GIS Database and Discussion for the Distribution, Composition, and Age of Cenozoic Volcanic Rocks of the **Pacific Northwest Volcanic Aquifer System Study Area**

By David R. Sherrod and Mackenzie K. Keith

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations and Acronyms

ka thousand years

Ma million years

NVASA Pacific Northwest Volcanic Aquifer System study area

USGS U.S. Geological Survey

GIS Database and Discussion for the Distribution, Composition, and Age of Cenozoic Volcanic Rocks of the **Pacific Northwest Volcanic Aquifer System Study Area**

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Abstract

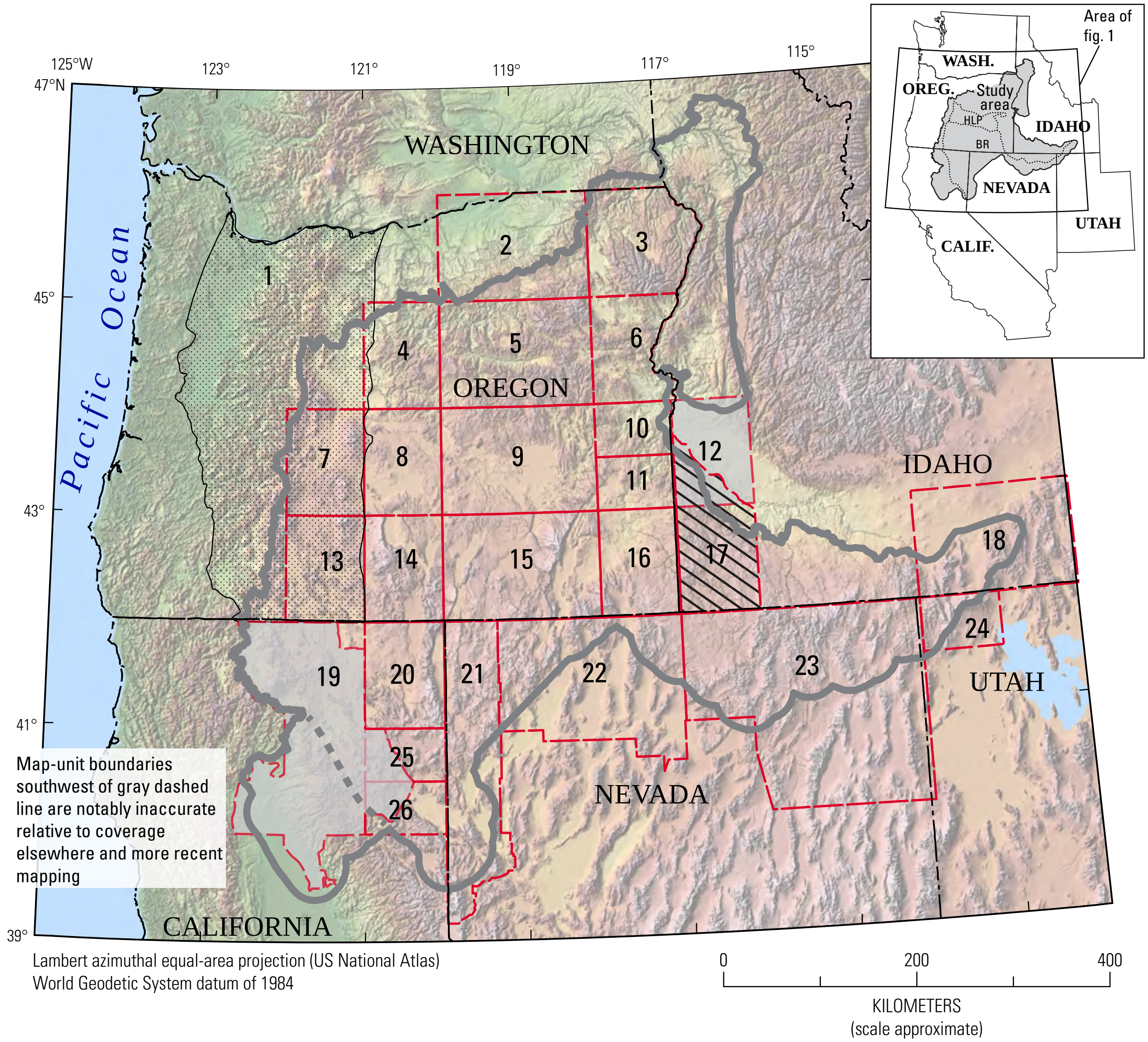
A substantial part of the U.S. Pacific Northwest is underlain by Cenozoic volcanic and continental sedimentary rocks and, where widespread, these strata form important aquifers. The legacy geologic mapping presented with this report contains new thematic categorization added to state digital compilations published by the U.S. Geological Survey for Oregon, California, Idaho, Nevada, Utah, and Washington (Ludington and others, 2005). Our additional coding is designed to allow rapid characterization, mainly for hydrogeologic purposes, of similar rocks and deposits within a boundary expanded slightly beyond that of the Pacific Northwest Volcanic Aquifer System study area. To be useful for hydrogeologic analysis and to be more statistically manageable, statewide compilations from Ludington and others (2005) were mosaicked into a regional map and then reinterpreted into four main categories on the basis of (1) age, (2) composition, (3) hydrogeologic grouping, and (4) lithologic pattern. The coding scheme emphasizes Cenozoic volcanic or volcanic-related rocks and deposits, and of primary interest are the codings for composition and age.

