotted where gradational. Conspicuous contacts between lava flows or welding zones within map units shown locally

Unconformity along caldera wall--Dashed where approximately located; dotted where concealed

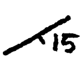


San Luis caldera
Creede caldera
Bachelor caldera



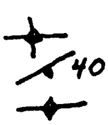
Fault--Dashed where approximately located; dotted where concealed or occupied by intrusive rocks. Bar and ball on downthrown side

Quaternary block slump--Hachures on downthrown side



Strike and dip of bedding
Inclined

Strike and dip of foliation



Horizontal
Inclined
Vertical

Direction and plunge of lineation

Inclined

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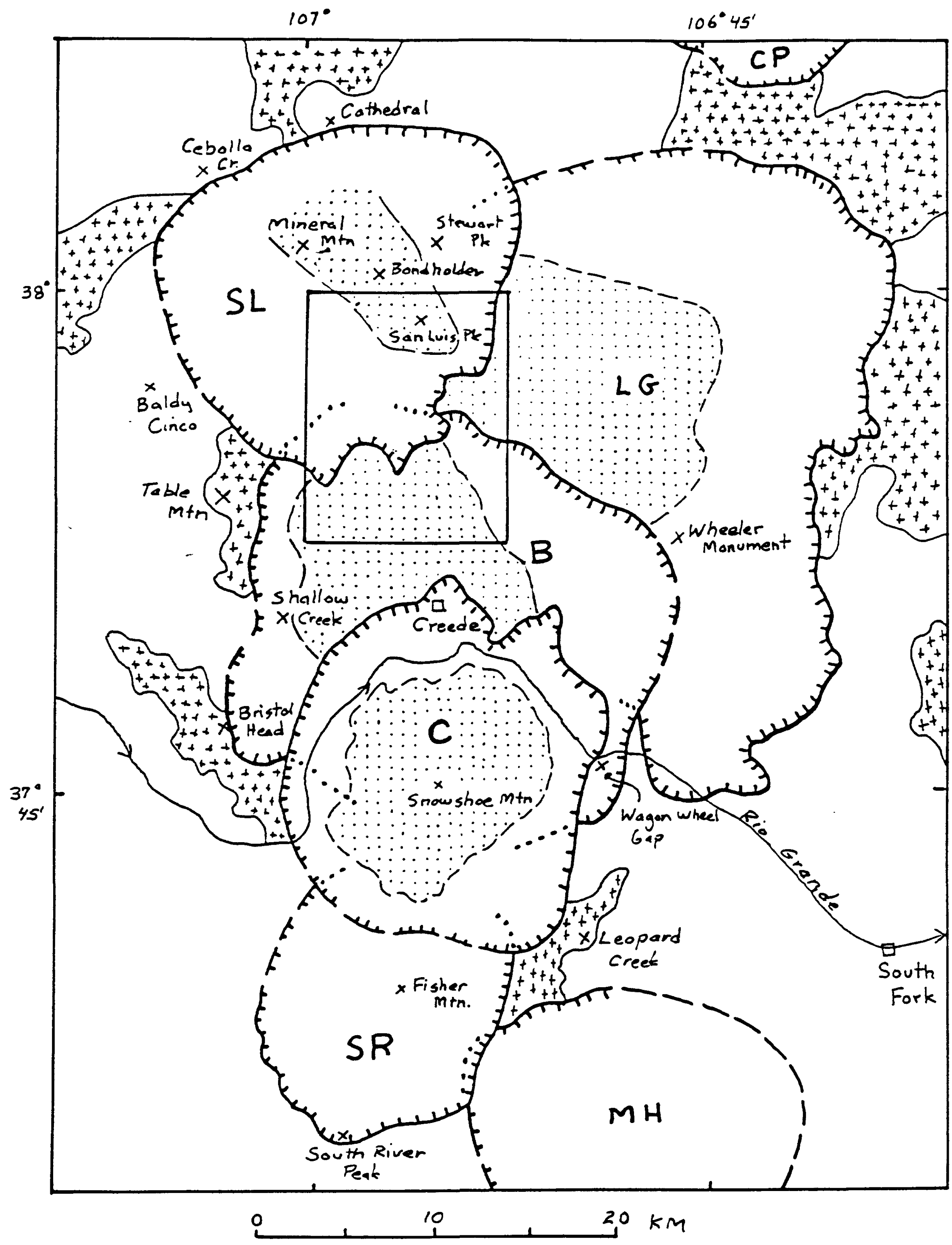

Figure 1. Index map of the central San Juan Mountains, showing location of the San Luis Peak quadrange and some geographic features noted in the text. Caldera margins are indicated by hachured lines; stipple pattern, intracaldera resurgent uplifts. Key to calderas: B, Bachelor; C, Creede; CP, Cochetopa Park; LG, La Garita; MH, Mount Hope; SL, San Luis; SR, South River. Cross pattern: early intermediate-composition volcanic rocks (precaldera). Unpatterned: caldera related ash-flow tuffs and lavas.

