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U.S. GEOLOGICAL SURVEY

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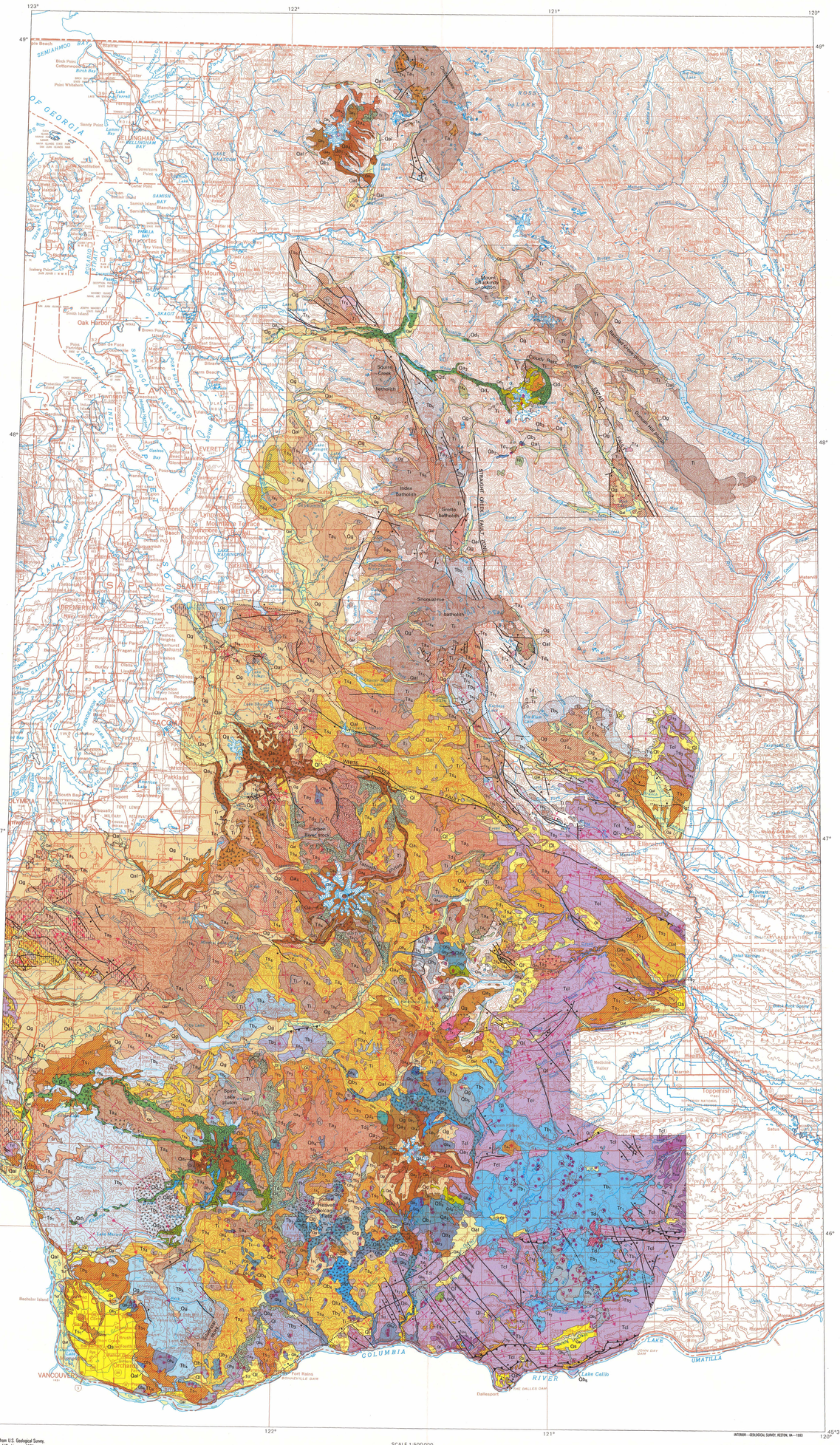
MAP I-2005 (SHEET 1 OF 2)
Explanatory pamphlet accompanies map



Base from U.S. Geological Survey, State of Washington, 1981
Lambert Conformal Conic projection based on standard parallels 33° and 45°, numbered lines indicate the 50,000-meter Universal Transverse Mercator grid, zones 10 and 11

SCALE 1:500 000
10 0 10 20 30 MILES
10 0 10 20 30 KILOMETERS
CONTOUR INTERVAL 500 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1993

Geology compiled in 1983–88
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GEOLOGIC MAP OF UPPER EOCENE TO HOLOCENE VOLCANIC AND RELATED ROCKS IN THE CASCADE RANGE, WASHINGTON

By
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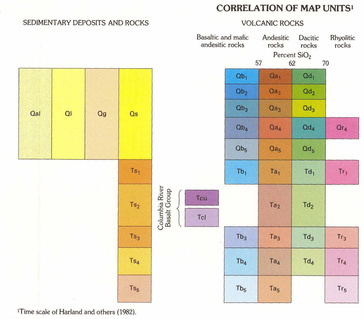
1993

CORRELATION OF MAP UNITS[1]



[1]Time scale of Harland and others (1982).