Introduction

A substantial part of the U.S. Pacific Northwest is underlain by Cenozoic volcanic and continental sedimentary rocks. Where widespread, these strata form important aquifers. For example, the Columbia River Basin is underlain largely by the mostly middle Miocene Columbia River Basalt Group. The hydrogeology of the Columbia River Basalt Group is well studied (for example, Vaccaro, 1999; Kahle and others, 2011; Ely and others, 2014; Vaccaro and others, 2015; Burns and others, 2015), inasmuch as the strata are relied on heavily for irrigation and potable domestic water. Elsewhere in the region, hydrogeologic assessments of volcanic strata and their relation to basin groundwater are less extensive or lacking.

Future assessments of Pacific Northwest aquifers will be aided by identifying useful rock-formation characteristics. Two key predictors of groundwater flow and discharge—lithology and age of volcanic rocks—have been identified by numeric-modeling studies along the east flank of the Cascade Range in Oregon (for example, Gannett and others, 2001; Lite and Gannett, 2002). From this observation comes the possibility that two-dimensional statistical analysis, using fundamental lithologic criteria, might allow preliminary basin assessments to proceed in the absence of more sophisticated modeling. These criteria can be extracted from geographic information systems-based (GIS-based) geologic maps (scales 1:250,000 or 1:500,000) coded suitably for composition and age, similar thematically to 1970s geologic maps that depicted age and composition of volcanic rocks at regional scale (Luedke and Smith, 1982, 1983; scale 1:1,000,000).

The legacy geologic mapping presented with this report contains new thematic categorization added to state digital compilations published by the U.S. Geological Survey for Oregon, California, Idaho, Nevada, Utah, and Washington (Ludington and others, 2005). The 2005-series maps were, in most cases, digitized from printed state-scale (1:500,000) maps. Ludington and colleagues also added tabular data that brought uniformity to the classification of geologic units and structural features. Our additional coding is designed to allow rapid characterization, mainly for hydrogeologic purposes, of similar rocks and deposits within a boundary (fig. 1) encompassing the Pacific Northwest Volcanic Aquifer System study area (NVASA; https://or.water.usgs.gov/proj/geothermal/index.html).



Map No.	Map Name	Citation
1	Cascade Range, Oregon	Sherrod and Smith, 2000
2	Pendleton 1°×2° quadrangle	Walker, 1973
3	Grangeville 1°×2° quadrangle	Walker, 1979
4	East half of Bend 1°×2° quadrangle	Swanson, 1969
5	Canyon City 1°×2° quadrangle	Brown and Thayer, 1966
6	Oregon part of Baker 1°×2° quadrangle	Brooks and others, 1976
7	West half Crescent 1°×2° quadrangle	MacLeod and Sherrod, 1992
8	East half Crescent 1°×2° quadrangle	Walker and others, 1967
9	Burns 1°×2° quadrangle	Greene and others, 1972
10	Vale 30'×60' quadrangle	Ferns and others, 1993a
11	Mahogany Mountain 30'×60' quadrangle	Ferns and others, 1993b
12	Boise 1°×2° quadrangle	Mitchell and Bennett, 1979
13	West half Klamath Falls 1°×2° quadrangle	Sherrod and Pickthorn, 1992
14	East half Klamath Falls 1°×2° quadrangle	Walker, 1963
15	Adel 1°×2° quadrangle	Walker and Repenning, 1965
16	West half Jordan Valley 1°×2° quadrangle	Walker and Repenning, 1966
17	Western part, Owyhee County	Ekren and others, 1981
18	Pocatello 1°×2° quadrangle	Rember and Bennett, 1979
19	Cascade Range, California	J.G. Smith, unpub. USGS map
20	Alturas 1°×2° quadrangle	Gay and Aune, 1958
21	Northern part of Washoe County, Nevada	Bonham, 1969 (in Hess and Johnson, 1996)
22	Humboldt County, Nevada	Willden, 1964 (in Hess and Johnson, 1996)
23	Elko County, Nevada	Coats, 1987 (in Hess and Johnson, 1996)
24	Grouse Creek 30'×60' quadrangle	Miller and others, 2012
25	Eagle Lake 30'×60' quadrangle	Grose and others, 2014
26	Susanville 30'×60' quadrangle	Grose and others, 2013

Figure 1 caption on next page

Figure 1. Map showing Pacific Northwest Volcanic Aquifer System study area and extent of intermediate-scale supplemental geologic maps used to specify the age and composition of polygons. Short-dashed line (gray) within study area marks a boundary southwest of which existing state-map map-unit boundaries from Ludington and others (2005) are notably inaccurate relative to the other coverages and more recent mapping. Labels HLP and BR on inset map denote High Lava Plains and Basin and Range Provinces, as discussed in text.

This document describes the effort underlying the newly compiled map and associated tabular data. To be useful for hydrogeologic analysis and to be more statistically manageable, compilation maps from Ludington and others (2005) were assembled into a regional map and then categorized on the basis of (1) age, (2) composition, (3) hydrogeologic grouping, and (4) lithologic pattern. The coding scheme emphasizes Cenozoic volcanic or volcanic-related rocks and deposits, and of primary interest are the codings for composition and age. These codings were derived from the state maps as well as larger-scale 1:250,000- or 1:100,000-scale geologic maps (fig. 1). In a few cases, spatial and columnar data for the GIS-based polygons have been modified to enrich the geologic depiction or to correct labeling errors found in the source maps.

Map Compilation and Updates to Spatial Data

Map Area

The Pacific Northwest Volcanic Aquifer System study area (NVASA) includes several interior-draining basins in western Oregon, northeastern California, southwestern Idaho, northern Nevada, northwestern Utah, and southeastern Washington. The area is defined broadly by the province of volcanic rocks emplaced during the last 17 million years. The area is diverse temporally and compositionally, including some rocks as old as Precambrian, but the study area as originally defined was intended to focus on Tertiary and Quaternary volcanogenic rocks.

