Geologic History of the Late Pleistocene Missoula Floods and Effects on the Modern Mid-Willamette Valley Landscape

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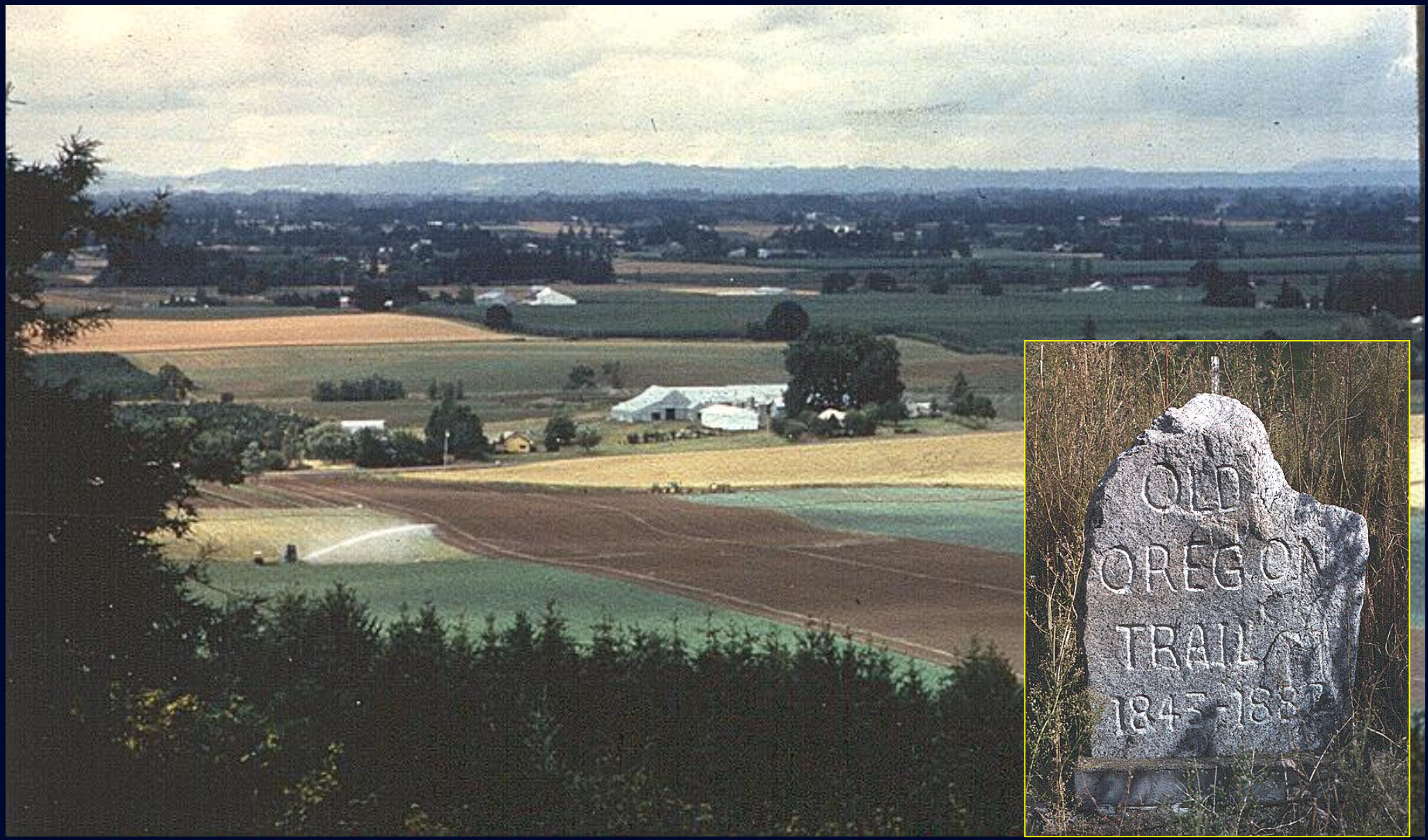
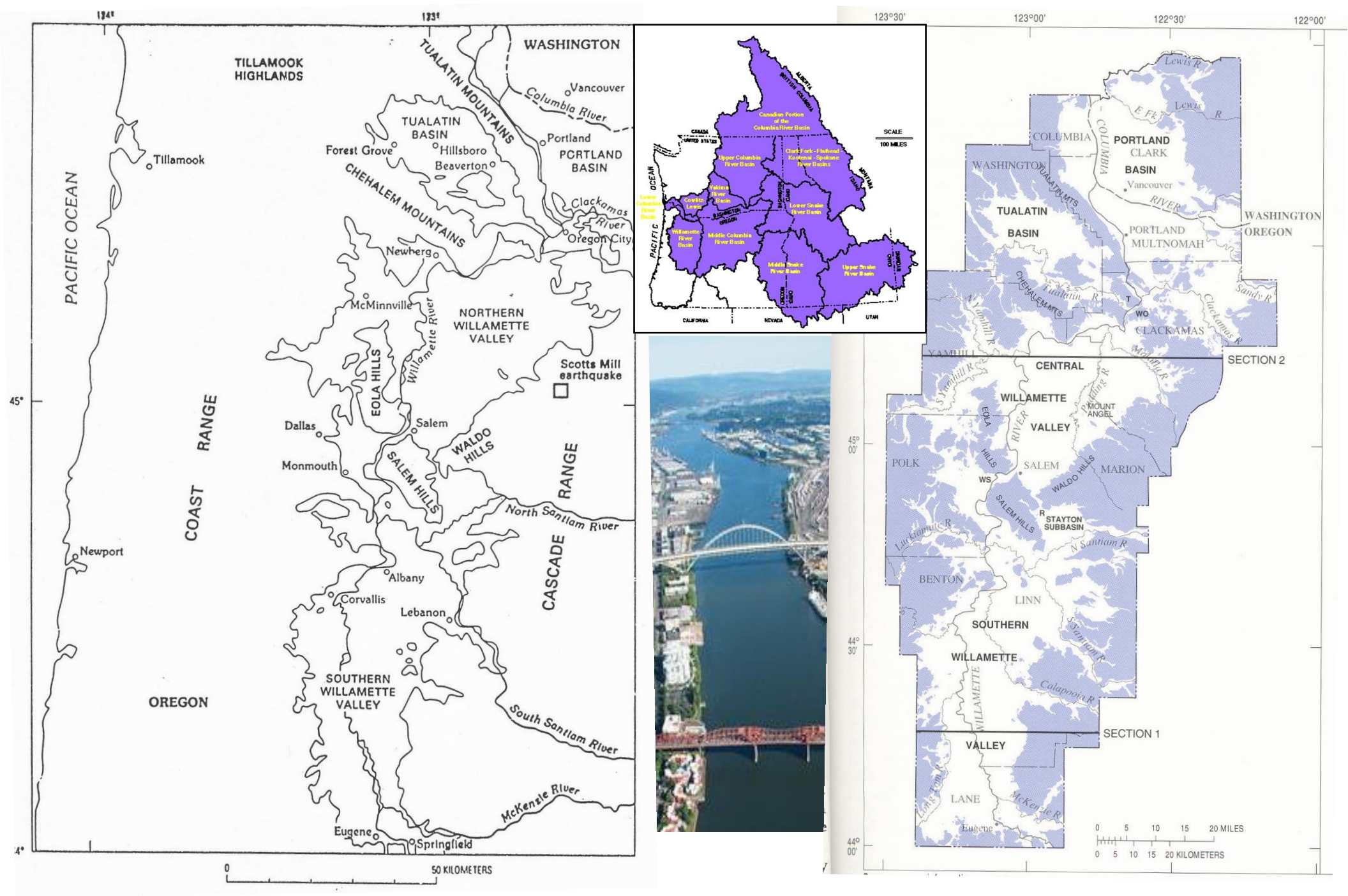
- Geologic Setting
- Glacial Lake Missoula
- Channeled Scablands / Columbia Gorge
- Willamette Valley-Missoula Flood Effects
- Summary and Conclusion

GEOLOGIC SETTING

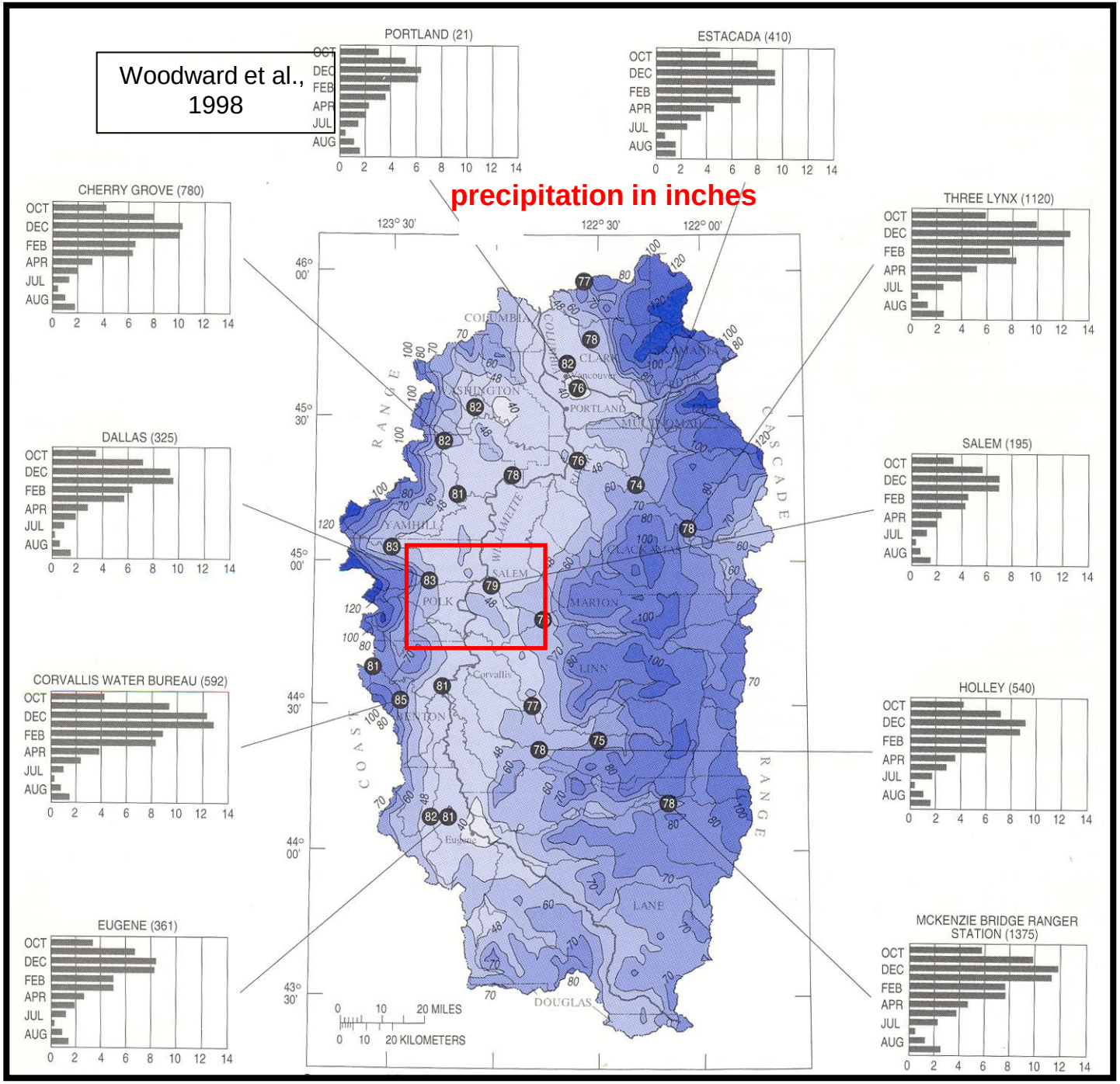

OLD
OREGON
TRAIL


124°
123°
WASHINGTON
TILLAMOOK HIGHLANDS
TUALATIN MOUNTAINS
Vancouver
Columbia River
TUALATIN BASIN
Forest Grove
Hillsboro
Beaverton
Portland
PORTLAND BASIN
CHEHALEM MOUNTAINS
Clackamas River
Oregon City
Tillamook
PACIFIC OCEAN
Newberg
McMinnville
NORTHERN WILLAMETTE VALLEY
Willamette River
EOLA HILLS
Scotts Mill earthquake
45°
Dallas
Salem
WALDO HILLS
Monmouth
SALEM HILLS
COAST RANGE
CASCADE RANGE
North Santiam River
Newport
Albany
Corvallis
Lebanon
SOUTHERN WILLAMETTE VALLEY
OREGON
South Santiam River
McKenzie River
Eugene
Springfield
44°
0
50 KILOMETERS
CANADA
UNITED STATES
ALBERTA
BRITISH COLUMBIA
Canadian Portion of the Columbia River Basin
SCALE
100 MILES
Upper Columbia River Basin
Clark Fork - Flathead Kootenai - Spokane River Basins
Yakima River Basin
Lower Columbia River Basin
Cowlitz-Lewis
WASHINGTON
OREGON
IDAHO
MONTANA
Lower Snake River Basin
Willamette River Basin
Middle Columbia River Basin
Middle Snake River Basin
Upper Snake River Basin
NEVADA
UTAH
CALIFORNIA
PACIFIC OCEAN
123°30'
123°00'
122°30'
122°00'
Lewis R
E Fk Lewis R
COLUMBIA
PORTLAND CLARK BASIN
Vancouver
WASHINGTON
TUALATIN MTS
RIVER
TUALATIN BASIN
WASHINGTON
OREGON
PORTLAND MULTNOMAH
CHEHALEM MTS
Tualatin R
Sandy R
T
WO
CLACKAMAS
Clackamas R
Molalla R
YAMHILL
SECTION 2
CENTRAL
WILLAMETTE
VALLEY
MOUNT ANGEL
EOLA HILLS
Pudding R
POLK
SALEM
MARION
WS
WALDO HILLS
SALEM HILLS
R
STAYTON SUBBASIN
Luckiamute R
N Santiam R
45° 00'
BENTON
LINN
SOUTHERN WILLAMETTE
S Santiam R
Calapooia R
SECTION 1
VALLEY
Long Tom R
LANE
McKenzie R
Eugene
44° 30'
44° 00'
0 5 10 15 20 MILES
0 5 10 15 20 KILOMETERS

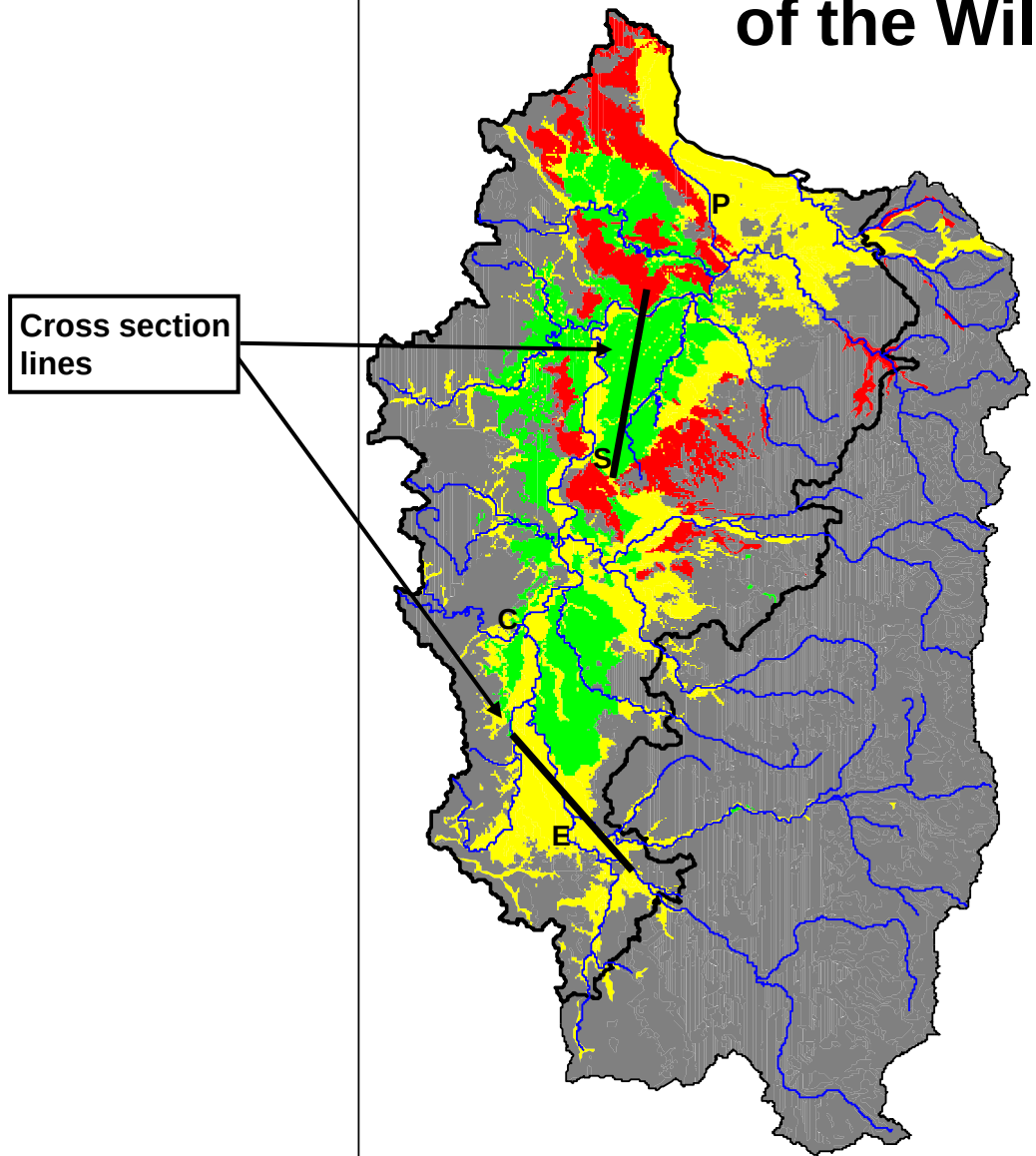

08.09.2005

Willamette Basin Average Monthly Precipitation

(1961-1990)



Generalized Geology of the Willamette Valley

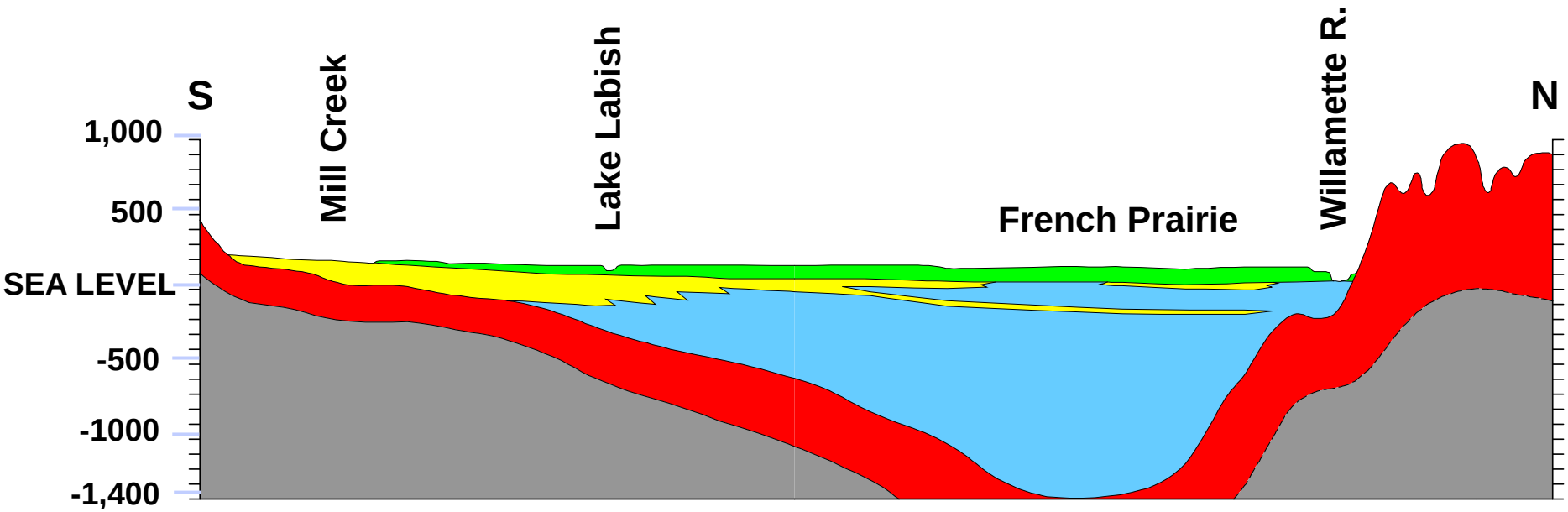


- Willamette Silt
- Alluvium and basin-fill sediment
- Columbia River Basalt Gp
- Marine sedimentary rocks And Cascade Range rocks