MAP UNITS

The Cascade Range suite of volcanic, volcaniclastic, and nonvolcanic sedimentary rocks is stratigraphically complex compared to miogeosynclinal or continental-shelf sedimentary rocks. The complexity results from the intricate way in which volcanic and volcaniclastic rocks were formed, deposited, and reworked in a subaerial arc environment. Hundreds of small overlapping and intertonguing volcanogenic and sedimentary units compose the range; thus, individual lithostratigraphic units are discontinuous and commonly intricately interbedded. In addition, the rocks are poorly exposed in many places, and distinctive widespread marker units are uncommon. Lithologic correlations, even of similar stratigraphic sequences, are unreliable without corroborating radiometric ages or detailed mapping.

Most previous authors responded to the range's stratigraphic complexity by either (1) trying to distinguish and name each different lithologic unit in an area or (2) grouping many heterogeneous lithologic units into a few broadly defined formations. These formations were thought to characterize an area, to define a volcanic episode, or to have volcanogenic significance. The first approach led to a proliferation of local formation names without regional significance. The second approach led to the application of a few imprecisely defined formation names across a wide area.

To avoid the problems of nomenclature, conventional stratigraphic units were not used for this map. Rather, I interpreted previous studies and my own field observations using a conceptual model of volcanic and sedimentary processes. The model is based chiefly on the models of Smedes and Prostka (1972) and Vessell and Davies (1981); the main criteria for subdivision are composition, age, and volcanic facies. The result is a more interpretative map than other maps of the Cascade Range, such as those of Luedke and Smith (1982) or Hammond (1980).

A hypothetical cross section that illustrates the model of volcanic and sedimentary processes and relations between deposits in the Cascade Ranges is shown (fig. 3). In this model, volcaniclastic sediments derived from a major volcano lap onto an older eroded volcano and simultaneously interfinger with contemporaneous deposits that were derived from other major volcanoes (fig. 3A). The resulting suite of volcaniclastic rocks represents many different depositional environments and volcanic sources. Intermittently erupted, highly mobile ash flows, lava flows, and large-volume debris flows may travel long distances down valleys. Far downstream these flows become interbedded with fine-grained, thin-bedded volcaniclastic deposits that are characteristic of a low-energy depositional environment. Large andesitic to dacitic volcanoes construct aprons of pyroclastic and epiclastic debris derived from dome growth and eruptions higher on their flanks. Basaltic-shield volcanoes overlap and interfinger with one another and with volcaniclastic sediments.

The facies relations interpreted from the volcanic and sedimentary deposits (fig. 3A), using the facies terminology of Smedes and Prostka (1972) and Vessell and Davies (1981), are shown (fig. 3B). The drawing emphasizes the interfingering between rock types that make up the different facies. The lithologic units are then combined into volcanic or sedimentary map units that have patterns showing genetic and facies information (fig. 3C).

The compositions of volcanic rocks shown on the map are based on weight percent of SiO_2. Where SiO_2 content is unknown, I interpreted it from published rock descriptions or my own field studies. Publications that include chemical analyses are noted in the "Source References" (sheet 2). The volcanic rocks are divided into the following groups: (1) rhyolite, more than 70 percent SiO_2; (2) dacite, 62 to 70 percent SiO_2; (3) andesite, 57 to 62 percent SiO_2; and (4) basalt and mafic andesite (basaltic andesite or olivine andesite of many workers), less than 57 percent SiO_2.

Ideally, it would be better to subdivide the last category into two separate groups—basalt and mafic andesite. However, petrography and field appearance are generally not good predictors of SiO_2 content for Cascade rocks that contain less than 57 percent SiO_2. Field classification proved unreliable, and maps that have sufficient detail and supporting chemical analyses are largely lacking not only for Quaternary rocks, but for Tertiary rocks of the Western Cascade Range as well.

Age is another important criterion used to categorize Cascade volcanism. The choices of temporal subdivisions, while somewhat arbitrary, are based on a mixture of traditional chronostratigraphic units and the more or less instantaneous geologic events (such as magnetic reversals) that punctuate Earth's history.

Map-unit ages are based on more than 300 radiometric ages. Publications containing radiometric age data are noted in "Source References." It should be emphasized, however, that this map shows geology as interpreted from field studies; lithostratigraphic relations take precedent over radiometric determinations. For example, an andesitic sequence shown as 7 to 2 Ma (unit Ta_7) might include a few andesite flows whose age is somewhat outside this interval to avoid showing inconsistent lithologic relations with overlying and underlying lithologic units.