Our primary geologic map sources are digital compilations of statewide coverages for Oregon, California, Idaho, Nevada, Utah, and Washington (Ludington and others, 2005). These coverages were combined and trimmed to encompass the NVASA.

Incorporation of More Recent or Higher-Resolution Mapping

Maps that were digitized to make the 2005 data release (Ludington and others, 2005) are printed full-color compilations dating to the 1990s, and most are based on map sources no more recent than the late 1980s. Regardless, the addition of new linework typically was avoided, since our goal was to add age and compositional information to an existing set of small-scale maps, not create a wholly new rendition. A newer California state map, published in 2010 (scale 1:750,000; Jennings and others, 2010), concentrates its revisions mostly on faults and Quaternary sedimentary deposits useful for recognizing fault age. That map is little changed in the northeast corner of California (coincident with our study area), compared to the much older 1979 version that was digitized for 2005 publication. In Oregon, an ongoing compilation of geologic mapping is released periodically in digital format by Oregon’s Department of Geology and Mineral Industries. The most recent release (Smith and Roe, 2015) favors large-scale data without alignment of contacts or blending of map units across individual map-area boundaries. Consequently, that compilation possesses numerous internal edge effects. In contrast, basin-scale analysis requires compilations that bridge, rather than preserve, contrasts.

Nevertheless, some minor local changes in geologic mapping were made by us to increase detail. In Oregon, for example, the Jordan Craters lava flows were added (from map by Hart and Mertzman, 1983) so that all of the state’s Holocene volcanic rocks could be shown. And in rare cases, incomplete digitization of the paper maps underlying Ludington and others (2005) was found when trying to assign age or composition. For example, the line separating an alluvial-fan deposit and lava flow along Old Maids Canyon northeast of Madras (44.6800°, −120.9824°) on the printed Oregon state map was missed during digitization. For our purposes it was deemed better to subdivide the polygon correctly than to code the whole area as one or the other unit.

Elsewhere in areas lacking detailed geologic map data, additional published mapping could have supplemented the state maps, but the effort would have far exceeded available staff time. One example lies in the southwest corner of the map area where recent geothermal interest in the Lassen volcanic area has led to updated mapping (for example, Clynne and Muffler, 2010).

State Boundaries Minimized

Political boundaries may follow geographic features, but rarely are they aligned along geologic features. Since state-based compilations for Oregon, California, Idaho, Nevada, and Washington (Ludington and others, 2005) underlie the geologic compilation and coding for this study, state borders formed polygon boundaries when compiling the maps into a single file. This provincial artifact was removed where possible, dependent upon the amount of evidence available and interpretation required to match adjacent polygons across state borders. An example of how state borders were dissolved through interpretation of map units is found in the northwesternmost corner of Utah (fig. 2), where valley-floor alluvium along Goose Creek forms a polygon of some breadth that ends abruptly at the Nevada-Utah state line. Mapped alluvium resumes along a different alignment in Utah, tapering to a point (losing its breadth) just south of the Idaho state line. In Idaho it expands in width and resumes its trace north downstream (fig. 2). This misalignment was minimized by overlaying the geologic-unit layer on modern 100,000-scale topographic maps and using the valley's morphology to constrain positional changes in the geologic-unit polygons (fig. 2).

