



QUANTERRA ADMINISTRATIVE DOCUMENT – RA01 11.06.2003

## **QUANTERRA**

INTERNATIONAL INDEPENDENT CENTER OF CLIMATE CHANGE IMPACT ON  
NATURAL RISK ANALYSIS IN MOUNTAINOUS AREA

### *Activity report*

# **Report on the project COLTOP3D for March 2003: Stay of Michel Jaboyedoff at GSC - Ottawa**

By  
**M. Jaboyedoff**  
**Quanterra**  
and  
**R. Couture**  
**Geological Survey of Canada (NRCan)**

[www.quanterra.org](http://www.quanterra.org)

<http://www.nrcan.gc.ca/gsc/>



**Quanterra**

**Chemin de la Tour-Grise 28**  
**1007-Lausanne**  
Tel. + 41 79 752 35 15  
E-mail: [mail@quanterra.org](mailto:mail@quanterra.org)



*Commission géologique du  
Canada / Geological Survey of  
Canada*

Natural Resources Canada, 601 Booth  
Street, Ottawa, Ontario K1A 0E8

Ressources naturelles Canada, 601  
rue Booth, Ottawa (Ontario) K1A 0E8  
Government of Canada/Gouvernement  
du Canada



# Table of Contents

<b>1. INTRODUCTIVE ABSTRACT .....</b>	<b>3</b>
1.1 PRELIMINARY REMARK.....	3
1.2 GENERALITIES .....	3
1.3 OBJECTIVES OF THE VISIT .....	3
<b>2. ACTIVITY .....</b>	<b>3</b>
2.1 EXCHANGE AND CONNECTION WITH GSC STAFF .....	3
2.2 PRESENTATION OF RANDA ROCKFALL.....	4
2.3 NEW METHODOLOGICAL DEVELOPMENT IN COLTOP3D .....	4
<b>3. ACHIEVEMENTS .....</b>	<b>6</b>
3.1 THE PROGRAM COLTOP3D.....	6
3.2 MOU PROJECT.....	6
<b>4. FUTURE WORKS AND COLLABORATIONS .....</b>	<b>8</b>
<b>5. FINANCES .....</b>	<b>8</b>
<b>6. BENEFITS FOR QUANTERRA AND GSC .....</b>	<b>8</b>
<b>7. ACKNOWLEDGMENTS .....</b>	<b>9</b>
<b>APPENDIX I: .....</b>	<b>10</b>
<b>APPENDIX II : COLTOP3D PROJECT PROPOSAL .....</b>	<b>11</b>

## **1. Introductory abstract**

### **1.1 Preliminary remark**

*This document is a report of the stay of M. Jaboyedoff (Quanterra) at the Geological Survey of Canada (GSC) in Ottawa during March 2003. Appendixes are added to the report in order to have a complete file of this project, continuation of this project will lead to further documents (e.g. future activity report, publications).*

### **1.2 Generalities**

Quanterra is an organization being created, which deals with natural hazards in mountainous areas. The beginning of its activity is dedicated to initiating projects and taking contacts with groups of research of high level, especially in slope instability hazard assessment. The GSC developed activity in this research topic since several years, which is demonstrated by the *Canada Landslide Project* (formerly the Canadian Landslide Loss Reduction Program) within the NRCAN's Natural hazards and Emergency Response Program.

During the Annual Assembly of the European Geophysical Society meeting in Nice in April 2002 Dr. Réjean Couture (GSC) and Dr. M. Jaboyedoff (Quanterra) decided that collaboration between both organizations could be fruitful. At the end of 2002 a proposal of project (Appendix II), mainly financed by Quanterra, was submitted to R. Couture and Dr. P. Bobrowsky. They both agreed with the project. Thus a stay for March 2003 was planned and realized, a computer and an office was supply to M. Jaboyedoff. An amount of 2,000 \$CAN was paid by the GSC to M. Jaboyedoff for accommodation and expenditures accordingly to the Treasury Board of Canada's regulations.

### **1.3 Objectives of the visit**

The primary objective of this stay was to write a prototype of the program COLTOP3D dedicated to digital terrain model (DTM) analysis and visualization (Appendix II). Some well-known rock slope instabilities from the Canadian Rocky Mountains were used to test the capabilities of the program. This goal was achieved during the stay.

M. Jaboyedoff and GSC landslide group of research benefited of several stimulating discussions and ideas of project. Also, M. Jaboyedoff gave a presentation at *Geological Survey of Canada - Quaternary Discussion Group*.

## **2. Activity**

### **2.1 Exchange and connection with GSC staff**

During the stay of M. Jaboyedoff in GSC, several contacts were made. The exchanges with R. Couture and Dr. S. Evans were particularly intensive

because the project was designed in the field of interest of those two researchers. Discussions about possible future projects were held.

Many discussions about natural hazard assessments with Dr. D. Perret delineated many possible future directions of research. Subject of quick clays and earthquakes was mentioned, especially in the perspective of grain size and clay mineralogy with Jan Aylsworth.