At present, there is not sufficient data to determine if significant changes in composition or the rate of volcanism took place throughout the Cascade Range between 45 and 17 Ma. Therefore, this timespan is arbitrarily divided into approximately 10-m.y. intervals.

The last 2 Ma is subdivided into shorter intervals because of the important inverse relation between age and geothermal potential (Smith and Shaw, 1975). However, many Pliocene and younger rocks have few radiometric age determinations. Geomorphic features such as depth of erosion, topographic inversion of intracanyon lava flows, and the relative youthfulness of adjacent volcanoes were used to assign undated younger rocks to particular age divisions. Relative geomorphic youth was used most effectively to date Quaternary volcanic rock because their landforms are still relatively well preserved and adjacent volcanoes of different ages may show sharp geomorphic contrasts.

The intervals chosen and reasons for selecting them are discussed below. The subscripts used for each interval correspond to the subscripts used in the "Description of Map Units."

Q_1, **0 to 12 ka:** This interval begins at the end of the last major glaciation in the Cascade Range and adjacent Puget Sound lowland in the latest Pleistocene and includes the entire Holocene (Waitt and Thorson, 1983; Porter and others, 1983). Most Cascade researchers relate young volcanic deposits to glacial stratigraphy; thus, the 12-ka limit for this map unit. Young volcanic deposits dated by the ^{14}C method are readily assigned to this unit.

Q_2, **12 to 25 ka:** This interval extends from the end of the last major glaciation in the Cascade Range backward to include the period of time for which reliable ^{14}C ages are still fairly easily determined. I distinguish this interval because it highlights a group of young volcanic rocks that are important in making geothermal evaluations. The base of this unit is close to the 24-ka boundary suggested by Imbrie and others (1984) as the boundary between oxygen-isotope stages 2 and 3, which is considered by many to separate the late Wisconsin from the middle.

Q_3, **25 to 120 ka:** This interval extends beyond the time for which reliable ^{14}C ages are readily determined to near the middle Pleistocene-late Pleistocene boundary. Ages are not easily determined by any radiometric method on Cascade rocks in this age range, and so some rocks may be incorrectly assigned to this period. Imbrie and others (1984) suggested 128 ka for the boundary between middle and late Pleistocene, whereas Richmond and Fullerton (1986) suggest 132 ka.

Q_4, **120 to 730 ka:** The boundary between the Matuyama Reversed-Polarity and Brunhes Normal-Polarity Chrons marks the base of this period. Some recently published geologic maps include magnetic polarity of stratigraphic units from direct measurements (for example, see Clayton, 1980).

Q_5, **730 ka to 2 Ma:** This interval begins at the base of the Pleistocene and ends at the Matuyama Reversed-Polarity Chron (Harland and others, 1982). Although 2 Ma does not mark any obvious structural or stratigraphic break in the evolution of the Cascade Range, it does mark the maximum age for likely geothermal targets as defined by Smith and Shaw (1975).

T_1, **2 to 7 Ma:** In Washington and northern California, 7 Ma marks the approximate onset of renewed volcanism in the Cascades after a period of relative volcanic quiescence. In Oregon, most rocks exposed along the crest of the Cascade Range are younger than about 7 Ma. Along the boundary between the High Cascades and the Western Cascades physiographic subprovinces in Oregon, 7 Ma approximately corresponds to radiometric ages obtained from the base of a widespread sequence of basalt and basaltic andesite lava flows—the "ridge-capping basalt" of Sherrod (1986), "basalt of the early High Cascades eruptive episode" of Priest and others (1983), or the base of the "volcanic rocks of the High Cascade Range" of Smith and others (1982). East of the crest, volcaniclastic sediments derived from the Cascade Range in Oregon began accumulating about 7 Ma in the upper part of the Deschutes basin and now comprise the Deschutes Formation of Smith (1986b). In all three states, recognizable constructional volcanic landforms predominate in rocks of this age.

T_2, **7 to 17 Ma:** Much of this interval seems to be one of low volcanic flux at both the north and south ends of the Cascade arc but not in the middle. In southern Washington and northern Oregon, stratigraphic relations between the Columbia River Basalt Group and Cascade rocks suggest that the Cascade arc was relatively inactive from approximately 17 to 13 Ma. The Columbia River Basalt Group erupted between 17 and 6 Ma on the basis of K-Ar ages (Swanson and others, 1979; McKee and others, 1981), but more than 80 percent of the group erupted between 16.5 and 14 Ma (Hooper, 1980). Cascade-related volcanogenic interbeds are present locally between flows of the Columbia River Basalt Group that lapped up against and extended across the Cascade Range. In Washington, the interbeds are generally thin and are composed of air-fall ash. Locally, thicker accumulations of sediment and reworked ash are found in paleovalleys. Cascade lava flows or thick volcanic debris-flow deposits derived from Cascade sources have not been mapped as interbeds between flows of the Grand Ronde Basalt and the older Wanapum Basalt. The small aggregate thickness of Cascade-related strata between successive flows of the older part of the Columbia River Basalt Group suggests that while the Grande Ronde and older Wanapum vents were active, there were only a few active Cascade vents in southern Washington and northern Oregon.