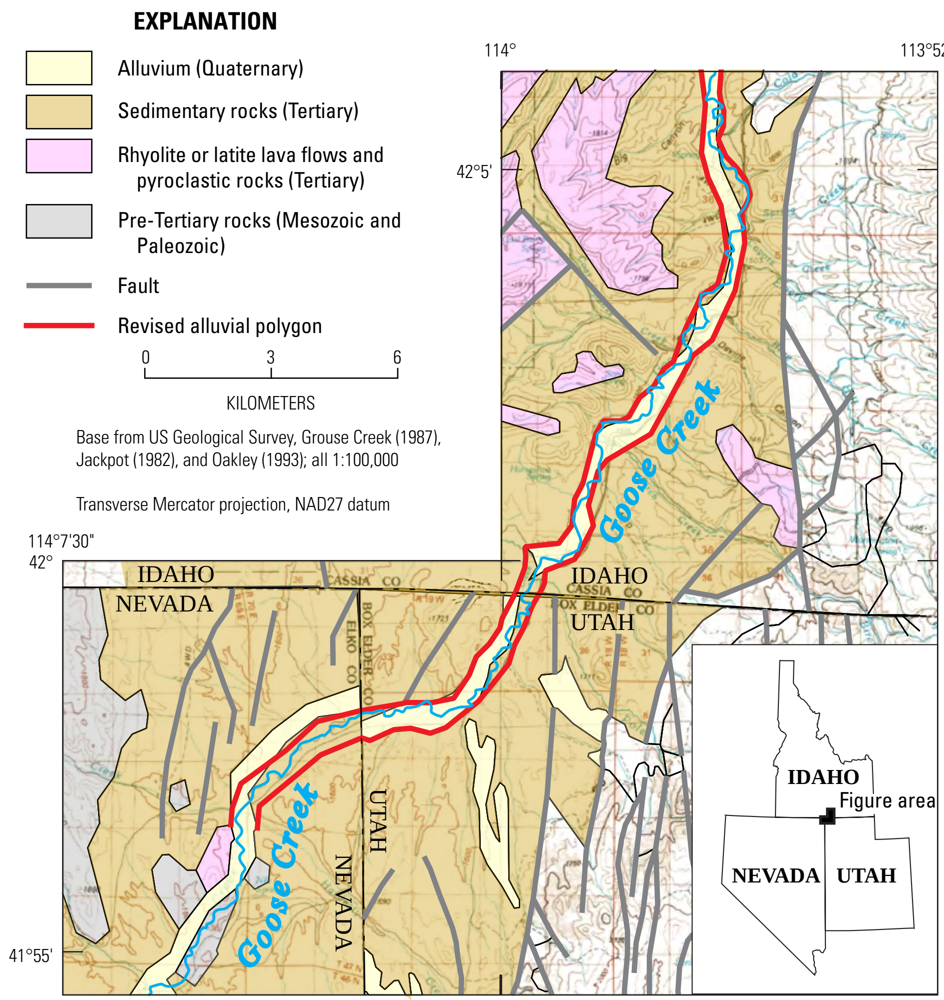


Figure 2. An example of an alluvial (Qal) map unit where Nevada, Utah, and Idaho boundaries meet. All map-unit boundaries from Ludington and others (2005). Goose Creek flows broadly north. Red lines show the revised alluvium boundaries, continuous across state lines, whose contacts rely on 100,000-scale topographic quadrangles and geomorphic interpretation to minimize internal edge effects.

More common are the edge effects arising where somewhat differently defined lithologic units are mapped to the state boundaries (fig. 3). Where the lithologic distinctions are minimal, we combined polygons to remove the artificial boundary between them. Even so, some short residual jogs persist along state boundaries. State boundaries are readily apparent, however, where left unmodified by us in those places where the defined lithologic-unit contrasts are too great to resolve without field work.

The Snake River defines part of the boundary between Idaho and Oregon and between Idaho and Washington. The Snake is sufficiently broad to form open water (polygon) at scales as small as 1:500,000. In those cases the U.S. Geological Survey's (2014) National Hydrography Dataset was used during the map assembly. This medium-resolution dataset contains 1:100,000-scale polygon (area) files that produced a visually attractive open-water map-unit polygon, the centerline of which corresponds to the Idaho-Oregon or Idaho-Washington state boundaries.

Structural Units Compilation

GIS files of faults represented by polylines for each state (Ludington and others, 2005) were also merged into one polyline shapefile covering the study area. No edits were made to increase the resolution or correct continuity across state and polygon boundaries. This file includes information such as fault or structure type, for example, certain normal fault or uncertain syncline, taken directly from Ludington and others (2005).

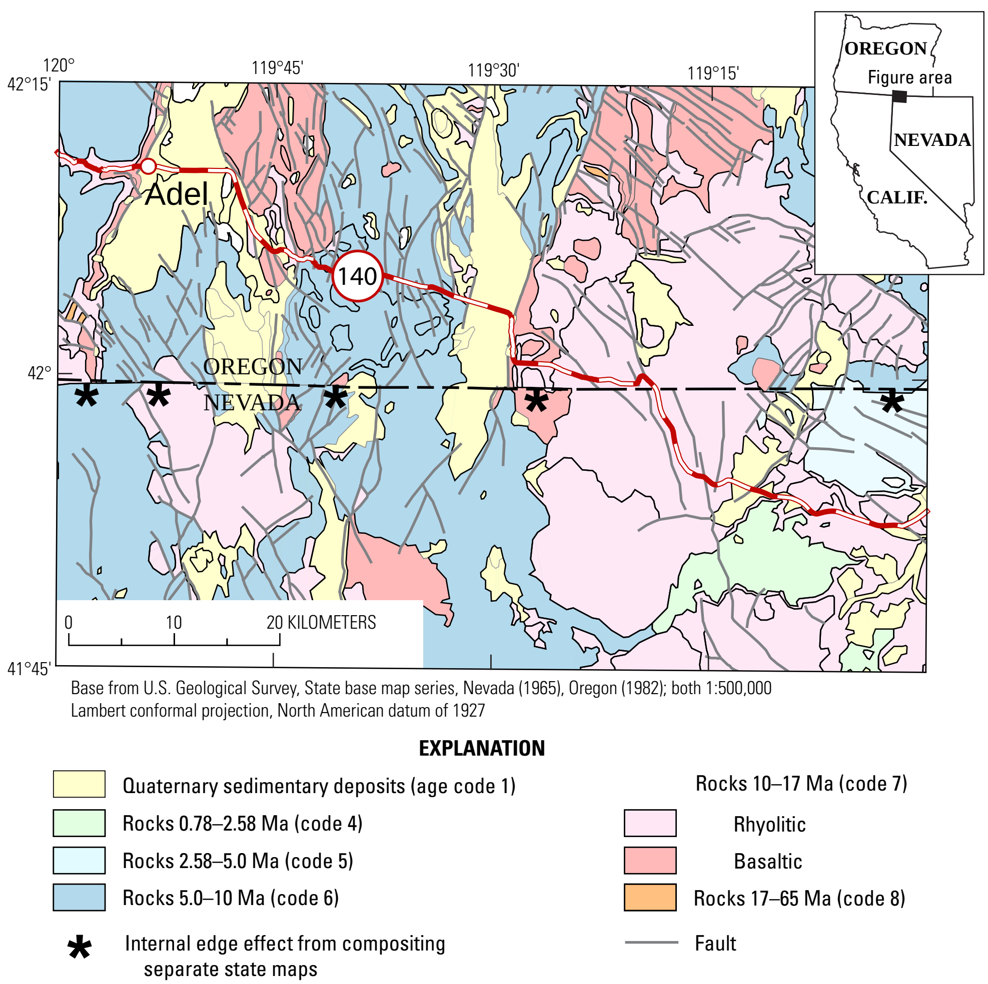


Figure 3. Internal boundary effects from compositing separate state maps. Example is along the southern Oregon-northern Nevada boundary. Asterisks show places where stratigraphic units have incomplete or no match across state line, resulting in contact that coincides with latitude of state line (just south of lat 42°N.). Quaternary sedimentary deposits bury several graben floors, and their contacts were generally easy to match at state line, as were widespread basalt lava sequences, extensive rhyolite domes, and ash-flow tuff. See table 1 for definition of age codes.