M. Jaboyedoff participated to some social activities of the Landslide group.

## **2.2 Presentation of Randa Rockfall**

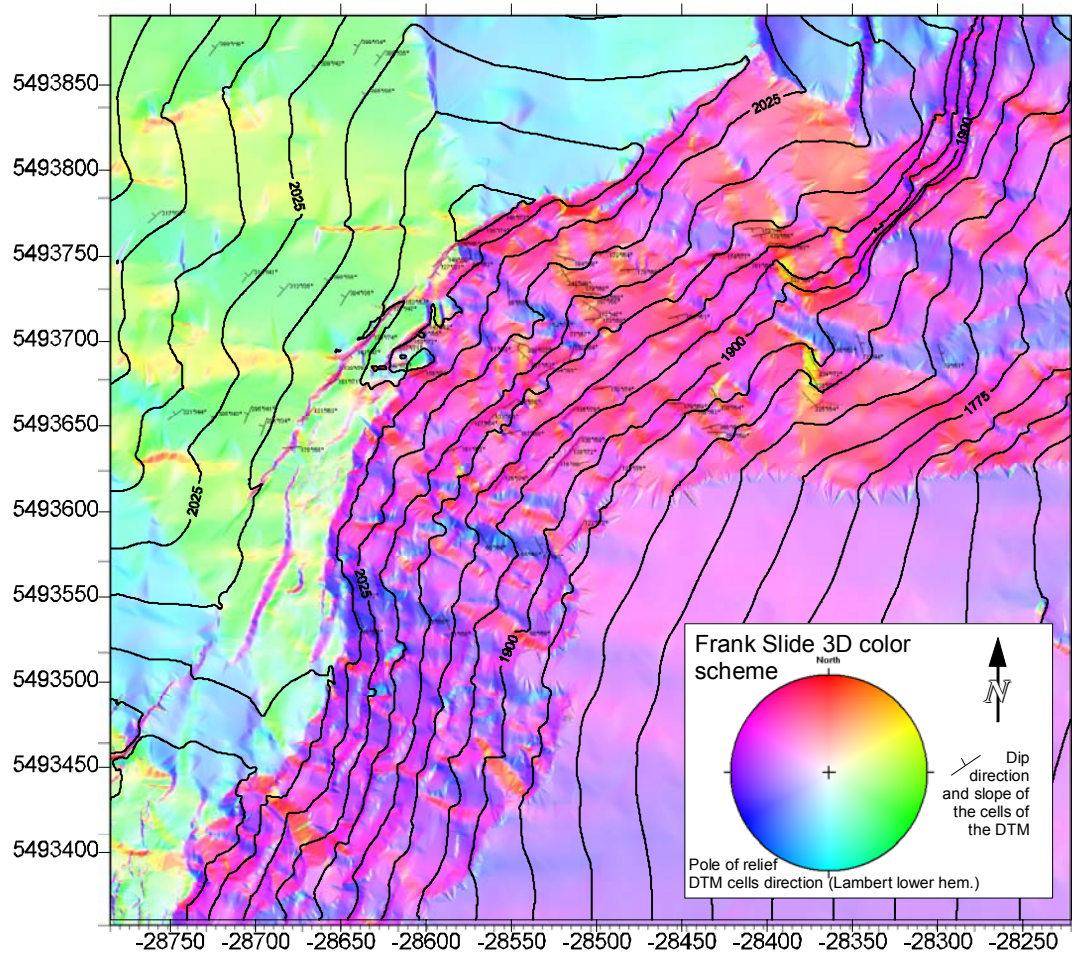


**Fig. 1:** illustration of the 30 millions m<sup>3</sup> rockslide of Randa. Left: the scar and the deposit. Right: the dust cloud during the second stage of the rock fall (Documents source: [www.crealp.ch](http://www.crealp.ch)).

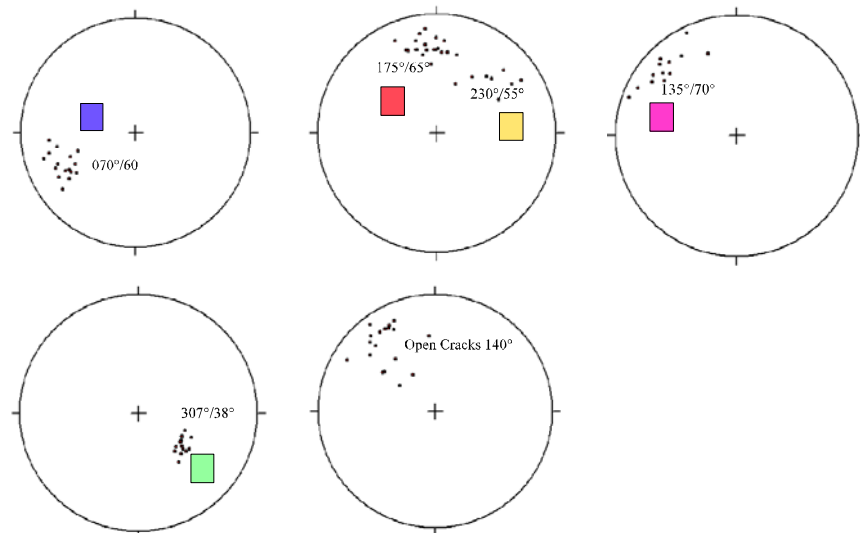
On 18<sup>th</sup> March M. Jaboyedoff presented a talk within the framework of the GSC's Quaternary Discussion Group about *The 1991 Randa rockslides (Valais, Switzerland): Past, present and future* (Fig. 1 and Appendix I) organized by Dr. Ch. Zdanowicz. Some 20 peoples attended. The following discussions and questions lasted around 20 minutes underlying the interest of GSC's scientists.

## **2.3 New methodological development in COLTOP3D**

In this project, a software was developed, COLTOP3D, which analyzes the topography from a DTM. Its functionalities are basically to visualize a DTM with specific colors for each direction of DTM cell using stereographic projection. Its second aim is to analyze topographic orientations by histograms or points displayed by stereographic projection. Stereographic projection of joint sets or frequency is also implemented.



**Fig. 2:** “3D color representation” of a part of the Turtle Mountain (Alberta) and of the scar of Frank slide. Various joint sets are visible and the steep slopes indicate present instabilities. The isolines are taken from SURFER output.



**Fig. 3:** Steronet (Lambert lower hem.) of different joint sets detected on the DTM of the figure 2. The average dip direction and slope of cells indicated by dip symbol on figure 2 are displayed. The colored squares correspond to the mean color of the joint sets orientations. The “open cracks” correspond to the steep slope limiting the current instabilities.



### **3. Achievements**

#### **3.1 The program COLTOP3D**

During his stay in at GSC, M. Jaboyedoff developed the prototype of COLTOP3D. Basically a color scheme was developed based on HSI (Hue Saturation Intensity) wheel giving a specific color for each orientation of the space (strike/dip). A window displays topography with the color scheme. Moving the mouse on the map gives the dip and strike values. By clicking, it is possible to display the topographic dip. A 3D histogram can be displayed as well by selecting a topographic area.

By clicking on one point and giving an orientation, a fault can be drawn on the map. It is also possible to draw a fault by choosing 3 points. The next step is to introduce a least square method for more points.

Stereographic projection of joint sets frequency is implemented, it permits to estimate the direction for which the fracturing is maximum.

The program has been tested using a DTM of the Frank slide of the GSC. Preliminary results show that large joint sets can be detected from a DTM (Figs. 2 and 3). It clearly shows that the joint sets have a strong influence on the topography and in the Frank slide failure mechanisms. Also, the use of 3D histogram of relief shows that topography is shaped by large joint sets.

