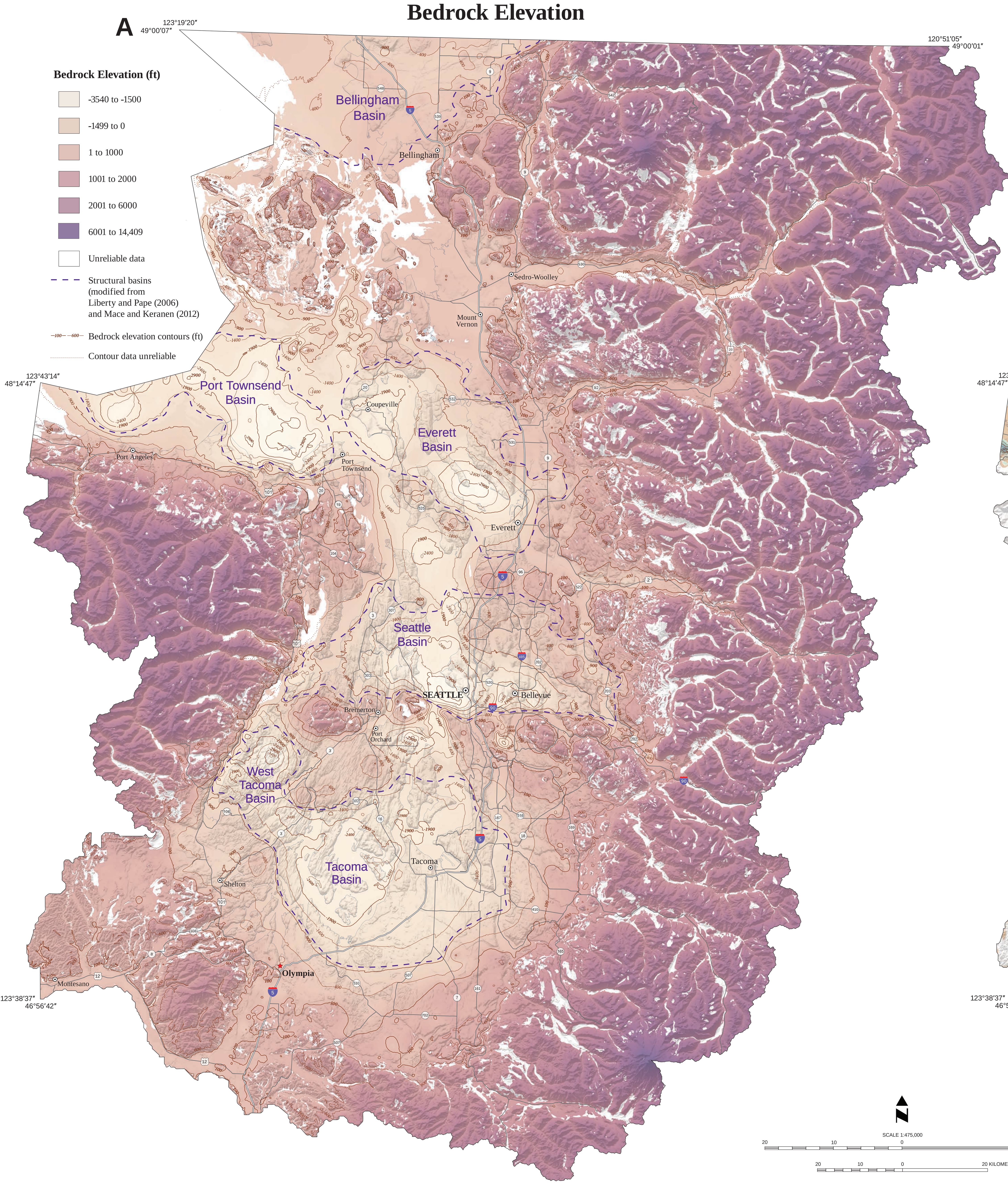
WASHINGTON STATE DEPARTMENT OF Natural Resources
Peter Goldmark - Commissioner of Public Lands
Division of Geology and Earth Resources
David K. Norman - State Geologist