Explanation of Coding Categories

The following sections present the components ascribed by us as additions to previously existing columnar data of the state geologic map databases. The methods are described briefly, and a table including all possibly recoded categories is provided for each.

Age (AgeCode)

Rock age is represented by integer values that represent time intervals (table 1). The intervals are briefer for younger rocks and deposits because these commonly are more narrowly defined stratigraphically; for example, a younger stratigraphic unit may comprise only one or a few lava flows whereas an older unit may contain thick sequences of lava flows. The intervals are sequential from 2 to 9 for most rocks in the map area. A special case applies to Quaternary sedimentary rocks and deposits, which may span from the early Pleistocene (code 4) to the late Holocene (code 2) and are more difficult to categorize precisely; therefore, those ages are grouped together and assigned a value 1, which spans the periods of time otherwise distinguished by codes 2, 3, and 4 for Quaternary volcanogenic deposits. Some Quaternary volcanogenic features and older volcanogenic or sedimentary features were assigned broad age-range codings in the original state maps and were also difficult to categorize. These polygons are assigned an age value of -999.

Age assignments rely on stratigraphic relations combined with radiometric ages. Hundreds of new radiometric ages and thousands of chemical analyses have been published in the 25–40 years since publication of the older state compilation maps (as digitized in Ludington and others, 2005); many of the ages and some chemical data were incorporated in our assignments. For categorizing ages, the following regional compilations of radiometric ages were helpful:

- Great Basin Geoscience Data Base (Raines and others, 1996);
- Radiometric Ages from Rocks of the Great Basin (Coolbaugh, 2000);
- National Geochronological Database (Sloan and others, 2003);
- Radiometric Age Information Layer for Oregon, release 1 (RAILO-1) (Ricker and Niewendorp, 2011);
- Nevada Quaternary Volcanic Ages (Nevada Bureau of Mines and Geology, 2012).

Additionally we examined some recent publications encompassing areas where newer information allowed better estimations of age. For example, many broad swaths of basalt lava-flow units on the state-compilation maps across the High Lava Plains of south-central Oregon were categorized by

Table 1. Age coding for rocks within the Northwest Volcanic Aquifer System study area

[Sparse Tertiary intrusive rocks may be assigned codes 5, 6, 7, or 8 but may actually be younger. Abbreviations: ka, thousand years; Ma, million years]

AgeCode	Age range
	Quaternary
1	Quaternary sedimentary rocks and deposits, age spans two or more of the following three time intervals
2	0–13 ka, Holocene volcanogenic rocks
3	13–780 ka, upper and middle Pleistocene volcanogenic rocks
4	0.78–2.58 Ma, lower Pleistocene volcanogenic rocks
	Tertiary
5	2.58–5.0 Ma, Pliocene igneous and sedimentary rocks
6	5–10 Ma, upper Miocene igneous and sedimentary rocks
7	10–17 Ma, middle Miocene igneous and sedimentary rocks
8	17–65 Ma (remainder of the Tertiary), lower Miocene, Oligocene, Eocene, and Paleocene igneous and sedimentary rocks
	Pre-Tertiary
9	Igneous, sedimentary, and metamorphic rocks
-999	Age range not assigned

using ages from newer studies (for example, Jordan and others, 2004; Scarberry and others, 2009; and Wypych and others, 2011).

We sought to sharpen the age distinction for some units whose ages were presented broadly on the original state maps. Many basalt lava sequences in the High Lava Plains and Basin and Range provinces (see inset map on fig. 1 for locations) were once known only to be Pleistocene or Pliocene (Quaternary or Tertiary), which led to the mnemonic map symbol QTb familiar to many geologists. Today, sufficient ages exist to assign most polygons with confidence to one of our coded time periods; most are either Pliocene (code 5) or lower Pleistocene (code 4).

Another broad grouping, Eocene to Pliocene, appeared on the original maps owing to the need to generalize stratigraphic sequences at state-map scale of presentation. The widespread distribution of well-documented middle Miocene basalt, however, allows an increasingly clear distinction between pre- and post-middle Miocene age assignments. This distinction is important hydrogeologically, because the middle Miocene lava sequences commonly are (1) thick, (2) exposed as structurally high features in mountain ranges across the region, and (3) plunge into the subsurface of many basins. Also, permeability contrasts between pre- and post-middle Miocene units (between codes 8 and 5) tend to be larger than among many of the younger age classes owing to greater alteration of glass in lower Miocene and stratigraphically lower units.

The number of radiometric ages is insufficient, however, to assign rocks confidently in some areas. Regardless, patterns are apparent (fig. 4). In south-central Oregon, which encompasses the central part of the Northwest Volcanic Aquifer study area, the age of exposed bedrock volcanic rocks is generally younger westward, from middle Miocene (code 7) to late Miocene (code 6) to Pliocene (code 5). This pattern is partly related to exposure: middle and upper Miocene rocks likely lie buried beneath Pliocene and Quaternary volcanogenic strata in the western part of the map area. But burial is not the entire explanation, inasmuch as the few younger rocks that are found in the eastern part of south-central Oregon form only isolated occurrences dotted sporadically across the landscape.

