Challenges in Evaluating Mining Impacts in the Periglacial Environment of the South American Andes

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Introduction

The South American Andes have abundant mineral resources, which attracts mining. Many deposits are located in remote locations and at high elevations characteristics of dry, periglacial environments. Periglacial landforms such as rock glaciers, protalus ramparts, gelifluction slopes, pattern ground and ice wedges dominate over glaciers and, glaciaretes [*Corte 1988*].

As in many high mountain environment, the distribution of permafrost and its landforms is heterogeneous and sporadic, being dependent on elevation, slope angle, slope aspect, vegetation (or the lack thereof) and micro topography that affects the distribution of snow accumulation and creates cold air sinks. It is not uncommon to find features such as active rock glaciers at elevations lower than the lower probable permafrost altitude limit. These are examples of periglacial landforms that are i) a legacy from past colder climates and ii) prove of mass movements through ice deformation in this environment. Rock glaciers, which often form close to the lower elevation limit of permafrost, have the capacity of creeping considerable distances over millennia which sometimes results in their presence in terrain lacking permafrost.

As a result of the heterogeneity of surficial conditions, which affect thermal ground characteristics, especially aspect and snow accumulation, the distribution of ground ice is highly variable and is greater in valley bottoms where the slopes are flatter and colluvial or fluvial sediments allow the aggregation of ground ice.

The South American Andes currently are facing a unique combination of geophysical conditions that challenge the evaluation of environmental impacts resulting from mining activities. First, permafrost related terminology finds local variations that sometimes contradict definitions coined in the northern hemisphere and that may confuse the decision making. Second, the heterogeneity of mountain periglacial conditions, in contrast to the Arctic, makes the evaluation of impacts a probabilistic issue where a regular approach usually overestimates the interaction between permafrost and the projects affected area. Third, the international debate on the hydrological importance of the periglacial environment and ground ice commonly found in landforms such as active rock glaciers, affects the evaluation of environmental impacts. This is especially the case in the light of the new regulations that some South American countries have passed, with the objective of protecting water resources within the periglacial environment (e.g., Argentine National Glacier Act Law 26.639).

Environmental regulations

Government regulator sinvarious countries in South America have passed regulations or guidelines which are oriented towards the protection of the periglacial and glacial environments. However, these new regulations do not define why the periglacial environment needs to be preserved and which characteristics require protection. The temporal dynamics of the periglacial environment considering the duration of certain projects, the spatial heterogeneity of mountain permafrost and its ice content challenge regulatory agencies to define the purpose of the regulations. Hence, questions with respect to the validity of such laws and guidelines have emerged. For example, if there is a project which occurs largely in dry permafrost, which is part of the periglacial environment, is there the need to preserve the thermal state only for the sake of temperature? Or is it the protection of the ground ice the focus of these regulations? If so, does any and every amount of ground ice require protection or would it be better to further the understanding of the mountain permafrost hydrology and protect the features that contribute to and affect the hydrology of mountain basins on a measurable and significant level? Hence, is there a critical and site specific ground ice content that warrants protection? These are just a few questions that come to mind when reading the new regulations pertaining the Andean periglacial environment. In essence, and as with every case of unknown environments, the key conditions that must be met is the understanding of its physical characteristics and related processes in order to have regulations which are properly targeted to effectively achieved their protecting role.

Terminology and geomorphic classification

The evaluation of the impacts related to any kind of project requires the establishment of a conceptual and terminological framework that defines the landforms and processes that warrant consideration in the respective evaluation. This conceptual framework ought to be understood and agreed upon by the different entities that partake in the evaluation and approval process (proponent of the project, stakeholders and the respective authorities and governing agencies). If these various groups involved do not share a common definition scheme, the overall objective of the impact evaluation is undermined since the focus of attention tends to move to the redefinition and understanding of landforms and geo-processes rather than an objective assessment of the project’s activities and related impacts. Further, it is difficult for the general public to understand potential impacts from certain projects if even the parties directly involved do not share a unified definition for certain terms. Such uncertainties may be used to manipulate interest groups. Although the International Permafrost

Association and UNESCO have agreed in an official permafrost and glacier related terminology, projects located in South America experience difficulties due to local variations of the internationally accepted definitions. Currently the main issues arise from differences in the definition and understanding of (a) the periglacial environment and the distinction between glacial and periglacial, (b) the definition of permafrost and (c) the definition of rock glaciers and the distinction between uncovered (white) glaciers and rock glaciers.

The *periglacial environment* is conventionally defined as those environments in which frost action and/or permafrost related processes dominate (French, 2000; French & Thorn, 2006).However, in South America, the existence of permafrost is a condition sine qua non to define an environment as periglacial, whereas this is not the case in the northern hemisphere. On the other hand, the *glacial environment* is defined as areas covered by glaciers or other perennial surface snow and ice masses today, i.e., environments that are *glacierized* (not *glaciated*) [*Cogley 2011*]. Furthermore, the definition of *glaciers* also varies. In Chile, government guidelines define glaciers under Lliboutry [*1956*].They consider a glacier to be «every perennial ice mass, formed by snow accumulation, independently from its shape, size and dynamics". This definition does not recognize the existence of forms such as glacierets and snow / ice patches.

Data limitation

The pronounced heterogeneity of periglacial conditions of mountain environments, usually results in (a) a poor understanding of local conditions and how they affect the project and (b) a potential overestimation of the interaction between periglacial landforms and the areas affected by a particular project. Projects that are under budget and time constrictions usually don't recognize the necessity to invest resources to conduct detailed studies on the periglacial environment. Hence, conclusions are usually drawn from a limited amount of potentially non-conclusive observations. The combination of limited observations and inappropriate extrapolations can result in an overestimation of impacts by the stakeholders and regulatory agencies on the one hand, and potential impact underestimation by the project proponents.

Periglacial hydrology

An additional source of discrepancies and confusion is the understanding of the hydrology of the mountain periglacial environment. Within the periglacial hydrology, it is crucial to appropriatelyasses the hydrological role of permafrost and the active layer. Because of their high ice contents rock glaciers are particularly scrutinized irrespective of their glaciogenic or cryogenic origin. Various studies have addressed the hydrological role of permafrost underlain terrain and rock glaciers in mountain areas [*e.g.,Corte, 1976; Krainer&Mostler, 2002*]. The heterogeneity of the conditions, in combination with the several different types of observations needed to quantitatively asses its hydrology and the subsequent costs, have resulted in studies which address the issue qualitatively [*Arenson & Jakob 2010*]. One of the most important challenges with respect to determining the water contribution of the periglacial environment is its field measurement program. It is not uncommon to observe an overestimation of the water contribution from rock glaciers, which is directly assumed to come from the melting of ground ice within this landform. This mainly results from the difficulty of separating the hydrographs in their different components of flow, where snow melt and shallow ground water originating from areas upslope, are erroneously combined with the specific amount of water derived from ground ice melting [*e.g.,Marangunic, 1976*].

Conclusions

The evaluation of construction related impacts in the arid South American Andes is challenging. The main issues concern:

(a) definitions, terminology and theoretical framework,

(b) heterogeneity of mountain periglacial environment and permafrost conditions; and

(c) the hydrological role of permafrost and related landforms such as rock glaciers.

These issues need to be resolved to ascertain scientifically-based environmental impact assessment in such environments, which help project proponents and stakeholders alike. This requires additional scientific studies that address potential impacts from construction activities in such environments and a joint international effort and initiatives for consensus-building on the topics of terminology, heterogeneity of mountain conditions and the hydrological role of permafrost landforms and the periglacial zone.

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