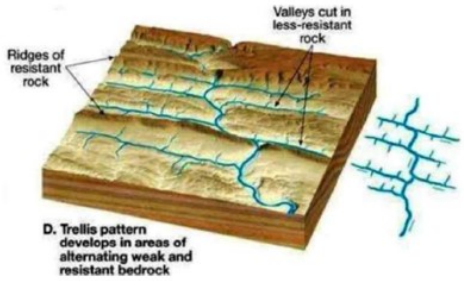
Undertaking #23: Clarification of trellis-style drainage

As Requested By: Mr. Ignasiak (Osler, Hoskin & Harcourt LLP - counsel for Benga Mining Limited)

Response: The request was made to search out a definition of "trellis" drainage that would apply to the style of drainage noted in the Project area. The original definition provided in CIAR #553 pdf pg. 72, (from the Oxford dictionary) is shown below from CIAR #875, slide presentation pdf pg. 7:

Drainage patterns as evidence of fault patterns

"A drainage pattern in which tributaries join at high angles, often approaching right angles, which is common in areas with rocks of different strengths (thus resistance to erosion) and in areas with regular series of folds (anticlines and synclines)."



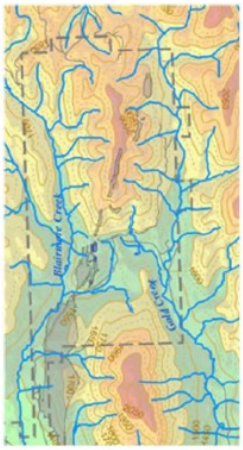


Figure 1, PDF pg. 72 of CIAR #553

The occurrence of trellis-style drainage in the Project area is direct evidence of north-south and west-east trending fault systems, which is consistent Benga's site investigations. West-east faults have not been included, explicitly, in Benga's modelling.

Additional definitions have been accessed from online e-books. The first is "The Physical Environment: An Introduction to Physical Geography"[1], and is as follows:

> ***"Trellis drainage*** *patterns look similar to their namesake, the common garden trellis. Trellis drainage develops in folded topography like that found in the Appalachian Mountains of North America. Down-turned folds called synclines form valleys in which resides the main channel of the stream. Short tributary streams enter the main channel at sharp angles as they run down*

[1] *Pidwirny, M. (2006). "The Drainage Basin Concept".* Fundamentals of Physical Geography, 2nd Edition, *http://www.physicalgeography.net/fundamentals/10aa.html,* Date visited: November 25, 2020

sides of parallel ridges called anticlines. Tributaries join the main stream at nearly right angles."

The second is "Fundamentals of Physical Geography"[2] where the following definition is provided:

***"Trellised** drainage patterns tend to develop where there is strong structural control upon streams because of geology. In such situations, channels align themselves parallel to structures in the bedrock with minor tributaries coming in at right angles."*

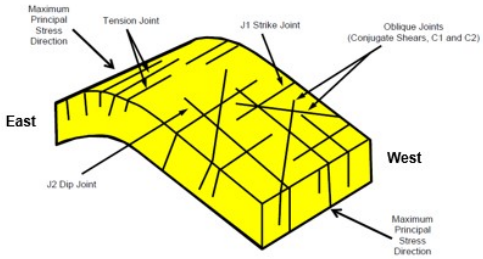
From a review of the drainage pattern in the study area, as noted by the left image in the previous slide, there is evidence to support this style of drainage in the Project area. This is noted by the direction of trend for the tributary streams draining off Grassy Mountain, as well as the mountain ranges to the west and east, including how they join the mainstems of Gold and Blairmore creeks at high angles.

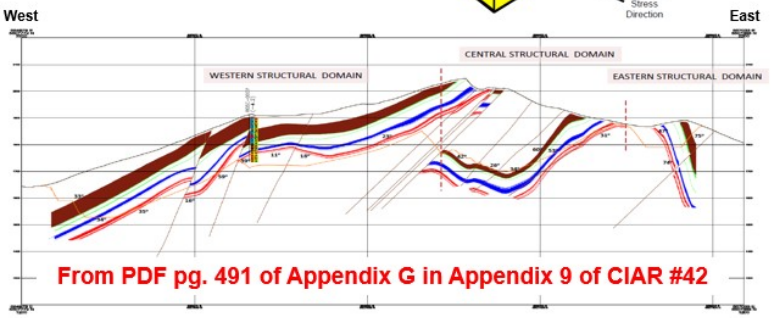
There may be some ambiguity in using the term "trellis" when other complexities in the drainage style are noted to exist as a result of structural control beyond just **folding** of the formation beds. This is evident in the Project area based on the cross-section information shown at the bottom of the slide provided on the following page (from CIAR #875 pdf pg. 6). Also evident in the same slide, and noted by Benga in their 2016 Field Investigation and Engineering Geology (documented by Golder Associates), is the occurrence of north-south trending "J1 Strike Joints", west to east dipping "J2 Dip Joints", and SW-NE and NW-SE trending "Oblique Joints" (or conjugate shears C1 and C2) shown in the top image. The presence of the large Morin Tear Fault and numerous west-east "Transverse, intensely fractured faulted zone" indications on the east side of Gold Creek (as shown in CIAR #892, Figure 3, pdf pg. 6) is consistent with these faulting patterns.

[2] *Ritter, Michael E. The Physical Environment: An Introduction to Physical Geography. https://www.earthonlinemedia.com/ebooks/tpe_3e/ title_page.html, Date visited: November 25, 2020.*

Complex geological setting

From PDF pg. 573 of Appendix B in Appendix 9 of CIAR #42





From PDF pg. 491 of Appendix G in Appendix 9 of CIAR #42

Example rock core photo

(from PDF pg. 575-689 of Appendix C in Appendix 9 of CIAR #42)

Benga has indicated that the Project area is geologically and structurally complex, with fault and fracture control on groundwater flow, including west-east faults (as reinforced by AQ#5 - Coalition - Cooley_veins_AAPG - Water Topics.pdf, now marked as Exhibit CIAR 892). This type of conditions is nearly impossible to mimic accurately within a modelling framework.

Although the co-occurrence of **folding** and **faulting** does not exactly meet the textbook definition of "trellis drainage", it is clear that both of these structural influences have affected the rocks of the study area. Given the degree of disturbance known to have occurred by mountain-building forces, the drainage pattern could therefore be described as more of a "hybrid" system including the drainage styles described below:

Referenced from footnote source[1]:

> ***"Parallel*** drainage patterns are often found in areas with steep relief or where flow is over non-cohesive materials."
>
> and
>
> "Areas with tectonic faults or bedrock joints can cause streams to take on a grid-like or ***rectangular*** pattern."

Referenced from footnote source[2]:

> ***"Parallel drainage*** *patterns form where there is a pronounced slope to the surface. A parallel pattern also develops in regions of parallel, elongate landforms like outcropping resistant rock bands. Tributary streams tend to stretch out in a parallel-like fashion following the slope of the surface. A parallel pattern sometimes indicates the presence of a major fault that cuts across an area of*

steeply folded bedrock. All forms of transitions can occur between parallel, dendritic, and trellis patterns."

and,

*"The **rectangular drainage pattern** is found in regions that have undergone faulting. Streams follow the path of least resistance and thus are concentrated in places were exposed rock is the weakest. Movement of the surface, due to faulting, off-sets the direction of the stream. As a result, the tributary streams make sharp bends and enter the main stream at high angles."*