This overall pattern of westward youth is interrupted at the major fault escarpments, where older strata crop out in the toes of fault blocks. The stratigraphic layers exposed in the escarpments may be subdivided, but away from there, in the topographically gentler areas, distinguishing the ages of undated but compositionally similar units can prove vexing. In our coding, spatial boundaries may be ill defined between stratigraphic groups assigned to age class 7 versus 6 or 6 versus 5, at least at state-map scale. Consequently, the hydrogeologic significance of age assignments that differ only by one unit among the 7-6-5 age classes (for example, coded as 7 instead of 6) may diminish in importance.

Included along the margins of the NVASA are Precambrian rocks (225 polygons total: California, Nevada, Utah, and Idaho). These are included in age class 9, pre-Tertiary, in our coding. Map users interested in isolating them should analyze the column UNIT_AGE by using a search string that will return Proterozoic as a partial age term.

Composition (CompCode)

The polygons demarcating volcanic rock units were assigned composition mainly on the basis of designations in the original compilation (Ludington and others, 2005). Columnar data added for composition, as text abbreviations, were intended to match the chemical-composition scheme for volcanic rocks as used on previous USGS maps showing distribution of Cenozoic volcanic rocks by composition and age (for example, Luedke and Smith, 1982, 1983). Compositional divisions are based on silica content: basalt, 46–54; andesite, 54–62; dacite, 62–70; and rhyolite, >70 percent SiO_2 (table 2). Additional abbreviations for lithology were added for nonvolcanic rocks or pre-Tertiary volcanic rocks to assign compositional data to every polygon.

The codes that indicate volcaniclastic (VC) or mixed-lithologic (MIX) strata are applied mainly for parts of Oregon Tertiary stratigraphic units Clarno or John Day Formations, respectively. Formations like these are regionally extensive groupings that lack detailed geologic mapping in some areas. To force a more restrictive compositional coding on them leads to overgeneralization.

Admittedly, the well-known four-part volcanic compositional spectrum—basalt, andesite, dacite, and rhyolite—is applied inexactly. For example, units designated on this map as basalt in the Cascade

Range include many lava flows typically described as basaltic andesite (provincially, 52–57 or 53–58 percent SiO_2), and those shown as andesite may include much basaltic andesite. Many silicic centers across eastern Oregon and northern Nevada, mapped originally as rhyolitic or silicic vent complexes and assigned a rhyolitic composition by us, are increasingly known to encompass andesite and dacite, some of which form extensive parts of those eruptive centers (for example, Johnson and Grunder, 2000; Boschmann, 2012).

