Island Geoscience 
Geoscience issues as they relate to water, land and air protection on Vancouver Island

Vol. 06, No. 02 – Summer 2009

Island Geoscience completes 5 years!

This issue marks the 20th edition of Island Geoscience since it began in the summer of 2004. One of its original goals was to provide government staff with an increased knowledge and understanding of the physical landscape and its relevance to ecosystems, sustainability, species and biodiversity.

The second goal was to inform engineers and geoscientists external to government about developments and ongoing geoscience work within government. While it has expanded slightly since then, I think we’ve succeeded rather well in meeting both goals.

Past topics included: cliff recession, landslides, climate change, karst landscapes and coastal erosion; to the more exotic salmon-driven sediment-transport, topographic signature of life on earth, and the geological signature of man. We’ve been treated to several guest authors from locally and around the world, and I’ve been thrilled at the quality of the articles.

In addition, we’ve introduced several key scientists working on geosciences related topics in government, and reviewed important books. The subscription list has grown to over 300 people and it continues to grow by word of mouth with each issue.

So thank you. And I hope you will continue to find something of interest within these and upcoming pages.

This quarter we have two articles for you: the first examines the ice age legacy and considers how this legacy impacts our landscape, and the second looks at the roll of sediment recharge in gullies and debris flow initiation. The second article summarizes a recent paper from the journal Geomorphology, and the authors propose a model whereby debris flow frequency increases with less material in the gully. It’s worth the read!

As always, Island Geoscience welcomes new submissions or ideas for articles. If there are topics you would like to see covered, or if you have an article or idea you would like to contribute, please send me your ideas at: richard.guthrie@gov.bc.ca

Past issues of Island Geoscience are here: http://www.for.gov.bc.ca/hfd/LIBRARY/Island_Geoscience.htm

Enjoy the summer!

Rick.

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A debris flow in the Beaufort's on Vancouver Island.
Legacy of an ice age: Our inherited landscape.

Walsh Glacier in Alaska. Photograph from the Simon Fraser University, Quaternary Geoscience Research Group.

The surface of the earth is constantly beset by forces, driving processes that change its shape in perpetuity. The features of the earth, the rivers, hillslopes and coastlines, are evidence of the forces currently at work or that have been at work in the past. Heat transfer from the center of the earth drives tectonic forces, which in turn build the Earth’s surface creating mountains, volcanoes, and exposing new rock. Water, wind and heat loss all work with gravity to break down the new land, and in so doing, leave their fingerprints across the terrain.

Coastal British Columbia is a rugged fiordal landscape of steep U-shaped valleys, dramatic rivers and bold peaks. This mountainous coast owes much of its surface expression to events that occurred over ten millennia ago, and we live within the inherited landscape that remains.

Coastal BC was subject to at least three glaciations in the Pleistocene, scouring deep valleys from the mountains, plastering eroded sediment onto hillslopes and valley floors, and backfilling those valleys with outwash gravels. Each new glaciation, however, largely removed evidence of the ones before. It is the most recent Fraser glaciation that we can easily identify today.

Coastal BC’s climate grew colder and wetter about 29 000 years ago, and alpine glaciers began forming on the highest peaks, eventually coalescing and forming valley glaciers. As the ice continued to grow, the Cordilleran ice sheet was formed, that would reach a maximum size of 900 km wide and 2000-3000 m thick. The growth of the Cordillera ice sheet is shown for Vancouver Island and the nearby coast in Figure 1.

The massive erosive power of a glacier can be conceptualized briefly by calculating the amount of pressure imposed on the Earth’s surface by glacial ice. The specific gravity of glacial ice is estimated at slightly higher than 0.9. A vertical column of ice of the dimensions 1000 m × 1 m² exerts, therefore, a downward force of approximately 9 000 kN (F=kg·m/s²). This is equivalent to a pressure on the surface m² of 9 000 kPa (1Pa=1N/m²). Compare this calculation with other common measures of pressure (Table 1) and it becomes easier to understand just how glaciers are able to erode mountains so effectively.