The advantage of the 3D color schemes is to display instantaneously the steep slope limiting the present instable rock masses in the present scar.

These preliminary results will be detailed in future common works of Quanterra and GSC (e.g. open file, scientific papers).

Most of the goals described in the project (Appendix II) were achieved, except one concerning the tracing of faults based on least square method. The result is a prototype program, which must be improved in the future months. Several formats and printing options must be added. Also exports such as geotiff format must be elaborated. Color schemes for flat regions have to be developed. The reading text file routine must be improved in order to obtain quicker file opening. Furthermore the use of API for bitmap file must be implemented.

#### **3.2 MOU Project**

From the beginning of Quanterra, R. Couture and M. Jaboyedoff decided to collaborate. In December 2002 the decision was made to write a project of MOU joining GSC and Quanterra.

## Rock instability hazard assessment based on detailed topographic analysis

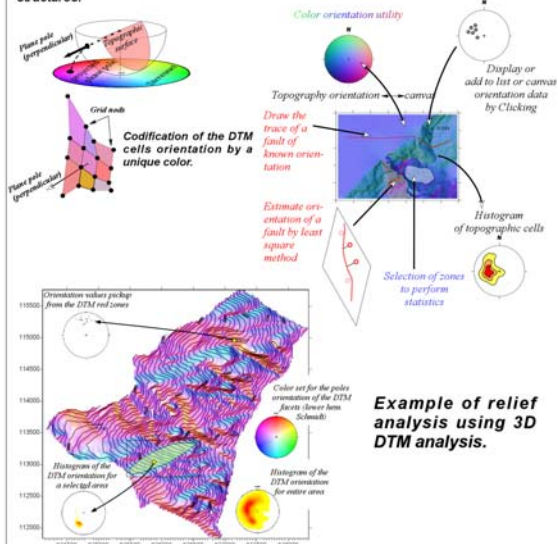
This project is supported by the Geological Survey of Canada (R. Couture).

M. Jaboyedoff (1,2), F. Baillifard (1,3), J.-D. Rouiller (1)

(1) CREALP (Research Center on Alpine Environment), Industrie 45, CH-1951 Sion, (2) Quanterra, Tour-Grise 28, CH-1007 Lausanne, (3) Institute of Geology and Paleontology, University of Lausanne, BFSH2, CH-1015 Lausanne

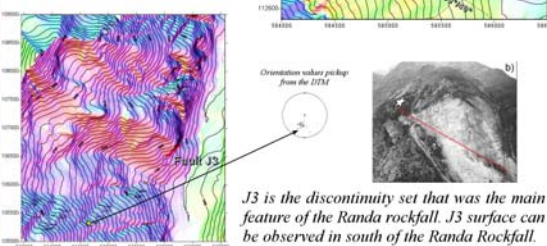
Assuming that rock instabilities are generated by the conjunction of particular structural and morphological settings, analysis of the topographic relief using DTMs (digital elevation model) provides essential results for the hazard assessment of rock instability. The accuracy of the results is dependent on the mesh size of the DTM.

Three-dimensional topographic analysis is performed by using the orientation of each single cell of the DTM, and provides a "3D shaded relief". This analysis allows the identification of the main structures that shape the landscape, especially from a tectonic perspective. This leads to the identification of the main potential rock slope failure mechanisms produced by discontinuities. Using these results, the area where potential plane or wedge sliding may occur can be detected, as well as the density of dangerous structures.



### Rock slope geomorphological analysis using DTM.

Possible interpretation for the Cretaux landslide origin. This zone seems located at the intersection of 2 large faults ( $290^\circ/40^\circ - 000^\circ/40^\circ$ ).



Residuals obtained by the subtraction of a DTM and a smoothed topography allows the detection of either convex or concave morphologies. Depending on the smoothing parameters used, convex relief can correspond to potentially unstable spurs, and concave relief can correspond to thalwegs indicative of local areas affected by higher erosion rates. The combination of these two features and the use of different smoothing parameters allows the detection of unstable spurs in local areas prone to high erosion.

The regional is calculated using an averaging method. In order to determine the smoothing matrix, three parameters have to be considered:

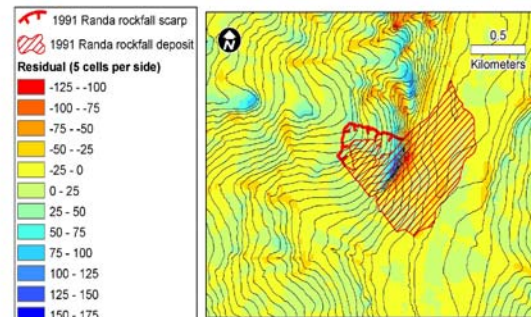
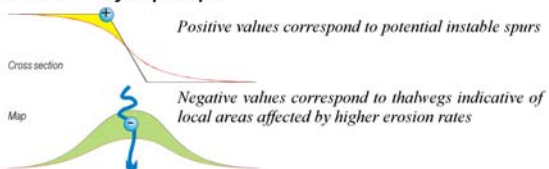
The weight of the matrix center.

The number of rows considered on either side of the center.

The number of columns considered on either side of the center.

The residual is calculated by subtracting the effective altitude (deduced from the DTM) from the smoothed altitude (deduced from the regional).

### Residual analysis principle



The area corresponding to the topography before the 1991 Randa rockslides shows the presence of a potential instable spur. It corresponds to the highest residual value of the Mattertal Valley ( $\sim 250 \text{ km}^2$ ).

Cell size of the DTM	25 m
Weight of the matrix center	1
Rows considered on either side of the center	5 (125 m)
Columns considered on either side of the center	5 (125 m)

Combining residual analysis and structural analysis allows rock hazard instability assessment. This method can be refined by using other instability factors such as proximity to observed regional faults, observed scree slopes, or poor geomechanical properties. Depending on the data available, these instability factors must be classified.

This method provides a useful tool for a primary rock instability hazard assessment as a first approach for large areas without a detailed field survey.

**Fig. 4:** The poster presents in EGS-EUG-AGU joint assembly in Nice in April 2003. The poster presents preliminary results of COLTOP3D (see Appendix II for the original abstract written before the stay in Ottawa). The GSC collaboration with R. Couture is mentioned on the left upper corner.

