Brenning, A. (2008): The impact of mining on rock glaciers and glaciers: examples from Central Chile. In: B. S. Orlove, E. Wiegandt & B. Luckman (eds.), Darkening peaks: glacier retreat, science, and society. University of California Press, Berkeley. Chapter 14, p. 196-205.

14

# The Impact of Mining on Rock Glaciers and Glaciers

## EXAMPLES FROM CENTRAL CHILE

*Alexander Brenning*

Glaciers and rock glaciers in the semiarid Andes constitute natural stores of water that control the runoff of mountain rivers, especially in the dry summer months. They are responsible for the water supply to the agglomerations of Santiago, Chile (5.3 million inhabitants), and Mendoza, Argentina (1.1 million inhabitants), and the irrigated land in the surrounding lowlands (Corte 1976; Barsch 1988; Schrott 1996; Brenning 2003, 2005*a*, *b*). Rock glaciers are of minor hydrological and geomorphological importance in the European Alps. However, the amount of water stored in them per unit area in the Andes between Santiago and Mendoza is one magnitude higher than in the Alps, and they constitute the only ice bodies in many catchments with summit altitudes of up to 4,500–5,000 m a.s.l. (Brenning 2005*b*). The importance of rock glacier water storage increases toward the arid north (Schrott 1996; Brenning 2005*b*). Their significance in the dry Andes is, however, very little known in Chile.

Rock glaciers have been characterized as the geomorphological expression of creeping bodies of ground ice in areas of mountain permafrost and have been attributed to periglacial and glacigenic conditions (Barsch 1988, 1996; Whalley et al. 1994; Figure 14.1). Since the formation of rock glaciers can in most cases be assumed to have begun in earlier periods of the Holocene or Pleistocene (Haeberli et al. 1999, 2003), most of their ice content (assumed to be 40–60% by volume) may be considered fossil frozen groundwater (Barsch 1977, 1996; Hoelzle et al. 1998; Arenson, Hoelzle, and Springman 2002). Only the ice contained within the seasonally frozen active layer of a rock glacier is exchanged on a yearly basis.

In the semiarid Andes, glaciers *sensu stricto* are most abundant in the Andean main range around the latitude of Santiago and Mendoza (latitude 33–34°S), where summit elevations frequently exceed 5,500 m a.s.l. and reach a pan-American maximum of 6,959 m at Cerro Aconcagua (Lliboutry 1956). Their importance is very limited outside these central parts and rapidly decreases northward.

The main human activities in the semiarid Andes are summer extensive pasturage of cattle, horses, and goats and mining; tourism is very limited. Major mining projects exploit mainly copper and gold reserves of low grade in remote

FIGURE 14.1. Active rock glaciers in a glacier-free cirque above 3,500 m a.s.l. on the west side of Cerro Catedral (4,765 m), Andes of Santiago, February 2002. (Photo by A. Brenning.)

areas of the Andes. Their development since the 1980s is characterized by enormous expansion projects that have made Chile the world's largest copper-producing country and one of the largest gold producers (CCAEC 1996). For example, from 1980 to 2000 Chilean gold and copper production showed sevenfold and fourfold increases, respectively (Lagos et al. 2002). This study focuses on the impact on rock glaciers and glaciers of mining activities at CODELCO División Andina, Los Bronces, and Pascua-Lama (Figure 14.2). Trends in public and governmental awareness and action are observed and related to recent political and legislative developments in Chile.

Although explicit environmental legislation goes back only to 1994, several earlier laws address environmental issues in Chile. In particular, the use of surface and underground water is regulated by the water code and administered by the Dirección General de Aguas (Dourojeanni and Jouravlev 1999). According to this law, any use of both glaciers and rock glaciers would require government approval. The Chilean Environmental Impact Assessment System was established in 1994 by Law No. 19.300 (Fundamental Environmental Law) and supplementary supreme decrees. Environmental impact studies and declarations have been obligatory since 1997 for most industrial and mining activities, and the Comisión Nacional del Medio Ambiente (CONAMA) and its regional agencies (COREMA) are responsible for their implementation. According to this law, the environmental agencies cooperate with the corresponding ministerial services in the evaluation process (Pizarro and Vasconi 2004), which is public and includes hearings designed to foster public participation (Padilla 1996; Sabatini and Sepúlveda 1996). Environmental impact studies and declarations are publicly accessible, in some cases even online (http://www.seia.cl; http://www.conama.cl).

