Proterozoic of the Pacific Northwest
Precambrian Review

Time Span: ~ 4.6 b.y. to 545 m.y.

-87% of geologic time (very dull!)

- 21 hours of 24 hr clock!
Relative Ages of Rocks

- Belt Supergroup rocks = ~1.5-1.4 b.y.
- Oldest regional rocks = 3.2 b.y. (Stillwater Complex, SW MT)
- Oldest rocks on Earth = 3.96 b.y.
- Earth age = 4.6 b.y.
Proterozoic Geologic Setting

Very little atmospheric oxygen

Biosphere: bacteria and blue-green algae
(stromatolites)

Tectonics: “modern” plate tectonics at work
Plate tectonics and recycling Earth’s crust

Tectonics drive the Rock Cycle!
Rodinia from late Archean through Proterozoic - the first Supercontinent?

Laurentia assembles:
N. America, Greenland, western Europe

- larger, stable continents form
- constant refinement of paleogeographic reconstructions
Belt Supergroup rocks - the local story

Belt-Purcell Supergroup (Canada/U.S.)

Little Belt Mts - sill through mountain (Walcott, 1890's)
Rock types (varying metamorphism, predominately low grade)

90% is fine sand or smaller grain size (chemical weathering working)

Middle Proterozoic age from sills/flows and zircons

Very thick sediment package!
Lack of land plants to stabilize sediment

- braided stream systems
- unconfined sheet flow
- much sediment deposited by waning $H_2O$ currents (fining upward sequences)
Modern offshore sediment distribution “bands”
Igneous Rock Types

Sills: igneous intrusions follow layers
- alteration at contact zones

Basalt flows: surface eruptions
- pillow lavas after entering water
Reading the rocks: clues from the sedimentary structures

Common shallow water indicators:

- salt casts
- raindrop impressions
- mudcracks!
Modern Day Mud Cracks

Notice how the edges of the cracked mud curl upwards as they contract during the drying process.
shallow water ripples
Cross beds from sediment transport

Which way was up?
Stromatolites: algal “heads”

- alternating layers of blue-green algae & sediment
Topography surrounding the basin - clues from the sediment textures and sediment composition

Sediment influx w/ subsidence: isostacy

- basin remains shallow over time
Belt Stratigraphy

Stratigraphic Units:
- Supergroup
- Group
- Formation
- Member
- Bed
How to subdivide 10 miles of stratigraphic section into workable units?

Sediment types of Winston used for accurate descriptions & communication
Table 26.1: Geologic Column, Glacier National Park

<table>
<thead>
<tr>
<th>Time Units</th>
<th>Rock Units</th>
<th>Geologic Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Era</td>
<td>Period</td>
<td>Epoch</td>
</tr>
<tr>
<td></td>
<td>Tertiary</td>
<td>Major erosional interval</td>
</tr>
<tr>
<td>Mesozoic</td>
<td>Montana</td>
<td>Return of seas depositing Cretaceous beds; Laramide orogeny—folding, uplift, thrust faulting, vertical faulting.</td>
</tr>
<tr>
<td>Paleozoic</td>
<td>Major erosional interval</td>
<td></td>
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</tbody>
</table>

Late Precambrian (Proterozoic Y) Belt Supergroup

- Kintla (Mt. Shields): Red argillite, increasing aridity
- Shepard: Red to yellowish brown argillite, stromatolites
- Snowslip: Pale red to green argillite, pillow lava, ripple marks, mudrocks
- Helena (Siyeh): Tan dolomite, diorite sill, oolite zone, stromatolites
- Empire: Buff to tan argillite and quartzite; copper
- Grinnell: Red to purplish red argillite and quartzite; ripple marks, mud cracks
- Appekunny: Gray to greenish argillite and quartzite; ripple marks, tidal mud flats
- Altyn (east): Tan- to cream-colored limestone and dolomite, stromatolites, ripple marks (shallow water)
- Prichard (west): Dark gray to black argillite (deep water)
- Waterton (Alberta): Red brown to gray dolomite

Sources: Alt and Hyndman, 1986; Harrison, 1972; Raup et al, 1983.
Correlation of Belt Supergroup units from Kellogg area to Glacier National Park
Lower Belt (Prichard Formation)

Purcell sills/lavas: 1.5 b.y. near base
- dark and "rusty" (sulfide mins)
- deep $H_2O$ @ bottom; shallows up

Turbidite deposition:
waning density currents
Fig. 3.—Correlation of banded member over 12 miles. CL and ML are from Cooper Lake and Moyie Lake sections, British Columbia. (Locations shown on Figure 1.)

Fig. 4.—Correlation of banded member, 85 miles separation between locations EF and JS. EF and RR are from East Fork Creek and Ruby Ridge sections, Idaho; JS is from Jim Smith Park section, British Columbia. (Locations shown on Figure 1.)
Is the Belt basin an aulacogen?

