<u>Geologic Stability of Skagit Gorge</u>

(Dr. J.L. Riedel, Geologist, October, 2024)

Skagit Gorge is one of the deepest and longest and deepest canyons in the North Cascades, a mountain range of exceptional relief and scenery that is viewed by more than a million visitors a year. The Gorge is a relatively young feature compared to the adjacent mountains and formed during initial Pleistocene continental glaciations ~2 M years ago (Simon-Labric et al. 2014). Skagit Gorge cuts across a former regional hydrologic divide breached by the spill-over of glacial lakes trapped in valleys to the north (Riedel et al. 2007). The erosion of a regional divide at Skagit Gorge joined the formerly Fraser-bound upper Skagit River with the westward flowing lower Skagit. Another important result of this process is that the upper Skagit Valley has no mountain barriers between it and the Fraser and Okanogan basins to the north. Parts of these large rivers temporarily joined Skagit River during the last ice age, providing an avenue for fish migration and further deepening Skagit Gorge, perhaps resulting in the incision of the broad shelf cut by the most recent passage of the ice sheet between 18,000 and 14,000 years ago (Photo 1).

The Gorge has two distinct morphologies separated by a sharp bend in the river at Diablo (Map 1). Upper Skagit Gorge above Diablo Dam bears the erosional scars left by the ice sheet in the form of glacially scoured bedrock benches and hillsides on the lower canyon walls. A narrow canyon cuts below the glacial rock benches, forming an inner gorge known as Diablo Canyon where Diablo and Ross Dams are seated (Photo 1). The lower Gorge is a particularly large V-shaped canyon and lacks the extensive bedrock benches of the upper Gorge. The walls of Skagit Gorge rise steeply above the river to more than a mile above the river at the west end. Near-vertical walls of an inner Gorge rise about 300 ft. above the river in the upper Gorge.

Several tributary streams further segment the Gorge, the largest having their own deep canyons (e.g. lower Stetattle Creek, Thunder Arm). These smaller canyons were deeply eroded as their base level was lowered by the rapid ice -age cutting of Skagit Gorge. Several follow faults, including Sourdough, Rhode, and Gorge creeks. The smaller streams leave debris cones or alluvial fans where they meet Skagit River, and funnel snow avalanches down to the gorge floor.

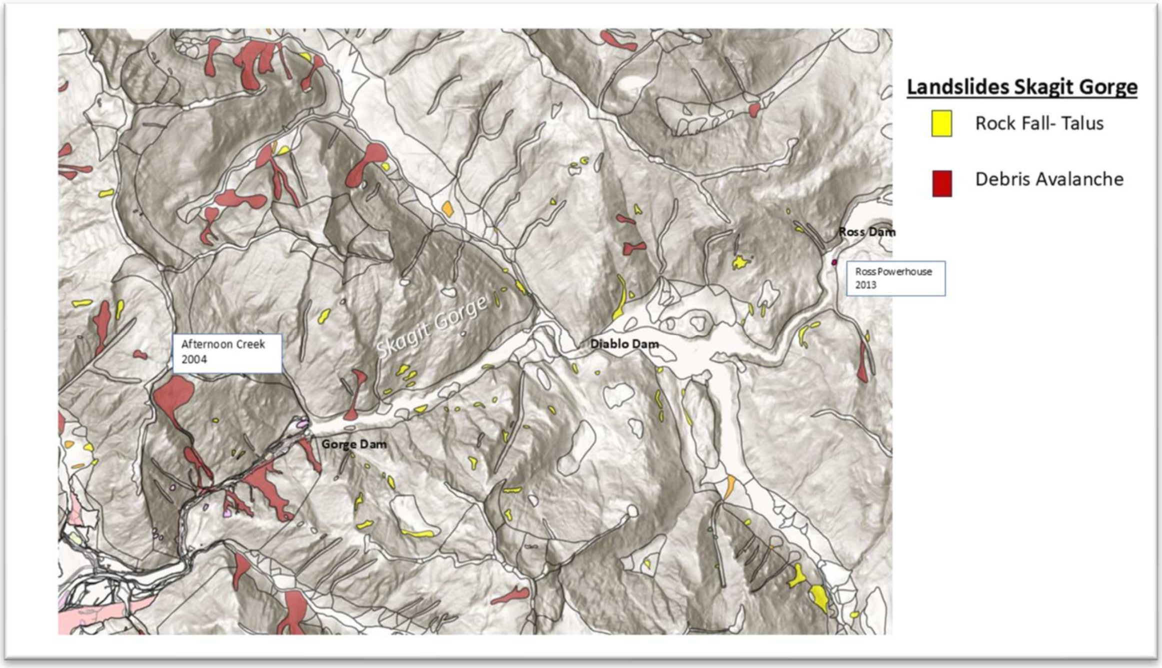
The bedrock of Skagit Gorge is Skagit Gneiss. SCL relicensing study GE-02 identified Skagit Gneiss as having the highest relative hazard ranking for rock falls within the entire project area from the Canadian border to Seattle (Table 1). There are two distinct types of Skagit Gneiss, a metamorphic rock, including paragneiss and orthogneiss. Lower Skagit Gorge is composed of orthogneiss, metamorphosed from granitic rocks (Tabor and Haugerud 1999). Most of the large landslide scars mapped by NPS in Skagit Gorge occur in the orthogneiss (Map 1). The cluster of landslides in the orthogneiss includes six large failures (Map 1). Incessant rock falls and the remains of these landslides choke the river bed within lower Skagit Gorge.