Gannett & Caldwell, 1998

0 10 20 30 MILES

NORTH-SOUTH SECTION THROUGH THE CENTRAL WILLAMETTE VALLEY



Willamette Silt

Alluvium and coarse-grained basin-fill deposits

Fine-grained basin-fill deposits

Columbia River Basalt Group lava

Marine sediments and Western Cascade rocks

Gannett & Caldwell, 1998

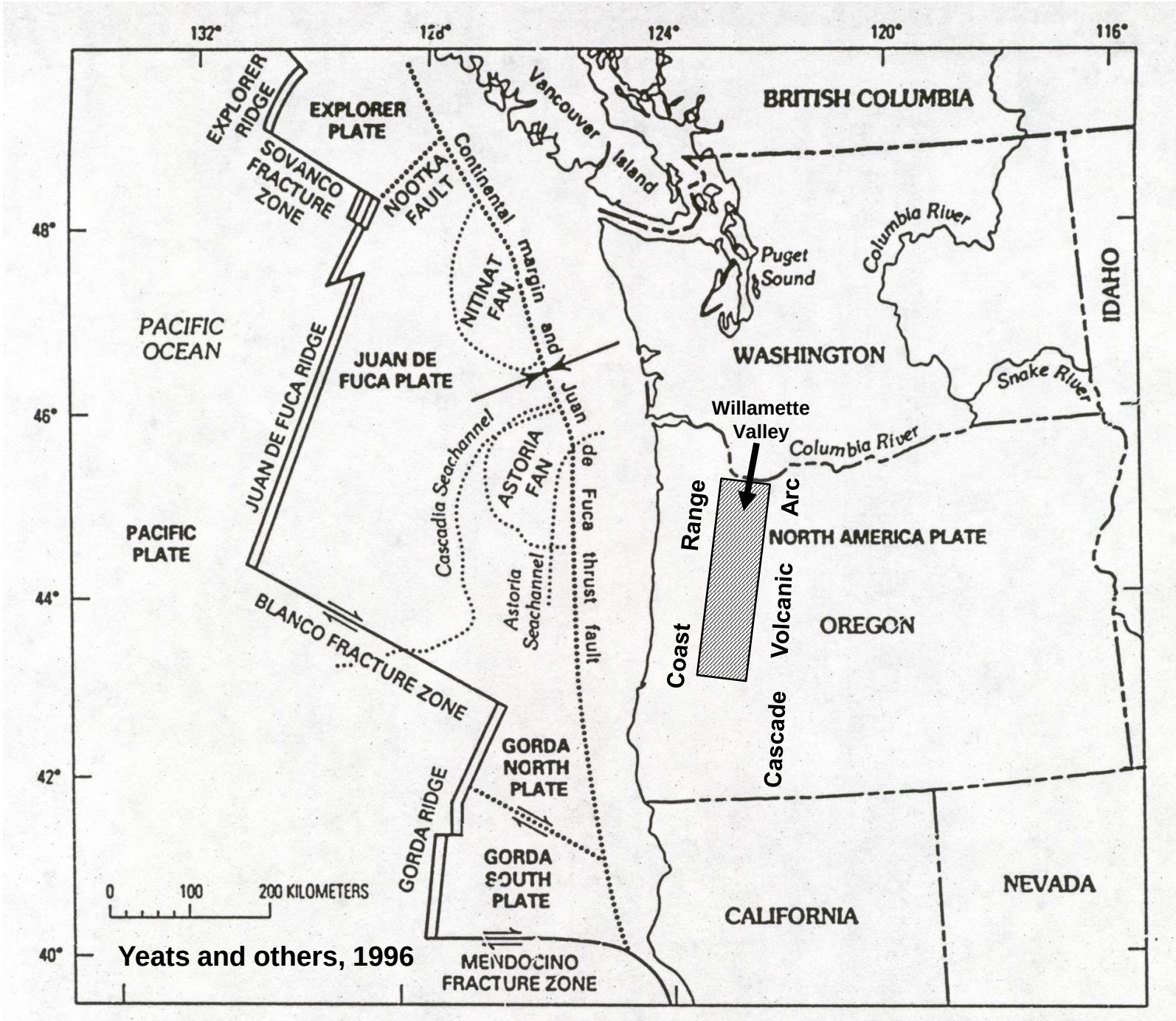
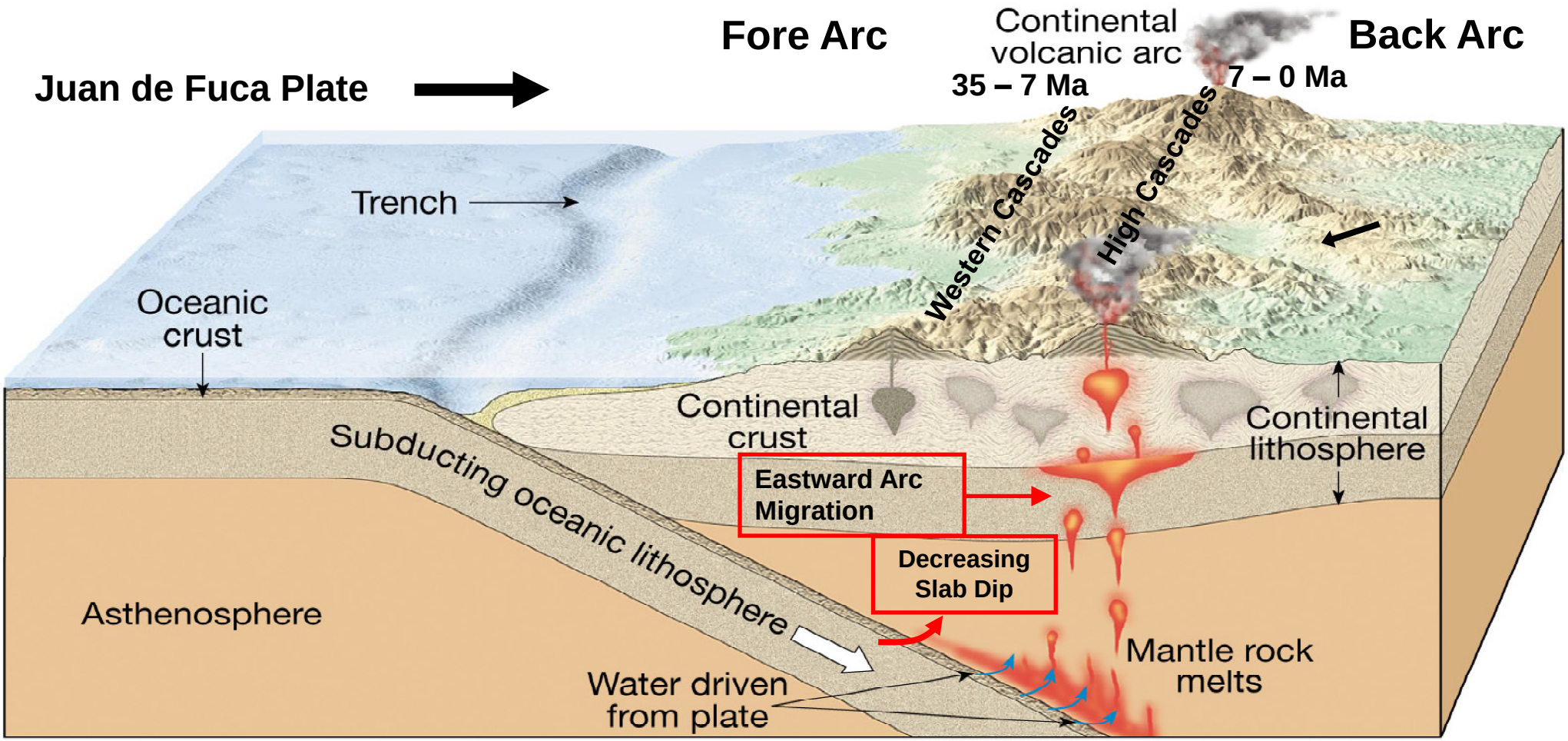
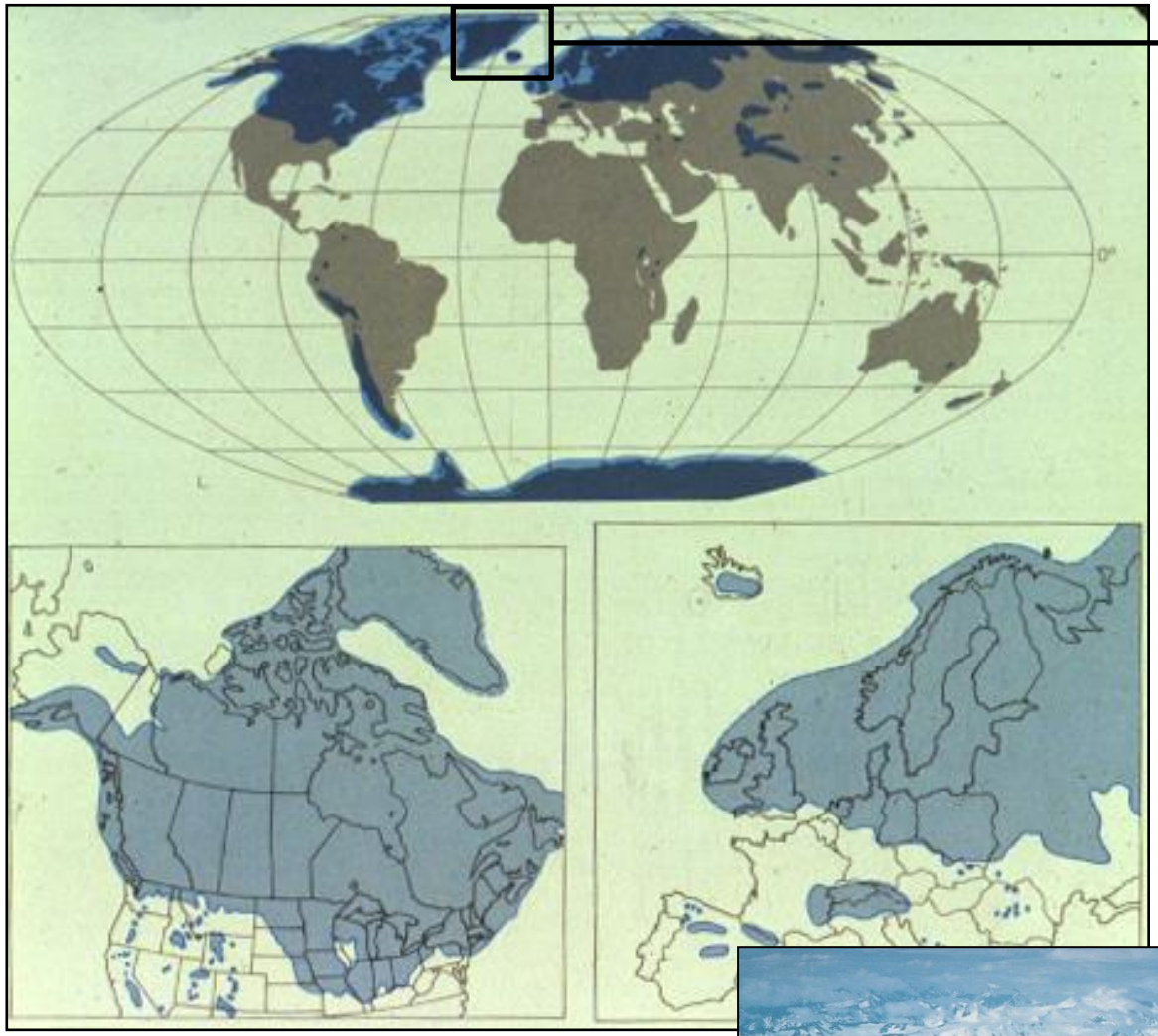
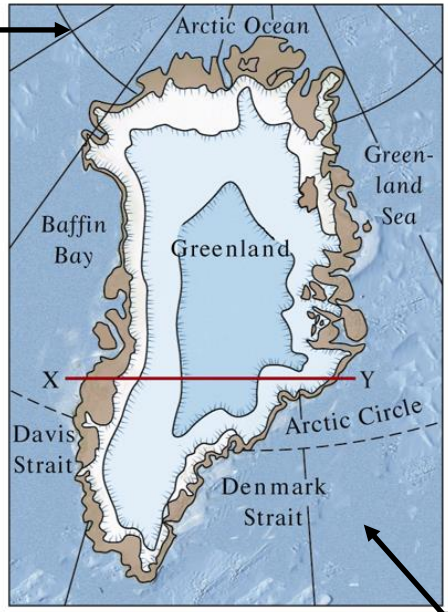
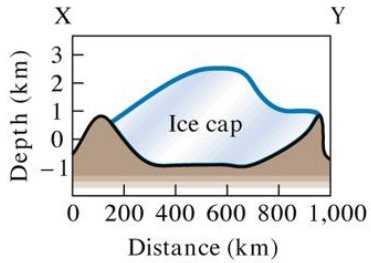

132°
128°
124°
120°
116°
48°
46°
44°
42°
40°
EXPLORER RIDGE
EXPLORER PLATE
SOVANCO FRACTURE ZONE
NOOTKA FAULT
Continental margin and
NITINAT FAN
Vancouver Island
BRITISH COLUMBIA
Puget Sound
Columbia River
IDAHO
PACIFIC OCEAN
JUAN DE FUCA RIDGE
JUAN DE FUCA PLATE
WASHINGTON
Snake River
Willamette Valley
Columbia River
Juan de Fuca thrust fault
Cascadia Seachannel
ASTORIA FAN
Astoria Seachannel
PACIFIC PLATE
Coast Range
Volcanic Arc
NORTH AMERICA PLATE
OREGON
BLANCO FRACTURE ZONE
GORDA NORTH PLATE
GORDA RIDGE
GORDA SOUTH PLATE
Cascade
NEVADA
CALIFORNIA
MENDOCINO FRACTURE ZONE
0 100 200 KILOMETERS
Yeats and others, 1996

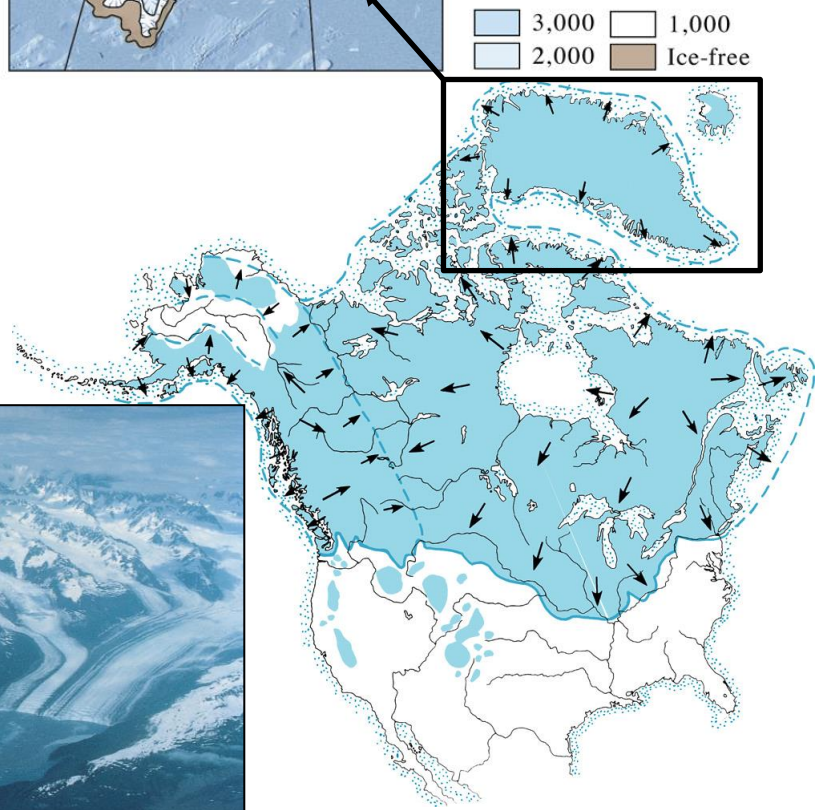
Plate Tectonic Framework







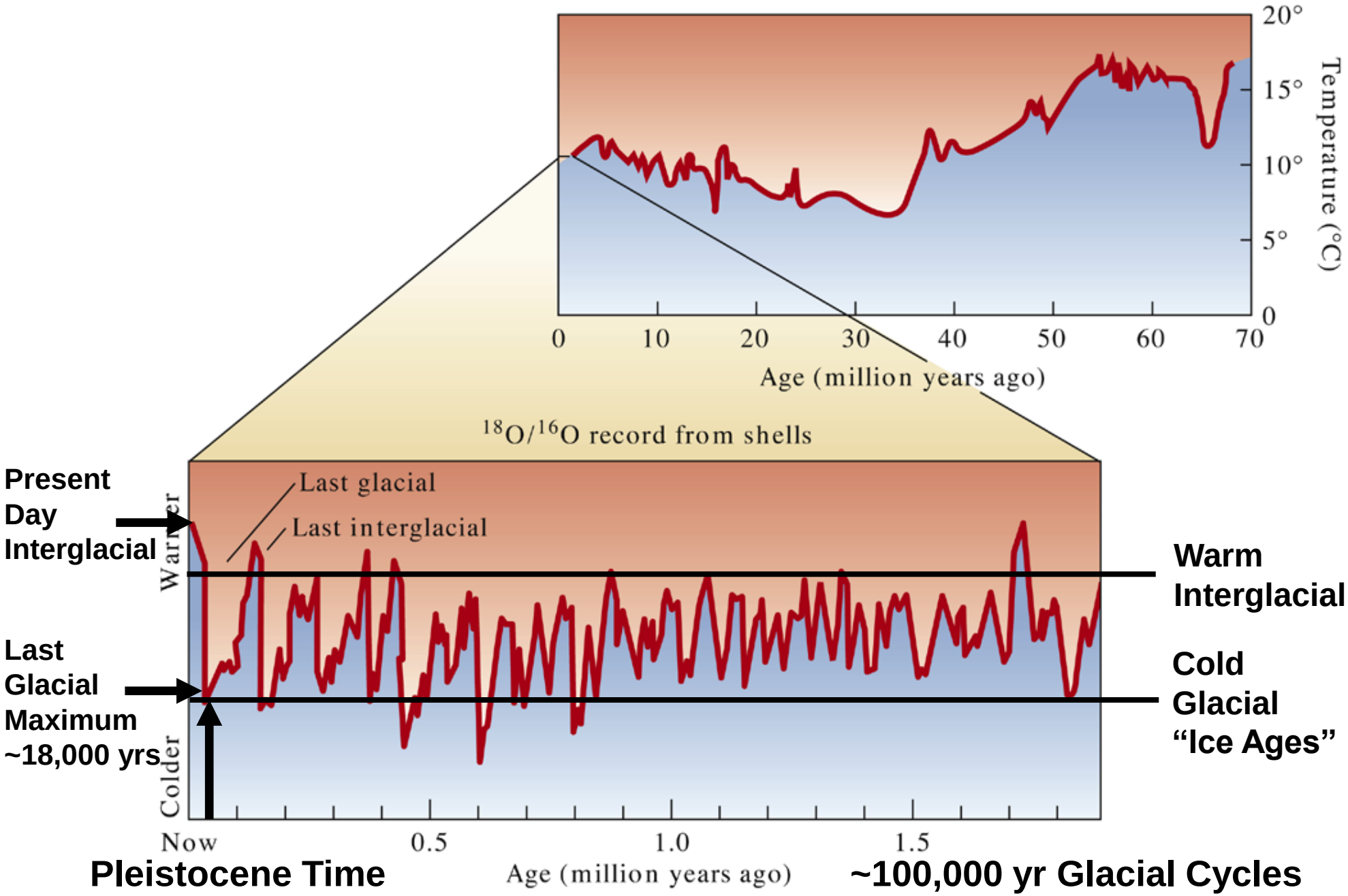




Last “Ice Age”