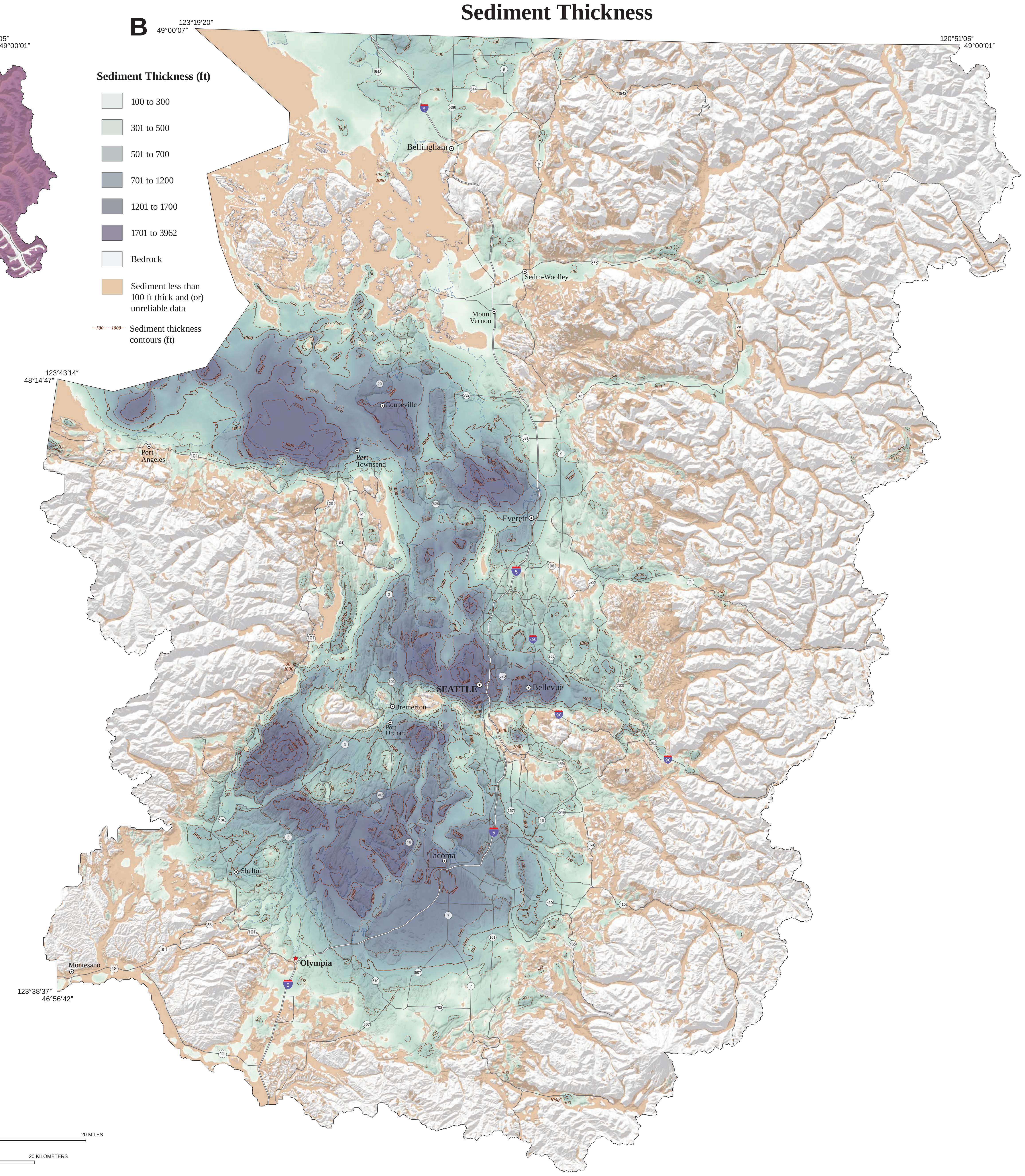
Bedrock Elevation and Unconsolidated Sediment Thickness in the Puget Lowland, Washington