Absence of volcanic rocks in Washington that are between 13.5 and 7 Ma is evidence for continuing volcanic quiescence in Washington during this interval. However, in northern Oregon, thick sequences of volcaniclastic rock began forming in late Wanapum time (Sherrod and Smith, 1989a).

At the other end of the Cascade arc in southwestern Oregon, the youngest rocks of the "volcanic rocks of the Western Cascade Range" of Smith and others (1982) are approximately 17 Ma. No rocks were mapped that are 17 to 7 Ma, suggesting that here, too, this interval was a time of relative volcanic quiescence. In northern California, the thickness and age data of Vance (1984) and Hammond (1983) indicate that the volume of volcanogenic rocks deposited per million years was an order of magnitude less during this interval than from the beginning of Cascade volcanism to 17 Ma and from 7 to approximately 4 Ma. However, the volcanic inactivity charcteristic of this interval is not typical for the entire range. In west-central Oregon, 17 Ma marks the onset of extensive andesitic to basaltic volcanism that formed the Sardine Formation (Peck and others, 1964).

T_3, **17 to 25 Ma:** Several ash-flow sequences in the Western Cascade subprovince of Oregon and northern California have K-Ar ages between 25 and 23 Ma (Smith and others, 1982; Hammond, 1983; Vance, 1984; and N.S. MacLeod, written commun., 1987); thus, 25 Ma is a somewhat arbitrary but convenient division. The lower boundary of this interval is also conveniently close to the Oligocene-Miocene boundary (about 24 Ma) to be useful in classifying rocks mapped simply as Oligocene or Miocene in age without corroborating radiometric ages.

T_4, **25 to 35 Ma:** The base of this interval generally corresponds to the time when volcanism was widely established in the Cascade Range from central Oregon northward.

T_5, **35 to 45 Ma:** The base of this interval is the approximate age of the base of several isolated calc-alkaline but presumably arc-related volcanic sequences in Washington and Oregon. Examples are the Tukwila Formation and Goble Volcanics in Washington and the Fisher Formation of west-central Oregon.

DESCRIPTION OF MAP UNITS

SEDIMENTARY DEPOSITS AND ROCKS

Qal — **Alluvium (Holocene and Pleistocene)**—Poorly sorted to moderately sorted sand, gravel, and silt deposited in valleys of active major streams. Many small areas omitted for clarity. Locally includes glacial and alluvial fan deposits

Qf — **Landslide deposits (Holocene and Pleistocene)**—Debris from mass-wasting processes, including slumps, earth flows, block glides, debris flows, and rockfalls. Landslides are most common where competent lava flows overlie weaker sediments or ash flows. Landslides that cover less than a few square kilometers are generally *not* shown

Qg — **Glacial deposits (Holocene and Pleistocene)**—Unconsolidated to moderately indurated, slightly to deeply weathered, bouldery to clayey till that forms moraines and drift sheets. Locally includes glacial outwash and related glaciofluvial and glaciolacustrine deposits. Many small areas omitted for clarity, especially moraines and till in mountain valleys and cirques. Locally, glacial deposits less than approximately 100 m thick are not shown to emphasize bedrock units, especially in the Puget Sound lowland

Qs — **Quaternary sediments and sedimentary rocks, undivided**—Mostly unconsolidated sand, gravel, and lacustrine deposits. Commonly includes deposits mapped by original authors (fig. 4, sheet 2) as older alluvium, terrace deposits, upland gravel, basin-filling sediments, or undifferentiated Quaternary sediments. Along the Columbia River, includes flood deposits that were deposited during the catastrophic emptying of glacial Lake Missoula at approximately 13 ka

Tertiary sedimentary rocks—Rocks ranging in age from 2 to approximately 45 Ma: Ts_1, 2 to 7 Ma; Ts_2, 7 to 17 Ma; Ts_3, 17 to 25 Ma; Ts_4, 25 to 35 Ma; Ts_5, 35 to 45 Ma

Patterns—In addition to primary age designation shown by color, patterns may be used to indicate different kinds of Tertiary sedimentary rocks:

No Pattern — **Dominantly volcaniclastic sandstone, siltstone, granule conglomerate, and mudstone closely related to volcanic processes in time and location**—Sedimentary units shown without pattern correspond to fine alluvial facies and distal part of coarse alluvial facies of Smedes and Prostka (1972) and to distal volcaniclastic facies and outer part of medial volcaniclastic facies of Vessell and Davies (1981). Sandstone, siltstone, granule conglomerate, and mudstone dominate. Most sequences include beds interpreted as debris-flow deposits, hyperconcentrated stream-flow deposits, and ash-flow tuff. Sedimentary sequences whose origin and mode of formation are not closely related to active volcanism are excluded, even where individual beds contain significant amounts of volcanic detritus. Beds are generally a few centimeters to 1 m thick. Unit grades laterally and vertically into other sedimentary or volcanic rock units as relative number of other rock types increases.