## DIVISIÓN ANDINA AND LOS BRONCES: LARGE-SCALE MINING IN A PERIGLACIAL ENVIRONMENT

Rock glaciers were first studied in Chile by Lliboutry (1961, 1986) in the area of the current Los Bronces and División Andina mines. This area was later also visited by the rock glacier researcher D. Barsch in January 1982 (cf. Barsch 1988 and Barsch 1996: 26), a time when local morphology still had not been much altered by mining. Since then, the overwhelming growth of both mines in the area has produced a strong geomorphological impact (Figure 14.3).

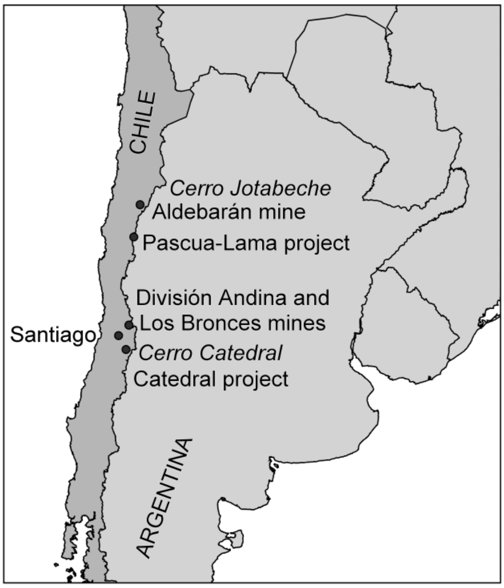


FIGURE 14.2. The study area.

The development of the Los Bronces mine started in the 1830s at several small copper and silver extraction sites situated around 3,500 m a.s.l. Since the exploitation of high-grade minerals was limited by the basic technology, the construction of an underground mine in 1915 and the fusion of several small companies increased production. As a consequence of the conflicts arising during this concentration, the company was named Disputada de Las Condes (*Minería Chilena* 1993).

Disputada was nationalized in 1972 and later sold to Exxon Minerals during the military regime in 1978. The new owner initiated a process of modernization, which increased copper production from 8,400 to 37,000 tons per year by around the year 2000. Today the possibility of an increase to 200,000 tons per year is being evaluated (Editec 2000). The Los Bronces rock mill at 3,500 m a.s.l. is connected by a 57-km-long ore pipeline with the concentrator plant of Las Tórtolas, situated in the forelands of the Andes north of Santiago (*Minería Chilena* 1993). Since 2001 Disputada has been owned by the South African company Angloamerican.

Just north of Los Bronces at División Andina, the state-owned Corporación Nacional del Cobre de Chile (CODELCO) exploits the same copper reserve as Disputada. Extraction began here in 1864 in the western part of the current mine (Holmgren and Vela 1991), and an underground mine started to operate in 1970. After nationalization in 1971, the mine was incorporated into CODELCO in 1976 under the name of División Andina. In 1980, open-pit mining of high-grade minerals began at the Sur-Sur pit (Arcadis Geotécnica 2001). In 1998 an expansion project almost doubled copper production at División Andina, reaching 249,000 tons of refined copper in 1999 (Editec 2000). Current expansion projects are intended to reach an annual production of 400,000 tons of copper in 2006 and of 650,000 tons in 2012 (Arcadis Geotécnica 2001; *Minería Chilena* 2005*c*). Figure 14.3 is a cartographic representation of the development of mining activities in the División Andina and Disputada de Las Condes areas.

The vast rock glacier areas in the Upper Blanco catchment have been affected by mining activities at least since the Sur-Sur pit of División Andina began to operate in 1980. Since then, two rock glaciers identified by Lliboutry (1961) have disappeared almost completely (Table 14.1). The current expansion project at División Andina provides for an enlargement of the Sur-Sur mine to a total area of 375 ha and the construction of two new waste-rock disposal areas with a total surface area of 497 ha, according to the approved environmental impact study (Arcadis Geotécnica 2001; Figure 14.3, Table 14.1). Thus, more than 8 $km^2$ of high mountain area will be strongly impacted. The operations imply the destruction or degradation of about 1.4 $km^2$ of rock glaciers, according to the same study. Furthermore, my inquiries at the Dirección General de Aguas (Departamento de Administración de Recursos Hídricos and Centro de Información de Recursos Hídricos, Santiago) indicated that the agency was unaware of any of these past or proposal removals and alterations of rock glaciers at División Andina.