Global Ice Maximum
25% Earth Land Area
~18,000 Years Ago

GEOLOGIC FOSSIL RECORD OF PAST GLOBAL CLIMATE OVER TIME

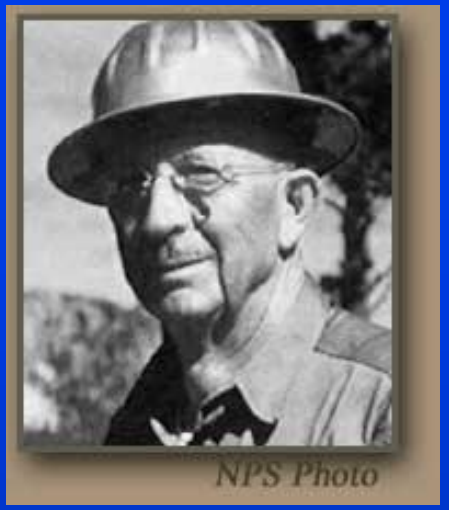


“Last Ice Age”

Pacific Northwest

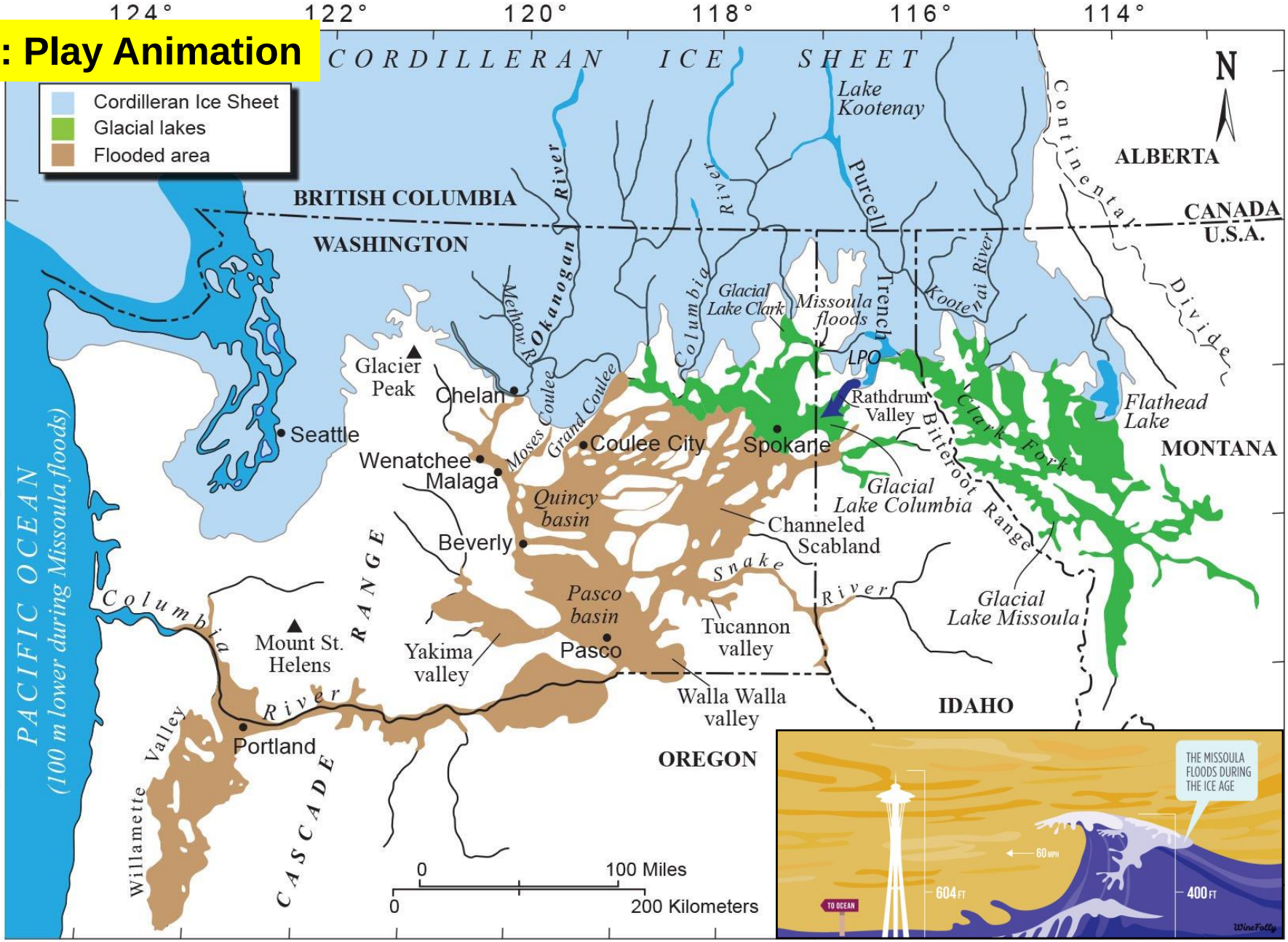
Missoula Floods Story

Missoula Floods Overview

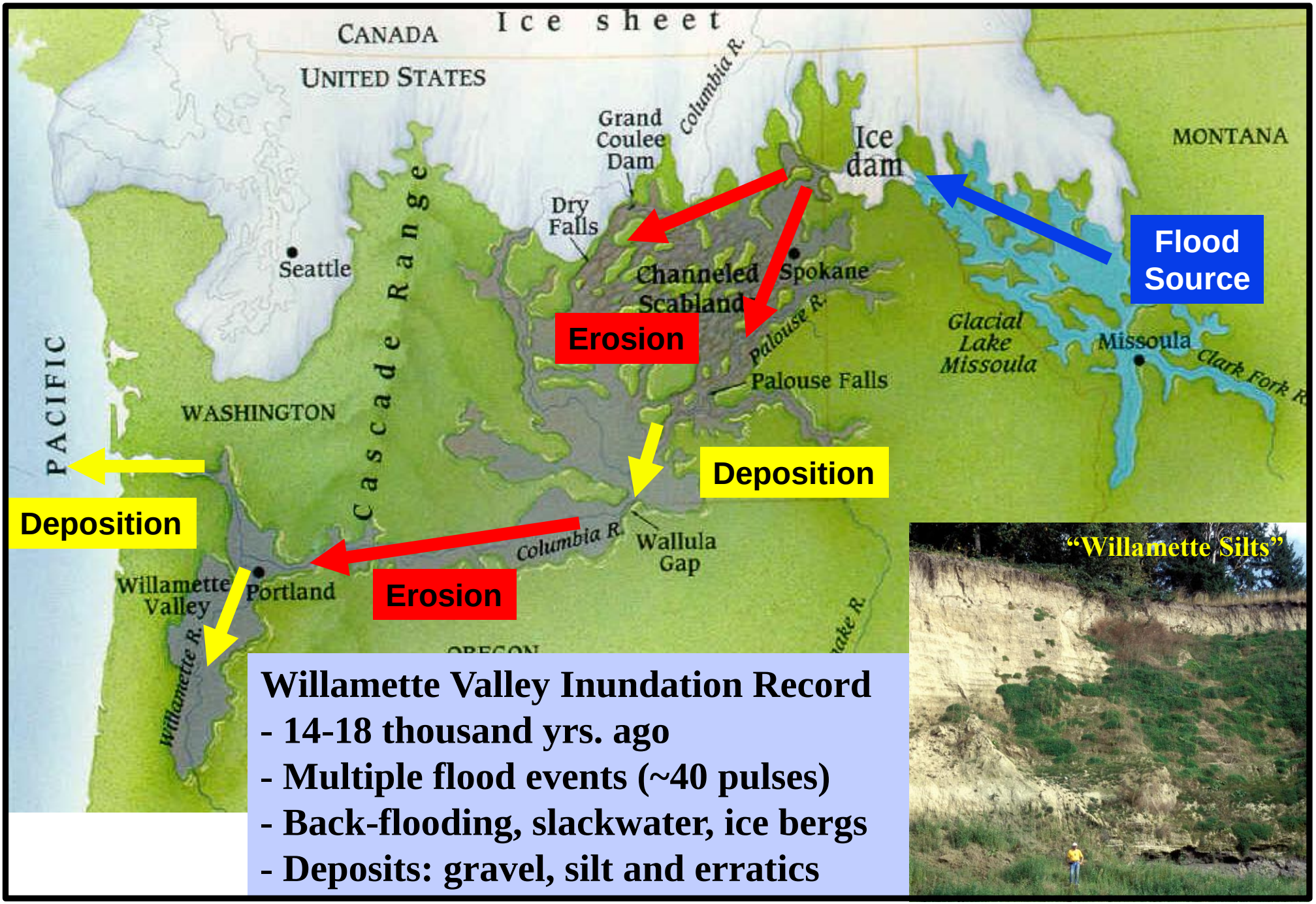


- **"Spokane Flood" hypothesis:** originally proposed by J Harlen Bretz, in the 1920s. Scientific debate lasted for 40 years, until agreement on evidence
- **Flood source:** ancient glacial lake Missoula, northwestern Montana, glacial ice dams in North Idaho
- **Flood path impact zone:** eastern Washington, Columbia River basin, Columbia Gorge, Willamette Valley, offshore seafloor
- **Landscape evidence:** lake deposits in western Montana, Channeled Scablands of eastern Washington, large flood deposits indicating high water levels, erratics and flood deposits in Willamette Valley
- **Flood magnitude:** maximum Lake Missoula volume = 2200 km^3 (Lake Erie + Lake Ontario), maximum flood discharge ~ 10 million m^3/sec (~10x global output of all modern rivers combined)
- **Frequency and timing:** dozens to over one hundred related flood events from 14,000-18,000 years ago; all variable timing and size

NOTE: Play Animation



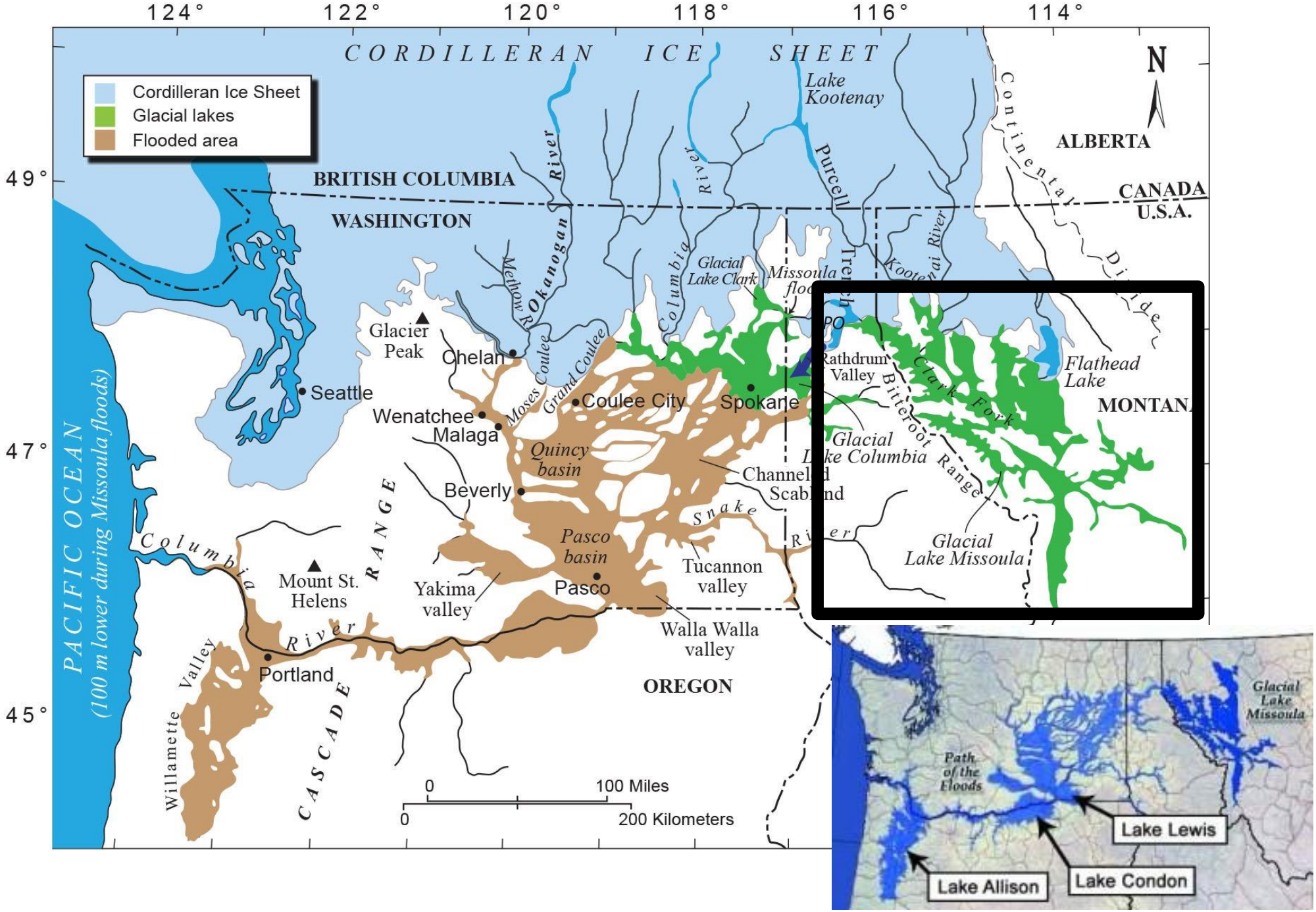
Late Pleistocene Paleogeography of the Pacific Northwest (~18,000 yrs ago)

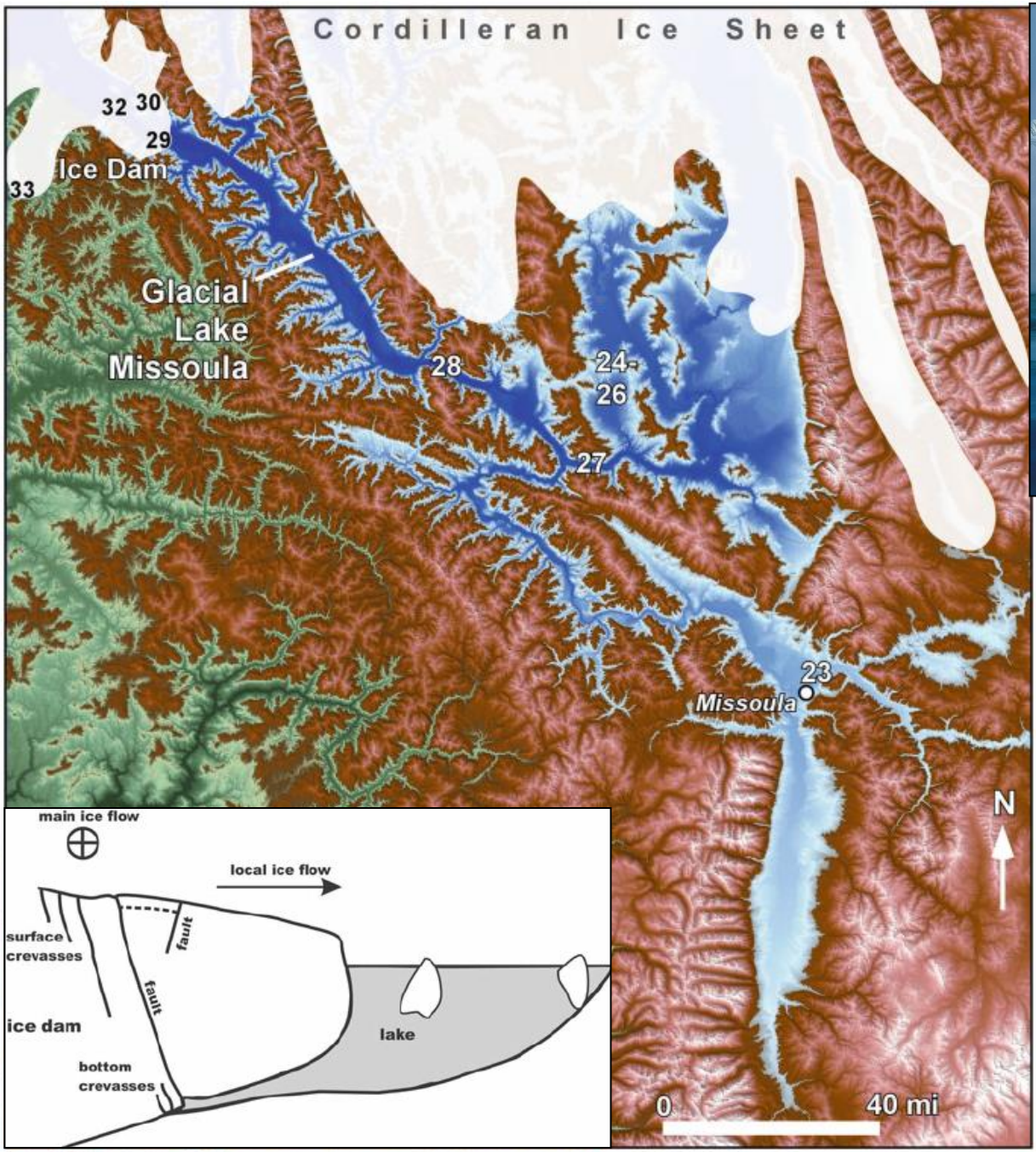


Willamette Valley Inundation Record

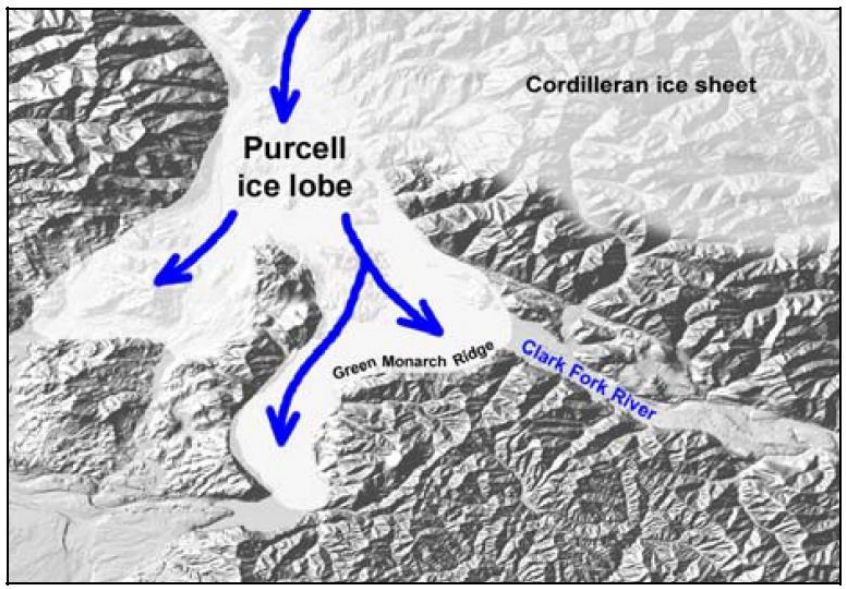
- 14-18 thousand yrs. ago
- Multiple flood events (~40 pulses)
- Back-flooding, slackwater, ice bergs
- Deposits: gravel, silt and erratics

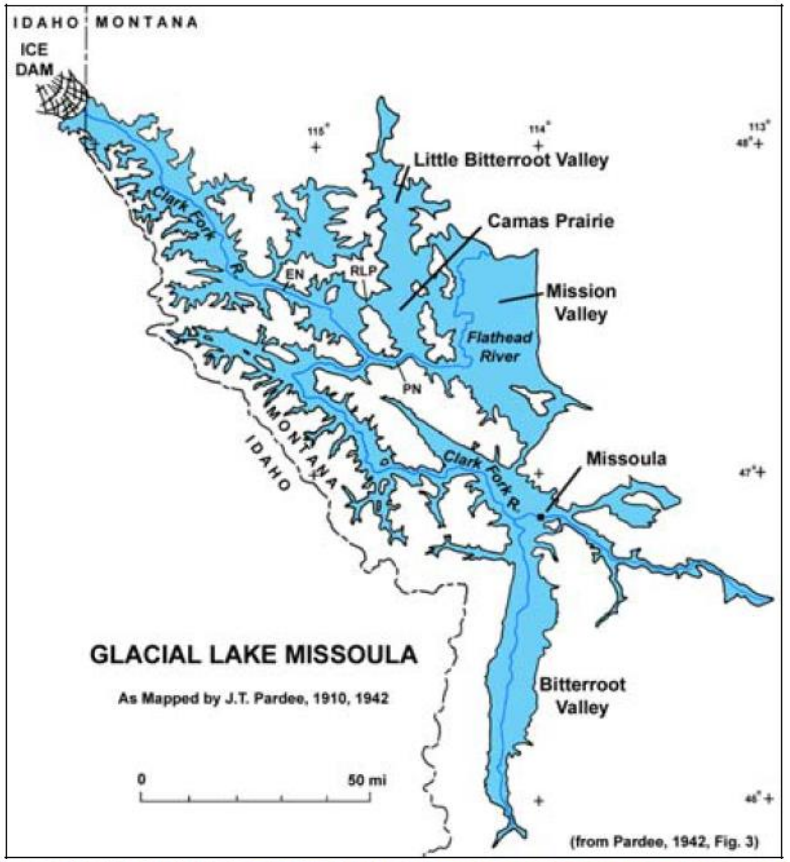
GLACIAL LAKE MISSOULA


124°
122°
120°
118°
116°
114°
49°
47°
45°
N
Cordilleran Ice Sheet
Glacial lakes
Flooded area
CORDILLERAN ICE SHEET
Lake Kootenay
ALBERTA
BRITISH COLUMBIA
WASHINGTON
CANADA
U.S.A.
Continental Divide
Purcell Trench
Kootenai River
Columbia River
Okanogan River
Methow
Glacial Lake Clark
Missoula flood
Glacier Peak
Chelan
Moses Coulee
Grand Coulee
Coulee City
Spokane
Seattle
Wenatchee
Malaga
Quincy basin
Beverly
Channeled Scabland
Snake River
Pasco basin
Pasco
Tucannon valley
Yakima valley
Walla Walla valley
Columbia River
Mount St. Helens
CASCADE RANGE
Portland
Willamette Valley
OREGON
PACIFIC OCEAN
(100 m lower during Missoula floods)
0
100 Miles
0
200 Kilometers
Rathdrum Valley
Flathead Lake
MONTANA
Clark Fork
Bitterroot Range
Glacial Lake Columbia
Glacial Lake Missoula
Path of the Floods
Lake Lewis
Lake Allison
Lake Condon



