# *Geochronology of the Ellensburg Formation-constraints on Neogene volcanism and stratigraphic relationships in central Washington*

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# GEOCHRONOLOGY OF THE ELLENSBURG FORMATION—CONSTRAINTS ON NEOGENE VOLCANISM AND STRATIGRAPHIC RELATIONSHIPS IN CENTRAL WASHINGTON

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## INTRODUCTION

This paper reports recently acquired K-Ar dates from the Neogene sedimentary section and from intrusions in the adjacent Cascade Range. These new data aid assessment of the stratigraphic history and correlation of Neogene sediments, help define the timing of late Miocene volcanism in the Cascades, and place constraints on volcanic source areas. Reconstructing this volcanic record has been difficult because of late Neogene uplift and erosional dissection of the proximal volcanics, and because most dated intrusions are either too old or too young to represent magmatism recorded in the Ellensburg Formation (Smith and others, 1988). This study also illustrates the utility of isotopic dating to resolve stratigraphic problems in sedimentary basins.

**Methodology.** Most of the dated samples (table 1, fig. 1) were collected from air-fall or ash-flow tuffs intercalated with the Neogene sediments. Three hornblende-dacite clasts from debris-flow deposits within the Ellensburg Formation were also dated. Clasts of this composition are characteristic of syneruptive detritus in the Ellensburg Formation (Smith and others, 1988). One such clast (table 1, sample locality 7) contained radial thermal joints indicating *in situ* cooling from high temperature. Two additional dated samples were collected from hypabyssal plutons located

**TABLE 1. Sample and analytical data for K-Ar dates**

| Sample locality | Sample number | Lat (N) | Long. (W) | Lithology | Mineral dated | Potassium data | Potassium mean | Rad Ar pm/g data | Rad Ar pm/g mean | % Atm. Ar data | % Atm. Ar mean | Reported dated + err (Ma) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | UAKA87-89 | 46.86 | 121.23 | Dacite porphyry plug | biot. | 6.155<br>6.282<br>6.123 | 6.187 | 50.26<br>50.18<br>50.42<br>50.54 | 50.35 | 62.6<br>64.0<br>59.8<br>61.6 | 62.0 | 4.69 ± 0.17 |
| 2 | UAKA87-90 | 46.33 | 120.18 | Dacite pumice from pumice-clast debris-flow deposit | horn. | 0.234<br>0.229<br>0.233 | 0.232 | 4.10<br>4.17<br>4.07<br>4.25 | 4.15 | 69.1<br>68.6<br>69.3<br>67.9 | 68.7 | 10.28 ± 0.28 |
| 3 | UAKA87-91 | 46.59 | 120.54 | Dacitic vitric-crystal air-fall tuff | plag. | 0.207<br>0.198<br>0.205 | 0.203 | 4.04<br>3.94<br>3.91<br>3.92<br>3.86 | 3.93 | 48.6<br>47.4<br>45.7<br>48.5<br>46.9 | 47.4 | 11.12 ± 0.36 |
| 4 | UAKA87-92 | 46.54 | 120.54 | Dacitic vitric-crystal air-fall tuff | horn. | 0.443<br>0.425<br>0.422<br>0.433 | 0.431 | 3.44<br>3.81<br>3.42<br>3.43 | 3.53 | 79.8<br>77.7<br>80.6<br>80.3 | 79.6 | 4.72 ± 0.28 |
| 5 | UAKA87-93 | 46.65 | 120.58 | Dacitic vitric-crystal air-fall tuff | horn. | 0.135<br>0.137<br>0.132 | 0.135 | 1.69<br>1.70<br>1.78<br>1.76 | 1.73 | 82.7<br>82.7<br>81.9<br>84.7 | 83.0 | 7.41 ± 0.36 |
| 6 | UAKA87-94 | 46.90 | 121.25 | Dacite porphyry plug | horn. | 0.853<br>0.858<br>0.841 | 0.851 | 13.03<br>13.00<br>12.96<br>12.97 | 12.99 | 40.6<br>40.7<br>40.7<br>40.8 | 40.7 | 8.79 ± 0.20 |
| 7 | UAKA87-96 | 47.09 | 120.69 | Prismatically jointed dacite clast from debris-flow deposit | horn. | 0.243<br>0.244<br>0.238 | 0.242 | 4.49<br>4.56<br>4.34<br>4.31 | 4.43 | 67.6<br>67.7<br>69.3<br>69.4 | 68.5 | 10.53 ± 0.37 |
| 8 | UAKA87-97 | 46.74 | 120.67 | Dacitic pumice from reworked lapillistone | horn. | 0.219<br>0.231<br>0.236<br>0.231 | 0.229 | 3.75<br>3.84<br>3.85<br>3.29 | 3.68 | 59.1<br>58.3<br>58.6<br>65.3 | 60.3 | 9.25 ± 0.25 |
| 9 | UAKA87-98 | 46.82 | 121.02 | Dacitic ash-flow tuff | horn. | 0.259<br>0.255<br>0.253 | 0.256 | 5.00<br>5.08<br>4.95<br>5.03 | 5.02 | 60.8<br>61.5<br>63.4<br>61.1 | 61.7 | 11.28 ± 0.37 |
| 10 | UAKA87-197 | 46.42 | 120.76 | Dacitic vitric-crystal air-fall tuff | horn. | 0.255<br>0.254<br>0.253<br>0.254<br>0.259 | 0.255 | 3.62<br>3.24<br>3.54 | 3.46 | 51.2<br>56.1<br>51.7 | 53.0 | 7.82 ± 0.30 |