In the area of the Los Bronces mine of Disputada de Las Condes, a comparison of aerial photographs (Hycon 1955 and Geotec 1997) shows that rock glaciers have also been removed

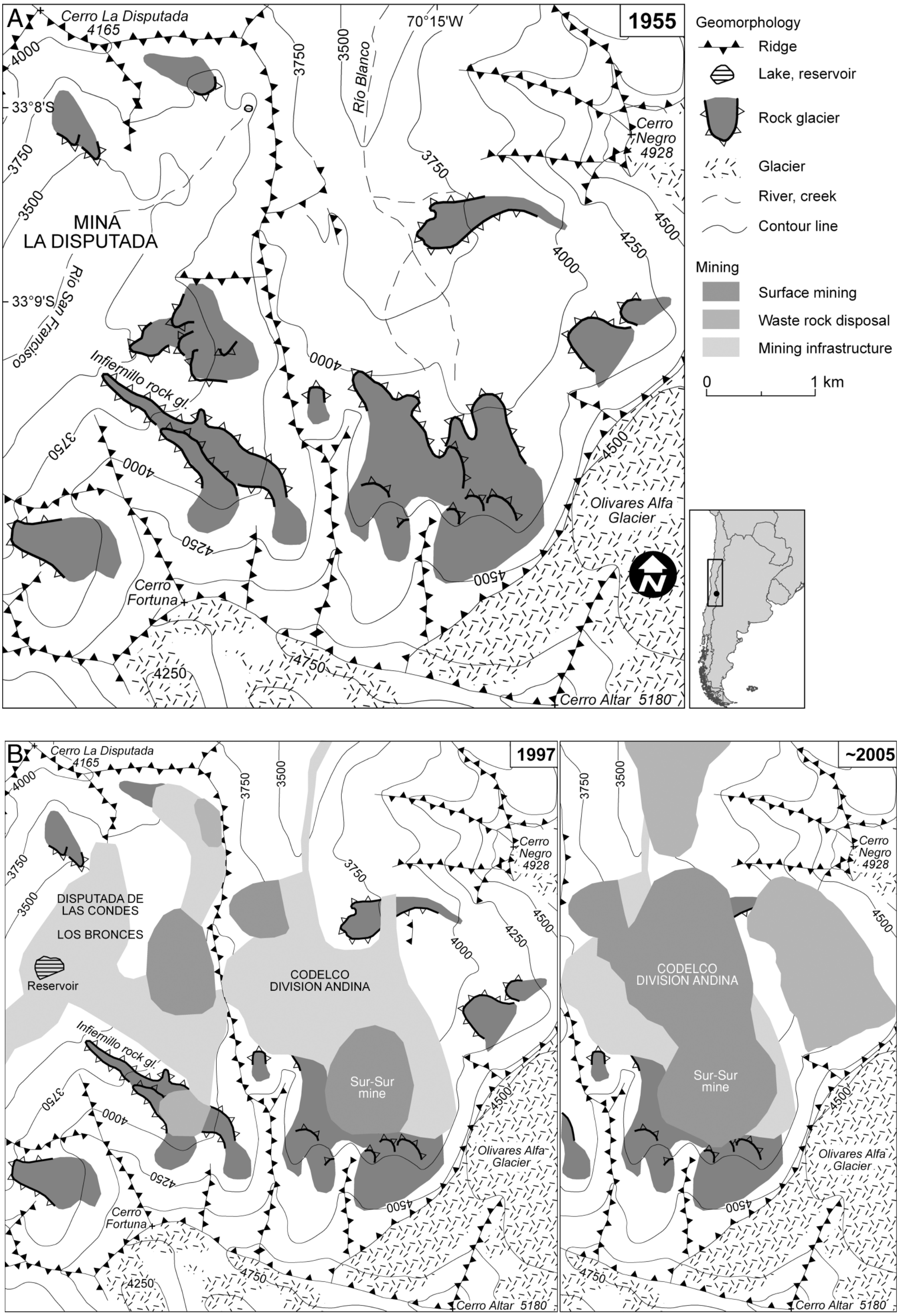


FIGURE 14.3. Geomorphological impact of open-pit mining on rock glaciers at División Andina and Los Bronces. (A) 1955, (B) 1987 and ~2005. Cartography based on Llibountry (1961), Arcadis Geotécnica (2001), and aerial photography of 1955 and 1997 (Hycon, no. 4300, and Geotec, flight Juncal, no. 5585).