Sedimentary units shown without pattern formed predominantly by immediate reworking of penecontemporaneous primary volcanic deposits or, less commonly, directly from volcanic processes. Most beds formed as a result of immediate erosion and redeposition of primary volcanic or volcaniclastic deposits that were presumedly mostly unconsolidated and probably gravitationally unstable. Tops, distal parts, and aquagene parts of mass-flow deposits are particularly susceptible to reworking into better sorted and finer grained beds. Large volumes of volcaniclastic material may be quickly transported and redeposited to form these sequences.

Beds that have quite different mechanisms of sediment transport and deposition are interlayered in unit. A typical stratigraphic section would be dominated by volcanic graywacke, sandstone, and siltstone but would have interbeds of coarse volcanic diamicton and ashy tuff. Volcanic graywacke, sandstone, and siltstone beds are thin to medium bedded and fine grained. They typically show sedimentary features indicating transport by normal stream flow and deposition by traction-dominated grain-by-grain mechanisms. A few beds have characteristics of deposits transported and deposited by hyperconcentrated stream flows. Diamictons are dominantly matrix supported and have planar bed forms. Beds are 0.5 to 3 m thick. Angular volcanic clasts are dominant constituent of coarse fraction. Beds of diamicton show features typical of transportation by debris flow or hyperconcentrated stream flow and deposition en masse (Janda and others, 1981; Smith, 1986a; Pierson and Costa, 1987), although a few volcanic diamictons are ash-flow tuffs. Ashy tuffs, in contrast, are generally thin, and average grain size is less than 0.5 mm. Because ashy tuffs are fine grained and mantle preexisting topography, they are interpreted as having been deposited from ash falls.

All components of unit were probably deposited at some distance from volcanic sources. Graywacke, sandstone, and siltstone are interpreted as channel and overbank deposits that accumulated on aggrading volcanic dispersal aprons that had relatively low gradients. Volcanic diamictons probably moved off flanks of active volcanoes as channelized mass flows that choked existing streams and then spread out over distal parts of aggrading volcanic aprons as thin sheets. Ash-flow tuffs also probably followed existing valleys off flanks of active volcanoes and spread out over distal parts of aggrading volcanic aprons.

Some rocks included in unit, such as air-fall tuff, formed directly from volcanic processes

Continental sedimentary rocks not directly related to volcanic processes—Dominantly sandstone, conglomerate, and mudstone that lack primary volcanic detritus. Sediments interpreted as being deposited far from active volcanoes or deposited during periods of volcanic quiescence. Also includes volcaniclastic sediments that were transported by normal fluvial and eolian processes and deposited by traction-dominated grain-by-grain mechanisms. Sedimentary sequences whose origin and mode of formation were a direct response to penecontemporaneous volcanic activity are not included. Commonly, sediments were deposited in alluvial fans, along river valleys, or in freshwater lakes. In original reports (fig. 4, sheet 2), deposits typically include older alluvium, terrace deposits, stream deposits, some glacial outwash deposits, alluvial fans, lacustrine sediments, windblown deposits, conglomerate, sandstone, siltstone, shale, and coal

Marine, brackish-water, and deltaic sedimentary rocks—Mostly sandstone, siltstone, shale, and mudstone. Includes minor coal and conglomerate. Sediments interpreted as being deposited in open ocean, in estuaries, in brackish-water swamps, or in deltas. In many places, rocks formed in these different environments are interbedded, as they are throughout much of the extensive Eocene and early Oligocene deltaic systems of western Washington (Snavely and others, 1958; Fisher, 1961; and Buckovic, 1979). In original reports (fig. 4, sheet 2), deposits include mostly sandstone, siltstone, mudstone, shale, coal, and conglomerate. Because of their fine-grain size and abundant weathered component of uncertain provenance, it is impossible to determine whether or not specific lithologic units were deposited in response to volcanic events

VOLCANIC ROCKS

Basaltic and mafic andesitic rocks

Columbia River Basalt Group (Miocene)—Comprises voluminous tholeiitic basalt flows of Miocene age. Most lava issued from dike swarms located 400 km east of the Cascade Range, flowed west across area of present-day Columbia Plateau, and lapped against older rocks of the Cascade Range. Some lava flooded through low gaps in the range in northern Oregon and southern Washington. Although not part of Cascade-arc volcanism, the Columbia River Basalt Group forms an important stratigraphic horizon. Informally divided into:

Tcu — **Upper part**—The Saddle Mountains Basalt as defined by Swanson and others (1979). The Saddle Mountains Basalt forms about 1 percent of total volume of the Columbia River Basalt Group and was erupted between 13.5±3 and 6 Ma. All members of the Saddle Mountains Basalt, except the Pomona Member, are restricted to Columbia Plateau east of map area. The 12-Ma Pomona Member followed approximate course of modern Columbia River through the Cascade Range (Anderson, 1980; Tolan and Beeson, 1984). Potassium-argon ages (Swanson and others, 1979) indicate that the Pomona Member erupted between about 12 and 10.5 Ma. (Preferred age of the Pomona Member is 12 Ma according to D.A. Swanson, oral commun., 1987). A few outcrops of the Pomona in Columbia River gorge (Anderson, 1980) are too small to show at map scale

Tcl — **Lower part**—The Wanapum and Grande Ronde Basalts as defined by Swanson and others (1979). The older Grande Ronde Basalt is the most widespread unit of the Columbia River Basalt Group in the Cascade Range. In the overlying Wanapum Basalt, only the Frenchman Springs Member is widely distributed in the Cascade Range. The Priest Rapids Member of the Wanapum defines a narrow intracanyon path along axis of Bull Run syncline in northern Oregon (Vogt, 1981); other members never crossed the range. Potassium-argon ages (Swanson and others, 1979; McKee and others, 1981), as well as structural data (Reidel, 1984), suggest that the Wanapum and Grande Ronde Basalts were erupted between 17 and 13.5 Ma

Qb_1, Qb_2, Qb_3, Qb_4, Qb_5, Qb_6 — **Quaternary basaltic and mafic andesitic rocks**—Dominantly lava flows but includes some near-vent breccia and pyroclastic rocks. Rocks range in age from 0 to 2 Ma: Qb_1, 0 to 12 ka; Qb_2, 12 to 25 ka; Qb_3, 25 to 120 ka; Qb_4, 120 to 730 ka; Qb_5, 730 ka to 2 Ma

Tb_1, Tb_3, Tb_4, Tb_5 — **Tertiary basaltic and mafic andesitic rocks**—Dominantly lava flows but includes some near-vent breccia and pyroclastic rocks. Rocks range in age from 2 to approximately 45 Ma: Tb_1, 2 to 7 Ma; Tb_3, 17 to 25 Ma; Tb_4, 25 to 35 Ma; Tb_5, 35 to 45 Ma

Andesitic rocks

Qa_1, Qa_2, Qa_3, Qa_4, Qa_5 — **Quaternary andesitic rocks**—Dominantly flows and domes but includes some near-vent breccia and pyroclastic rocks. Rocks range in age from 0 to 2 Ma: Qa_1, 0 to 12 ka; Qa_2, 12 to 25 ka; Qa_3, 25 to 120 ka; Qa_4, 120 to 730 ka; Qa_5, 730 ka to 2 Ma

Ta_1, Ta_2, Ta_3, Ta_4, Ta_5 — **Tertiary andesitic rocks**—Dominantly flows but includes some near-vent breccia and pyroclastic rocks. Rocks range in age from 2 to approximately 45 Ma: Ta_1, 2 to 7 Ma; Ta_2, 7 to 17 Ma; Ta_3, 17 to 25 Ma; Ta_4, 25 to 35 Ma; Ta_5, 35 to 45 Ma

Dacitic rocks

Qd_1, Qd_2, Qd_3, Qd_4, Qd_5 — **Quaternary dacitic rocks**—Dominantly flows and domes but includes some near-vent breccia and pyroclastic rocks. Rocks range in age from 0 to 730 ka: Qd_1, 0 to 12 ka; Qd_2, 12 to 25 ka; Qd_3, 25 to 120 ka; Qd_4, 120 to 730 ka; Qd_5, 730 ka to 2 Ma

Td_1, Td_2, Td_3, Td_4 — **Tertiary dacitic rocks**—Dominantly flows and domes but includes some near-vent breccia and pyroclastic rocks. Rocks range in age from 2 to approximately 45 Ma: Td_1, 2 to 7 Ma; Td_2, 7 to 17 Ma; Td_3, 17 to 25 Ma; Td_4, 25 to 35 Ma

Rhyolitic rocks

Qr_4 — **Quaternary rhyolitic rocks**—Dominantly flows and domes but includes some near-vent breccia and pyroclastic rocks. Rocks range in age from 120 to 730 ka

Tr_1, Tr_3, Tr_4, Tr_5 — **Tertiary rhyolitic rocks**—Dominantly flows and domes but includes some near-vent breccia and pyroclastic rocks. Rocks range in age from 2 to approximately 45 Ma: Tr_1, 2 to 7 Ma; Tr_3, 17 to 25 Ma; Tr_4, 25 to 35 Ma; Tr_5, 35 to 45 Ma