Figure 1. The approximate growth of the Cordillera Ice Sheet over southern coastal British Columbia.

One can visualize coastal British Columbia as a sheet of ice with infrequent spines of rock, nunataks, breaking through the snowy landscape. Beneath the ice, rock was being eroded and transported toward the distal margins of the ice sheet in enormous quantities.
<table>
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<tr>
<th>Description</th>
<th>Pressure in kPa</th>
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<td>Pressure required to break a window</td>
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<td>Pressure required to push in a door</td>
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<td>Pressure required to destroy a wood frame house</td>
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<td>Pressure required to uproot mature trees</td>
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<td>Pressure required to move reinforced concrete structures</td>
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<td>Dry snow avalanche</td>
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<td>Hurricane Andrew Delta between the eye and the periphery</td>
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<td>Tsunami wave Δ in seawater pressure</td>
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<td>Tsunami wave impact</td>
<td>673</td>
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<tr>
<td>0.4 m wave hitting a dike</td>
<td>&lt;40</td>
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<tr>
<td>Debris flow depth &lt; 2 m</td>
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<td>Debris flow depth 2-3 m</td>
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<td>Debris flow depth 5-10 m</td>
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<tr>
<td>1 km thick glacier ice</td>
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<tr>
<td>Crushing pressure of an Anaconda killing a duck</td>
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<tr>
<td>Oklahoma bomb as it hit the building (attenuation is rapid)</td>
<td>4100</td>
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<tr>
<td>Point of impact of airplane hitting a building (twin towers)</td>
<td>56000</td>
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Table 1. Pressure (stress units) of various phenomena. Note: Δ = change.

At the peak of the Fraser glaciation all of North America, and not just coastal BC, was covered by ice. The Cordillera ice sheet met the Laurentide ice sheet east of the Rocky Mountains. In all, at least $18 \times 10^{18}$ L of the world’s water was tied up in ice over continental North America, representing slightly more than one percent of the world’s oceans. As a result, global (eustatic) sea level dropped by about 100 m.

Locally, however, the great weight of the ice pushed coastal BC down into the Pacific Ocean almost 300 m so that the relative sea level was 200 m higher than it is today.

Ice retreated rapidly toward the end of the Pleistocene. Relative sea level dropped rapidly (despite an increase in global absolute sea level as water was returned to the oceans) as the great weight of glaciers were removed from the land surface. Glacial outwash flooded the valleys of receding glaciers, depositing millions of tons of gravel. Debuttressed slopes failed and substantial coalescing fans were built up against lower valley walls and at the mouths of watersheds.

The climate grew warm and dry at the beginning of the Holocene, warmer and drier than modern times, and the terrain was quickly colonized by coastal Douglas fir. Humans began using the land about 8 000 years ago, gathering in small coastal communities. By 6 000 years ago, the coast was substantially wetter and western hemlock dominated. The climate has been moderately stable the last few thousand years, with hemlock and Cedar co-dominating on the coast.

The net result of British Columbia’s recent glacial history is that the energy and processes that formed our inherited terrain exceed the energy of processes currently remoulding the landscape. Understanding the current landscape therefore requires an understanding of the historical, current and projected processes and boundaries on which physical and biological systems rely.
Consider, by way of illustration, the stability of alluvial streams on Vancouver Island. Streams may be differentiated based on stream power and stream power is largely a product of volume and gradient. Stream morphology can be understood as the outcome of these two variables, however, it is also heavily influenced by other factors such as sediment availability, size and bank strength. Based on discharge and gradient alone, streams on Vancouver Island tend to fall on either side of a line that differentiates single- and multi-thread gravel channels. Based on this graph, one would expect to see more braided streams and fewer stable banks, shallower rivers and more mid-channel bars. In reality, however, most Vancouver Island streams occupy single (wandering) channels.