TABLE 14.1

*Rock Glacier Area and Ice Volumes Affected by División Andina and Los Bronces Mines*

| | DIVISIÓN ANDINA | LOS BRONCES |
|---|---|---|
| Original rock-glacier area[a] ($km^2$) | 2.6 | 1.9 |
| Alteration until 1997[a] | | |
| Removed by open-pit mining ($km^2$) | 0.5 | 0.2 |
| Covered by waste rock deposits ($km^2$) | — | 0.2 |
| Affected by mining infrastructure ($km^2$) | 0.2 | 0.4 |
| Water equivalent affected until 1997[b] ($10^6$ $m^3$) | >5 | >6 |
| Alteration 1997–2005[c] | | |
| Removed by open-pit mining ($km^2$) | 0.82 | n.a. |
| Degraded (waste rock, infrastructure) ($km^2$) | 0.58 | n.a. |
| Water equivalent affected 1997–2005[b] ($10^6$ $m^3$) | 10 | n.a. |

[a]Calculated from aerial photographs (Hycon, no. 4300, and Geotec, flight Juncal, no. 5585) and the environmental impact studies of Geotécnica Consultores (1996) and Arcadis Geotécnica (2001).
[b]Calculated assuming a minimum permafrost thickness of 20 m, an ice content of at least 40%, and an ice density of 0.9 g/$cm^3$ (Brenning 2005*b*).
[c]Expansion project of División Andina, data from Arcadis Geotécnica (2001).

and altered (Figure 14.3, Table 14.1). Most information available from Los Bronces concerns the deposition of mine waste on the Infiernillo rock glacier beginning in August 1990. The Infiernillo is an active tongue-shaped rock glacier 2.5 km long. It extends from 3,600 to 4,300 m a.s.l. and covers 1.0 $km^2$. The upper central part (~0.2 $km^2$) of it, at ~4,000 m a.s.l., has been covered with waste rock from Los Bronces since August 1990. Its displacement has been monitored at several topographic points, and boreholes from prior to the deposition and some of the results have been published. Contreras and Illanes (1992) reported superficial displacement rates between 0.3 and 1.2 cm per day under natural (predepositional) conditions with strong seasonal variation and highest velocities in spring and especially autumn. The initial deposition of 14 million tons of waste rock led to an immediate increase in rock glacier surface velocity to a peak of about 20 cm per day. This value is extremely high compared with measurements of rock glacier velocities under natural conditions (Barsch 1996; Grebenets, Kerimov, and Bakcheev 1997; Arenson, Hoelzle, and Springman 2002; Roer 2003). Velocities stabilized after this initial period but at higher levels than before the deposition (Contreras and Illanes 1992). Further data on waste-rock deposition and creep rates have not been published, but the addition of 30 million tons of waste between 1992 and 1997 was planned.

The deposition of debris on a rock glacier may have various long-term effects, some of which are rather speculative in the absence of observational data. First, geochemical weathering of the waste rock is likely to produce acid rock drainage that may affect water discharge from the rock glacier even after mine closure (Ripley, Redman, and Crowder 1995; Andía, Lagos, and Danielson 1999; EPA 2001). Second, natural geothermal heating will raise the lower permafrost boundary within decades after deposition and affect rock glacier stability, which is partially temperature driven (Burger, Degenhardt, and Giardino 1999). Third, new permafrost may develop in the waste rock within years to decades (Grebenets, Kerimov, and Bakcheev 1997). This permafrost is, however, unlikely to be ice-rich because of its distance from the rock glacier's rooting zone and the artificial compaction of the deposited material, and it will probably be patchy and vary in ice content depending on local material properties.

The issues discussed above need further investigation to determine the potential hazards arising from the Infiernillo rock glacier. A destabilization of the waste-laden rock glacier was tentatively considered by Contreras and Illanes (1992); possibly triggered, for example, by seismic activity, such an event might produce a catastrophic mass movement affecting the industrial areas of the mines (especially Los Bronces at the Infiernillo rock glacier) and extend downstream, perhaps to the lower parts of the river as far as Santiago. The 1965 tailings dam failure at Disputada that killed 200 people (Aliste, Moraga, and Alvarez 1966) and a (natural) landslide in the Colorado catchment (Andes of Santiago) in 1987 (Casassa and Marangunic 1993; González-Ferrán 1994) demonstrate the effects of such hazards. Therefore, the warning of Burger, Degenhardt, and Giardino (1999) to avoid rock glaciers in the siting of essentially all structures must be kept in mind in the context of waste-rock deposits.