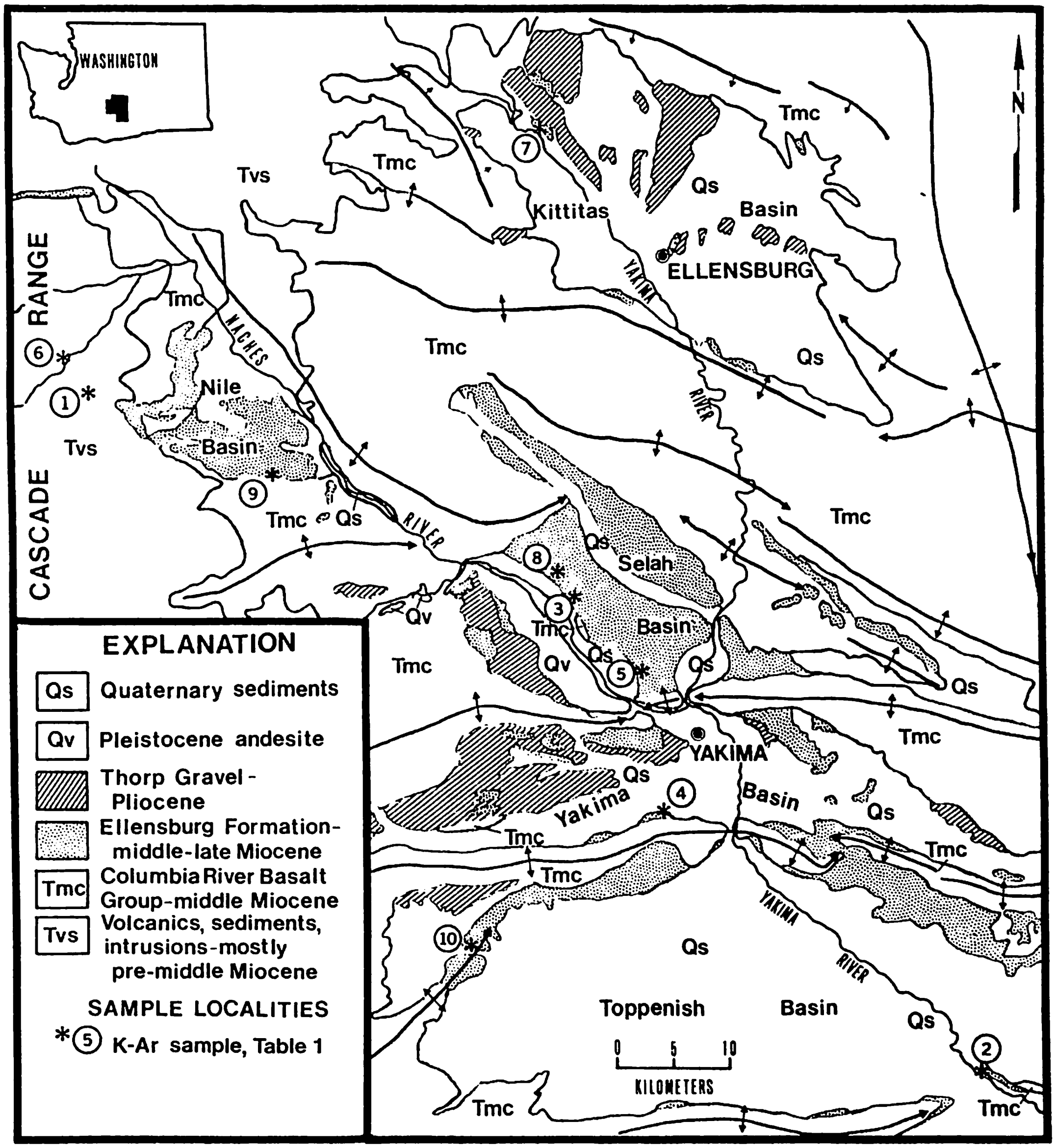


**FIGURE 1. Generalized geologic map of the west-central margin of the Columbia Plateau in Washington, showing sample localities. Neogene sedimentary deposits are largely restricted to basins between anticlines of the Yakima fold belt.**

on the east flank of the Cascade Range. Pure separates of hornblende, biotite, or plagioclase were obtained using standard magnetic and heavy-liquid techniques. Separates were examined for uniformity of optical properties to exclude contaminant grains. Potassium was analyzed by atomic absorption spectophotometry. Three splits of each sample were analyzed, and each sample was concurrently analyzed with a rock standard to monitor precision. Analyses were repeated if the spread between extreme measured values exceeded 2.0% and/or the measured potassium content of the standard differed by more than 2% from the accepted value. Samples for argon analyses were fused in induction-heated molybdenum crucibles suspended in air-cooled fusion envelopes that had first been evacuated and baked for 2 days at 257°C. Two or more aliquots were analyzed separately by gas-source mass spectrometry.

Volcaniclastics of the Ellensburg Formation, east of the Cascade Range, have been described by several authors (Schmincke, 1964; Luker, 1985; Smith, 1987; Smith, 1988). The Ellensburg Formation is intercalated with and overlies flood lavas of the Columbia River Basalt Group, erupted from fissures 225 to 450 km east of the Cascade Range. Most of the Ellensburg Formation volcaniclastics overlie 17.0 to 10.5 Ma basalts (Long and Duncan, 1982; McKee and others, 1977; Watkins and Baksi, 1974). These basalts offlap the Cascades so that suprabasalt volcaniclastic sediments overlie progressively older basalts to the west. Correlation of these upper Ellensburg Formation volcaniclastics has been hampered by discontinuous outcrop belts in basins of the Yakima fold belt, and different ages of underlying basalts. Stratigraphic relationships (Smith, 1988) suggest that dacitic volcaniclastic deposition may have been diachronous in different basins. Variable contact relationships exist, therefore, between Ellensburg Formation strata and the overlying, intrabasinal basaltic gravels generally assigned to the Pliocene Thorp Gravel.