Purcell Lobe Clark Fork Ice Dam

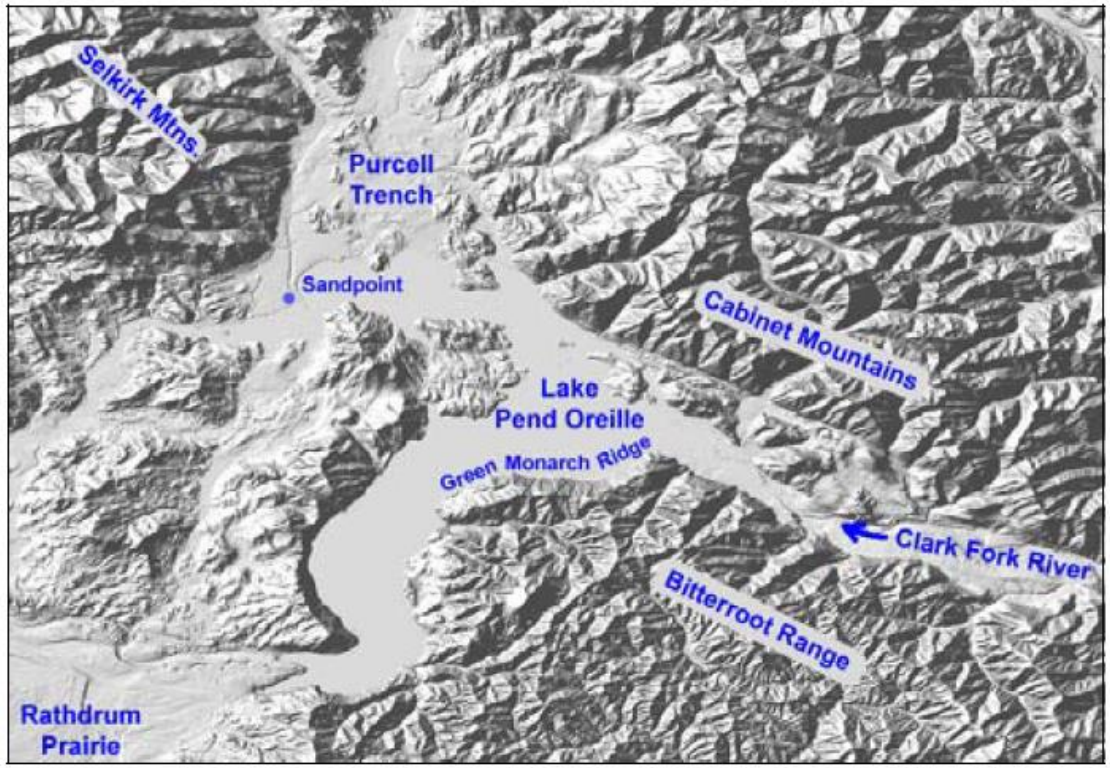


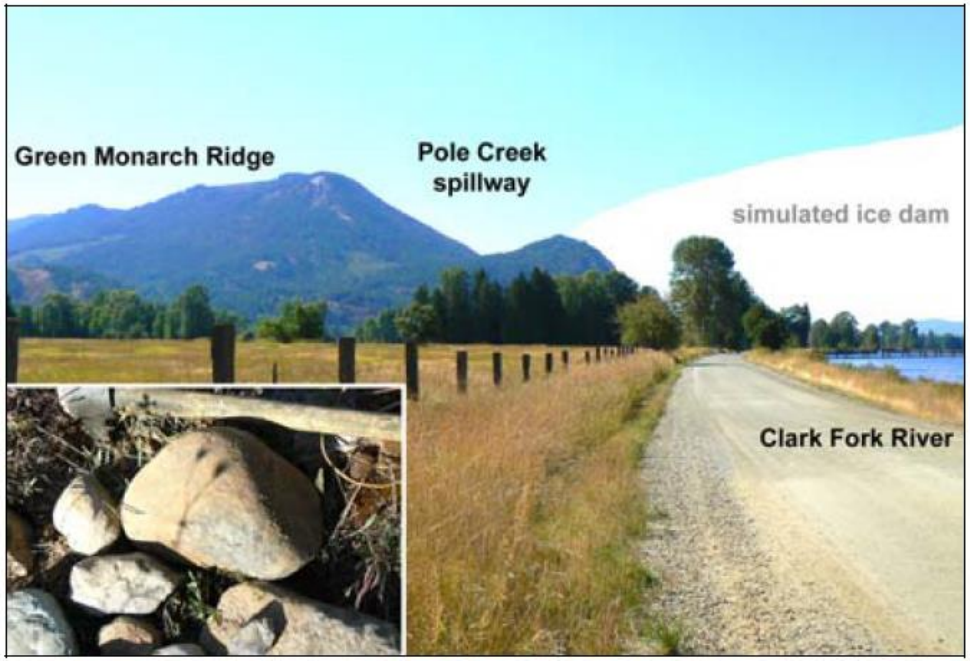


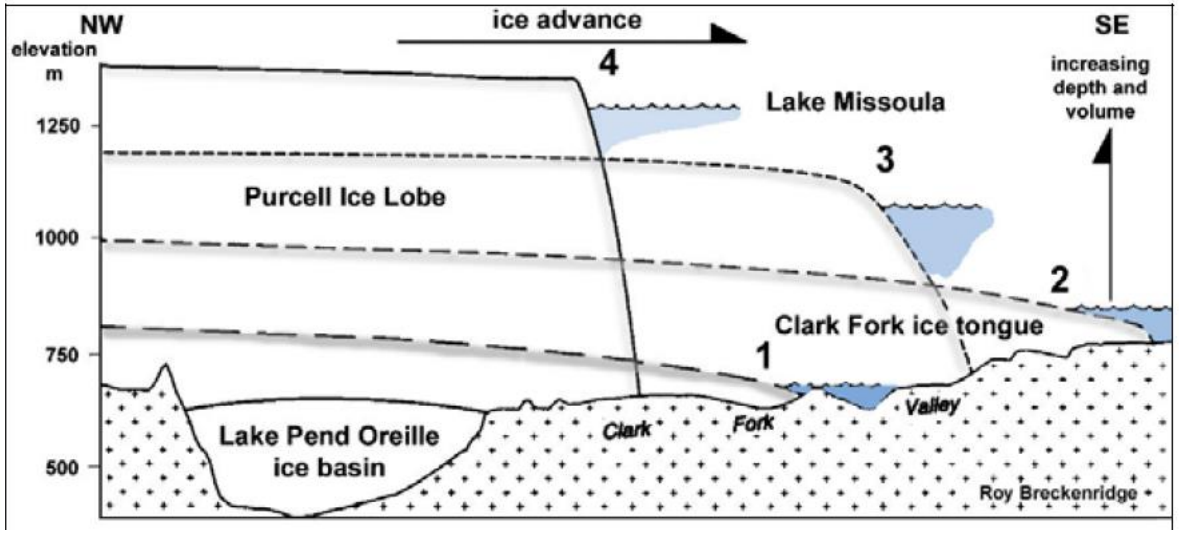
GLACIAL LAKE MISSOULA STATISTICS:

Area = 2900 mi^2 [7500 km^2]
Max Lake Elevation = ~4250 ft [1295 m]
Max Lake Depth at Missoula = 950 ft [290 m]
Max Lake Depth at Ice Dam = 2000 ft [700 m]
Max Lake Volume = 530 mi^3 [2200 km^3]
Volume Scale: > Lake Erie + Ontario combined

Clark Fork, Idaho (Ice Dam Locality)

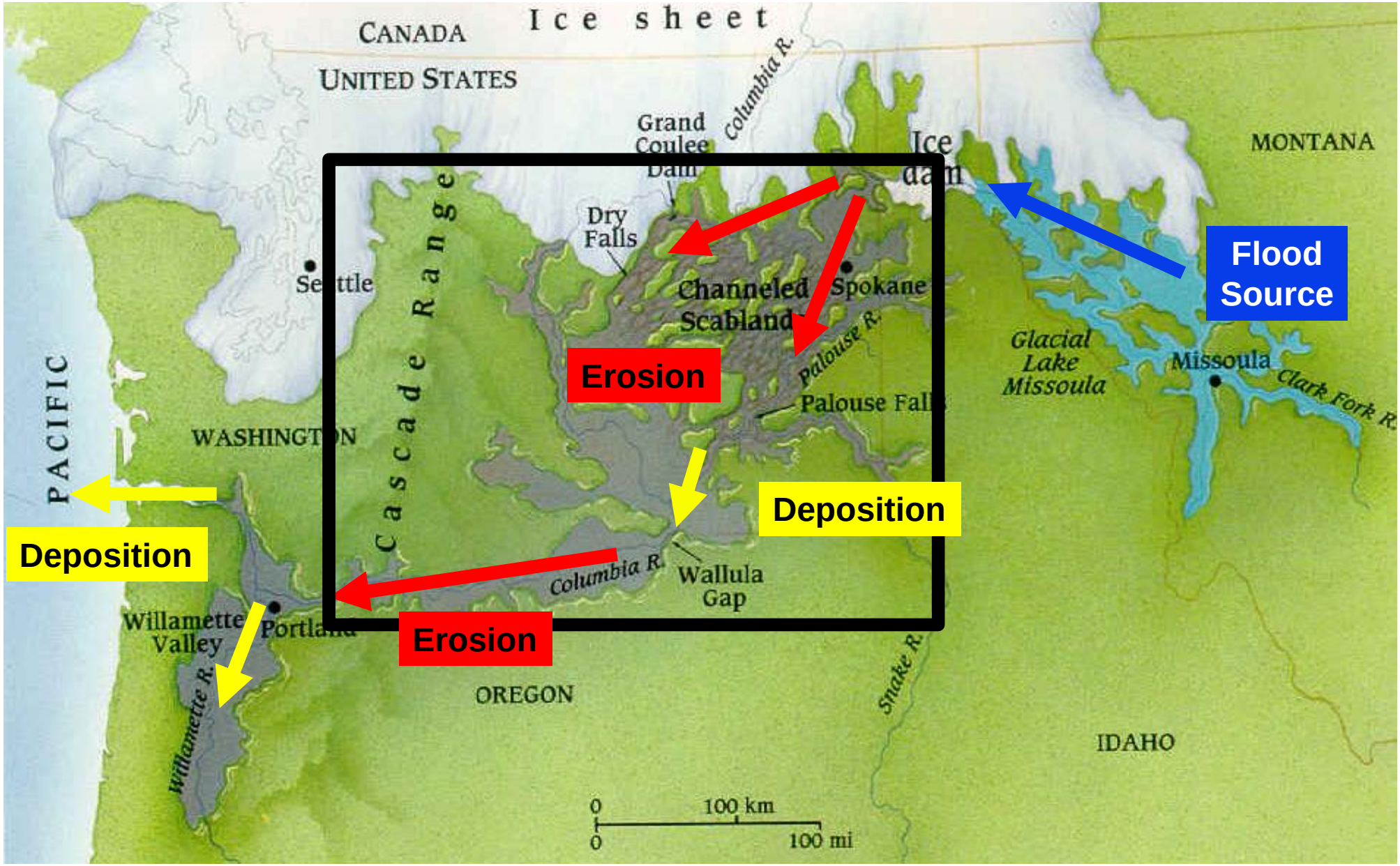


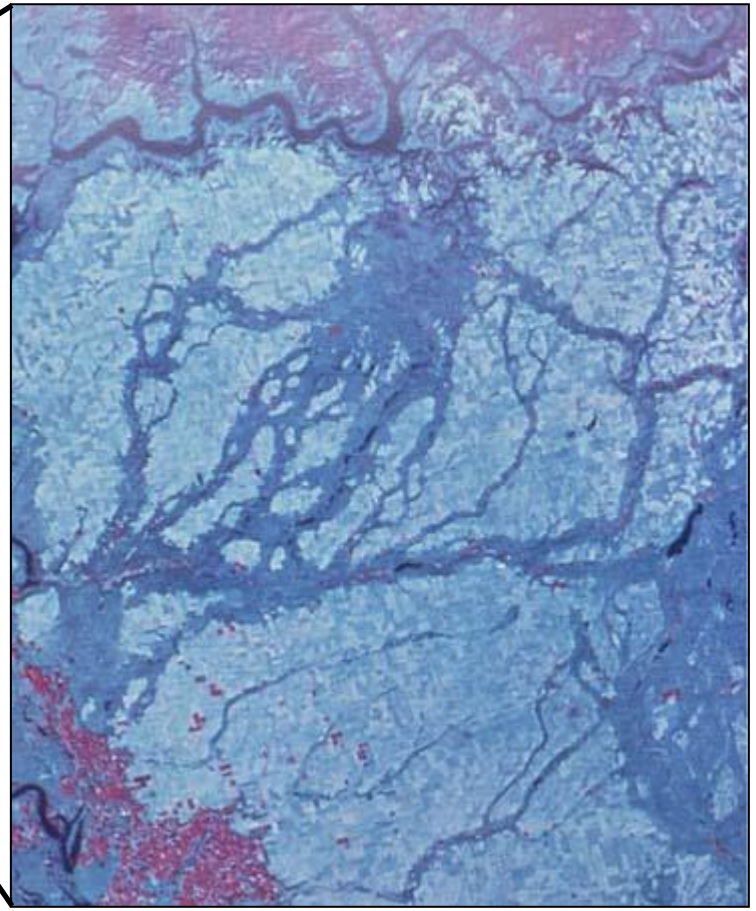




Lee, 2009

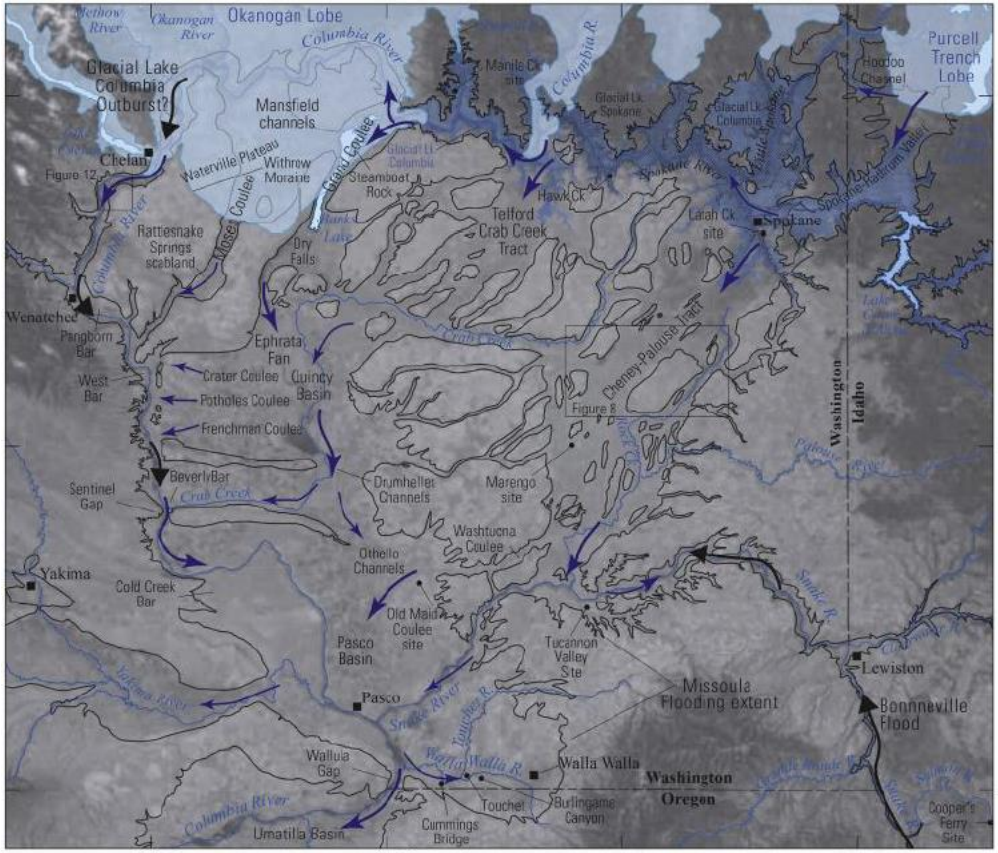
CHANNELED SCABLANDS AND COLUMBIA GORGE

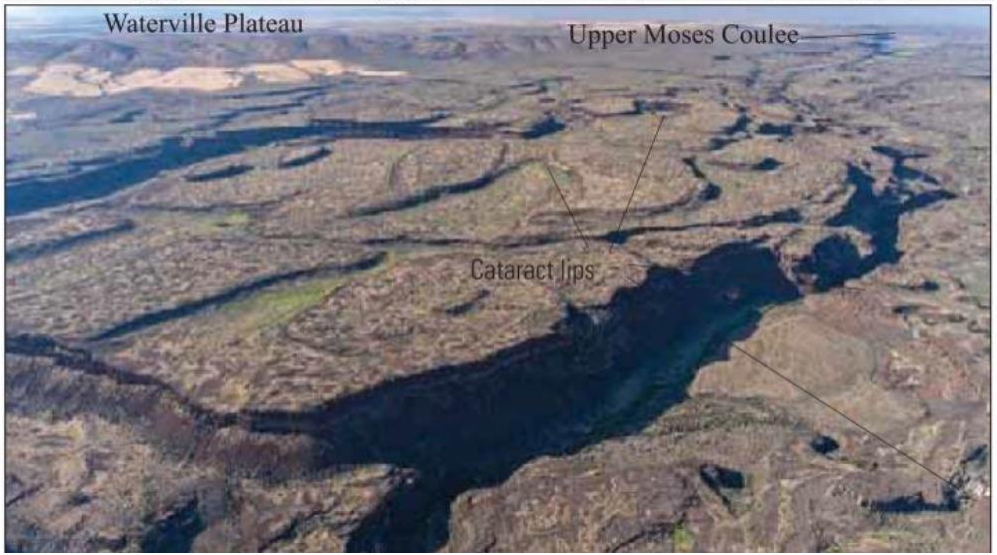

CANADA
Ice sheet
UNITED STATES
Columbia R.
Grand Coulee Dam
Ice dam
MONTANA
Dry Falls
Cascade Range
Seattle
Channeled Scabland
Spokane
Flood Source
Glacial Lake Missoula
Missoula
Clark Fork R.
Palouse R.
Palouse Falls
Erosion
PACIFIC
WASHINGTON
Deposition
Deposition
Columbia R.
Wallula Gap
Willamette Valley
Portland
Erosion
Willamette R.
OREGON
Snake R.
IDAHO
0
100 km
0
100 mi