Patterns—In addition to primary age and composition of volcanic rocks shown by color, patterns may be used to indicate volcanic facies or special chemical characteristics:

No Pattern — **Volcanic rocks deposited mostly near vents**—Units shown without pattern are products of concurrent volcanism and deposition, and they generally correspond to vent facies of Smedes and Prostka (1972) or to core facies and proximal volcaniclastic facies of Vessell and Davies (1981). Unit also includes lava that flowed down valleys or spread over lowlands far removed from vents. Typical constructional volcanic features include stratovolcanoes, shield volcanoes, domes, and smaller monogenetic volcanoes. Larger volcanic edifices commonly intertongue in complex ways with each other and with rocks of other map units (fig. 3); most intertonguing relations are too detailed to show at map scale. Vent areas, particularly those of stratovolcanoes and shield volcanoes, contain undifferentiated lava flows, flow breccia, and near-vent pyroclastic deposits. Generally, these individual vent-facies units cannot be shown separately, particularly in older rocks where original constructional forms are poorly preserved. Constructional volcanic edifices more than a few million years old are generally poorly preserved and difficult to recognize

Volcanic diamicton—Unsorted to poorly sorted, poorly layered to well-layered deposits of direct volcanic origin that contain wide range of clast sizes. Corresponds to more distal part of vent facies of Smedes and Prostka (1972) and medial volcaniclastic facies of Vessell and Davies (1981). Deposited from cold- or warm-fluid flows that moved rapidly downslope propelled by gravity. Generally described by original authors (fig. 4, sheet 2) as catastrophic. Includes mudflow deposits, some mass-flow deposits not further described by original authors (fig. 4, sheet 2), debris flows, landslides triggered by volcanic action, some deposits designated only as tuff breccia, and deposits mapped as volcanic diamicton but not more specifically identified. Also includes young mudflow deposits and debris-flow deposits downstream from major stratovolcanoes. Lava flows are rare

Pyroclastic-flow deposits—Most deposits are poorly sorted, are rich in lithic clasts, and are nonwelded to partly welded. Pumice is common in ash-flow tuff but not in block-and-ash-flow deposits. Plagioclase is most common phenocryst; variable amounts of clinopyroxene, orthopyroxene, and amphibole are also present. Plagioclase may constitute as much as 20 percent of deposits; clinopyroxene, orthopyroxene, and amphibole rarely total more than 5 percent. Biotite, quartz, or sanidine present in only a few tuffs. Deposited from hot dry flows of particulate volcanic rock, intermixed air, and volcanic gas that move rapidly downslope propelled by gravity. Broad volcaniclastic aprons around major silicic stratovolcanoes (for example, Glacier Peak and Mount St. Helens) are composed of interbedded pyroclastic-flow deposits, avalanche deposits, volcanic debris-flow deposits, ash-flow deposits and glacial deposits. Pyroclastic-flow deposits generally make up a greater proportion of sections near the volcanoes' summits, but classification of these mixed sequences at this map scale is arbitrary. Volcaniclastic aprons generally grade downstream into sequences in which volcanic diamictons are dominant

In many rocks older than 10 Ma, pyroclastic-flow deposits, which were emplaced hot, are difficult to distinguish from mass-flowage deposits, which were emplaced cold. In many places, lithostatic loading compacted both kinds of deposits and flattened pumice clasts. Widespread very low grade metamorphic recrystallization of unstable glass, devitrified glass, and vapor phase alteration minerals created fine-grained aggregates of metamorphic minerals dominated by zeolites and smectitic phyllosilicates.

Determining original chemical composition is also difficult. Most pyroclastic-flow deposits contain extraneous lithic clasts, as much as 20 percent in some ash-flow tuffs. Extensive low-grade metamorphic recrystallization may also have changed chemical composition of some deposits. Present-day temperate-humid climate favors thorough chemical weathering of these very low grade metamorphic rocks, which further alters their original chemistry. Most deposits are presumed to be andesite or dacite, although some are rhyolite

Subaerial and subaqueous deposits of basaltic and andesitic ejecta—Dominantly cinder cones and palagonite-tuff rings. Includes intraglacial deposits of palagonite, palagonitized tuff, and pillow basalt (for example, moberg and tuyas)

Low-K_2O basalt—Basalt fields and extensive flows characterized by low silica and potassium content. SiO_2 content generally less than 49 percent and always less than 51 weight percent, K_2O content generally less than 0.39 percent and always less than 0.5 weight percent, and TiO_2 content generally less than 1.35 weight percent (Hart, 1982; Hart and others, 1984). Examples are young basaltic volcanoes north of Mount Adams and in the Indian Heaven volcanic field and Oligocene basalt along shore of Spirit Lake. Texture and mineralogy of low-K_2O basalt and basalt that contains more than 0.5 percent K_2O are similar, so low-K_2O basalt can be distinguished only in areas where there are abundant chemical analyses