Vancouver Island rivers may be compared to misfit streams, smaller rivers incising large alluvial valleys. In the Vancouver Island case, the rivers may not appear to be small, but the measure is relative to early post-glacial outwash of the same valleys. As sediment size increases, the power needed to move the material on a regular basis increases likewise. Looking at the graph, it is evident that lower power is needed to create a braided sand river than a braided gravel river. The channel gradient of Vancouver Island rivers over the Holocene is limited by underlying bedrock, but the discharge has reduced dramatically since the early post-glacial period. Post-glacial sediment sizes in the alluvial portions of rivers are very coarse, consisting of gravels in the cobble and even boulder size-range, effectively moving the threshold-lines upward on Figure 3. The gravel sizes are still within the range of sizes that may be transported by the rivers, especially in a large flood, but lower discharge relative to the size means that riparian vegetation is able to take root, banks become established, and despite the graph, single thread channels dominate. However, the proximity of a threshold between single and multi-thread channels also highlights the short term vulnerability of alluvial rivers to bank disturbance. If the banks are suddenly weakened (by riparian logging for example) the sudden drop in local bank strength means the river power is concentrated on a relatively small spatial area and channel destabilization may result. A sufficiently large storm may also remobilize unprotected (poorly...
vegetated) alluvial sediments, further changing the morphology of the system.

Upslope processes are similarly affected by ice from the Pleistocene. Morainal (till) deposits mantle our slopes, subject over the last several thousand years to gullying, mass wasting and erosion. The terrain itself has changed from a V-shaped landscape where the upslope is closely connected to the streams, to a U-shaped landscape where the coupling between upslope erosion and transport of sediment right out of the system may be separated by millennia. The implications are several: Material available for landslides, for example, exceeds by several orders of magnitude, the current rate of landsliding. The existence of a landslide does not mean that an area has been made safe (by having available sediment removed), but rather the opposite: it is an indicator of further likely instability. This occurs both because landslides do not always scour to bedrock along their path, but often simply expose more till than can then weather over a relatively short period of time, and because there remain many adjacent locations that are similarly susceptible to failure. On the other hand, the shape of the valleys means that in human time frames, the landslides are relatively decoupled from the fluvial system, and that the greatest impacts are felt locally as landslides move material from one slope position to a lower relatively stable one. While it is true that landslides in coastal BC frequently impact streams and aquatic habitat, the impacts are not nearly as severe as they would be if the valley geometry was different.

The above examples are illustrative in nature, and similar examples could be drawn from coastlines, lakeshores or karst systems. Our inherited landscape affects both the landforms and the processes that are active today. Understanding the role of this inheritance is crucial to adequately manage the landscape, particularly as we try to anticipate future changes to the physical system.

References and suggested readings:


Debris flow in gullies is a common mass movement process in coastal British Columbia, particularly during the wet winter months. The frequency and magnitude of debris flow can be affected by forestry activity, with consequences to downslope stream channels, riparian habitat, water quality and public safety. Understanding the processes resulting in debris flow is therefore of great importance for forest management activities.

In forested gullies, debris flow is typically supply-limited, and occurs as a two-stage process: an initial debris slide on the gully wall enters the gully channel, and either deposits therein or initiates a debris flow which then travels down the gully before depositing in a lower channel reach or the gully fan. The volume of debris stored in the gully channel has been identified as an important constraint on debris flow initiation, with the simplest supply-limited model (such as that proposed by Glade (2005) suggesting that once a debris flow has occurred and a gully channel has been scoured, debris stored in the channel has to recharge past some critical value before another debris flow can occur. The volume of debris stored in the gully channel is also an important constraint on the total volume of the debris flow reaching the fan, and hence on the downslope risk, since the volume of the initial failure is often only a small part of the resultant debris flow volume.

To study the interplay between in-channel debris storage and debris flow initiation, we studied two Fraser Valley watersheds, Norrish Creek and Chilliwack River (Figure 1). We selected 92 individual reaches in 53 previously logged gullies ranging from 0.06 to 10ha in size, and identified 62 separate slope failures on the gully walls (Figure 2). Thirty-seven of the failures initiated a debris flow, while 25 did not. Full details of our experimental method and characteristics of the study area are presented in Brayshaw and Hassan (2009).