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## GEOLOGIC SETTING

Hornblende-dacite lavas and tuffs were extruded over a large area of the central Washington Cascade Range from middle Miocene to Pliocene. Pliocene volcanic centers are marked by plugs and local accumulations of lava and tuff that occur east of the present Cascade Range crestline. These intrusive and extrusive rocks have been dated between 2.8 and 4.8 Ma by fission-track and K-Ar methods (Clayton, 1983; Phillips and others, 1986). Very few middle to late Miocene lavas or intrusions are known in the Washington Cascades (Frizzell and others, 1984; Walsh and others, 1987; Vance and others, 1988), but derivative pyroclast-rich volcaniclastic sediments occur locally on the west (Mullineaux and others, 1959) and extensively on the east side of the range.

These age data document a major influx of volcaniclastic material into the ancestral Naches and lower Yakima River drainage from about 12 to 7 Ma and the deposition of correlative strata in the Nile, Selah, and eastern Toppenish basins. Previously, no late Miocene volcanic centers were known in the vicinity of the Nile basin to serve as a source for this detritus. We report an 8.9 Ma age for a dacite plug suggesting that the late Miocene volcanism was a precursor to the well-documented Pliocene dacite magmatism in this area.

If all basaltic gravels overlying dacitic volcaniclastics are assigned to the Thorp Gravel, then the base of this unit is time transgressive. The type Thorp Gravel in the Kittitas basin is about 3.70 ± 0.20 Ma (Waitt, 1979). However, basaltic gravels overlying Ellensburg Formation dacitic volcaniclastics are slightly older than 4.72 ± 0.28 Ma in the western Yakima basin, and approximately 7.82 ± 0.30 Ma in the western Toppenish basin. The latter age is equivalent to Ellensburg Formation dacitic volcaniclastics in the Nile and Selah basins and also, probably, in the Yakima and eastern Toppenish basins. The basal contact of basaltic gravel on dacitic volcaniclastics is conformable in the Yakima and Toppenish basins and disconformable in the Kittitas basin. Interfingering of dacitic and basaltic gravels in the western Yakima basin makes unambiguous selection of a formational contact difficult.