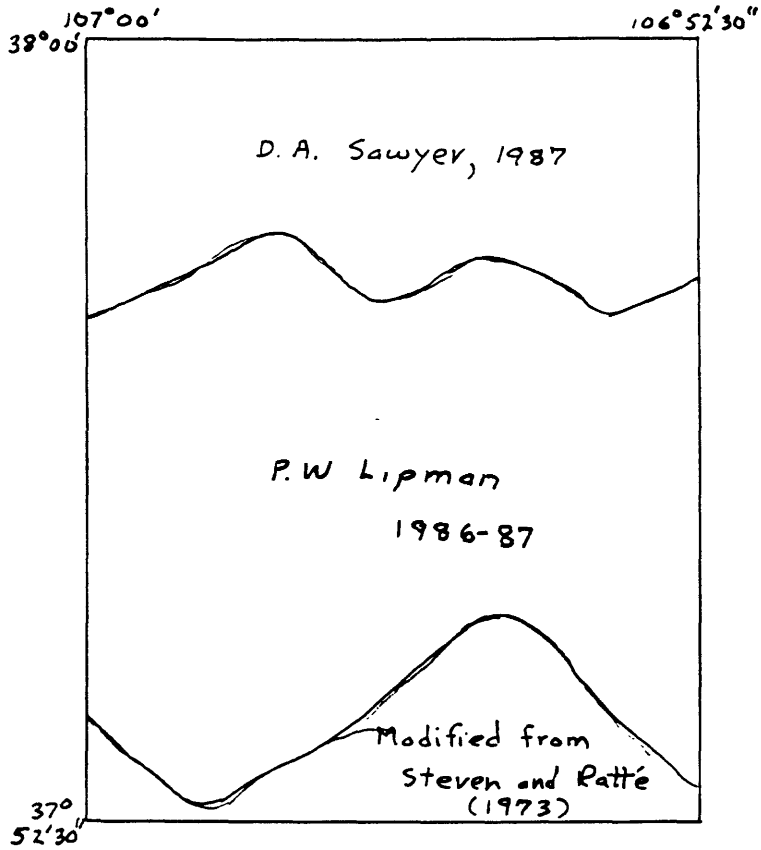

Figure 2. Areas of mapping responsibility, San Luis Peak quadrangle.