Channeled Scablands Erosional Features

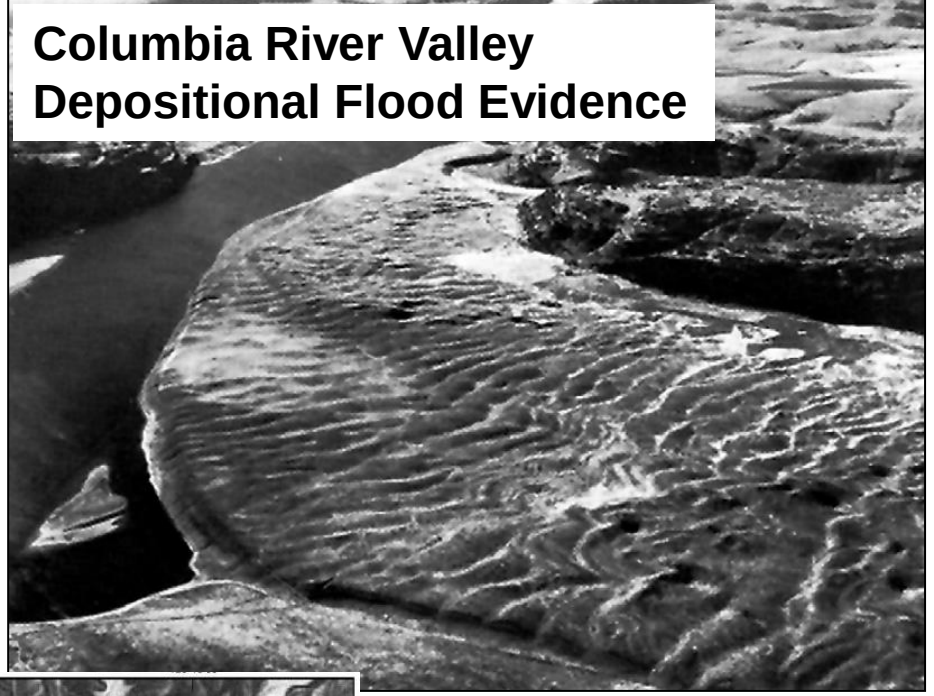
- **Bare bedrock, stripped soil**
- **Dry valleys, dry falls**
- **Butte and basin topography**
- **Localized gravel and slack-water deposits**

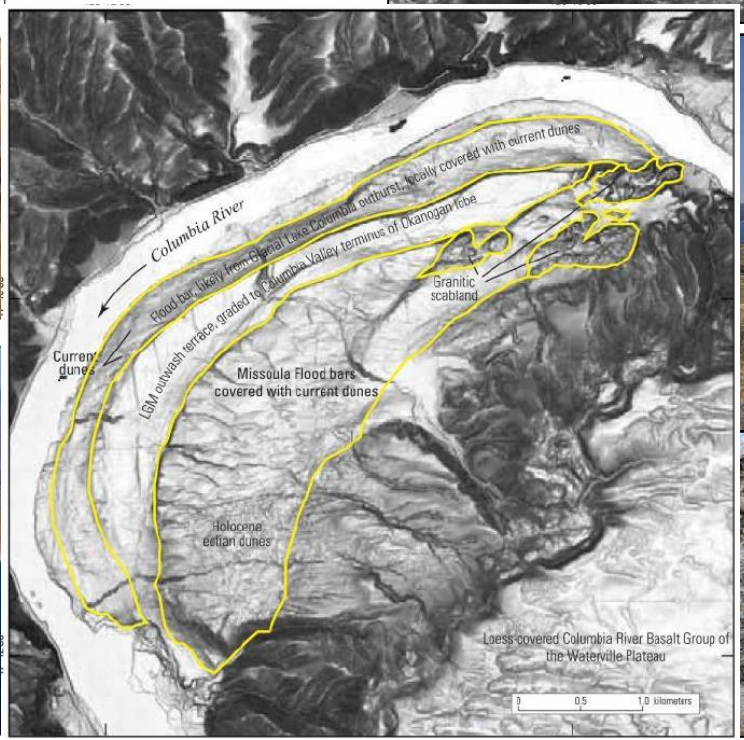

Okanogan Lobe
Purcell Trench Lobe
Glacial Lake Columbia Outburst?
Mansfield channels
Chelan
Figure 12
Waterville Plateau
Withrow Moraine
Moses Coulee
Steamboat Rock
Hawk Ck
Telford Crab Creek Tract
Lake Spokane
Spokane
Rattlesnake Springs scabland
Dry Falls
Wenatchee
Pangborn Bar
West Bar
Ephrata Fan
Crater Coulee
Potholes Coulee
Frenchman Coulee
Quincy Basin
Cheney-Palouse Tract
Figure 8
Washington
Idaho
Beverly Bar
Crab Creek
Sentinel Gap
Drumheller Channels
Marengo site
Washtucna Coulee
Othello Channels
Yakima
Cold Creek Bar
Old Maid Coulee site
Pasco Basin
Tucannon Valley Site
Missoula Flooding extent
Lewiston
Bonneville Flood
Pasco
Wallula Gap
Walla Walla
Washington
Oregon
Touchet
Burlingame Canyon
Cummings Bridge
Umatilla Basin
Cooper's Ferry Site


Waterville Plateau
Upper Moses Coulee
Cataract Jips

- **Giant Current Ripples**
- **Mega-Flood Gravel Bars**
- **Outsized Boulder Deposits**

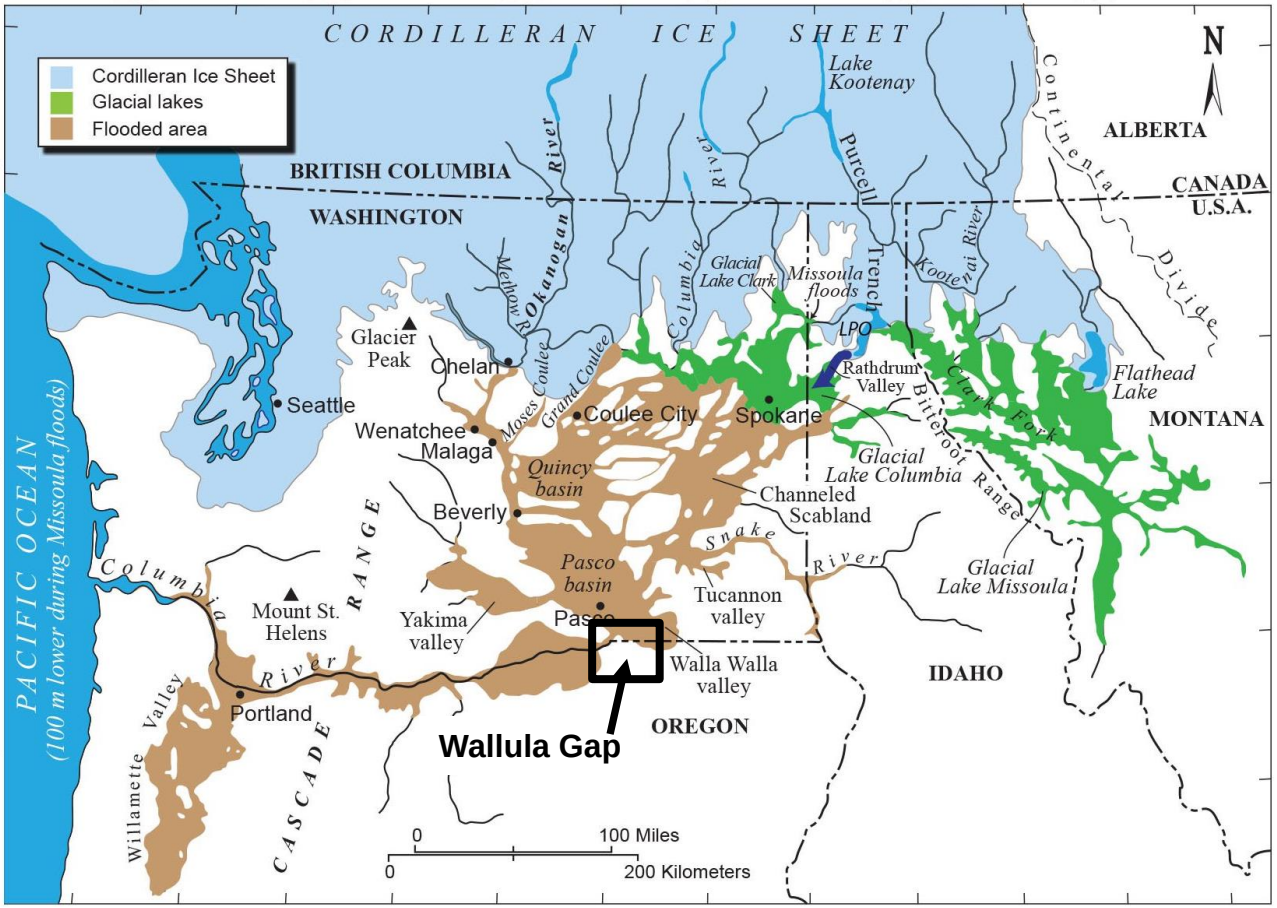
Columbia River Valley Depositional Flood Evidence

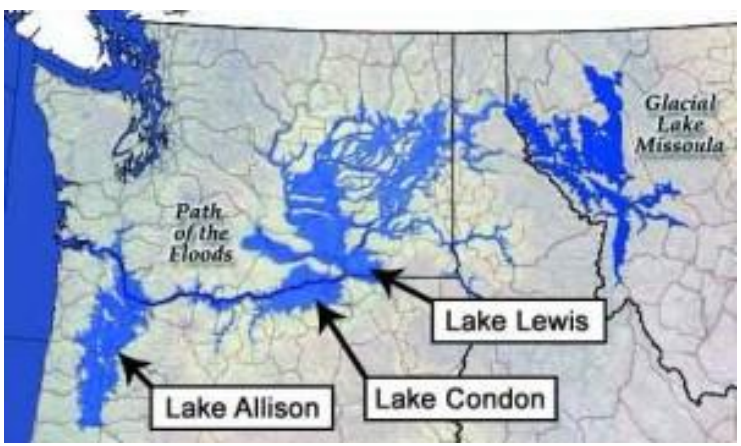




Columbia River
Wallula Gap Narrows

- Constricted Back Flooding
- Lake Development
- Localized Deposits
- Discharge Spill Point
  - Q = ~10 million m^3/sec
  - X10 Global River Output
  - Velocity = 90 km/hr



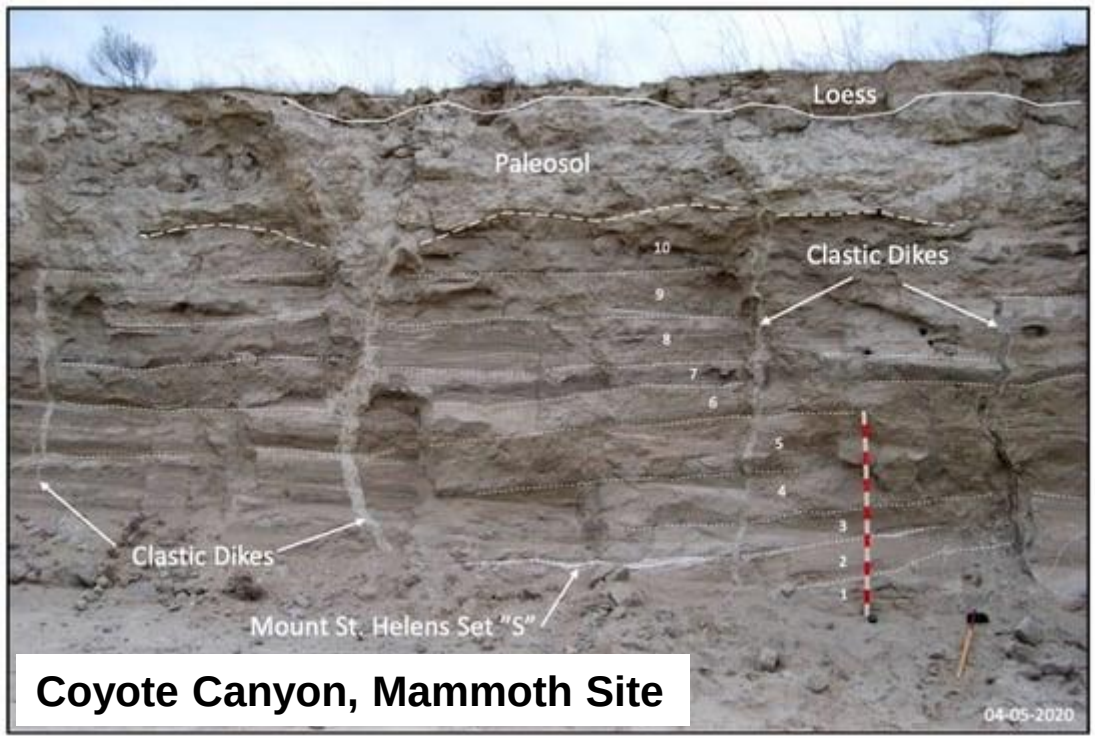


Burlingame Canyon, Touchet Formation

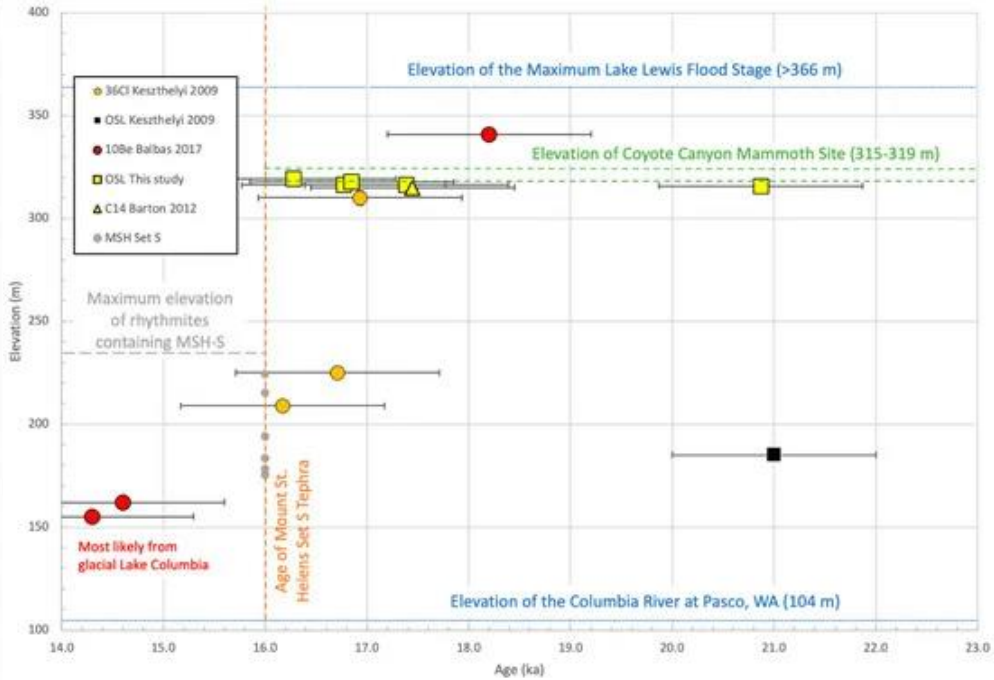
Walla Walla Area
Glacial Lake Lewis, Washington

- Localized Slackwater Deposits
- Repetitive Sediment Layers
- Multi-Event Flood Evidence
- Numerical Age Dates
  - ➢ 14,000-18,000 Years Ago

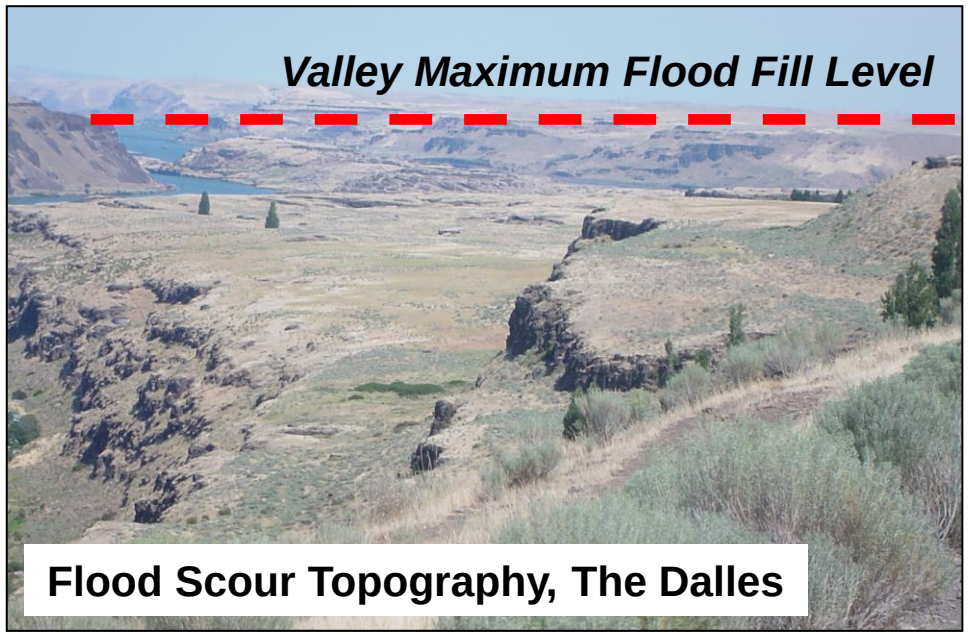
(Waitt, 1984; Last and Rittenour, 2021)