The project of a MOU was discussed during a meeting bringing together Pat Lloyd (*Business Policy Analyst, International Division, ESS, NRCan*), R. Couture and M. Jaboyedoff on 24<sup>th</sup> March 2003. P. Lloyd considered the MOU acceptable, suggesting that future and present projects may be added, but a delay is caused by the time needed to finalize the creation of the Quanterra Foundation. The MOU will be signed as soon as Quanterra will obtain its final legal form.

## **4. Future works and collaborations**

As mentioned above the program COLTOP3D must be finalized, mainly introducing export and printing facilities, but also implementing more efficient algorithms of image display and file reading.

The program is operational, and then the results can be used for publications. A first planned publication is an Open-file report of the GSC during the summer 2003, using various DTM from the Canadian Rockies. M. Jaboyedoff will write this paper in collaboration with R. Couture and Steve Evans from the GSC.

Another paper is planned in the EOS review of AGU related mainly to Frank slide (by Jaboyedoff and Couture). A third paper will be probably written with the same authors in collaboration with people from the CREALP Switzerland in the NHSS journal (by Jaboyedoff, Baillifard, Couture).

## **5. Finances**

The finance was supported by Quanterra for around 10,000 \$CAN and by 2000 \$CAN from GSC for accommodation and expenditures (see Appendix II).

## **6. Benefits for Quanterra and GSC**

The stay of M. Jaboyedoff at the GSC in Ottawa within the *Canada Landslide Project* group permits to Quanterra to establish strong link with GSC team justifying the future MOU. GSC has benefited of the Swiss expertise on rock slope hazards assessment through discussions with one of its experts. Personal and group exchanges were fruitful leading to the continuation of the COLTOP3D project and some other future projects were considered.

A first poster was presented in EGS-EUG-AGU joint assembly in Nice in April 2003 indicating the collaboration with GSC (Figure 4). As already mentioned further publications are planned for the summer 2003.



## 7. Acknowledgments

M. Jaboyedoff thanks very much all the *Canada Landslide Project* group for its warm welcome, funding support, and hope to renew this experience.

The May 13<sup>th</sup> 2003, Lausanne and Ottawa

Dr. Michel Jaboyedoff  
Quanterra



Dr. Réjean Couture  
Geological Survey of Canada

## Appendix I:

**Geological Survey of Canada - Quaternary Discussion  
Group  
Commission Géologique du Canada - Groupe de  
Discussion sur le Quaternaire**

**The 1991 Randa rockslides (Valais, Switzerland):  
Past, present and future**

M. Jaboyedoff, F. Baillifard, M. Sartori, P. Ornstein, J.-D. Rouiller

presented by/ présenté par

**Michel Jaboyedoff**

*Quanterra, Lausanne & CREALP - Research Centre on Alpine  
Environments, Sion  
(Switzerland / Suisse)*

**Sam Gamble Hall, 615 Booth Street, Tuesday 18 March 2003, 13:30.  
Salle Sam Gamble, 615 rue Booth, Mardi 18 Mars 2003, 13:30.**

### **Abstract /**

About 30 million cubic meters of rocks fell from a rock face near the village of Randa (10 km north of Zermatt) in two main stages: the first one on April 18, 1991, and the second one on May 9, 1991. No fatalities were reported except a few horses, cows and sheep. 31 chalets were buried. Both events caused the deposit of 10 to 40 cm of dust in a radius of approximately 1 km from the rockslide area.

The April 18<sup>th</sup> event interrupted the railway line connecting Zermatt to the Rhône Valley. The May 9<sup>th</sup> event was forecasted using detailed field, seismic and geodetic surveys; the area was evacuated. The railway line was buried for 800 m and the road for 200 m. The fallen rock mass dammed the Vispa river. About 30 houses were flooded, due to heavy rainfalls and snowmelt. The Swiss army succeeded in digging a channel before a potential catastrophic failure of the dam, which will have destroyed all the downstream villages.

The rockslide is located in a busy alpine valley, especially frequented by tourists visiting Zermatt and the Matterhorn (Cervin). The total economical impact is difficult to estimate, but the cost of works and surveys exceeded \$CAD 110'000'000.

Both 1991 rockslide events are the results of particular slope conditions and structures. The structural settings were particularly unfavorable: a moderately steep continuous fracture cut the base of the rock face and three persistent joint sets divided it into large blocks, preventing a rock-avalanche-type deposit. Those joints promoted the development of two ancient landslides above the rock face. These pre-existing instabilities had as results on one hand to provoke an excess load on the top of the rock face, and on the other hand to increase the permeability of the substratum and therefore the infiltration rate. This promoted groundwater circulations that favored rock weathering and water overpressure. Those processes led to rock fatigue and to the creation of big blocks that suffered small movements, breaking progressively the remaining rock bridges.

Observations of precursory small rockfalls during the 10 years before the 1991 events illustrate the progressive mobilization of the rock blocks. The 1991 rockslides finally occurred during a snow-melt period. Jets of water near the basal slip plane were observed just before and during the 1991 events, indicating that water overpressure acted as releasing process.

At the present time, the upper part of the scar is still slowly moving towards the Southeast at a maximum speed of 1.5 cm/year. The movements are monitored by monthly geodetic and extensometric survey. A database was specially designed to facilitate the monitoring. This database will also be used for the monitoring of other instabilities. This present day instability forced the authorities to move the road and the railway line, to prevent them to be hit by the potential new rockslide.