SL Peak

Figure 4. -- CORRELATION OF MAP UNITS

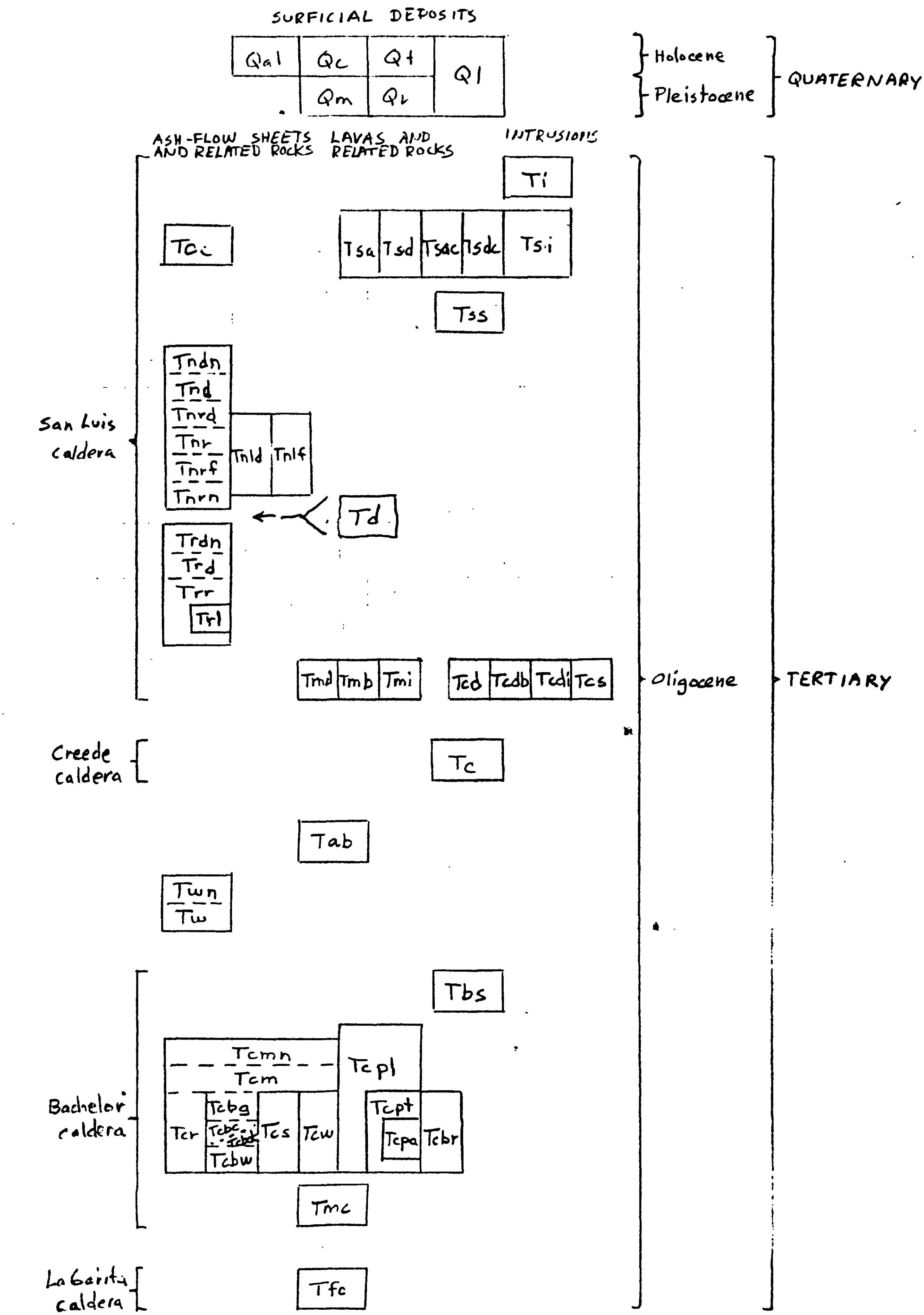

TABLE 1. Ash-flow sheets, calderas, and radiometric ages in the central San Juan Mountains (Ages generalized to 0.05 Ma from Lanphere, 1988)

Ash-flow sheet	Associated caldera	Age (Ma)
Nelson Mountain	San Luis	26.15
Rat Creek Tuff	San Luis (?)	26.45
Snowshoe Mountain Tuff	Creede	26.80
Wason Park Tuff	South River (?)	27.15
Carpenter Ridge Tuff (includes Bachelor and Mammoth Mountain members)	Bachelor	27.60
Fish Canyon Tuff	La Garita	27.80
Masonic Park Tuff	Mount Hope	28.25

TABLE 2. Preliminary revised stratigraphic nomenclature for volcanic rocks near Creede, Colorado, as used for San Luis Peak quadrangle and adjacent areas, in comparison with that in earlier maps and reports

