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Sediment sourcing in Cascade watersheds and nearshore dispersal of terrestrial sediment and contaminants using multivariate geochemical analysis

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Sediment for habitats and species

- Sufficient sediment of good quality sustains tide flats, beaches, and marshes used by valued Salish Sea species.

- Watershed and shoreline development alters sediment flows, introduces contaminants, and curtails inputs to the coast.

- Conservation, management, and recovery of coastal habitats and species requires an understanding of land-based sediment and contaminant sources and dispersal in the coastal ocean.

- Sediment sourcing and dispersal are described in the Nooksack River/Bellingham Bay using principal component analysis of sediment composition.
Sediment collection

Bellingham Bay, March 2019
- Delta front, urban waterfront, urban creeks, Chuckanut, Samish Bay
- N=36 used in PCA

Nooksack River, Sept 2017
- lowlands: floodplain (~45 km)
- uplands: North Fork, Middle Fork, South Fork, Mt. Baker
- N=25 used in PCA
Methods

Analytical methods

• Oven dry, dry sieve to get fine sediment, <0.063 mm
• Total sediment decomposition by sodium peroxide fusion (AGAT Laboratories)
• Quantification by ICP-MS

Statistical methods

• Identify 12 relatively refractory elements and ratios characteristic of watershed rock types
  • Al, Cr, La, Mg, Nb, Ni, Rb, Sr, Th
  • La/Yb, Eu anomaly, total REE content
• Log-transform for normality
• R Statistical Software
• Principal component analysis (PCA) ‘prcomp’, standard-normal, singular value decomposition
• Characteristic elements in PCs show sediment sources
• Geographic score plots show dispersal
PCA results: 4 significant PCs, explain 87% of geochemical variance in surface fine sediment

<table>
<thead>
<tr>
<th>Percent of variance</th>
<th>Cumulative variance</th>
<th>Dominant variables</th>
<th>Attributed to:</th>
<th>Dominant variables</th>
<th>Attributed to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(+) pattern</td>
<td></td>
<td>(-) pattern</td>
</tr>
<tr>
<td>PC1</td>
<td>39%</td>
<td>39%</td>
<td>La, ΣREE</td>
<td>Chukanut Formation (sandstone)</td>
<td>Eu</td>
</tr>
<tr>
<td>PC2</td>
<td>28%</td>
<td>67%</td>
<td>Ni, Cr</td>
<td>Ultramafic rocks (South Fork, Boulder Cr.)</td>
<td>Sr</td>
</tr>
<tr>
<td>PC3</td>
<td>11%</td>
<td>78%</td>
<td>Rb</td>
<td>marine shale (e.g. Nooksack Formation)</td>
<td>Cr</td>
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<tr>
<td>PC4</td>
<td>9%</td>
<td>87%</td>
<td>Al</td>
<td>clay minerals</td>
<td></td>
</tr>
</tbody>
</table>

Eigenvalue of each PC
significant if ≥ 1.0

Variance explained by each PC

Proportion
Cumulative
Principal Components 1, 2 variable loadings, site scores

PC1  Mt. Baker  ( - )  plagioclase  
(high Eu)

PC2  Ultramafic  
rocks (Ni, Cr, Mg)

PC2  Mt. Baker  
volcanics (Sr)

Chuckanut  PC1  
granitic rocks  ( + )  
(high REE)

TAB, PD = Mt. Baker volcanic rocks
Blue = lowlands, steams
Green = South Fork Nooksack ultramafic
Black = Nooksack North, Middle Forks, Bellingham Bay

PROXIMITY = SIMILARITY
Principal Components 3, 4 variable loadings, site scores

PC3 ( - ) Mt. Baker heavy minerals (Cr)

PC4 ( + ) Clay minerals (high Al)

PC4 ( - ) Sandy sediment (low Al)

Marine shale (Rb) ( + )

PROXIMITY = SIMILARITY

TAB, PD = Mt. Baker volcanic rocks
Blue = lowlands, steams
Green = South Fork Nooksack ultramafic
Black = Nooksack North, Middle Forks, Bellingham Bay
dispersal of fines from Chuckanut formation

dispersal of fine grained-sediment from South Fork UM rocks

CHUCKANUT sandstone
PC 3, 4 score plots

- dispersal of fines from North Fork/ marine shale (green)
- occurrence of clays (blue), sand (white)
Organic matter sourcing

Both $\delta^{13}$C, $\delta^{15}$N show:

- east Bellingham Bay dominated by terrestrial C, N
- Chuckanut coast, Samish Bay dominated by marine C, N
Summary

• The Nooksack River, with headwaters on Mt. Baker, a Cascade volcano, carries sediment from a wide range of rock types that can be distinguished on a geochemical basis in the nearshore.

• Fine-grained ultramafic sediment from the South Fork of the Nooksack river accumulated on the east side of the Delta.

• Fine-grained sediment along the urban Bellingham Bay waterfront was primarily volcanic from the North, Middle Forks of the Nooksack River, and organic matter from terrestrial sources.

• Sediment south of Bellingham Bay was primarily sourced from the Chuckanut coast, and organic matter from marine sources.

• Linkages between sediment-associated contaminants and sources/land uses are being explored to inform risk assessments.
Thank you!

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• email Renee Takesue (rtakesue@usgs.gov) for more information about this study