## **Appendix II : COLTOP3D project proposal**



PROJECT - 01

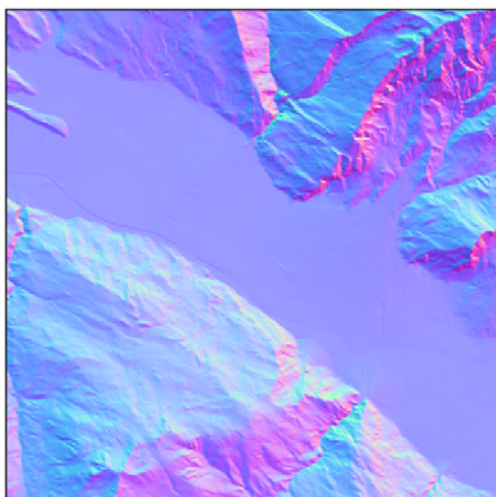
16.01.2003

---

## **QUANTERRA**

INTERNATIONAL INDEPENDENT CENTER OF CLIMATE CHANGE IMPACT ON  
NATURAL RISK ANALYSIS IN MOUNTAINOUS AREA

### *Project Proposal*



Design of a pseudo-  
3D topographic  
analysis computer  
program:

***COLTOP-3D***

*By M. Jaboyedoff*

[www.quanterra.org](http://www.quanterra.org)

**Quanterra**

Chemin de la Tour-Grise 28

1007 Lausanne

Tel. + 41 79 752 35 15

E-mail: [mail@quanterra.org](mailto:mail@quanterra.org)



**Abstract:**

*The design of a program of topographic analysis based on digital elevation model (DTM) is presented here. This software **COLTOP-3D** can be used to analyze the structures, especially faults, shaping the morphology.*

*Maps as well as stereonets displaying colors depending on the orientation will be implemented. Histograms of topographic surface are planned. The design of tools useful to analyze topography in a structural way is planned. Faults tracing will be implemented based on orientation and surface points.*

*The functions and the main points of the project are presented.*





## Table of contents

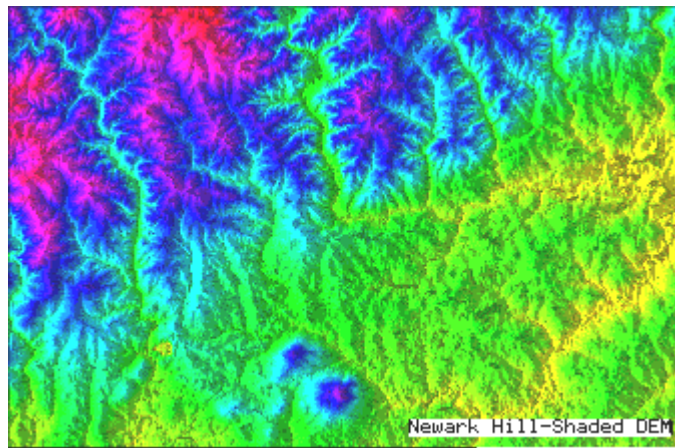
<b>1. AIMS OF THE PROJECT PROPOSAL.....</b>	<b>4</b>
<b>2. PREVIOUS WORKS .....</b>	<b>5</b>
OTHER WORKS .....	5
PREVIOUS PROGRAMMING WORKS IN GEOLOGY OF THE AUTHOR .....	5
<b>3. 3D REPRESENTATION .....</b>	<b>5</b>
COLOR .....	5
MAPS .....	6
ORIENTATION DEFINITION USING POINTS, CANVAS OR SPREADSHEET .....	6
MEAN ORIENTATION .....	6
<b>4. 3D ANALYSIS: HISTOGRAM OF TOPOGRAPHIC DTM CELLS ORIENTATION .....</b>	<b>7</b>
IN NUMBER.....	7
WEIGHTED .....	9
LOCAL ESTIMATION .....	9
<b>5. 3D FAULT TRACING .....</b>	<b>9</b>
TRACES .....	9
LEAST SQUARE FAULT TRACES USING POINTS .....	9
3D FAULT BUFFER .....	9
SIMULATION .....	9
<b>6. STEREONET OF FRACTURING DENSITY .....</b>	<b>9</b>
FRACTURING DENSITY CANVAS.....	10
<b>7. PROGRAMMING.....</b>	<b>10</b>
<b>8. PLANNING .....</b>	<b>10</b>
<b>9. COLLABORATION .....</b>	<b>11</b>
<b>10. PUBLICATION .....</b>	<b>11</b>
<b>11. FINANCING.....</b>	<b>11</b>
<b>12. PERSPECTIVES .....</b>	<b>12</b>
<b>13. PREPARATION OF NICE 2003 .....</b>	<b>12</b>
<b>14. REFERENCES .....</b>	<b>13</b>



# 1. Aims of the project proposal

*This proposal has to be accepted by the different partners. Please let M. Jaboyedoff know if you agree with this project or if major remarks have to be made.*

For a long time we have been looking for a program that is able to analyze the topography based on digital elevation model (DTM) files. Several functionalities such as slope derivatives, slope aspects etc... are available (Fig. 1) (Burrough and McDonnel, 1998), especially in GIS environment. Despite those functions, 3D analyses of topographical structures are not really available. The present project will partly fill this gap by writing the program **COLTOP-3D** based on a pseudo 3D representation and a 3D analysis.



**Fig. 1:** Example of standard DTM GIS treatment combining elevations colors and shading under grass environment.  
(From: <http://www.udel.edu/johnmack/frec682/682syll.html>).

Its main goal is to create a tool to visualize the topography, with colors indicating the orientations of the cells of the DTM combining in one attribute strike and dip, a kind of 3D shading. Starting from this orientation analysis on the image, histograms etc... functionalities will be developed.

Additional tools will be introduced dedicated to the faults and joints structure analysis.

The project is designed to realize the software in two or three steps, with intermediary results. The first version of the program resulting from the first phase will be written by M. Jaboyedoff in GSC (Ottawa) with R. Couture and P. Bobrowsky during March 2003.

## 2. Previous works

### *Other works*

Looking at different computer programs (Envi, Ilwiss, PCI...), asking different people and searching on Internet (<http://pubs.usgs.gov/of/2001/of01-223/paradis.html>, [http://rst.gsfc.nasa.gov/Sect11/Sect11\\_5.html](http://rst.gsfc.nasa.gov/Sect11/Sect11_5.html)), we did not find any traces of such a program. It seems that the 3D colors exists in topographic representations, but it is not used for structural purpose (<http://geopubs.wr.usgs.gov/open-file/of02-282/>).

Standard GIS and computer programs performed many DTM analysis such as watersheds, floods level estimations, etc...

### *Previous programming works in geology of the author*

Two programs have already been written on this topic. The first, **Matterocking** was written for the CREALP (Research Center on Alpine Environment) and can be found on the web at [www.crealp.ch](http://www.crealp.ch). This program permits to compare topography with structural data, in order to detect the areas where rock discontinuities can favor instability by sliding mechanisms. A probabilistic approach is proposed (Rouiller et al., 1998).