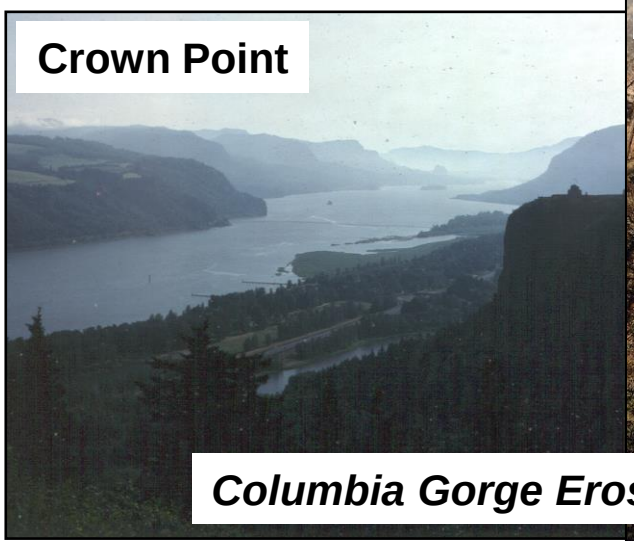


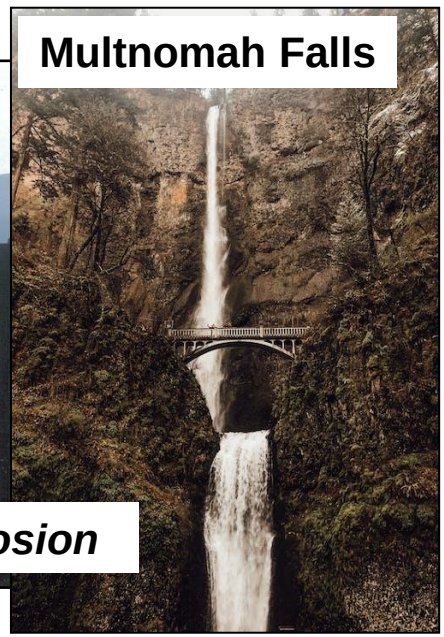
Coyote Canyon, Mammoth Site

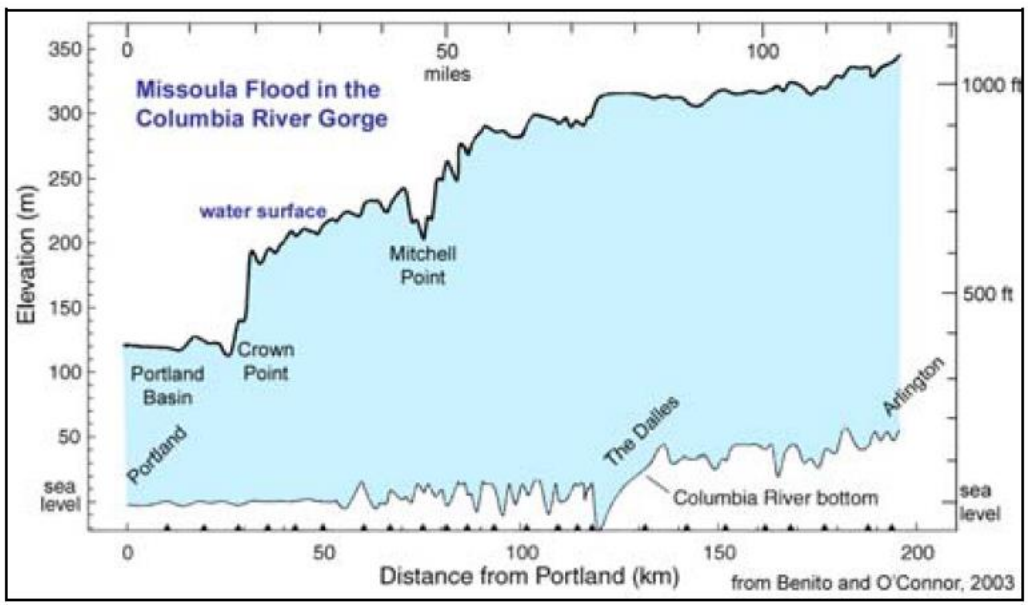


Columbia Gorge – Missoula Flood Features

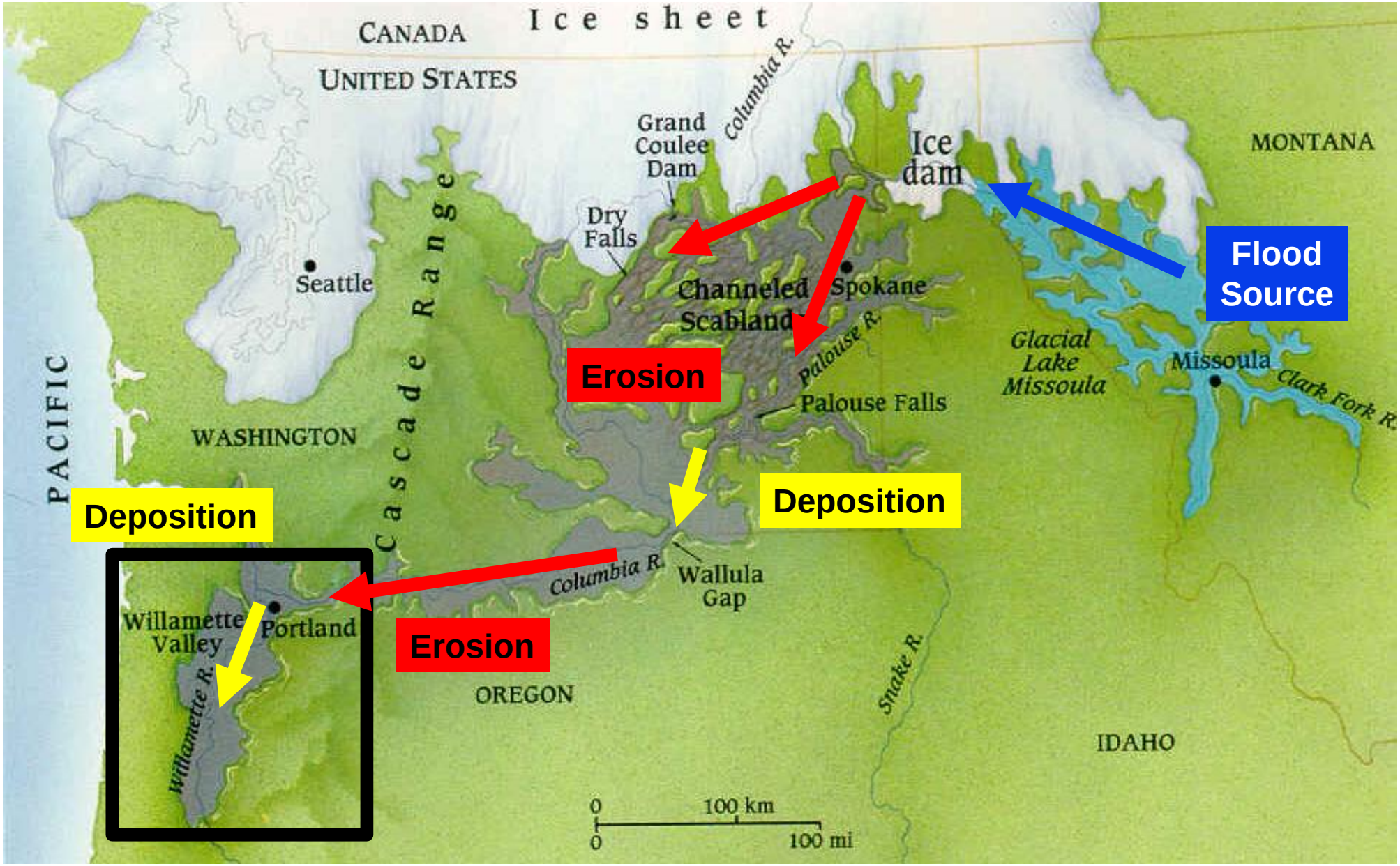






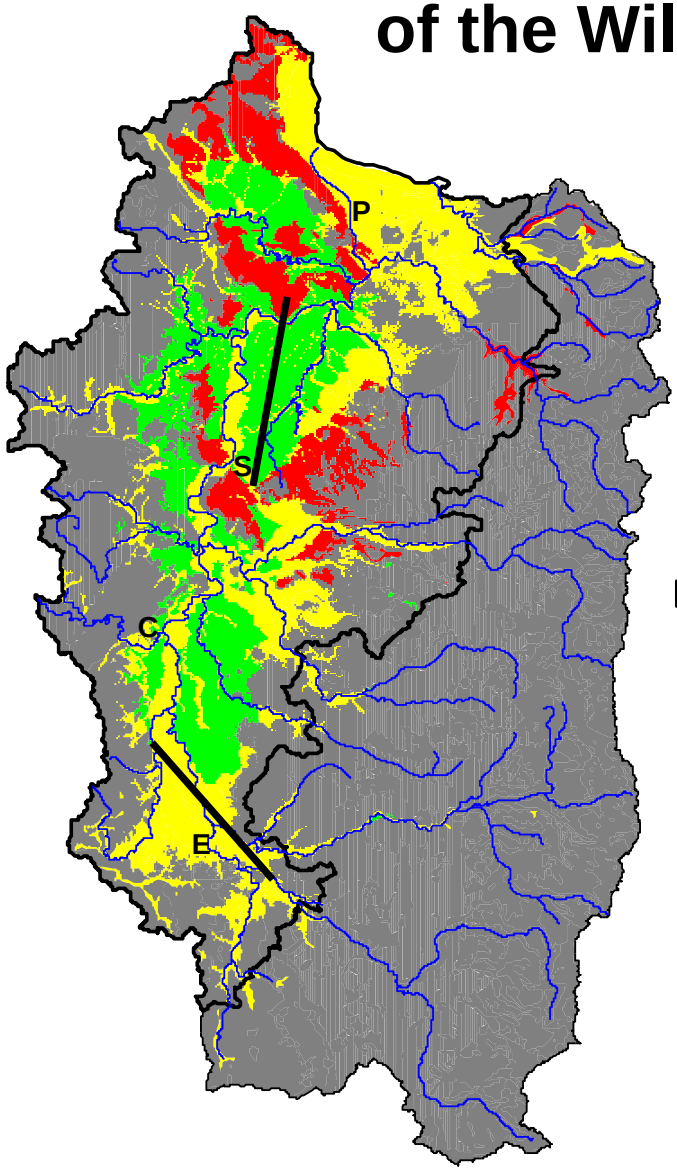


WILLAMETTE VALLEY-MISSOULA FLOOD EFFECTS


Ice sheet
CANADA
UNITED STATES
Columbia R.
Grand Coulee Dam
Ice dam
MONTANA
Dry Falls
Seattle
Cascade Range
Channeled Scabland
Spokane
Flood Source
Palouse R.
Glacial Lake Missoula
Missoula
Clark Fork R.
Erosion
Palouse Falls
PACIFIC
WASHINGTON
Deposition
Deposition
Columbia R.
Wallula Gap
Willamette Valley
Portland
Erosion
Willamette R.
OREGON
Snake R.
IDAHO
0
100 km
0
100 mi

Jim O'Connor, 2003

Generalized Geology of the Willamette Valley

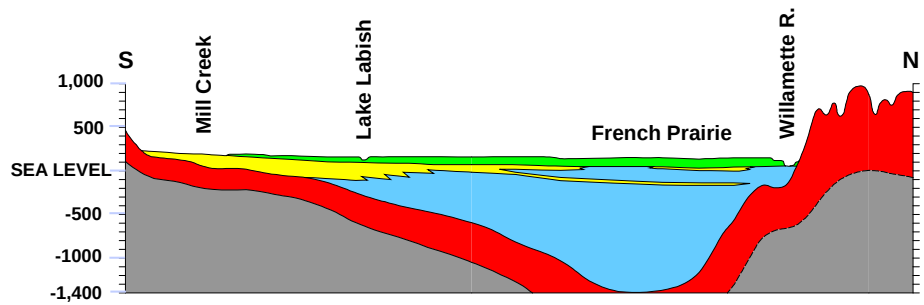


- Willamette Silt
- Alluvium and basin-fill sediment
- Columbia River Basalt Gp
- Marine sedimentary rocks And Cascade Range rocks
- Fine-grained basin deposits

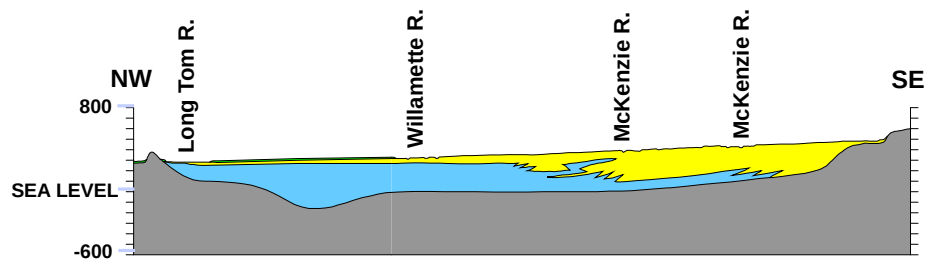
Gannett & Caldwell, 1998

0 10 20 30 MILES

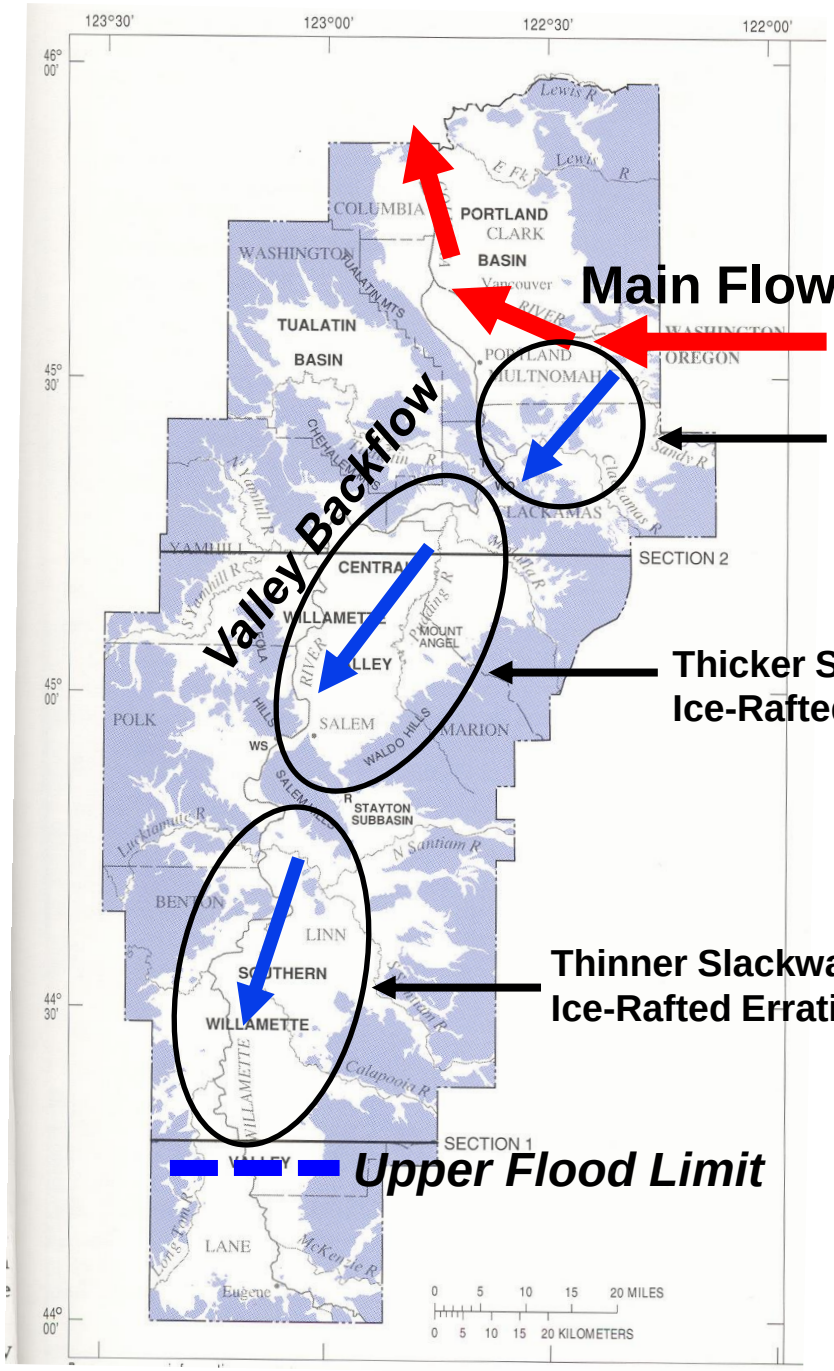
NORTH-SOUTH SECTION THROUGH THE CENTRAL WILLAMETTE VALLEY



NORTHWEST-SOUTHEAST SECTION THROUGH THE SOUTHERN WILLAMETTE VALLEY



Missoula Flood Deposits - Willamette Valley



Main Flow

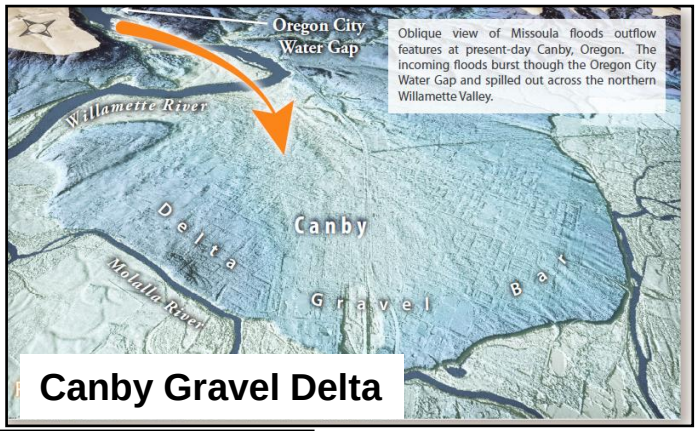
Valley Backflow

Spillway Gravel
Ice-Rafted Erratics

Thicker Slackwater Silt
Ice-Rafted Erratics

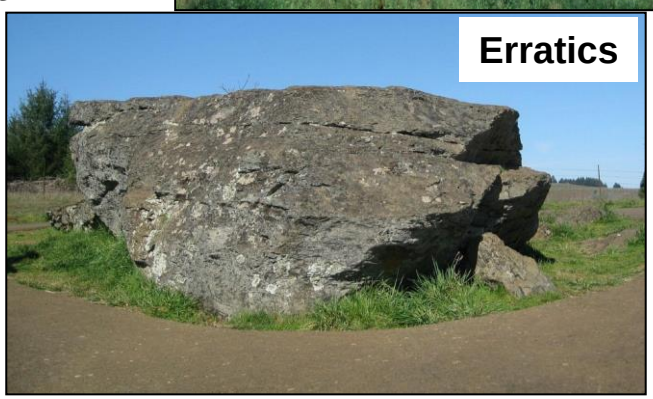
Thinner Slackwater Silt
Ice-Rafted Erratics

Upper Flood Limit



Canby Gravel Delta

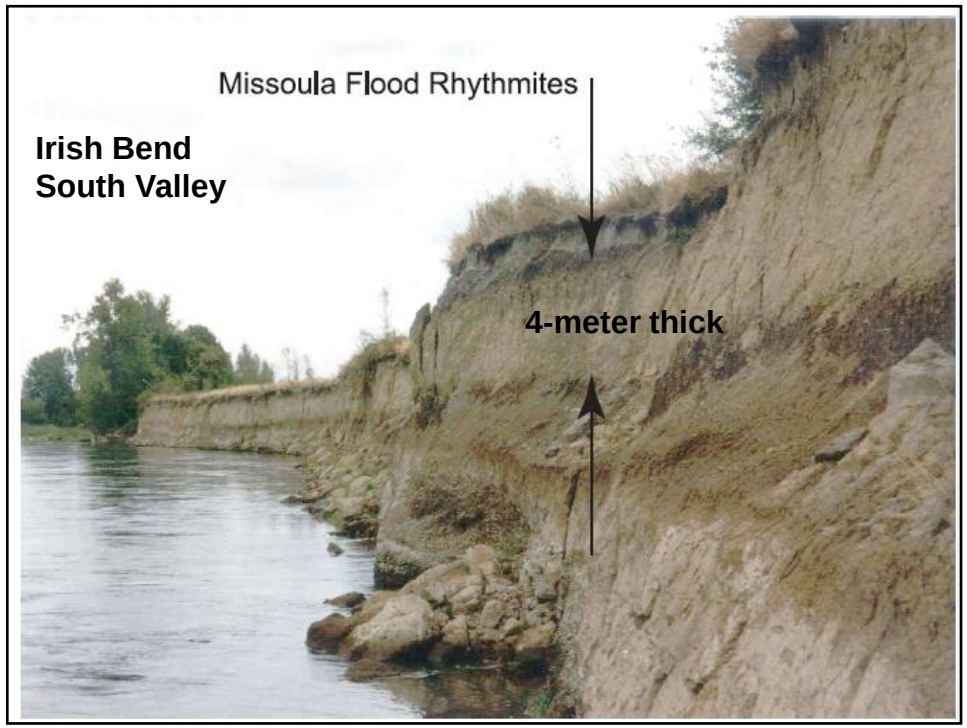
Willamette Silt



Erratics

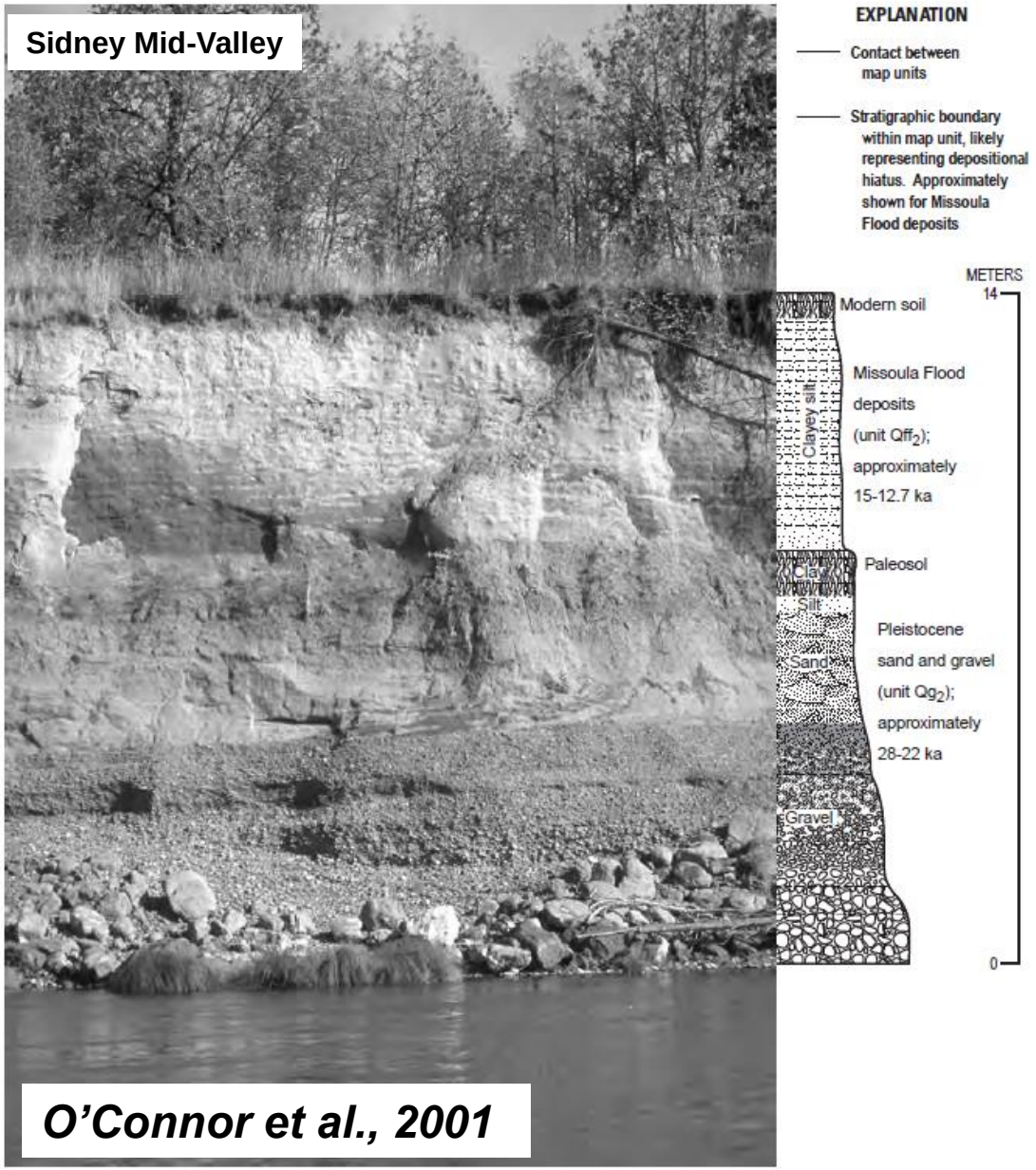
O'Connor et al., 2001;
Burns and Coe, 2012