## DISCUSSION OF DATES

**Kittitas Basin.** At least 100 m of Ellensburg Formation overlies and is intercalated with Grande Ronde Basalt of the Columbia River Basalt Group (17 to 15.5 Ma; Long and Duncan, 1982) in the Kittitas basin. Coarse-grained volcaniclastics occur between flows of the Grande Ronde Basalt and stratigraphic relationships farther south suggest that similar sediments entered the Kittitas basin until at least 12 Ma (Smith, 1988). The Ellensburg Formation is disconformably overlain by the Thorp Gravel, from which fission track ages of 3.64 ± 0.74 Ma and 3.70 ± 0.20 Ma have been obtained for intercalated tuffs (Waitt, 1979). A K-Ar age of 10.53 ± 0.37 Ma (table 1, sample locality 7) was determined for a sample collected within the Ellensburg Formation, 25 m below the Thorp Gravel. It is unclear how much Ellensburg Formation may have been removed by erosion prior to deposition of the Thorp Gravel, but the preserved top of the formation in the Kittitas basin appears to be about 10.5 Ma.

**Selah Basin.** Coarse-grained volcaniclastic sediments first appear in the Selah basin (fig. 1) directly beneath a 12 Ma (McKee and others, 1977) Columbia River basalt flow; approximately 350 m of sediment overlie this basalt (Smith, 1988). A volcanic ash sample collected 25 m above the 12 Ma lava has an age of 11.29 ± 0.36 Ma (table 1, sample locality 3), suggesting no significant hiatus in the influx of volcaniclastics at the horizon of the basalt. A K-Ar age of 9.25 ± 0.25 Ma (table 1, sample locality 8) was obtained for the top of the 350 m-thick type section of the Ellensburg Formation in the Selah basin.

The 12 to 9.25 Ma age for the bulk of the Ellensburg Formation in the Selah basin is consistent with the occurrence of Clarendonian vertebrate fossils (Smiley, 1963; Schmincke, 1964); the Clarendonian stage is 9 to 12 Ma (Berggren and others, 1985). Younger Hemphillian (5 to 9 Ma) fossils have been found (Martin, 1979) in a section of Ellensburg Formation that occupies a paleovalley incised into the main body of the unit (Smith, 1988). A volcanic ash at this vertebrate locality has yielded an age of 7.41 ± 0.36 Ma (table 1, sample locality 5), which is consistent with the age of the fauna. Therefore, on the basis of these dates and stratigraphic relations, it appears that volcaniclastics entered the Selah basin over the period from approximately 12 Ma to about 7.4 Ma.

**Nile Basin.** In the Nile basin, coarse-grained Ellensburg Formation volcaniclastics rest unconformably on 17 to 15.5 Ma Grande Ronde Basalt. An ash-flow tuff about 85 m above the basalt yields a K-Ar age of 11.28 ± 0.37 Ma (table 1, sample locality 9). No primary pyroclastic lithologies occur near the top of the section. The Westinghouse Hanford Company obtained a 7.0 ± 1.0 Ma apatite fission-track age for a dacite debris-flow clast at the top of the section (B. N. Bjornstad, written commun., 1987). Although the apatite was low in uranium (only 201 fossil tracks counted in 18 crystals), this age is consistent with lithologic similarities that imply correlation of the suprabasalt Ellensburg Formation in the Nile and Selah basins (Schmincke, 1964; Smith, 1988).

**Yakima Basin.** Coarse-grained volcaniclastic sediments overlie 12 Ma Columbia River basalt in the western Yakima basin (fig. 1). On the south side of the basin an overturned section of Ellensburg Formation (50 m thick) grades upward through 35 m of interbedded dacitic and basaltic gravel into 18 m of entirely basaltic gravel mapped as Thorp Gravel by Bentley and Campbell (1983). This basaltic gravel is capped by a paleosol and overlain by 7 m of lacustrine mudstone. A bioturbated tephra occurs in the paleosol above the basaltic conglomerate and has yielded a K-Ar age of 4.72 ± 0.28 Ma (table 1, sample locality 4). The relatively young age of this sample and the gradational contact between Cascade-derived and intrabasinal volcaniclastics in the Yakima basin suggest an insignificant hiatus to produce a disconformity like that developed in the Kittitas basin between dacitic and basaltic sediments. Similar exposures of interbedded basaltic and dacitic sediments occur elsewhere in the western Yakima basin. The overlying lacustrine sediments may be related to regional Pliocene lakes that are better exposed in strata of the Ringold Formation, 65 km east of the area shown in figure 1 (Smith and others, in press).