The second software, **CONEFALL** is dedicated to the cone method (Evans and Hungr, 1993) and will be soon available on Internet ([www.quanterra.org](http://www.quanterra.org)). It was written in collaboration with the EPFL (Ecole polytechnique fédérale, Lausanne, Suisse). It allows producing grid files of propagation areas, based on the idea that a rockfall can only propagate within a cone centered on its source point.

The structure of the program **Mattercliff** was designed by M. Jaboyedoff, but written by the CREALP (Research Center on Alpine Environment) by J.-Y Delèze. The program is dedicated to the simple geometrical characterization of discontinuity sets (Jaboyedoff et al., 1996). It is also available on the website [www.crealp.ch](http://www.crealp.ch).

## 3. 3D representation

The pseudo-3D representation requires that each orientation of topographic cell possesses a unique color. To be useful, several choices of colors must be offered by the program. Furthermore, the orientations have to be quantifiable to analyze the structures shaping the morphology. For that purpose, tools have to be added to the two basic functionalities maps and color canvas.

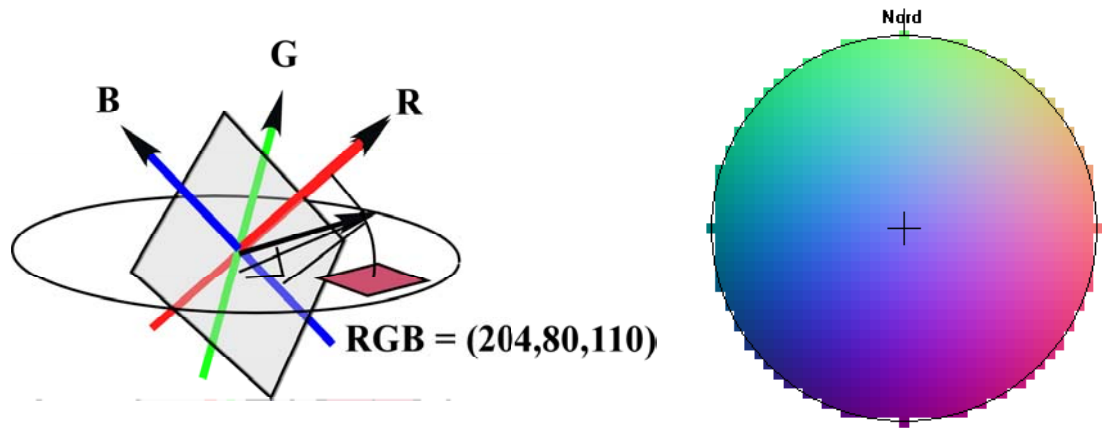
### *Color*

Representation of color orientation in 3D will be performed using Schmidt stereonet (canvas). It can be achieved by using projections of the poles of



the cells of topography on the vectors of the RGB colors (Red, Green, Blue).

A function must be created using the principle illustrated in Fig. 2, using the change in orientation of the vectors and their lengths.



**Fig. 2:** (left) One solution to use RGB and Schmidt projection, RGB vectors are in color and the vector perpendicular to the topographic cell is black. It is projected on RGB vectors. (right) Example of results of colors defined using orientations (this colors does not correspond to the one used in Fig. 3).

### **Maps**

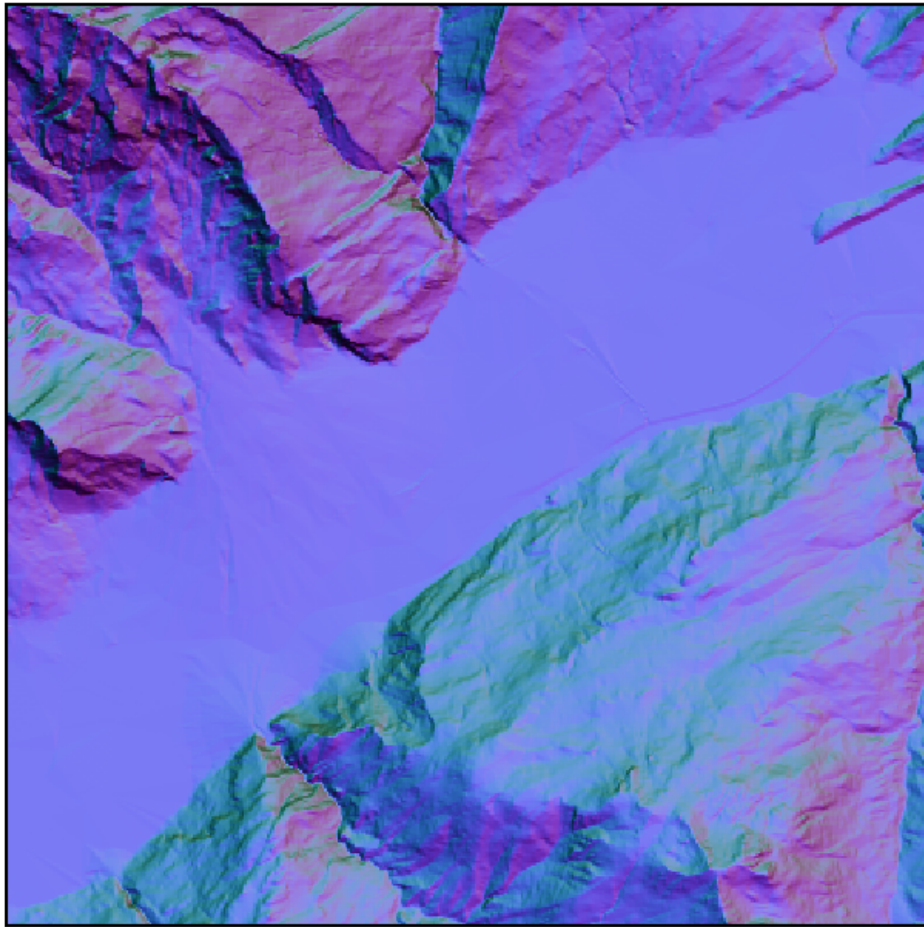
Maps are simply used to display the cells of the DTM using the colors defined by the canvas (Figs. 2 and 3). An inverse function of that underlying Fig. 2 must be developed to obtain orientations when the mouse is displaced on the colored map. The display of selected orientation alone will also be implemented.

### **Orientation definition using points, canvas or spreadsheet**

By clicking on the map, the dip and direction will be displayed on the map. Such results will be either printed on a canvas or printed in a list file that can be stored in a text file (Fig. 4).