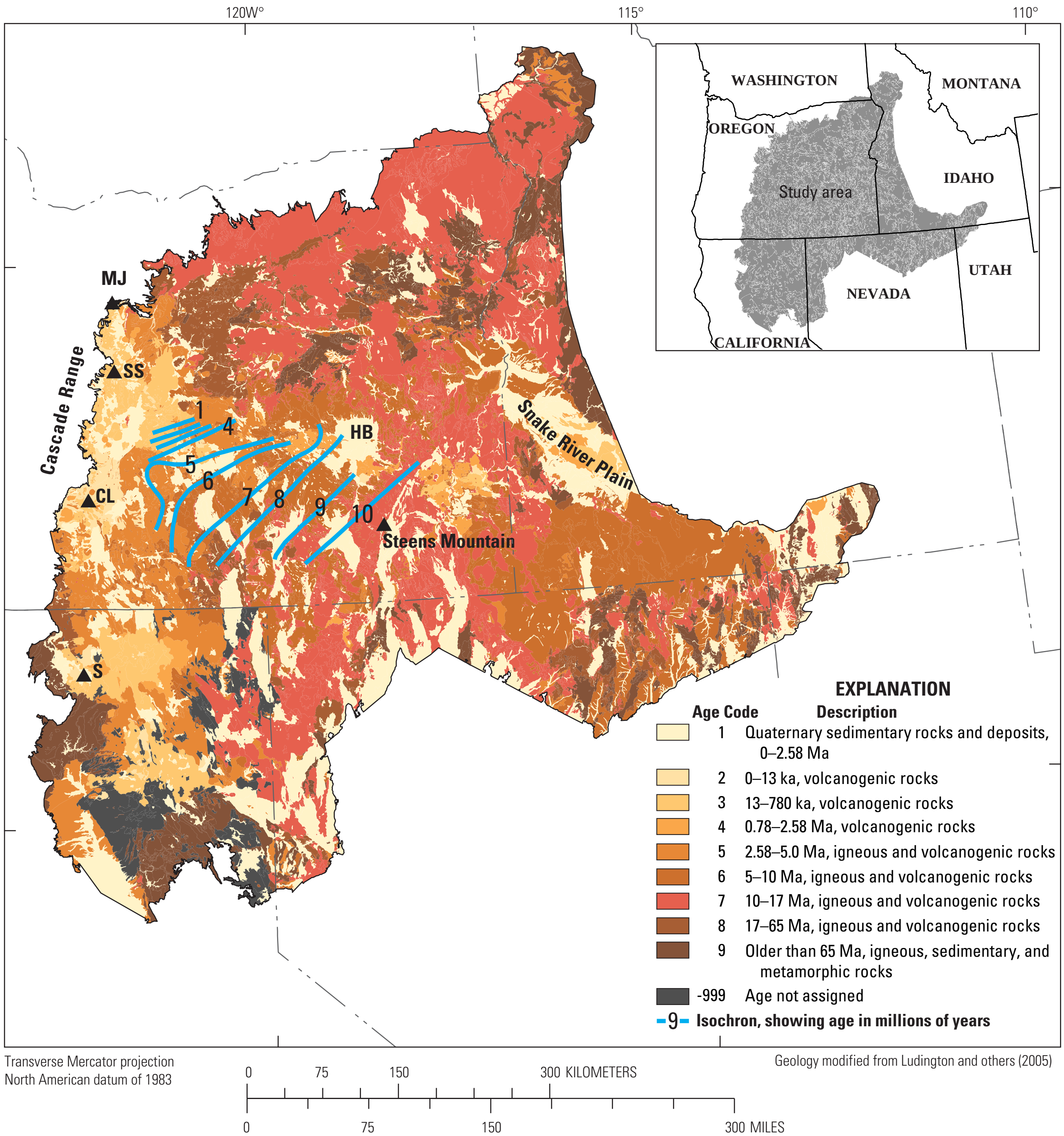


Figure 4. Geologic map for the Pacific Northwest Volcanic Aquifer System study area coded by age (Age Code) to illustrate a general east-to-west trend in decreasing rock age. Abbreviations: CL, Crater Lake; HB, Harney Basin; MJ, Mount Jefferson; S, Shasta; SS, South Sister; Ma, million years; ka, thousand years. Isochrons show rhyolite age progression for silicic domes emplaced across High Lava Plains in Oregon (MacLeod and others, 1976; Walker and MacLeod, 1991).

Table 2. Composition code and description for geologic units coded from Ludington and others (2005) for the Pacific Northwest Volcanic Aquifer System study area

CompCode	Composition (volcanic) or lithology
B	Basalt (46–54 percent SiO_2)
A	Andesite (54–62 percent SiO_2)
D	Dacite (62–70 percent SiO_2)
R	Rhyolite (>70 percent SiO_2)
VC	Volcaniclastic rocks
S	Sedimentary rocks
MIX	Mixed lithology, volcanic, volcaniclastic, sedimentary rocks
pTv	pre-Tertiary volcanic rocks
pTi	pre-Tertiary intrusive rocks
CARB	Carbonate, limestone, and marble
META	Metamorphic rocks (excluding marble)
Ti	Tertiary intrusive rocks
G	Glacier
OW	Open water

Table 3. Hydrogeologic grouping and coding of rocks with broadly similar hydrogeologic aspects largely related to age and lithology

HydroGeo	Assignment
Sed_Q	Fragmental sedimentary deposits and rock of Quaternary age
Sed_T	Fragmental sedimentary rock of Tertiary age
Sed_pT	Fragmental sedimentary rock of pre-Tertiary age (including volcaniclastic)
B_CRB	Columbia River Basalt Group, not restricted by age
CO3	Carbonate and biologic sedimentary rock, not restricted by age
Meta	Metamorphic rock, not restricted by age
Intrus	Intrusive igneous rock, not restricted by age
Extrus	Extrusive igneous rock, not restricted by age
OW	Open water
NA	Not applicable, includes open water and glaciers

Hydrogeologic Grouping (HydroGeo)

The Hydrogeologic Grouping coding permits a rapid assemblage of a few rock types with broadly similar hydrogeologic aspect (largely owing to age and lithology). For example, the thick lava sequences of the Columbia River Basalt Group (code B_CRB) have been well studied for their water-bearing capacity, both for recharge and reservoir potential. Kahle and others (2011) offer this hydrologic description of the Columbia River Basalt Group: a series of productive aquifers consisting of permeable interflow zones separated by less permeable flow interiors. Another useful grouping is all Quaternary sedimentary deposits (Sed_Q), including units described on source maps as alluvium, dunes, fan deposits, surficial deposits, and terrace deposits. Many of the Quaternary sedimentary deposits are moderately to highly permeable, but the grouping (Sed_Q) includes less permeable units such as till, landslide, and playa deposits. Generally, older sedimentary units decrease in permeability with age; therefore, classifications for Tertiary and pre-Tertiary sedimentary groups are also included (Sed_T and Sed_pT). Carbonates, metamorphic rocks, and intrusions are assigned to separate groups because each has distinctive influence on the flow of groundwater, regardless of age (for example, see Toth, 2009). Extrusive volcanic rocks, aside from the Columbia River Basalt Group, may have trends in permeability associated with variation in composition. Those rocks are broadly grouped as extrusive (Extrus) here but could be divided further on basis of chemical composition.

The HydroGeo grouping is not as intricate or sophisticated as its name might imply. Instead, it provides a way to quickly select all the polygons that encompass certain rock types; for example, all the Quaternary sedimentary units, regardless of their source-map designator or manner of deposition.

Lithologic Pattern (LithPatter)

It was deemed useful to add information that may help users understand permeability contrasts within some groupings. For example, permeability of basaltic vent rocks ranges widely. Therefore, scoria cones (coded as scoria cone, table 4) might be distinguished from tuff cones, which are often well-cemented, clay-rich palagonitic beds (coded palagonite tuff). These distinctions, for polygon assignment, were typically gleaned from the source-map information. As another example, ash-flow tuff sheets may vary from unwelded (AFT_u) to highly welded (AFT_w)—with decreasing permeability—or even so densely welded (AFT_d) as to be rheomorphic and hydrologically more like thick rhyolite lava flows than like their less-welded pyroclastic counterparts; the latter is described in several publications for ash-flow tuffs in Idaho (for example, Ekren and others, 1984). Distinctions of welding are rarely available in the state-scale source-map codings and are therefore applied only where we have some personal knowledge or access to suitably detailed map publications.

The term shield volcano applies to the many moderate-size, low-profile volcanoes built chiefly of lava flows that are broadly similar in composition. It applies readily to volcanoes of the open plains, where their geomorphic form is expressed, and to several of the younger volcanoes in the Cascade Range. The term is rarely assigned to lava-flow sequences in fault-block escarpments because the evidence of volcanic edifice is difficult to establish. Readers seeking parallel naming conventions might recognize the absence of composite volcano as a pattern term. Composite volcanoes comprise rocks that are diverse both compositionally and by way of their extrusive structures; for example, domes versus lava flows. The volcanic-structure distinctions are commonly discernible even at state-map scale, so those more specific terms typically prevail.