by
Daniel W. Eungard

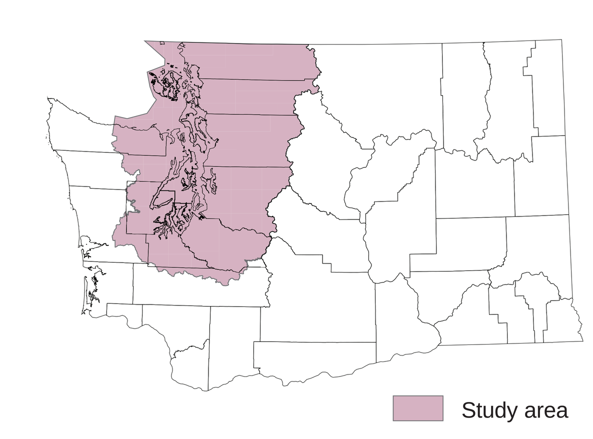
Bedrock Elevation



Sediment Thickness



SCALE 1:475,000
20 10 0 20 MILES
20 10 0 20 KILOMETERS



INTRODUCTION

The Puget Lowland is part of the Puget–Willamette trough that extends about 200 mi north to south from Vancouver, British Columbia, to 20 mi south of Centralia, Wash., and up to 120 mi from the foot of the Cascade Range westward to the foot of the Olympic Mountains, narrowing southward into the Willapa Hills (Fig. 1 in pamphlet). Elevations in this region vary from 14,411 ft at the peak of Mount Rainier to sea level at Puget Sound and the Strait of Juan de Fuca.

The Puget Lowland has accumulated thousands of feet of unconsolidated sediment from several alpine and continental glaciations as well as fluvial sediments from adjacent mountain ranges. This report provides a digital representation of the bedrock topography and thickness of overlying sediment in the Puget Lowland, refining earlier attempts by incorporating additional data and using computer modeling. The study area includes all areas hydrologically connected to Puget Sound and uses modified boundaries from Jones (1996) to more closely represent the extent of Pleistocene glaciation in the southern Puget Lowland.

This report and associated data also provide an estimate of local uncertainties within the model and a compilation of model input data. With this model, planners, public officials, and researchers will have a better tool for understanding the bedrock topography of the region and guiding larger-scale site-specific studies for infrastructure development, water use, seismic hazards, and many other applications.

REGIONAL GEOLOGY

The Puget Lowland is a forearc basin formed by the subduction of the Juan de Fuca plate beneath the North American plate and contains accumulated nonglacial sediments shed from adjacent provinces as well as glacial deposits from several late-Pleistocene Cordilleran ice advances. These deposits overlie pre-Quaternary marine sedimentary and volcanic bedrock, locally exposed as a result of uplift and deformation from numerous northwest-trending right-lateral strike-slip faults or east–west-trending reverse faults. These faults bound several deep structural basins filled with unconsolidated deposits to depths as much as 3,000 ft.

Three physiographic provinces surround the Puget Lowland (Fig. 1 in pamphlet): the Olympic Mountains, the Cascade Range, and the Willapa Hills. To the west, the Olympic Mountains are a predominantly Tertiary-age uplifted subduction complex composed of deep-marine siliciclastic rocks overlain by basalt flows and breccia. To the east, the Cascade Range is an uplifted forearc/volcanic arc built upon a series of pre-Tertiary fault–separated accreted terranes and Cretaceous to Tertiary metamorphic and plutonic complexes. Tertiary to Holocene dacitic to andesitic volcanic rocks both intrude and overlie these accreted terranes and plutonic complexes in the north. The southern Cascade Range consists of Tertiary to Holocene volcanic flows and thick sequences of volcaniclastic rocks. The Willapa Hills Province bounds the southern limit of the Puget Lowland and consists of low, rolling hills of basaltic volcanic rocks overlain by marine and nearshore sedimentary rocks.

For this model, we regard any consolidated geologic unit in the study area not underlain by unconsolidated sediments as bedrock. Generally, bedrock closely correlates to rocks of Miocene age and older, however, we also treated Holocene volcanic rocks as bedrock.

DATA PREPARATION AND MODELING METHODS

To generate elevation and thickness models for the Puget Lowland (Maps A and B, this plate), we integrated bedrock elevations from geologic maps, geologic cross sections, borehole data, and seismic profiles (Plate 2). Ten-meter DEMs compiled by Gesch and others (2002) merged with 10-m bathymetry data from Finlayson (2000) and 90-m bathymetry from the NOAA National Geophysical Data Center (2014) provide elevations for both the land and seafloor. This study did not utilize lidar-based elevation data, despite its greater elevation precision, due to the scale of the study, incomplete lidar coverage, and file-size limitations. Geographic Information System (GIS) modeling of bedrock elevations from these data sources provided an estimate of bedrock elevation and thickness where little to no bedrock control exists.