### **Mean orientation**

Selecting graphically an area of interest, the orientation canvas or files previously described will also be obtained for all cells located within the selected area.



**Fig. 3:** Example of map that can be obtained from a DTM with a mesh size of  $25 \times 25$  m. Note the similar orientation on both sides of the valley (DHM25, reproduce with the authorization of Office fédéral de la topographie BA034918).

#### 4. 3D analysis: Histogram of topographic DTM cells orientation

Analysis of topography is also based on simple statistics. Histogram of slopes and strikes will be implemented as well as 3D histograms (Fig. 4).

3D histograms can be compared to Schmidt density stereonets, but cells orientations replace measurements of dip.

##### ***In number***

Histograms are built by counting the number of cell orientations that make an angle smaller than a given limit with the orientation density to estimate. This is performed using scalar product. Results are divided by the surface area of the sector of sphere defined by the range of angle around the direction to estimate, that is a cone.



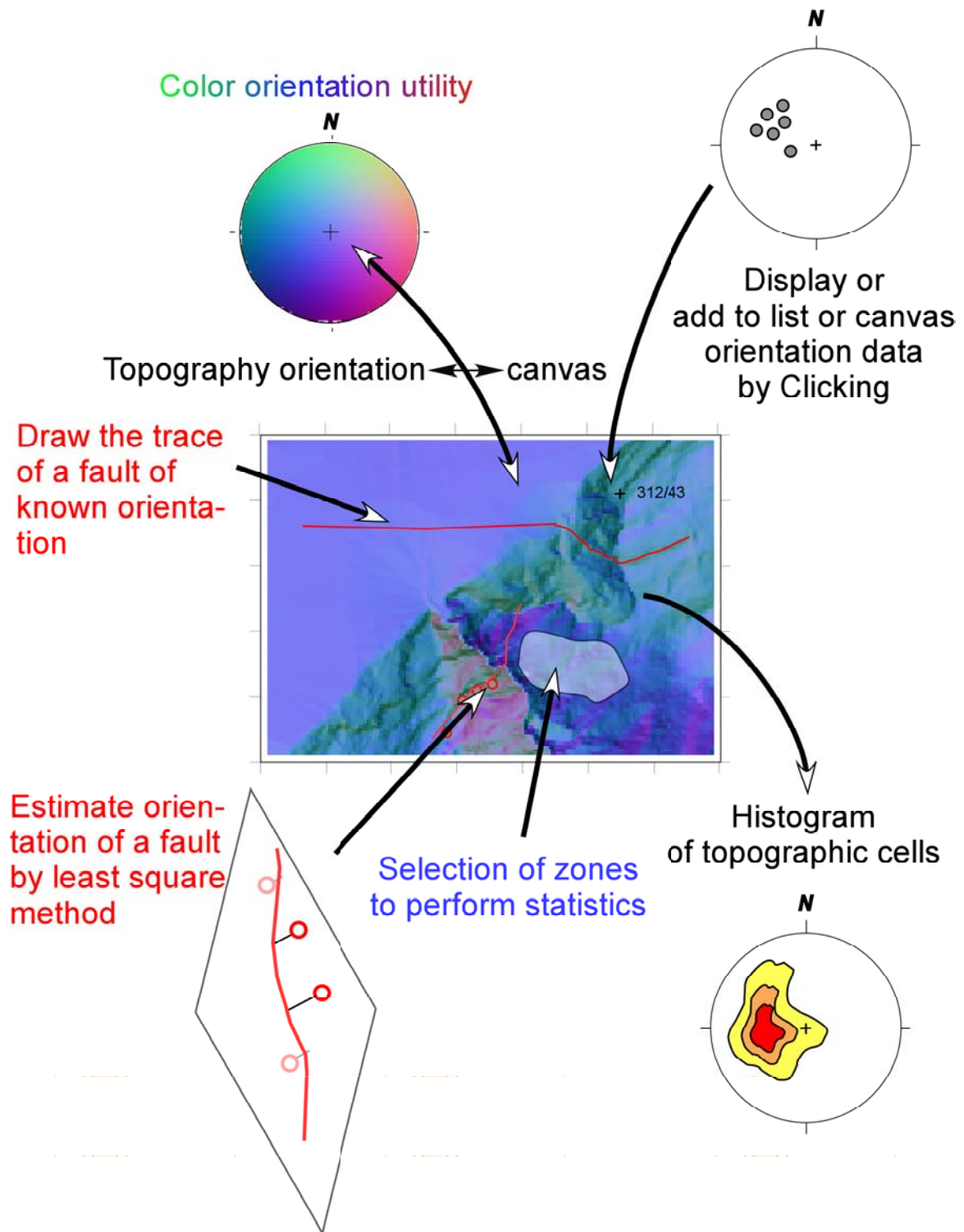


Fig. 4: Illustration of the different functionalities of the program COLTOP-3D.

***Weighted***

The 3D histogram can be weighted by the surface of the topographic cells. Instead of using simple counting of each orientation, they are multiplied by the surface. The results have to be normalized.

***Local estimation***

Histogram will also be possible within a sector of topography contoured manually.

**5. 3D fault tracing**

The analysis of the images and the statistic produced by COLTOP-3D leads notably to put hypothesis about large-scale structures such as faults and large joint sets (Fig. 4).

***Traces***

Knowing one point of a fault and its orientation, a function will be developed to obtain its trace on the topography. Spatial limits will be implemented too.

***Least square fault traces using points***

Sometimes a fault is suspected, but no orientations are clearly visible on the topography. Thus by placing points on the topography belonging to the supposed trace of the fault, the trace will be obtained using least square method to define a planar surface.

***3D Fault buffer***

The "buffer" function usually implemented in GIS permits to create a buffer around an object with a constant distance horizontally (Burrough and McDonnel, 1998). If a fault is oblique to the topography, this buffer should vary depending on the angle between the topography and the fault. A function that produces such buffers will be implemented.

***Simulation***

The function of fault tracing allows tracing a lot of faults. Using this function, simulations of fault display on the topography will be developed.