Creede GQ-1053 (Steven and Ratte, 1973)	Bristol, Head GQ-631 (Steven, 1967)	Spar City GQ-1053 (Steven and Lipman, 1973)	Durango map I-764 (Steven and others, 1974)	This report, OF 88-359 (Lipman and Sawyer, 1988)
MIOCENE ROCKS				
—	Hinsdale Formation	Hinsdale Formation	Hinsdale Formation	Hinsdale Formation
OLIGOCENE ROCKS OF THE SAN LUIS CALDERA				
Fisher Quartz Latite	Fisher Quartz Latite	—	Quartz Latite of Baldy Cinco	Volcanics of Stewart Peak*
—	—	—	Volcanics of Stewart Peak	Volcanics of Stewart Peak*
—	—	—	—	Rhyolite of Mineral Mountain+
—	—	—	Rat Creek Tuff (part)	Tuff of Cathedral Creek+*
—	—	—	(Not mapped separately)	Intracaldera sedimentary rocks*
Nelson Mountain Tuff	Nelson Mtn/Rat Cr Qtz Latite	—	Nelson Mountain Tuff	Nelson Mountain Tuff*
—	—	—	Rat Creek Tuff (part)	Tuff of Cebolla Creek+
Rat Creek Tuff	Nelson Mtn/Rat Cr Qtz Latite	—	Rat Creek Tuff	Rat Creek Tuff*
Fisher Quartz Latite	Fisher Quartz Latite	—	Fisher Quartz Latite	Dacite of McKenzie Mountain+*
Quartz latitic lavas	—	—	Quartz latitic lava	Silic dacite of Captive Inca mine+*
OLIGOCENE ROCKS OF THE CREEDE CALDERA				
Creede Formation	Creede Formation	Creede Formation	Creede Formation	Creede Formation*
Fisher Quartz Latite	Fisher Quartz Latite	Fisher Quartz Latite	Fisher Quartz Latite	Fisher Quartz Latite
Volcanics of Point of Rocks	—	—	Incl. w/Fisher Qtz Latite	Rhyolite of Point of Rocks
Snowshoe Mountain Tuff	—	Snowshoe Mountain Tuff	Snowshoe Mountain Tuff	Snowshoe Mountain Tuff
OLIGOCENE ROCKS UNRELATED TO IDENTIFIED CALDERAS				
Andesite of Bristol Head	Huerto Formation	Volcanics of Table Mountain	A, Bristol Hd / V, Table Mtn	Andesite of Bristol Head*
Wason Park Tuff	Wason Park Tuff	Wason Park Tuff	Wason Park Tuff	Wason Park Tuff*
Quartz latitic lavas	—	Local quartz latitic flows	Local quartz latitic flows	Local dacite flows
OLIGOCENE ROCKS OF THE BACHELOR CALDERA				
(not recognized)	—	—	(Not recognized)	Intracaldera sedimentary rocks+*
Carpenter Ridge Tuff	Tuff of Carpenter Ridge	Carpenter Ridge Tuff	Carpenter Ridge Tuff	Carpenter Ridge Tuff
Mammoth Mountain Tuff	Rhyolite of Sevenmile Creek	Mammoth Mountain Tuff	Mammoth Mountain Tuff	Mammoth Mountain member(dacite)+*
—	—	—	—	Outflow rhyolitic member
				Intracaldera assemblage
Phoenix Pk M, LaGarita Tuff	—	—	Phoenix Park M, LaGarita QL	Phoenix Park breccia member+*
Shallow Creek Quartz Latite	Shallow Creek Quartz Latite	—	Shallow Creek Quartz Latite	Shallow Creek breccia member+*
—	—	Volcanics of Wagon Wheel Gap	Volcanics of Wagon Wheel Gap	Wagon Wheel Gap breccia member+
Bachelor Mountain Tuff	Bachelor Mountain Rhyolite	—	Bachelor Mountain Tuff	Bachelor Mountain Member*
Rhyolitic intrusions	—	—	(not mapped separately)	Rheomorphic tuff unit+
Windy Gulch Member	—	—	(not mapped separately)	Windy Gulch zone+*
Campbell Mountain Member	—	—	(not mapped separately)	Campbell Mountain zone+*
Willow Creek Member	—	—	(not mapped separately)	Willow Creek zone+*
			Precaldera lavas	
Rhyolite of Miners Creek	Rhyolite of Miners Creek	—	Rhyolite of Miners Creek	Rhyolite of Miners Creek*
—	Huerto Formation	Huerto Formation	Huerto Formation	Huerto Formation
OLIGOCENE ROCKS OF THE LA GARITA CALDERA				
—	—	—	(not mapped separately)	Intracaldera sedimentary rocks
Outlet Tunnel M, LaGarita T	Fish Canyon Tuff	Fish Canyon Tuff	Fish Canyon / LaGarita Tuffs	Fish Canyon Tuff*
				La Garita Member (intracaldera)
OLIGOCENE VOLCANIC ROCKS PREDATING THE CENTRAL CALDERA CLUSTER				
Masonic Park Tuff (Lower M)	Welded tuff, unknown affin	T of Masonic Pk(upper/low M)	Masonic Park Tuff	Masonic Park Tuff
—	Huerto Formation	Conejos Fm / Volc,Leopard Cr	Early intermed lavas/breccias	Conejos Formation
—	(not mapped separately)	(not mapped separately)	Near-source facies	Lava flows
—	(not mapped separately)	(not mapped separately)	Volcaniclastic facies	Volcaniclastic rocks
—	—	—	Intrusions	Intrusions

--, Not present *, Unit in San Luis Peak Quadrangle +, New or redefined name: not yet formalized in geologic literature