**Toppenish Basin.** Volcaniclastic sediments in the western Toppenish basin are largely buried under Quaternary basin fill and are poorly exposed. A 4-m thick outcrop at the west end of the basin contains two tephras intercalated within basaltic gravel that overlie dacitic sandstones. A K-Ar age for one of the tephras is 7.82 ± 0.30 Ma (table 1, sample locality 10). These basaltic gravels are older than the type Thorp Gravel and basaltic gravels in the western Yakima basin.

In the eastern Toppenish basin at least 200 m of volcaniclastics and quartzite conglomerate, the latter representing deposition by the ancestral Columbia River, overlie a 10.5 Ma (McKee and others, 1977) Columbia River basalt flow. Exposures along the anticline north of the basin show that the volcaniclastics first entered the basin during the period between emplacement of 12 and 10.5 Ma lavas (Smith, 1988). An age of 10.28 ± 0.28 Ma (table 1, sample locality 2) for a sample within the basin is consistent with the age of the underlying 10.5 Ma basalt and suggests correlation of this section to the Ellensburg Formation in the Selah and Nile basins. Based on paleogeographic considerations, Fecht and others (1985) correlate a part of the overlying quartzite conglomerate to a conglomerate that overlies an 8.5 Ma basalt at the base of the Ringold Formation farther east. This correlation is supported by the occurrence of as much as 60 m of lacustrine mudstone above the quartzite conglomerate in the eastern Toppenish basin (Smith, 1988) that may correlate to lacustrine intervals of the Ringold Formation and to the lacustrine section in the western Yakima basin.

**Cascade Range.** The bulk of the Ellensburg Formation was derived from volcanic sources close to the Nile basin (Smith and others, 1988) between about 12 and 7 Ma. Pliocene dacites crop out along the ridges west and southwest of the Nile basin (Clayton, 1983), but late Miocene magmatism has only been indicated by a 6.3 ± 0.2 Ma age from an alteration zone where "rhyolite" intruded a larger early Miocene intrusion (Armstrong and others, 1976). Facies relationships and paleocurrent data in the Ellensburg Formation suggest a source area for the volcaniclastics close to the western margin of the Nile basin (Smith and others, 1988). We obtained two samples from intrusive dacite porphyrys in this area. One sample yielded a K-Ar age of 4.69 ± 0.17 Ma (table 1, sample locality 1) and suggests affinity to the Pliocene dacites. The other sample gave an age of 8.79 ± 0.20 Ma (table 1, sample locality 6), which is appropriate for an Ellensburg Formation source.

## CONCLUSIONS

This isotopic dating project demonstrates the spatial and temporal extent of late Miocene volcanism in the Washington Cascade Range. Erosion has removed the proximal volcanics, but dacitic volcaniclastic sediments of the Ellensburg Formation, deposited diachronously in different basins, record the volcanic episode. Dacite detritus entered the Kittitas basin between about 17 Ma and 10.5 Ma, with a significant hiatus before deposition of Pliocene basaltic gravels. The Ellensburg Formation volcaniclastics at the type area in the Selah basin range in age from about 12 to 7.4 Ma and are correlative with the section in the Nile basin that is slightly older than 11.3 Ma at the base and about 7.0 Ma at the top. Deposition of volcaniclastics in the western Yakima basin probably began at about 12 Ma. Dacitic detritus continued to enter the basin until the early Pliocene and interfingers with basaltic gravels, rather than being separated from the Pliocene section by a disconformity as illustrated at the type section of the Thorp Gravel in the Kittitas basin. The base of the volcaniclastic section in the eastern Toppenish basin occurs between 12.0 and 10.5 Ma basalt flows. The top of this section is definitely younger than 10.3 Ma and is probably younger than 8.5 Ma. Stratigraphic relationships in the western Toppenish basin are unclear because of poor exposure, but 7.8 Ma basaltic gravels rest conformably on dacitic volcaniclastics.

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