To represent bedrock elevation in areas with little bedrock control, refinement of the initial model used a process similar to that of Gao and others (2006), who incorporated select sediment wells that terminate below the modeled bedrock elevation. Sediment wells provide a minimum bedrock estimate in areas where little to no bedrock control exists. We used the deeper sediment wells to modify the bedrock elevation model, iteratively using wells in the upper decile of the sediment well dataset to recalculate the modeled surface. This process went through seven iterations until reaching the point at which any added sediment well would adjust the model by less than 50 ft in a given location (Table A in pamphlet).

The output of the iterative process is a modeled bedrock elevation surface that we consider a minimum estimate for locations lacking surficial outcrop. To better represent the bedrock elevation where surface outcrops exist, we merged the DEM and bathymetry (clipped by outcrop extent) with the bedrock model (Map A). Subtraction of the modeled bedrock elevation from the topographic elevation provides a calculated thickness of overlying sediment in the study area and also identifies areas where the model is unreliable by producing negative thickness values (Map B).

DISCUSSION

The greatest advantage of a bedrock elevation model is visualization of structural and geomorphic features that may or may not be apparent from surface topography alone. Many of these prominent features in the bedrock elevation model correspond to major fault zones (Fig. 4 in pamphlet), such as the Seattle fault zone, the southern Whidbey Island fault zone, and the Darrington–Devils Mountain fault zone, and to structural basins between each of these major fault systems. These faults form three of the largest basins within the Puget Lowland: the Everett basin, the Seattle basin, and the Tacoma basin.

The bedrock model has some significant limitations in modeling areas with sparse data or adjacent to bedrock exposures. Geologic cross sections provide some improvement to the model, allowing for greater bedrock control where none would otherwise exist. We recognize that cross sections are interpretations based on supporting data, such as geophysics, structural mapping, and borehole lithology, rather than directly measured data as used in the rest of the bedrock elevation model. Where supporting evidence provided confirmation of a cross section's validity, we opted to include the data in the model.

In thin-sediment areas, we expect the bedrock surface to closely match the topographic profile of the area. Where few subsurface data exist and where topography changes rapidly, the bedrock elevation model is unable to adequately reflect these topographic changes. This results in the bedrock elevation model 'floating' above the topography in these locations. Due to this unreliability in the model, we replaced the erroneous bedrock elevation with 'no data' (blank areas on Map A).

Subtraction of the bedrock elevation from the topographic raster determines the reliability of the bedrock elevation model. Negative sediment thickness values resulting from this calculation represent unreliable areas in the sediment thickness model; these areas are shown on Map B, and include areas with thickness values of 100 ft or less. In these areas, further work or additional data are required to determine either bedrock elevation or sediment thickness.

CONCLUSION

This model represents a significant step forward in understanding bedrock topography in the Puget Lowland. It is the first fully digital representation of bedrock at this scale; it incorporates a wider variety of data sources and a greater volume of data than used in previous bedrock elevation and (or) sediment thickness models. However, significant improvements to the model are possible with additional data and refined methods. For example, study-wide 1:24,000-scale mapping and complete mapping of the sea-floor would greatly improve the resolution of the mapped bedrock extent. This, in conjunction with refined methods of modeling in areas of shallow sediment thickness, would reduce the uncertainty in many areas. Incorporation of additional marine and on-land seismic track lines would greatly improve understanding of bedrock depth in deep structural basins. Though much seismic reflection data exists for the region, it currently has limited usefulness due to the lack of interpretation, its limited public availability, and significant discrepancies in calculated depths.

Lambert conformal conic projection
North American Datum of 1983
Shaded relief generated from U.S. Geological Survey 30-meter digital elevation model; sun azimuth 340°; sun angle 45°; vertical exaggeration 1.4
GIS by Daniel W. Eungard
Digital cartography by Ian J. Hubert, Anne C. Olson, and Jessica L. Czajkowski
Editing and production by Jessica L. Czajkowski