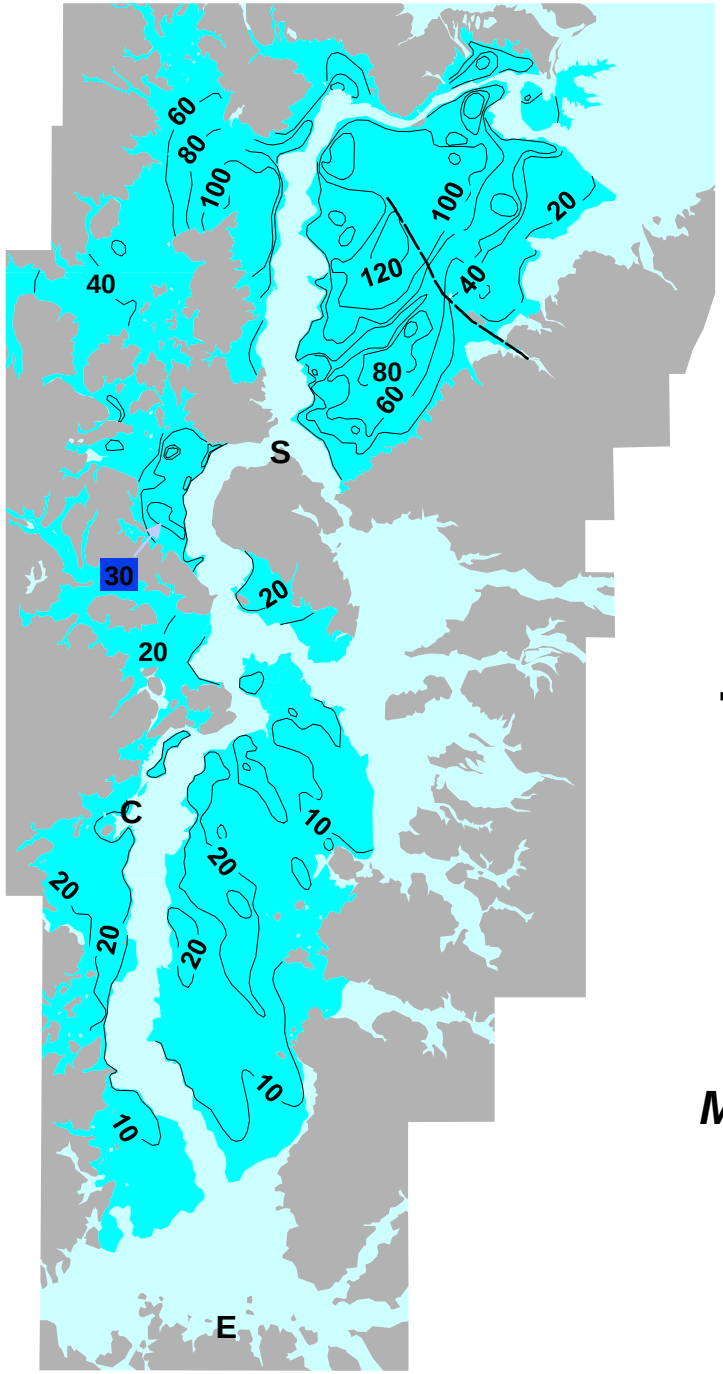
Missoula Flood Deposits



Willamette Silt

- Up to 30 m thick, northern valley
- 3-5 m thick, central valley
- Rhythmites: 40 beds up to 2 m thick
- Minimum 40 flood events recorded
- Thins to less than 1 m thick, south
- Age range: 13,000-16,000 years



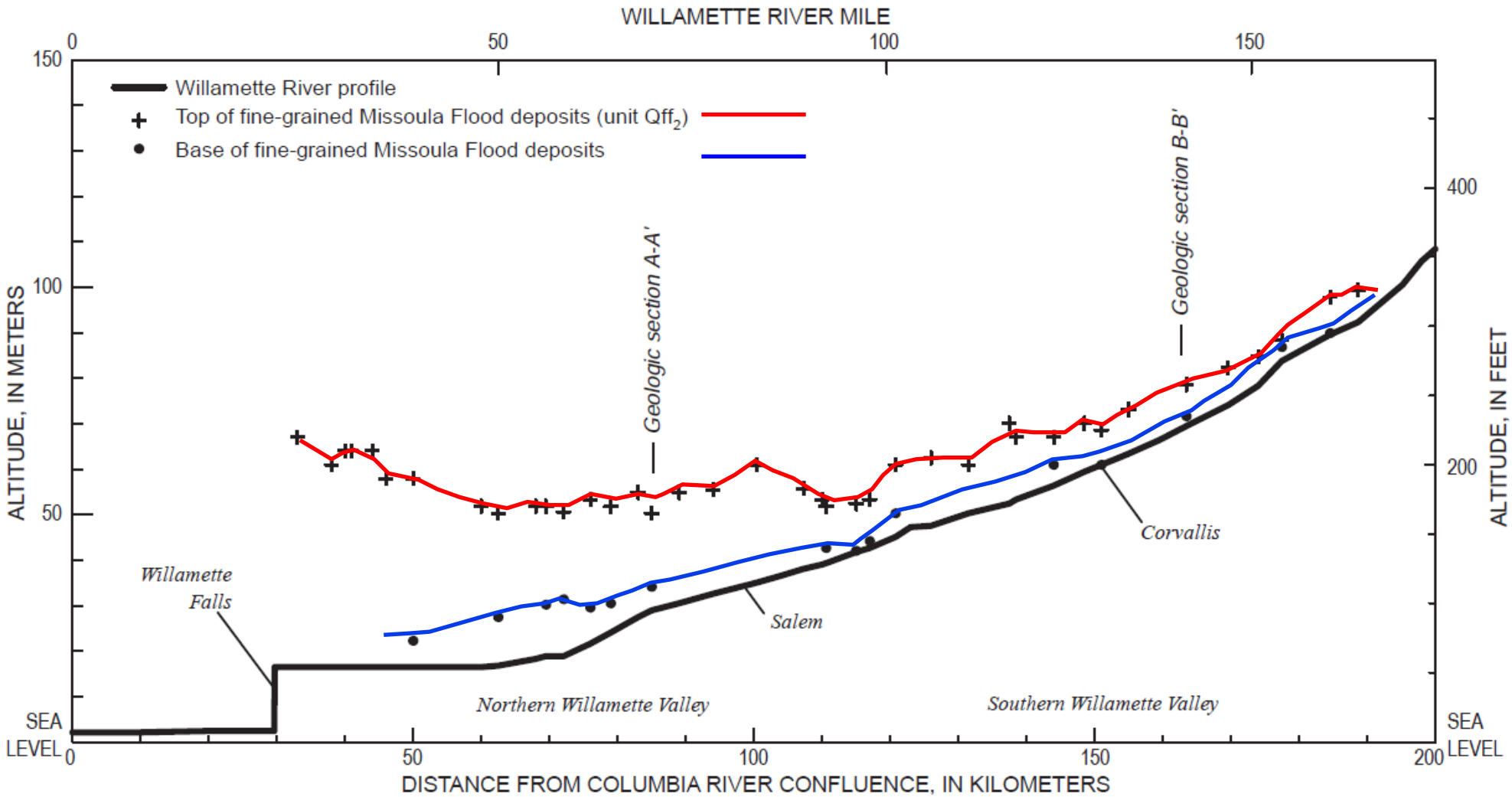


Thickness and Distribution of the Willamette Silt

(contour interval 10 and 20 ft)

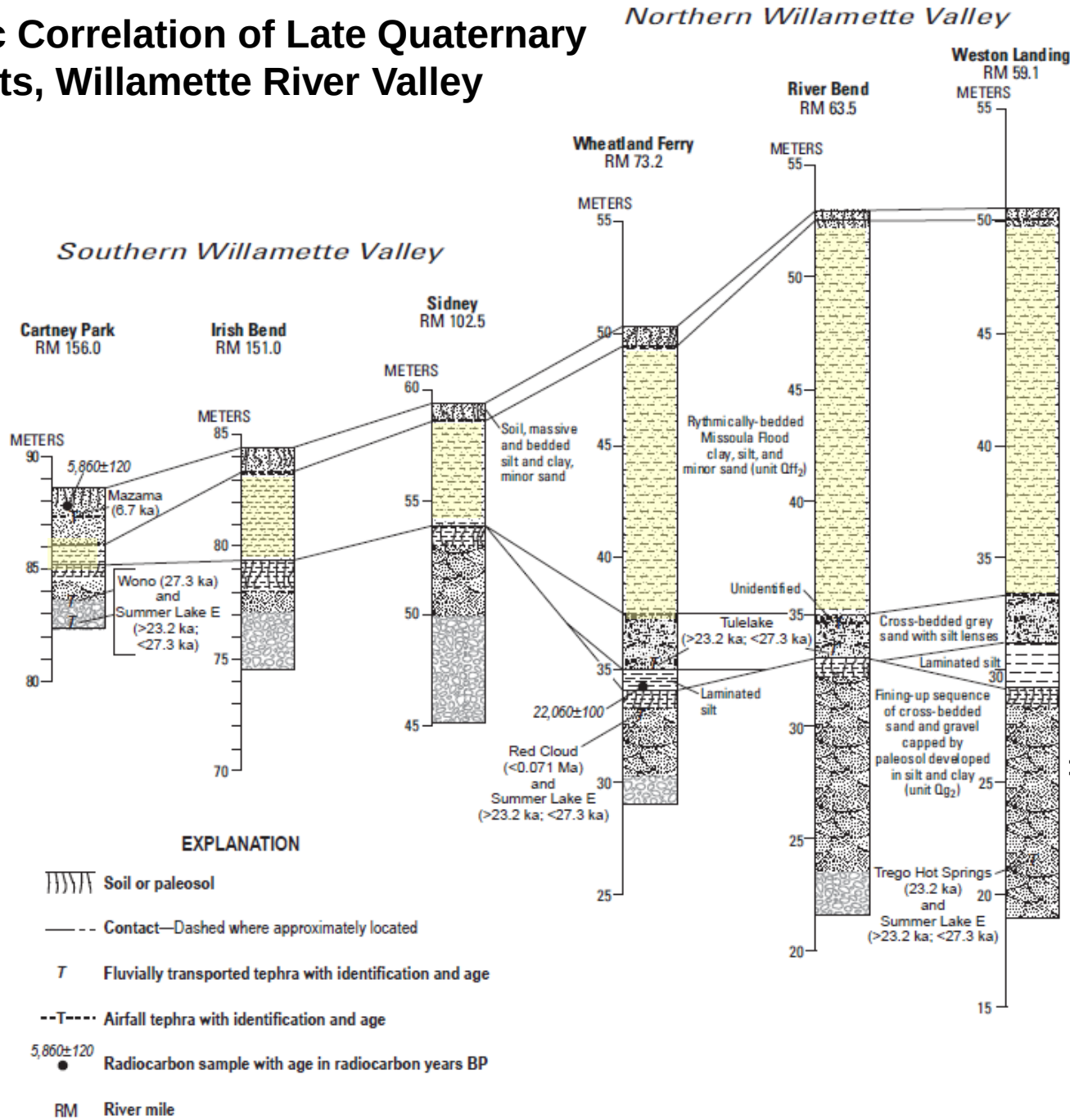
Marshall Gannett, 2003

Longitudinal Profile Showing Thickness Distribution of Willamette Silt Missoula Flood Fine-Grained Deposits (Qff2)



O'Connor et al., 2001

Stratigraphic Correlation of Late Quaternary Deposits, Willamette River Valley



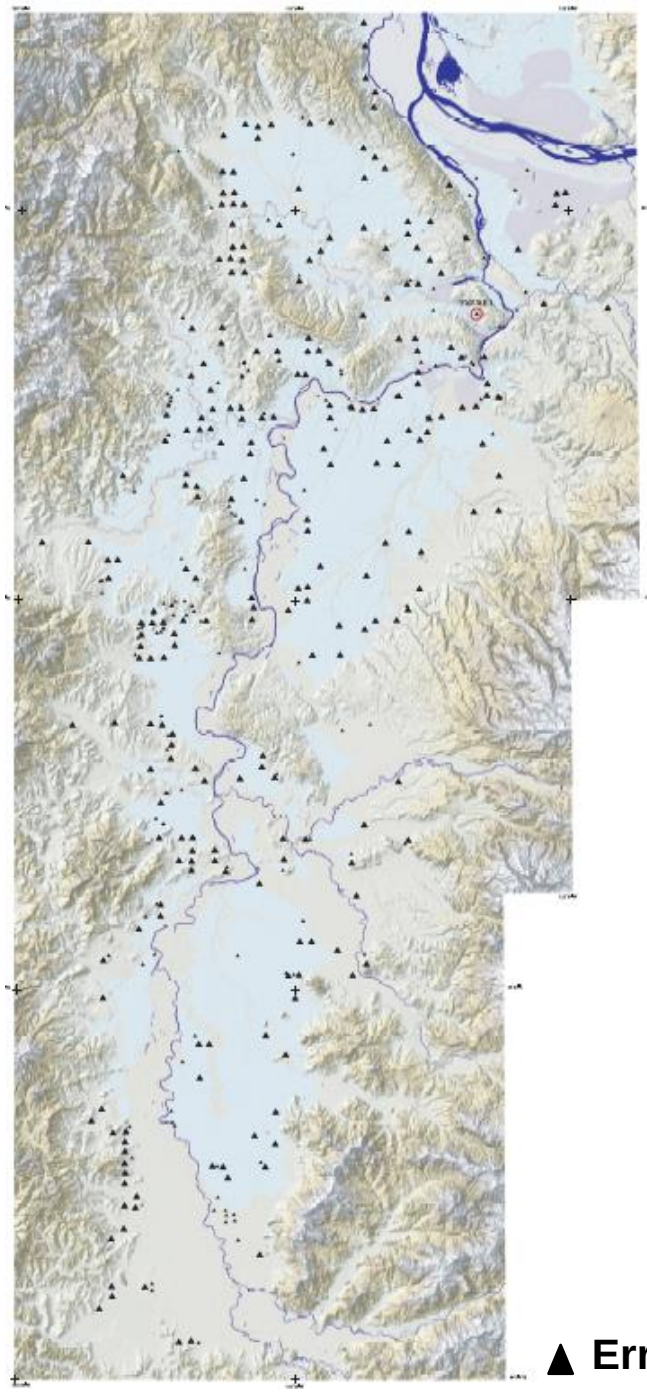
Post-Missoula
<12,000 yrs

Willamette Silt (Qff2)
14,000-18,000 yrs

Older Sand and Gravel
>20,000 to < 30,000 yrs

O'Connor et al., 2001

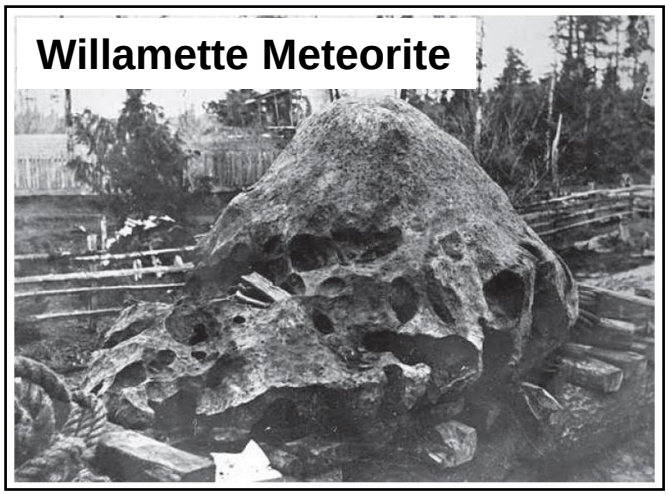
Erratic Location Map
Willamette Valley



▲ Erratic Location

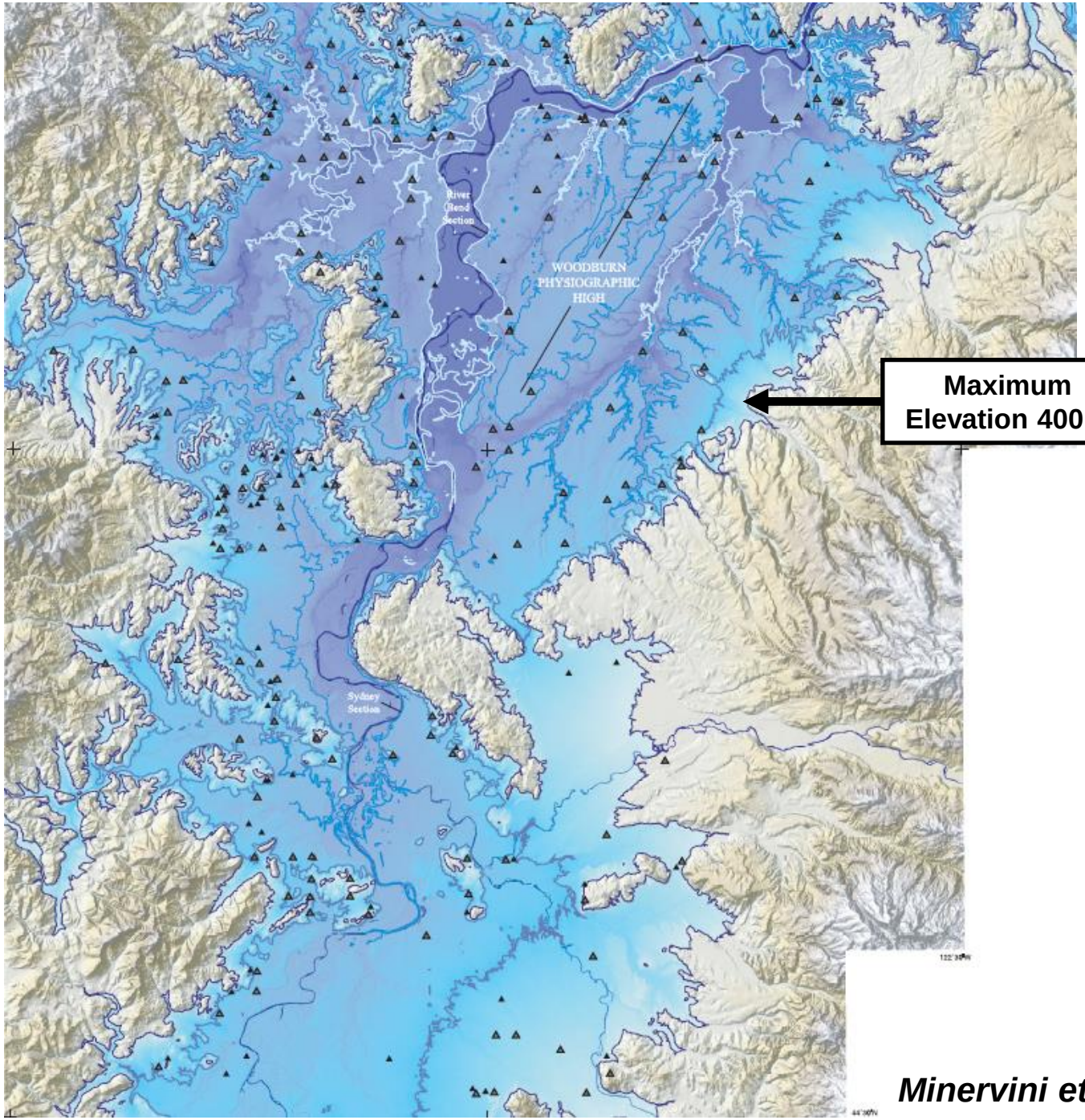
Missoula Flood Erratics

- Exotic boulder composition; Belt Supergroup
- Rock types found in Idaho-Montana-British Columbia
- Ice-rafted flood debris
- ~400 erratics mapped and located
- Erratics deposited as flood waters recede / ice melts
- Erratic elevations form high water marks over time