Upper Skagit Gorge is composed of paragneiss, or banded gneiss, which was metamorphosed from sedimentary rocks. The formerly horizontal bedding planes of the sedimentary rock are now tilted vertically within upper Skagit Gorge, leading to steep bedding planes between bands of the gneiss. Some of the rocks dip as high as 85 degrees near Ross Dam (Tabor et al. 2003). These act as failure planes for landslides, particularly rock falls and topples.

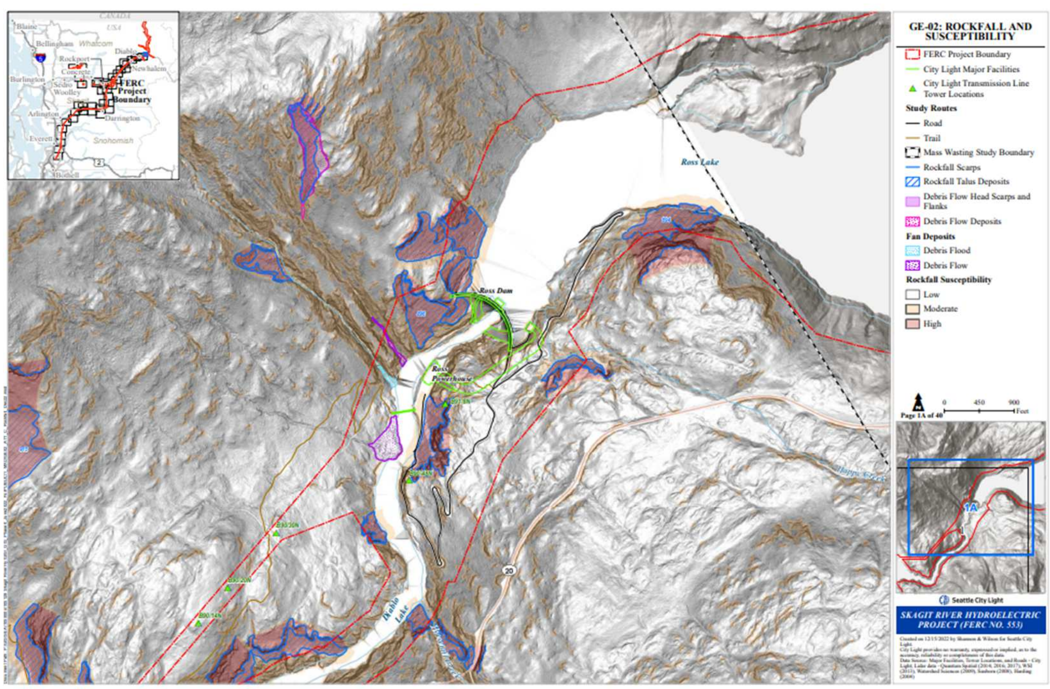
Bedrock slope instability in Skagit Gorge is illustrated by several recent landslides, including a 2013 slide near Ross Powerhouse (Map 2; Photo 2), a 2003 landslide at Afternoon Creek (Photo 3), rock falls at Diablo Powerhouse in 2006, and at numerous other sites in the Gorge (Map 1). All of these landslides were bedrock failures and involved little if any glacial or alluvial surficial deposits. Over-steepened slopes (cliffs) within the Gorge are particularly prone to mass failure by rock falls and rock avalanches.

Debris flows are another class of landslides that represent a considerable hazard in Skagit Gorge. More than a dozen debris flow tracts flow down the walls of Skagit Gorge, with two of the most active being Sourdough Creek and Afternoon Creek (Map 1). NPS mapping distinguishes debris cones from alluvial fans. The former have steep surface slopes (> 10 degrees) and are formed primarily by the accumulation of sediment from mass movements. Alluvial fans generally slope < 5 degrees and are formed by the accumulation of stream deposits by larger, lower gradient Skagit tributaries.