INTRUSIVE ROCKS

Qi — **Intrusive rocks (Quaternary)**—Includes rocks that have wide variety of textures and compositions. Small subvolcanic fine-grained intrusions of intermediate compositions are most common. Most dikes omitted for clarity

Ti — **Intrusive rocks (Tertiary)**—Intrusive rocks that have wide variety of textures and compositions. Granitic plutons of batholithic dimensions, medium- to coarse-grained textures, and dioritic to granitic compositions are most common in northern part of map. Small fine-grained to aphanitic intrusions of intermediate compositions, presumed to be subvolcanic magma chambers, are more common in southern part of map area. Most dikes omitted for clarity

Rocks not related to Cascade arc

Contact—Dotted where concealed

Contact between individual coalesced volcanoes or areas that have different patterns within same map unit

Faults—Dotted where concealed

Normal fault—Ball and bar on downthrown side

Thrust or high-angle reverse fault—Sawteeth on upper plate

Strike-slip fault—Arrows show relative horizontal movement

Folds—Dotted where concealed. Showing crestline and direction of plunge

Anticline

Syncline

Overturned syncline—Showing direction of dip of limbs

Monocline—Dotted where concealed

Abrupt decrease of dip in direction of arrows

Abrupt increase of dip in direction of arrows

Vents

Cinder cone, spatter cone, small intraglacial vent, or other small cone

Dome—In rocks older than a few million years, distinguishing individual domes is not possible in most places, and for these rocks, symbol generally indicates presence of a complex dome field and not individual domes

Shield volcano, lava cone, andesitic cone or large mafic volcano

Stratovolcano or large intermediate-composition volcano

Maar, palagonite-tuff ring, or tuff cone

Small volcano, undivided

Caldera—Showing approximate outline of known or inferred lithologic or structural margin that in most places corresponds to ring faults. Hachures point toward center of caldera

Exposed lithologic or structural margin

Buried lithologic or structural margin

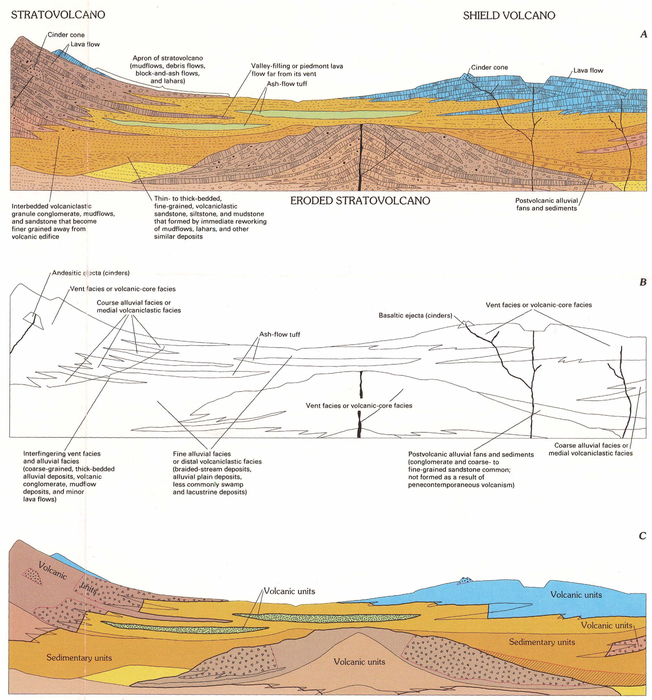


Figure 3. Hypothetical cross section through part of a continental arc illustrating conceptual model of volcanic and sedimentary processes and resulting deposits. *A*, typical volcanic and sedimentary features. *B*, facies relations (facies terminology is from Smeedes and Prostka, 1972, and Vessell and Davies, 1981). *C*, patterns used to show selected facies and rock types on map.

EXPLANATION

SEDIMENTARY UNITS
(Age indicated by general color on geologic map)

No Pattern — Volcaniclastic sandstone, siltstone, granule conglomerate and mudstone closely related to volcanic processes

Continental sedimentary rocks not directly related to volcanic processes

CONTACTS

Contacts as mapped in the field

Interpretative contacts between volcanic and sedimentary units

Interpretative contacts between different volcanic and sedimentary facies or genetic units within the same map unit

VOLCANIC UNITS
(Age indicated by general color on geologic map)

No Pattern — Volcanic rocks deposited mostly near vents—Includes large valley-filling lava flows

Volcanic diamicton—Unsorted deposits of warm or cold fluid flows of direct volcanic orgin. Mostly volcanic mudflow deposits and debris-flow deposits

Subaerial deposits of andesitic and basaltic ejecta—Mainly cinder cones

Pyroclastic-flow deposits

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