Figure 1. Location of study area in Fraser Valley region with watersheds and representative climate stations identified.

Channel gradient, initial failure volume, and angle of entry of failure into channel were significant variables influencing debris flow initiation, with steeper channels, larger initial failures, and lower angles of entry more likely to result in a debris slide becoming a debris flow. Volume of sediment already in the gully bed was also significant (Figure 3), but in a different way than expected: lower volumes of in-channel sediment were more likely to result in debris flow initiation, and as volume of in-channel sediment increased, so did the size of the initial failure required to initiate a debris flow (Figure 4). This effect was largely independent of channel gradient or angle of entry and was essentially the opposite of what we had...
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Figure 2. Aerial photo and sketched map of representative gully system showing measurement of reach-scale and at-a-point variables such as ICSS (in-channel stored sediment), reach gradient, channel gradient at entry of sidewall failure, failure volume, etc. Photo date 1993, study date 1996.

Figure 3. Box plots showing difference between failures producing debris flows (yes) or depositing in the gully bed (no) for: a) Channel gradient in degrees (CG); b) natural logarithm of failure volume in cubic meters (ln Vol); c) angle of entry of failure into gully in degrees (AOE); d) in-channel stored sediment in cubic meters per meter length of gully (ICSS)

expected to find based on the simple supply-limited model of debris flow initiation.

This result suggests a negative feedback mechanism between debris recharge and debris flow initiation (Figure 5). After a debris flow, a gully channel is typically scoured of sediment and therefore even small sidewall failures are likely to result in further debris flows, but with little sediment available to entrain, the resultant debris flows will be lower in total volume reaching the fan. However, if time passes with no debris flow and sediment recharges in the gully bed, our model suggests that this results in a corresponding increase in the requirements to initiate debris flow, and this results in a longer interval between debris flows and a larger event magnitude when they do occur. If a relatively constant rate of sediment recharge to the gully bed is assumed, the susceptibility of a gully to debris flow is therefore inversely proportional to the time since the last debris flow.
Figure 4. Relationship between natural logarithm of initial failure volume in cubic meters (lnVol), ebris flow occurrence, and in-channel sediment, expressed as: a) ICSS, cubic meters of sediment/m of channel length; b) mean sediment depth, cubic meters of sediment per square meter of channel; c) Interrelation of ICSS, channel gradient in degrees, and debris flow result with statistically significant divisions marked.

Since debris slides are more frequent after logging (eg. Guthrie, 2002), this suggests one reason why debris flows from gullies become higher-frequency and lower-magnitude after logging. In the past, management prescriptions for gullies have included removing woody debris from gully channels after logging; our research suggests that this would also increase the frequency of future debris flows by reducing the total volume of sediment in the channel and thereby lowering the recharge threshold for debris flow initiation.

Figure 5A. Simple supply-limited model of debris flow initiation, after Bovis and Jakob (1999) and Glade (2005). No debris flow is possible until sediment storage equals or exceeds unchanging recharge threshold. Once threshold is reached, any sufficiently large event results in debris flow.

Figure 5B. Revised model incorporating feedback mechanism between sediment storage and recharge threshold. As sediment storage increases over time, so does threshold required to initiate debris flow.

References:


Drew Brayshaw, is a PhD candidate in the Department of Forestry at the University of British Columbia. His research interests include flood frequency and sediment transport in small mountain watersheds. He also works part-time as a consulting hydrologist for Madrone Environmental Services Ltd. He can be reached at drew.brayshaw@madrone.ca

Dr. Marwan Hassan is a professor of fluvial geomorphology in the Geography Department at the University of British Columbia. His research interests include sediment transport, channel morphology and sediment yield and he has worked around the world including Botswana, Israel, Canada and Germany. He contributed a previous article to Island Geoscience that examined the role of salmon-driven bedload transport in streams (Summer 2008). Dr. Hassan can be reached at mhassan@geog.ubc.ca
Call for Papers:

This conference focuses on stream restoration questions of concern to project planners, designers, engineers, biologists, hydrologists, geomorphologists, regulators, and land managers.