In summary, Skagit Gorge is an unstable place prone to several classes of landslides. SCL and others recognized the risk and cost of building roads in the Gorge for 100 years, as illustrated by the inclined lift in Diablo and a century of barging material on Diablo Lake to Ross Dam and Powerhouse. Scars from rock falls on State Highway 20 in the Gorge and frequent road closure due to snow avalanche danger are other reminders.



Map 1. Landslides mapped within Skagit Gorge. Sources include NPS landform mapping, Washington DNR landslide Inventory, and Tabor and Haugerud 1999.



Map 2. Geologic hazards near Ross Dam as mapped in SCL study Ge-04. The 2003 landslide occurred from the walls of the inner gorge, and is located just to the south of Ross Powerhouse (blue cross-hatch).

Photo 1. Skagit Gorge at the site of Diablo Dam. Note the incision of narrow (20 ft. wide) inner canyon into the broader rock valley floor above.

Photo 2. Debris avalanche in 2013 just below Ross Powerhouse in Skagit Gorge.

Photo 3. View into Skagit Gorge along the path of the November 9, 2003 Afternoon Creek landslide, triggered by unusually heavy rainfall (Strouth et al. 2007). This slide was active in the mid-1900s according to anecdotal evidence.

Table 1. Relative rockfall hazard in SCL project area from study GE-04.

Map Geologic Unit(s)[1]	Geologic Unit Description[2]	Source	Percent of Study Area	Density (Talus Area/ Geologic Unit Area)	*Density Rank*	Productivity (Deposit Area [ft^2]/ Scarp Length [ft])	*Productivity Rank*	Prevalence (Geologic Unit Area/ Total Rock Unit Area)	Prevalence Rank	Relative Hazard Index[3]
TKSbg, TKso	Orthogneiss and gneiss rocks of the Skagit Gneiss Complex	Tabor et al. (2003)	9.26%	0.1815	1	474	3	16.74%	1	1
Jph(dj)	Darrington Phyllite (50–90%), semischist of Mount Josephine (10–50%)	Dragovich et al. (2002a)	0.57%	0.1349	2	1288	1	1.03%	12	2
TKns	Napeequa Schist	Tabor et al. (2003)	2.28%	0.0952	4	385	5	4.12%	6	2
Ec(h)	Sedimentary rocks of the Chuckanut Formation, Mount Higgins unit	Dragovich et al. (2003a)	1.46%	0.1317	3	496	2	2.65%	11	4
PDc	Mixed metamorphic rocks of the Chilliwack Group of Cairnes (1944)	Tabor et al. (2002, 2003)	2.88%	0.0612	9	354	7	5.20%	5	5
TKao	Orthogneiss rocks of the Alma Creek unit	Tabor et al. (2003)	0.50%	0.0817	6	396	4	0.91%	13	6
Kes	Shuksan Greenschist	Tabor et al. (2002, 2003)	8.44%	0.0436	11	284	11	15.25%	2	7
Tcdg	Granodiorite rocks of the Mount Despair unit	Tabor et al. (2003)	3.02%	0.0353	12	343	8	5.45%	4	7
JTRmc(e) JTRmt(e) JTRmv(e)	Low-grade metamorphic rocks of the Eastern mélange Belt	Dragovich et al. (2002b, 2003a)	1.71%	0.0505	10	376	6	3.10%	9	9

References

National Park Service. 2012. General Management Plan and Environmental Impact Statement for Ross Lake National Recreation Area.

Riedel, J.L, Haugerud, R.A., and Clague, J.J. 2007. Geomorphology of a Cordilleran Ice Sheet drainage network through breached divides in the North Cascades Mountains of Washington and British Columbia. Geomorphology 91: 1-18.

Simon-Labric, T., Brocard G.Y., Teyssier C., van der Beek P/A/, Reiners P.W., Shuster D.L., Murray, K.E. and Whitney D.L. 2014. Low-temperature thermochronologic signature of range divide migration and breaching in the North Cascades. Geological Society of America. Lithosphere.

Strouth, A., R. Burk, E. Eberhardt. 2006. The Afternoon Creek rockslide near Newhalem, Washington. Landslides 3: 175-179

Tabor, R.W., Haugerud, R.A. 1999. *Geology of the North Cascades: A Mountain Mosaic*. The Mountaineers, Seattle, WA. 143 p.

Tabor, R.W., Haugerud, R.A., Hildreth, W., Brown, E.H. 2003. Geologic Map of the Mount Baker 30-by 60 minute Quadrangle, Washington. U.S. Geologic Survey Geologic Investigations Series I-2660.