## THE PASCUA-LAMA PROJECT

Pascua-Lama is the name of a mining project of the Canadian Barrick Gold Company aiming at the exploitation of a binational gold (14.1 million ounces), silver (461 million ounces), and copper (180,000 tons) reserve in the arid III Region of Chile and the Argentine Province of San Juan. The extraction of minerals is planned to start in 2008. The mining activities will affect, according to the project's environmental impact study, a total area of 17.5 $km^3$ situated between 4,400 and 5,300 m a.s.l. (Geotécnica Consultores 2001). Analysis of 1996 aerial photographs of 1996 reveals the presence of glaciers and rock glaciers and hence of mountain permafrost.

As a consequence of the superficial extraction of minerals, which will mainly take place on Chilean territory, the removal of 10 ha of glacier is planned. The release of the environmental impact study for the project led to requests and petitions by local nongovernmental organizations and individuals concerned about its possible impact on the water supply for irrigation (*AreaMinera* 2004; *Minería Chilena* 2005*a*, *b*; *MiningWatch Canada* 2005).

In April 2001 the regional environmental agency COREMA (Atacama) approved the Pascua-Lama mining project with the precondition of complying with a glacier management plan. This plan permitted the proposed removal of up to 10 ha of glacier with blastings and excavators and stipulated their redeposition at some nearby location of similar geomorphological characteristics and at a similar altitude. From a glaciological point of view it was obvious that these conditions would in no way guarantee the conservation of the ice removed or lead to the reconstitution of a glacier at the place of deposition. On the contrary, it was likely that the redeposited pieces of glacier ice would disappear within years or decades. Only a comprehensive study of the energy and mass balance of the glacier to be removed and of the artificial ice body to be built would constitute a sound scientific base for such a relocation. Current glaciological and climatological knowledge in the remote and arid Andes of northern Chile is far from sufficient for this kind of research (cf. Kull, Grosjean, and Veit 2002; Corripio and Purves 2003).

After a period of low gold prices had delayed the development of the project, it was resubmitted in December 2004, facing the firm opposition of environmental groups and irrigation farmers (Arcadis Geotécnica 2004; *MiningWatch Canada* 2005). The environmental impact study was finally approved by COREMA Atacama in February 2006 subject to several limitations, including the prohibition of destruction or alteration of the glaciers in the project area (COREMA Atacama 2006).

## DISCUSSION

Further examples of potential future impacts of mining on rock glaciers in the Chilean Andes may be added to those presented above. For instance, road construction for the limestone mining project at Cerro Catedral in the Andes of Santiago (Compañía Minera Catedral, a subsidiary of the South American Gold Company), which has been explored and is now awaiting funding, and at the gold mine of Nevado Jotabeche in the

Atacama region (the Aldebarán Project of Compañía Minera Casale, a subsidiary of Arizona Star Resources of Canada and Angloamerican of South Africa), which is ready to operate, has already affected rock glaciers.

In the context of the tremendous growth of the Chilean mining industry (Moussa 1999; Lagos et al. 2002) and the existence of huge ore reserves in the high Andes, further cases of future degradation and destruction of rock glaciers and glaciers have to be expected in Chile. Therefore the question arises how these water resources can be effectively protected. It must be emphasized, however, that current legislation already formally provides the instruments that are necessary for impeding the destruction or degradation of glaciers and rock glaciers. Current politics lead contrarily to administrative decisions such as those described previously, which prioritize economic development and produce a strong discrepancy between what is written on paper and what is practiced on the ground (Carruthers 2001).