**6. Stereonet of fracturing density**

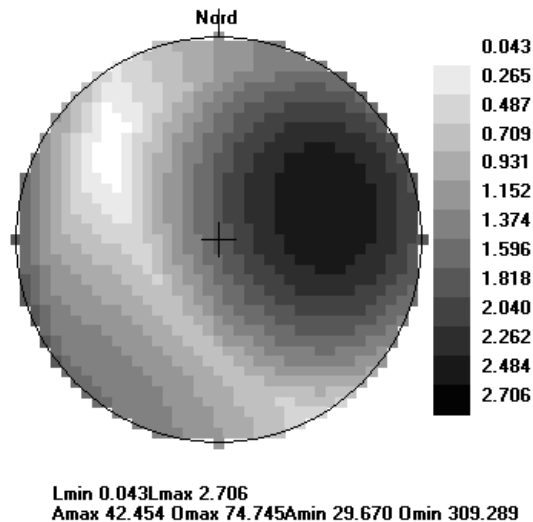
Joints sets can shape rock slopes. The analysis of the frequency of the main joint sets, compared to histograms of topography will be a tool to analyze the effect of fracturing on landforms development.



### ***Fracturing density canvas***

Following the theory of Hudson and Priest (1979 and 1983), the density of fracturing can be calculated in all directions of the space using the frequencies and orientations of the pole of the discontinuity sets (Fig. 5).

Comparing the results with small area of topography will be a test for the effect of fracturing on geomorphology.



**Fig. 5:** Example of frequency canvas of two discontinuity sets 130/30 and 60/60, assuming frequency of 1 and 2 respectively.

## **7. Programming**

The programming will be performed in Visual basic 6.0 using API functions (Stephens, 1999). The application will be a multi windows application (Mdi). Several types will be produced; some of them will be dependent on each other's. A function of color in 3D will be developed.

The colors will be displayed as bitmap, but they will be defined in a grid array of RGB colors using API. A function of map coordinates will be refined, in order obtain high quality outputs.

## **8. Planning**

As usual, it is difficult to establish a planning for computer programming. But because some routines partly exist, some stages will not be too difficult to reach.



The continuation of this project depends on the success of this first stage and on the results obtained using COLTOP-3D

<b>Travel</b>	1'500 CHF
<b>Accommodation</b>	1'000 CHF
<b>Salary</b>	7'500 CHF
<b>Expenditures</b>	1'000 CHF
	<hr/> 11'000 CHF

**Fig. 7:** Approximative costs of the first stage of COLTOP-3D program. The change between \$CAN is approximtly 1/1 with the CHF, thus accomodation and expenditures are supported by GSC.

## 12. Perspectives

Depending on the advance of the project, the possibility to introduce a background image to pseudo-3D representation have to be implemented, this will be useful to compare mapping.

The development of laser DTM (Lidar) of high resolution will increase the potential utility of COLTOP-3D.

Collaborations with private companies have to be considered.

## 13. Preparation of Nice 2003

A presentation in the EGS-EUG-AGU congress in Nice 2003, has already been submitted, containing partly subjects linked to COLTOP-3D. The abstract is:

### ***Rock instability hazard assessment based on detailed topographic analysis***

*M. Jaboyedoff (1,2), F. Baillifard (1,3), J.-D. Rouiller (1)*

*(1) CREALP (Research Center on Alpine Environment), (2) Quanterra, Lausanne, (3) Institute of Geology and Paleontology, University of Lausanne*

*support@quanterra.org/Tel: ++41+79-752-35-15/Fax: ++41+27-322-55-67*

*Assuming that rock instabilities are generated by the conjunction of particular structural and morphological settings, analysis of the topographic relief using DTMs (digital elevation model) provides essential results for the hazard assessment of rock instability. The accuracy of the results is dependent on the mesh size of the DTM.*

*Residuals obtained by the subtraction of a DTM and a smoothed topography allows the detection of either convex or concave morphologies. Depending on the smoothing parameters used, convex relief can correspond to potentially unstable spurs, and concave relief can correspond to thalwegs indicative of local areas affected by higher erosion rates. The combination of these two features and the use*





*of different smoothing parameters allows the detection of unstable spurs in local areas prone to high erosion.*

*Three-dimensional topographic analysis is performed by using the orientation of each single cell of the DTM, and provides a 3D shaded relief. This analysis allows the identification of the main structures that shape the landscape, especially from a tectonic perspective. This leads to the identification of the main potential rock slope failure mechanisms produced by discontinuities. Using these results, the area where potential plane or wedge sliding may occur can be detected, as well as the density of dangerous structures.*

*Combining residual analysis and structural analysis allows rock hazard instability assessment. This method can be refined by using other instability factors such as proximity to observed regional faults, observed scree slopes, or poor geomechanical properties. Depending on the data available, these instability factors must be classified.*

## 14. References

- Buurrough, P.A. and McDonnel R.A. 1998. Principles of geographical information systems. Oxford Univ. Press. Pp. 333.
- Evans, S., Hungr, O., 1993. The assessment of rockfall hazard at the base of talus slopes. Canadian Geotechnical Journal, 30, 620-636.
- Hudson, J. A. and S. D. Priest 1979. "Discontinuities and rock mass geometry." International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts 16(6): 339-362.
- Hudson, J. A. and S. D. Priest 1983. "Discontinuity frequency in rock masses." Int. J. of Rock Mech. and Mining Sc. and Geomech. Abstracts 20: 73-79.
- Jaboyedoff, M., Philipposian, F., Mamin, M., Marro, Ch. and Rouiller, J.-D. 1996. Distribution spatiale des discontinuités dans une falaise. Approche statistique et probabiliste, Rapport de travail PNR31, Hochschulverlag AG an der ETH Zürich.
- Paradis S.-J., Boutin, M., Boivin, R., and Larocque, H. 2001. From Conventional Airphotos, to 2.5D Maps and Digital Mosaic Terrain Reconstructions: A Simple but Complete Digital Technique Used at GSC-Québec. Canada Digital Mapping Techniques '01 -- Workshop Proceedings U.S. Geological Survey Open-File Report 01-223
- Rouiller, J.-D., Jaboyedoff, M., Marro, C., Philipposian, F. and Mamin, M., 1998. Pentes instables dans le Penninque valaisan. Matterrock: une méthodologie d'auscultation des falaises et de détection des éboulements majeurs potentiels. Rapport final du PNR31. VDF, Zürich, 239 pp.
- Stevens, R. 1999. Visual basic graphics programming. Wiley, 712 pp.