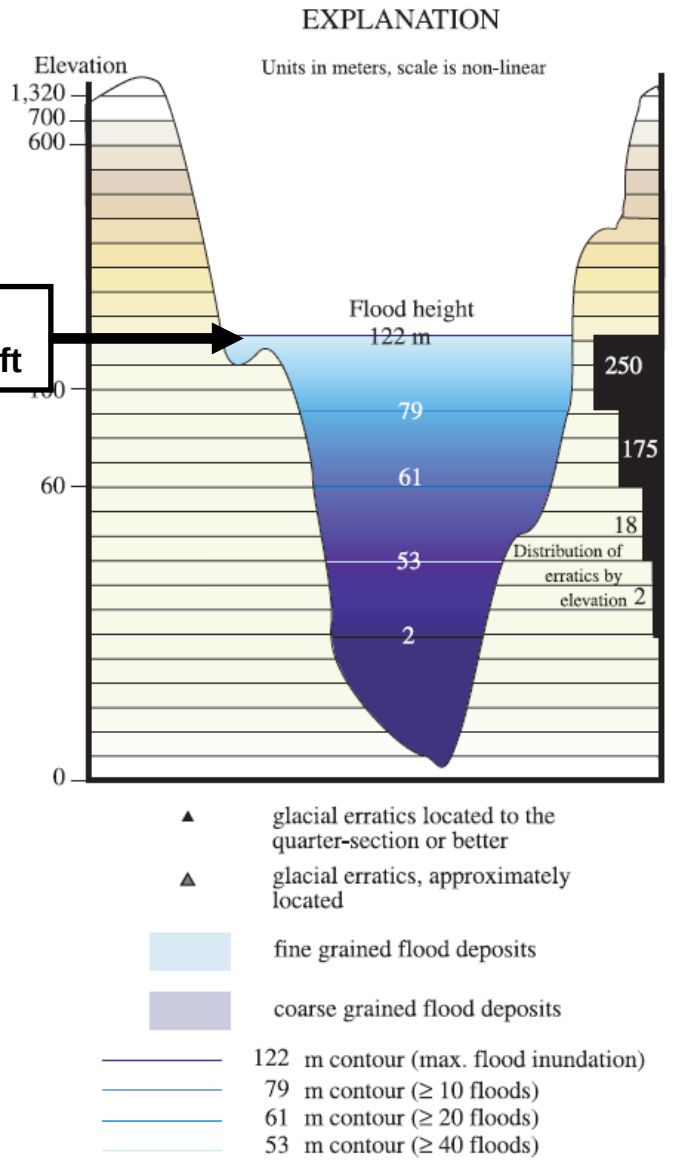


Minervini et al., 2003

Missoula Flood Inundation Map Mid-Willamette Valley



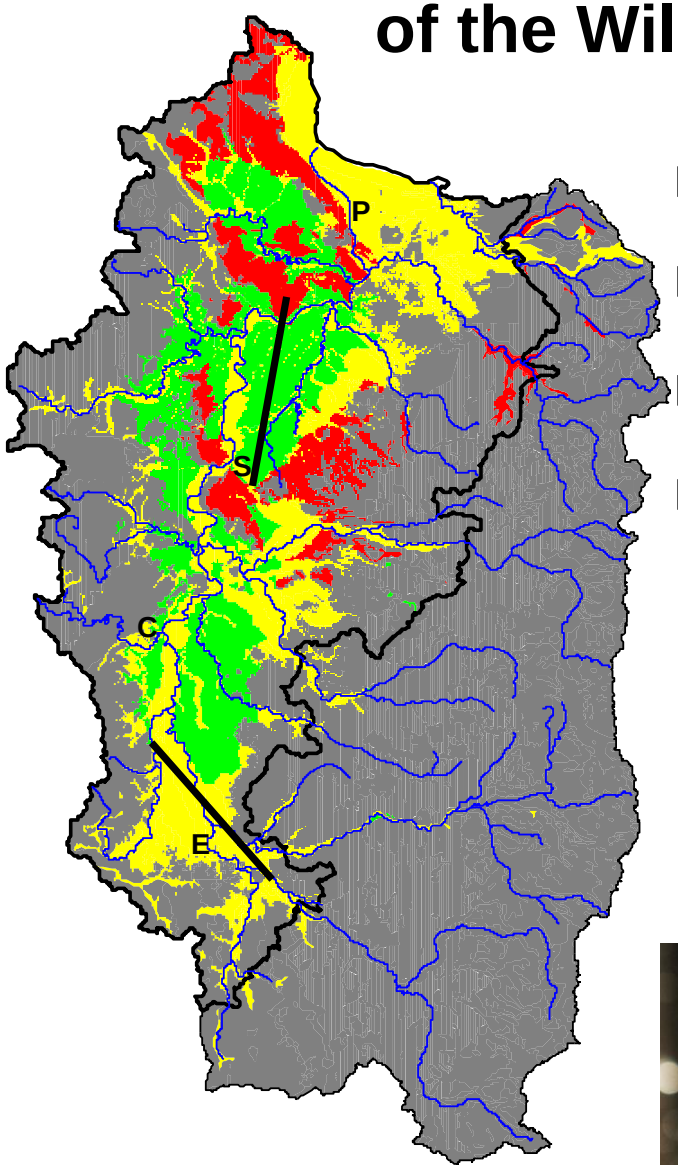
Maximum Elevation 400 ft



Minervini et al., 2003

Significance and Environmental Applications

Generalized Geology of the Willamette Valley



- Willamette Silt
- Alluvium and basin-fill sediment
- Columbia River Basalt Gp
- Marine sedimentary rocks And Cascade Range rocks

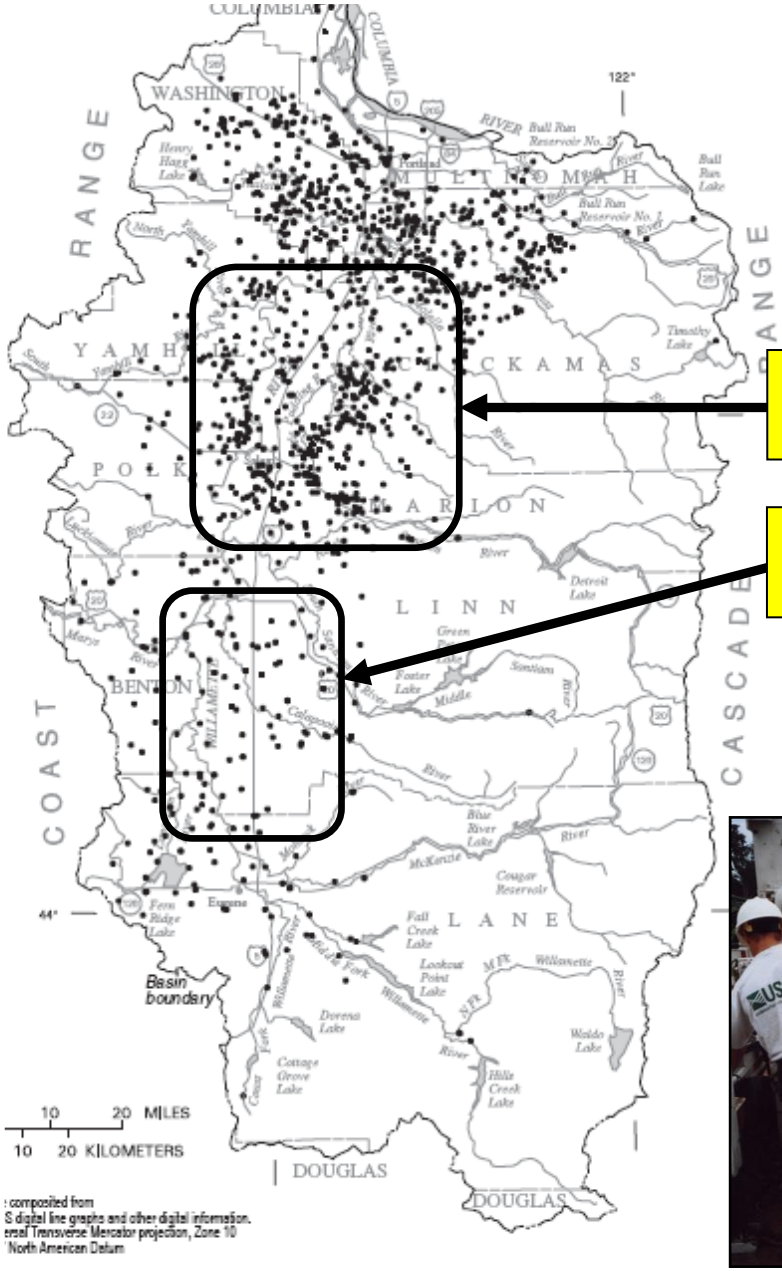
Gannett & Caldwell, 1998

0 10 20 30 MILES

Missoula Flood Legacy

- Bedrock-Sediment-Soil
- Agricultural Pay Dirt
- Cropping Systems

Willamette Valley
Well Location Map (Orzol et al., 1999)



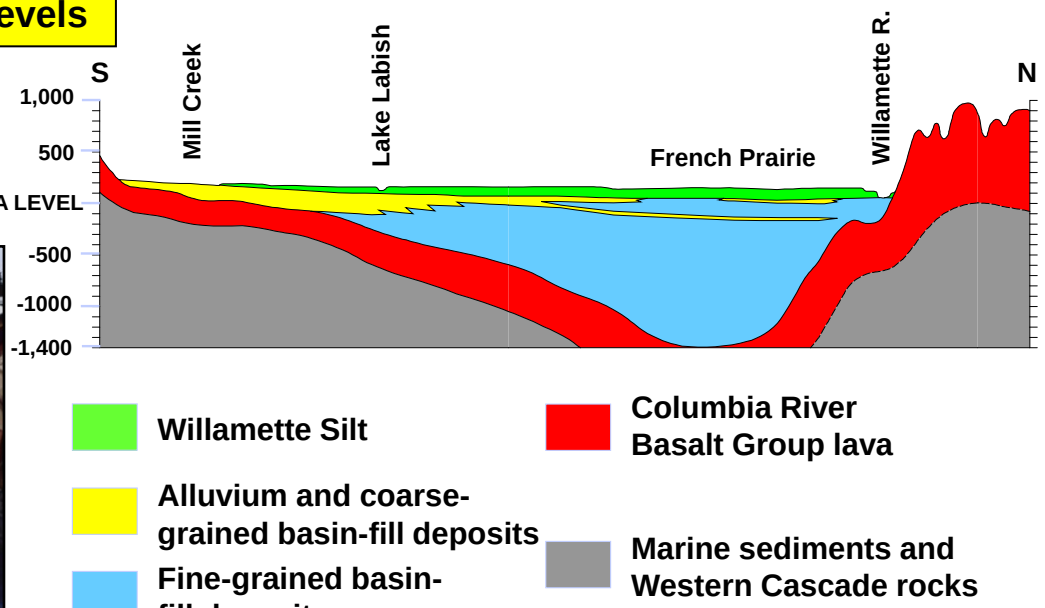
Thick Willamette Silt
Low Nitrate Levels

Thin Willamette Silt
High Nitrate Levels

Missoula Flood Legacy

- **Groundwater Aquifers**
  - **Columbia River Basalt**
  - **Willamette Gravel Aquifers**
- **Groundwater Quality**
- **Willamette Silt** ***(Haggerty, 2001)***
  - **Nitrate Water Quality Buffer**
  - **Low Permeability**
  - **Aquifer Protection**

NORTH-SOUTH SECTION THROUGH THE CENTRAL WILLAMETTE VALLEY



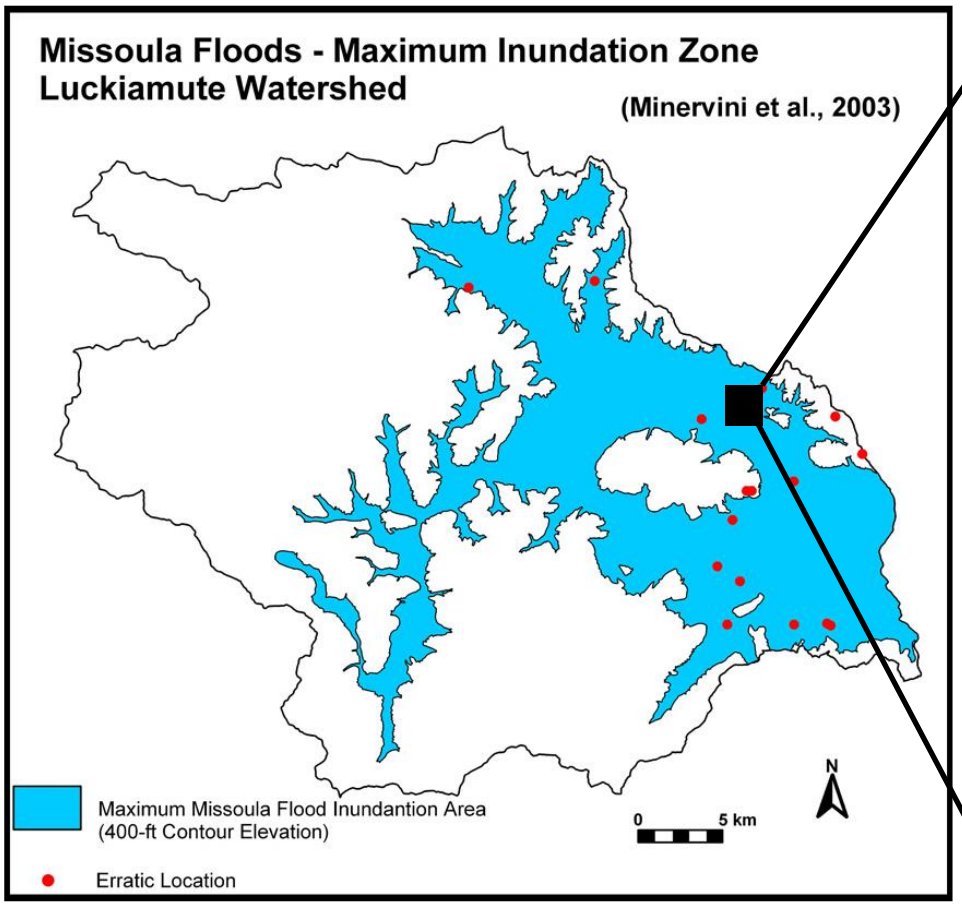
Gannett & Caldwell, 1998

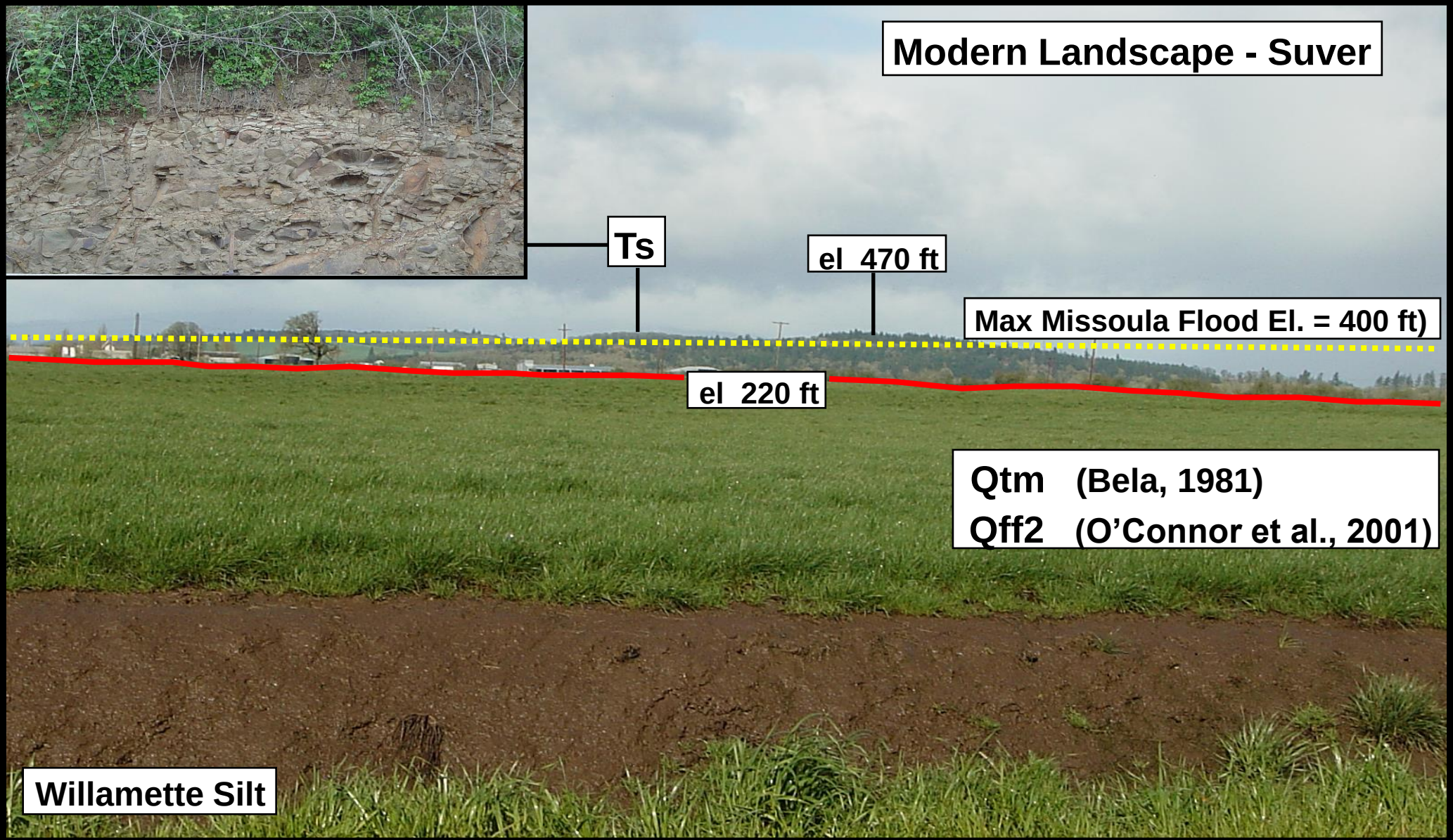
History of Research on Luckiamute River Basin Western Oregon University

1999-Present	WOU Geology and Biology Class Field Trips
2001	Environmental Science Institute Course Geomorphology, Env. Chemistry, Botany, Climatology
2002	Proposal Development (Watershed Learning Model)
2003-2004	Watershed Assessment with Luckiamute Watershed Council
2003-Present	Support of Luckiamute Watershed Council
2004-Present	Funded Research: Hydrogeomorphic Analysis (USGS / CWest)
2004-Present	Funded Reseach: Spatial Distribution of Invasive Plants (OCF)
2006-Present	Synergistic Research: Historical Land-Change Analysis

Luckiamute River, Helmick State Park

- **Present-Day Reworking of Missoula Flood Deposits**
- **Effects: Suspended Sediment, Salmonid Habitat and Water Quality**




Modern Landscape - Suver
Ts
el 470 ft
Max Missoula Flood El. = 400 ft)
el 220 ft
Qtm (Bela, 1981)
Qff2 (O'Connor et al., 2001)
Willamette Silt

SUMMARY AND CONCLUSION

- Earth climate cycles: Last Glacial Maximum ~18,000 Years Ago
  - Cordilleran Ice Sheet advanced into northern WA-ID-MT
- Ice dams, blockage and development of glacial Lake Missoula
- Multiple catastrophic outburst floods ~14,000-18,000 years ago
- Flood evidence: Missoula shorelines, Clark Fork erosion scars and spillways, Channeled Scablands topography, outsized flood deposits, Columbia Gorge landscape, Willamette Valley deposits
- Legacy large-scale Missoula Flood deposits and erosional features remain on the modern-day landscape in the Pacific Northwest
- Legacy Missoula Flood features influence present-day landuse, agriculture and groundwater resources in the Willamette Valley

MISSOULA FLOOD STORY
REFERENCED PRINCIPAL RESEARCHERS

(With All Due Respect to the Makers)

- G.K. Gilbert, 1800's Explorer and Geoscientist Extraordinaire (Deceased)
- J. Harlen Bretz, University of Chicago (Deceased Bretz Club President)
- Richard Flint, Yale University (Deceased "Pope of the Pleistocene")
- Vic Baker, University of Arizona
- Jim O'Connor and colleagues, US Geological Survey
- Richard Waitt, US Geological Survey
- Bruce Bjornstad, Ice Age Floods Institute
- Scott Burns, Portland State University
- Oregon Department of Geology and Mineral Resources (DOGAMI)
- Washington Geological Survey, Department of Natural Resources
- Dozens of other international researchers, students, and colleagues