The conclusions to be drawn are, however, not entirely pessimistic: Recent developments in the case of the construction of the GasAndes pipeline in 1996 and the Pascua-Lama project show that the local population has started to make use of the participatory instruments provided by the new environmental legislation (Padilla 1996; Sabatini and Sepúlveda 1996; *AreaMinera* 2004; *MiningWatch Canada* 2005; COREMA Atacama 2006). This process has to be seen in the context of 17 years of a military regime (1973–90) and the postdictatorship collapse of grassroots movements that made way for a deeply embedded neoliberalism (Carruthers 2001). If the trend toward increasing awareness and participation persists, then a better trade-off between mining and the environment may become possible. A prerequisite for this awareness is, however, comprehensive scientific knowledge of the natural environment and the diffusion of this knowledge into the society and governmental institutions. In the case of the Chilean Andes, much remains to be done in this respect.

Turning to a global perspective, several examples of direct human impact on glaciers and rock glaciers in other parts of the world and by activities other than mining have been reported (Fisch, Fisch, and Haeberli 1977; Haeberli and Keusen 1983; Giardino and Vick 1985, 1987; Haeberli 1992; Burger, Degenhardt, and Giardino 1999; Diolaiuti et al. 2001; Jurt 2004; Schwegler 2004). For example, the use of glacier crevasses as an unauthorized waste disposal site in South Tyrol (Italian Alps) has been observed (Jurt 2004). The operation of ski lifts on glaciers in the European Alps is well known, even though the use of hazardous substances such as fuel on these unprotected ice bodies and the alteration of physical surface properties affecting the glacier's energy balance are both problematic (Haimayer 1989; Diolaiuti et al. 2001). Rock glaciers have been partly removed in the construction of ski runs (Haeberli 1992). The Davidov glacier in the Tien-Shan Mountains (Kyrgyz Republic) was partly covered with gold mining waste in the late twentieth century (Aizen and Chugunov 1988; Aizen and Zakharov 1988; Homeniuk 2000).

These observations show that the anthropogenic destruction of glaciers and rock glaciers is neither a local Chilean phenomenon nor restricted to developing countries; it is in fact a global problem that raises the question of whether more effective protection of the mountain cryosphere in general is necessary on a global scale.

## ACKNOWLEDGMENTS

This work was financed by research scholarships from the German Academic Exchange Service in 2002 and 2004, which are gratefully acknowledged. I also thank the Centro de Información de Recursos Hídricos of the Chilean Dirección General de Aguas (Santiago), Raquel Yamal, and Gonzalo Barcaza for providing valuable information.

## REFERENCES CITED

Aizen, V. B., and A. P. Chugunov. 1988. Estimation of the Davidov Glacier response to artificial destruction of its terminus [in Russian]. *Data of Glaciological Studies (MGI)* 67:202–6.

Aizen, V.B., and V.G. Zakharov. 1988. Mass balance and flow velocity of the Davidov Glacier from researches in 1984–1985 [in Russian]. *Data of Glaciological Studies (MGI)* 67:67–82.

Aliste, J., A. Moraga, and L. Alvarez. 1966. Efectos del sismo de marzo de 1965. *Boletín del Instituto de Investigaciones Geológicas de Chile* 20. Santiago: Instituto de Investigaciones Geológicas.

Andía, M.E., G.E. Lagos, and L.J. Danielson. 1999. The challenges posed by mine closure in Chile. In *Proceedings of the Copper 99 International Conference, October 10–13, 1999, Phoenix, Arizona*. Warrendale, PA: Minerals, Metals, and Materials Society.

Arcadis Geotécnica. 2001. *Estudio de impacto ambiental Proyecto de Expansión División Andina*. Santiago.

———. 2004. *Estudio de impacto ambiental modificiones Proyecto Pascua-Lama*. Santiago/Copiapó.

*AreaMinera*. 2004. Pascua-Lama y sus posibles impactos ambientales y sociales: Interview with César Padilla, August 16. http://www.areaminera.com/ (accessed November 23, 2004).

Arenson, L., M. Hoelzle, and S. Springman. 2002. Borehole deformation measurements and internal structure of some rock glaciers in Switzerland. *Permafrost and Periglacial Processes* 13:117–35.

Barsch, D. 1977. Alpiner Permafrost: Ein Beitrag zur Verbreitung, zum Charakter und zur Ökologie am Beispiel der Schweizer Alpen. *Akademie der Wissenschaften zu Göttingen, Mathematisch-Physikalische Klasse* 3(31):118–41.

———. 1988. Rockglaciers. In *Advances in periglacial geomorphology*, ed. M.J. Clark, 69–90. Chichester: Wiley.

———. 1996. *Rockglaciers*. Berlin: Springer.