Relevant Notes (NotesAdded)

The “NotesAdded” field includes supporting radiometric-age criteria, stratigraphic or geographic names, source-map reference if not the state-map compilation, and additional lithologic notes for some of the polygons. These entries were added irregularly, but we felt they were important enough to retain with the re-categorized map. The lack of a data entry in the “NotesAdded” field does not signal the absence of supporting radiometric-age or other data.

Intent, Limitations, and Caveats

This newly coded map (database and fig. 4) was created for statistical analysis of hydrogeologic relations in the Pacific Northwest Volcanic Aquifer study area (NVASA). It is being published as a document of record, one we hope will be useful to others studying the stratigraphy and structure of the Pacific Northwest.

Conceptually, little is new from the broad categorization shown earlier by small-scale age-composition depictions of specific temporal periods (for example, 1:1,000,000-scale maps by Luedke and Smith: late Cenozoic volcanic rocks [1982]; early and middle Cenozoic volcanic rocks [1983]). Of value here is the greater detail in tabular data for rocks and deposits emplaced in the past 5 million years compiled into a single publication. In addition, this map includes thematic coding for broadly similar hydrogeologic properties (largely owing to age and lithology) and lithologic patterns.

The degree of certainty for which the age, composition, hydrogeologic group, and lithologic pattern were assigned varies among polygons. Any age or compositional information that appears was derived by comparing, in GIS, a preexisting map with the current map and making a wholesale assignment for the most likely composition and age of volcanic rocks. Some polygons have been individually inspected, commonly in conjunction with intermediate-scale maps or information from radiometric databases. In other cases, polygons were assigned in bulk to groupings of lithologically or temporally similar units in close geographic proximity. Still other polygons were recoded entirely on the basis of already existing codes, for units across broad geographic reaches of a given state. For example, narrow valley-floor alluvial sedimentary deposits with an “original label” of Qal were assigned the character “thin fill” for their LithPatter because they likely are not part of moderate to thick basin fills that include other Quaternary sedimentary units.

That said, ours is a thematically oriented map. It may have been wiser as a first step to coalesce small

Table 4. Lithologic pattern categories that may influence permeability on a finer scale than age, composition, or hydrogeologic grouping alone

[Abbreviations: m, meters]

LithPatter	Description
	Volcanic units
lava flows	Typically several flows and interbedded flow breccia
lava flows and tuff	Heterolithic aspect reduces permeability of map unit
AFT_u	Ash-flow tuff, unwelded or poorly welded
AFT_w	Ash-flow tuff, moderately welded
AFT_d	Ash-flow tuff, densely welded (rheomorphic)
shield volcano	Landform comprises lava flows; may include overlapping shield within area of one polygon
scoria cone	Mostly basalt or andesite vent deposits, but includes rhyolite scoria at Central Pumice Cone (Oregon, Newberry caldera)
palagonite tuff	Palagonite tuff
silicic vent	Landform comprising mostly rhyolite lava flows and near-vent deposits
dome or thick lava flows	Stubby lava, probably near vent
tuff	Chiefly ash-rich fine-grained pyroclastic volcanic rocks
tuff and tuff breccia	Like tuff but includes much coarse material (tuff breccia)
volcaniclastic	Pyroclastic or epiclastic volcanic rocks
small plug or sill	Mostly basalt or andesite compositionally and commonly fine grained
	Sedimentary units
alluvial fill, thin	Alluvial-fill deposit, commonly less than 30 m thick
alluvial fill, moderate	Alluvial-fill deposit, 30–300 m thick
alluvial fill, thick	Alluvial-fill deposit, more than 300 m thick
till	Glacial till deposit, not restricted by thickness
diamictite	Debris-flow deposit with substantial run-out
landslide	Landslide deposit, not restricted by thickness
	Heterolithic Tertiary formations
tuff and tuffaceous sedimentary rock	Ash-rich pyroclastic and epiclastic volcanic rocks
highly variable lithologically	Areas of ill-defined strata including lava flows, pyroclastic and epiclastic volcanic rocks, possibly some intrusions
	Pre-Tertiary rocks
pT volcanic and volcaniclastic	Pre-Tertiary volcanic and volcaniclastic rocks
coarse-grained plutonic	Coarse-grained intrusions, ranging from ultramafic to granitic
pT volcanic and metavolcanic	Pre-Tertiary volcanic and metavolcanic rocks
limestone, dolostone, or marble	Limestone, dolostone, or marble
	Other
plutonic	Plutonic rocks
NA	Not applicable. Includes pre-Tertiary sedimentary and metamorphic rocks because they do not have a "pattern" (may include some carbonate, metasedimentary, or intrusive rocks). Also includes open water and glaciers
NC	Not classified

polygons, such as vent deposits, into their surrounding lava-field polygon to simplify the presentation. Lost thereby, however, would have been the opportunity for users to deal with details of their choosing—to reassign age or composition to polygons of small areal extent. In addition, the act of simplification would have required greater documentation.

Herein lies the chief caveat for a user: Polygon size counts in the matter of age-composition assignments on a map of this scope and detail. The smaller the area of any geologic polygon on this map, the greater the likelihood it is miscoded—chiefly by age but sporadically by composition. Inspection of each small polygon for accuracy is unrealistic for the scope and application of this map. The task would be ponderous to examine every small polygon corresponding to the numerous scoria cones that dot the landscape of a volcanic terrane, for example. Therefore, part of our workflow involved selecting polygons by area to ensure extensive areas were properly coded.

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