(failed arm of rift triple-junction)
Ravalli Group

Shallow water conditions dominate
- exposed mudflats & alluvial aprons

St. Regis Formation

Revett Formation

Burke Formation
Common shallow water features in Ravalli Group Rocks

Isolated ripples in thin couplets (fining upward)
Middle Belt Carbonate
Wallace/Helena Formation: carbonate content
- connection to ocean?
- stromatolites (algal heads) common in Glacier Park
Wallace Formation:

- pinch & swell
- sediment type

Dark argillite caps & subjacent deformation at bases of sands
Missoula Group: back to wet/dry cycles

- Libby Formation
- Bonner Formation
- Mount Shields Formation
- Shepard Formation
- Upper Wallace (Snowslip)

Extensive mudcracked flats, distal fans, braided stream complexes
Extensive cracked and chip-rich strata, Missoula Group in Glacier

“armored mud balls”
Snowslip Fm.,
Western Montana
Oddities in the Belt

Why so many wet/dry oscillations?
- tidal?
- seasonal?
- eustatic sea level changes?

Overlooked unconformities?
- 100 m.y. without mt. building unusual!
Correlation across the basin

- matching units and lateral changes

- metamorphism and lack of fossils (acritarchs and stromatolites)
Economic Deposits in the Belt

Coeur d’Alene District: Silver Valley

- Lead (galena)
- Silver (tetrahedrite)
- Zinc (sphalerite)
Source of original mineralization?

- “black smokers?”
- syndepositional in PC time
- remobilization of ore minerals?
Current mining efforts

Environmental Concerns

Downstream contamination

- Pb travels as particles
- Zn transport in solution
Changes in mining over time

- first mill in 1886:
  - jig tailings (cubes)

- nature (streams) to remove tailings

- floatation method (1930): slimes

- 70 million tons into drainage

- pollution easements downstream
- smelter effects ($H_2SO_4$ production)
- 1968: last river discharge
- end of Cataldo dredging
Abandoned mines

- acid mine drainage concerns
- dissolved Zn in waters
- S from sulfide minerals
Tectonic History of Belt Basin

- Belt as a fault-bounded basin?

Continental rifting: ~1.5 by to create the basin

- Belt-Purcell deposition follows
Is the Belt basin an aulacogen?

(failed arm of rift triple-junction)

- mt. building @ end of Belt time

- Windermere Group deposition, 800my

- Snowball Earth follows!
Windermere Group deposition, 800my

- late Proterozoic, ~ 20,000 ft

- coarse, immature seds from uplift

- sediment wedge westward into open ocean

- diamictites, dropstones, glacial striations
glacial polish: age shown in roughness

- Pocatello Fm. - into Utah & Nevada
Snowball Earth?

-Late Proterozoic time
(after local Belt rocks)
1) Rodinia breaks up ~800 my ago

2) Many smaller continents with lots of rainfall near equator

3) Rainfall scrubs CO₂ from atmosphere

(less greenhouse gasses = cooler climate)

Breakup of a single landmass 770 million years ago leaves small continents scattered near the equator. Formerly landlocked areas are now closer to oceanic sources of moisture. Increased rainfall scrubs more heat-trapping carbon dioxide out of the air and erodes continental rocks more quickly. Consequently, global temperatures fall, and large ice packs form in the polar oceans. The white ice reflects more solar energy than does darker seawater, driving temperatures even lower. This feedback cycle triggers an unstoppable cooling effect that will engulf the planet in ice within a millennium.
4) White ice buildup reflects sunlight; more cooling

5) Cold dry air now limits removal of CO$_2$ from atmosphere

6) CO$_2$ from normal volcanoes builds up and starts to warm up climate

Average global temperatures plummet to -50 degrees Celsius shortly after the runaway freeze begins. The oceans ice over to an average depth of more than a kilometer, limited only by heat emanating slowly from the earth’s interior. Most microscopic marine organisms die, but a few cling to life around volcanic hot springs. The cold, dry air arrests the growth of land glaciers, creating vast deserts of windblown sand. With no rainfall, carbon dioxide emitted from volcanoes is not removed from the atmosphere. As carbon dioxide accumulates, the planet warms and sea ice slowly thins.
Concentrations of carbon dioxide in the atmosphere increase 1,000-fold as a result of some 10 million years of normal volcanic activity. The ongoing greenhouse warming effect pushes temperatures to the melting point at the equator. As the planet heats up, moisture from sea ice sublimating near the equator refreezes at higher elevations and feeds the growth of land glaciers. The open water that eventually forms in the tropics absorbs more solar energy and initiates a faster rise in global temperatures. In a matter of centuries, a brutally hot, wet world will supplant the deep freeze.
10) Intense evaporation and rainfall in hothouse conditions

11) Carbonate sediment forms in oceans as widespread limestones as a “carbon sink”

12) New life spreads out in newly warmed-up oceans

As tropical oceans thaw, seawater evaporates and works along with carbon dioxide to produce even more intense greenhouse conditions. Surface temperatures soar to more than 50 degrees Celsius, driving an intense cycle of evaporation and rainfall. Torrents of carbonic acid rain erode the rock debris left in the wake of the retreating glaciers. Swollen rivers wash bicarbonate and other ions into the oceans, where they form carbonate sediment. New life-forms—engendered by prolonged genetic isolation and selective pressure—populate the world as global climate returns to normal.
Precambrian Life

- stromatolites first appear in rocks 3.3 b.y ago

- variety of growth forms possible without grazers!
Ediacaran fauna - 670 m.y.

Multicellular organisms: heading toward the “Cambrian explosion”

Prokaryotes: no cell nucleus
- asexual reproduction
- not as much chance for mutations

Eucaryotes: complex cells (larger)
- nucleus contains genetic material
- sexual reproduction: gene sharing
- more mutations possible
- appear in Early Proterozoic