Brenning, A. 2003. La importancia de los glaciares de escombros en los sistemas geomorfológico e hidrológico de la Cordillera de Santiago: Fundamentos y primeros resultados. *Revista de Geografía Norte Grande* 30:7–22.

———. 2005*a*. Geomorphological, hydrological, and climatic significance of rock glaciers in the Andes of Central Chile (33–35°S). *Permafrost and Periglacial Processes* 16:231–40.

———. 2005*b*. Climatic and geomorphological controls of rock glaciers in the Andes of Central Chile: Combining statistical modelling and field mapping. Ph.D. diss., Humboldt-Universität zu Berlin.

Burger, K.C., J.J. Degenhardt, and J.R. Giardino. 1999. Engineering geomorphology of rock glaciers. *Geomorphology* 31:93–132.

Carruthers, D. 2001. Environmental politics in Chile: Legacies of dictatorship and democracy. *Third World Quarterly* 22:343–58.

Casassa, G., and C. Marangunic. 1993. The 1987 Rio Colorado rockslide and debris flow, Central Andes, Chile. *Bulletin of the Association of Engineering Geologists* 30:321–30.

CCAEC (Canada-Chile Agreement on Environmental Cooperation). 1996. *Environmental management in Chile*. http://canchil.gc.ca/English/Resource/Reports/ChileEM/ ChileEM_Index.cfm (accessed November 11, 2004).

Contreras, A., and J.L. Illanes. 1992. Depósito de lastre glaciar Infiernillo Sur Mina Los Bronces. In *43a Convención del Instituto de Ingenieros de Minas de Chile, La Serena, October 1992*. Santiago: Instituto de Ingenieros de Minas de Chile.

COREMA Atacama (Comisión Regional del Medio Ambiente, Región de Atacama). 2006. Resolución de calificación ambiental, studio de impacto ambiental modificaciones Proyecto Pascua-Lama. Resolución Exenta 024/2006, February 15. Copiapó, Chile.

Corripio, J.G., and R.S. Purves. 2003. The influence of penitentes on the energy balance of high-altitude glaciers in the dry Central Andes. *Geophysical Research Abstracts* 5:12738.

Corte, A.E. 1976. The hydrological significance of rock glaciers. *Journal of Glaciology* 17:157–58.

Diolaiuti, G.,C. D'Agata, M. Pavan, G. Vassena, C. Lanzi, M. Pinoli, M. Pelfini, M. Pecci, and C. Smiraglia. 2001. The physical evolution of and the anthropic impact on a glacier subjected to a high influx of tourists: Vedretta Piana Glacier (Italian Alps). *Geografia Fisica e Dinamica Quaternaria* 24:199–201.

Dourojeanni, A., and A. Jouravlev. 1999. *El Código de Aguas de Chile: Entre la ideología y la realidad*. Serie Recursos Naturales e Infraestructura 3. Santiago: United Nations.

Editec. 2000. *Compendio de la minería chilena*. Santiago.

EPA (Environmental Protection Agency). 2001. *Abandoned mine site characterization and cleanup handbook*. EPA 530-C-01-001. Seattle.

Fisch, W., Sr., W. Fisch, Jr., and W. Haeberli. 1977. Electrical D.C. resistivity soundings with long profiles on rock glaciers and moraines in the Alps of Switzerland. *Zeitschrift für Gletscherkunde und Glazialgeologie* 13:239–60.

Geotécnica Consultores. 1996. *Estudio de impacto ambiental Compañía Minera Disputada de Las Condes, Proyecto de Epansión–2, mina Los Bronces*. Santiago.

———. 2001. *Estudio de impacto ambiental Proyecto Pascua-Lama*. Santiago.

Giardino, J. R., and S. G. Vick. 1985. Engineering hazards of rock glaciers. *Bulletin of the Association of Engineering Geologists* 22:201–16.

———. 1987. Geologic engineering aspects of rock glaciers. In *Rock glaciers*, ed. J. R. Giardino, J. F. Shroder, and J. J. D. Vitek, 265–87. Boston: Allen and Unwin.

González-Ferrán, O. 1994. *Volcanes de Chile*. Santiago: Instituto Geográfico Militar.

Grebenets, V. I., A. G. Kerimov, and D. S. Bakcheev. 1997. Dangerous movements of technogenic rock glaciers, Norilsk, Russia. In *Engineering geology and the environment*, ed. P. G. Marinos, G. C. Koukis, G. C. Tsiambaos, and G. C. Stournaras, 689–92. Rotterdam: Balkema.