The intent of the Symposium is to focus on a multi-disciplinary approach to stream restoration design, hence a broad range of speakers and topics are encouraged. For further information on the Symposium please visit the RRNW website at http://rrnw.org

Proposals are sought for both oral and poster sessions and presentations that address the following focal topic areas related to stream restoration projects:
(1) estuary and tidal channel restoration,
(2) moving restoration research into practice,
(3) restoring urban streams, with emphasis on integrated stormwater management,
(4) social & institutional barriers and opportunities in restoring rivers and floodplains,
(5) restoration of mined stream corridors,
(6) biologic and/or vegetative monitoring of restoration projects,
(7) restoration permitting and construction case studies/lessons learned,
(8) land use and watershed changes for stream restoration,
(9) analysis of river behavior for stream restoration alternative analysis, and
(10) case studies, failures, successes and lessons learned.

Presentations should cover one or more of the suggested topics or some related subject that fits within the theme of this conference. Preference will be given to projects with post-construction performance and monitoring data that will be used in the presentation.

The deadline for session proposals is September 1st, while the deadline for oral and poster abstracts is September 30, 2009. Please submit up to a 500-word abstract to: submissions@rrnw.org

Author, title, affiliation, contact information and category (session, oral presentation, or poster) should be included at the top of the abstract (please use the abstract submittal form included below). Please use Microsoft Word format, and use "last name_first name.doc" as the file name.

For more information contact Rob Sampson at: Rob.Sampson@id.usda.gov

Introducing:

Paul Marquis is the current head of the Water Allocation Section with the Water Stewardship Division of the Ministry of Environment in Nanaimo. Paul supervises the team responsible for the administration of water licenses and approvals on Vancouver Island.

Paul is a Registered Professional Forester with a M.Sc. in hydrology from the University of British Columbia. He has also held positions as a
research scientist with the Ministry of Forests and Range, an Infantry Officer in the Canadian Armed Forces, a high school teacher and a flight instructor.

Though his current position is largely a desk job, in his free time, Paul enjoys backpacking, skiing and SCUBA diving.

Paul may be contacted at (250) 751-3239 or Paul.Marquis@gov.bc.ca

News:

On Thursday June 05th I defended my PhD thesis in a rigorous and comprehensive examination by an examining committee that included one of the world’s foremost geo-scientists, William Dietrich from the University of California at Berkeley. The questions were thoughtful and detailed, but also relevant and insightful. I passed unconditionally and the examining committee nominated my work for the W.B. Pearson medal that honours creative research in science at the PhD level.

One of the committee members (of seven) submitted his comments and questions, to be read by one of the other members in his absence, by paper. His comments were typical of the great things said at the end of the journey:

“The thesis provided to me for evaluation represents an excellent body of work. The candidate has taken a vexing scientific and engineering problem, understanding, quantifying and predicting landslide phenomena in a temperate mountainous environment, and cast a clear quantitative light onto issues previously obscured in the chiascuro of opinion, individual case histories, and inadequate tools. For this, the candidate clearly deserves to be awarded a PhD...this body of work has the feeling of a seminal contribution, and it should withstand the buffeting of time in a comely manner.”

-Letter to the Chair of the examining committee by Dr. M. Dusseault, PhD, PEng, Deputy-Director, Porous Media Research Institute and Professor of Geological Engineering, University of Waterloo, dated June 01, 2009.

The thesis titled, “The Occurrence and Behavior of Rainfall-Triggered Landslides in Coastal British Columbia” will be available in the national archives and the MOE/MOF libraries this fall, but I can send electronic copies to interested individuals. Many thanks to all those who have been supportive along the way!

-RHG