Haeberli, W. 1992. Construction, environmental problems, and natural hazards in periglacial mountain belts. *Permafrost and Periglacial Processes* 3:111–24.

Haeberli, W., D. Brandova, C. Burga, M. Egli, R. Frauenfelder, A. Kääb, M. Maisch, B. Mauz, and R. Dikau. 2003. Methods for absolute and relative age dating of rockglacier surfaces in alpine permafrost. In *Permafrost: Proceedings of the Eighth International Conference on Permafrost, July 2003, Zürich, Switzerland*, ed. M. Phillips, S. Springman, and L. Arenson, 343–48. Lisse: Balkema.

Haeberli, W., A. Kääb, S. Wagner, D. Vonder Mühll, P. Geissler, J. N. Haas, H. Glatzel-Mattheier, and D. Wagenbach. 1999. Pollen analysis and $^{14}C$ age of moss remains in a permafrost core recovered from the active rock glacier Murtèl-Corvatsch, Swiss Alps: Geomorphological and glaciological implications. *Journal of Glaciology* 45:1–8.

Haeberli, W., and H. R. Keusen. 1983. Site investigation and foundation design aspects of cable car construction in alpine permafrost at the "Chli Matterhorn," Wallis, Swiss Alps. In *Proceedings of the Fourth International Conference on Permafrost, Fairbanks, Alaska*, 601–5. Washington, DC: National Academic Press.

Haimayer, P. 1989. Glacier-skiing areas in Austria: A socio-political perspective. *Mountain Research and Development* 9:51–58.

Hoelzle, M., S. Wagner, A. Kääb, and D. Vonder Mühll. 1998. Surface movement and internal deformation of ice-rock mixtures within rock glaciers at Pontresina-Schafberg, Upper Engadin, Switzerland. In *Proceedings of the Seventh International Conference on Permafrost, June 1998, Yellowknife, Canada*, ed. A. G. Lewkowicz and M. Allard, 465–71. Nordicana 57. Quebec City: Centre d'Études Nordiques.

Holmgren, C., and I. Vela. 1991. Visita a la mina Los Bronces. In *Actas Congreso Geológico Chileno* 6, *Guía de Excursión* IC–5.

Homeniuk, L. 2000. Kumtor Gold Project, Kyrgyz Republic. *CIM Bulletin* 93 (1038):67–73.

Jurt, C. 2004. Perceptions of glacier retreat within an alpine municipality in South Tyrol. *Abstracts of Oral Presentations of the Wengen Workshop "Mountain Glaciers and Society," Wengen, Switzerland, October 6–8, 2004*. Fribourg: University of Fribourg.

Kull, C., M. Grosjean, and H. Veit. 2002. Modeling modern and Late Pleistocene glacio-climatological conditions in the North Chilean Andes (29–30°S). *Climatic Change* 52:359–81.

Lagos, G., H. Blanco, V. Torres, and B. Bustos. 2002. Minería, minerales y desarrollo sustentable en Chile. In *Minería y minerales de América del Sur en la transición hacia el desarrollo sustentable*, ed. Mining, Minerals and Sustainable Development Project, South America Work Team. Santiago: CIPMA/IDRC/IIPM.

Lliboutry, L. 1956. *Nieves y glaciares de Chile: Fundamentos de glaciología*. Santiago: Editorial Universitaria.

———. 1961. Phénomènes cryoniveaux dans les Andes de Santiago (Chili). *Biuletyn Peryglacjalny* 10:209–24.

———. 1986. Rock glaciers in the dry Andes. *Data of Glaciological Studies (MGI)* 58:18–24; 139–44.

*Minería Chilena*. 1993. Disputada de Las Condes: De los capachos a una faena que se proyecta al nuevo siglo. 145:43–7.

———. 2005*a*. Pascua-Lama: Chile movilizado por el traslado de 3 glaciares. http://www.mch.cl/(accessed April 19, 2005).

———. 2005*b*. Proyecto de Oro: Glaciares y contaminación. http://www.mch.cl/(accessed April 28, 2005).

———. 2005*c*. Puesta en marcha para el año 2012: División Andina desarrolla primeras fases de proyecto a 230.000 tpd. http://www.mch.cl/(accessed August 31, 2005).

*MiningWatch Canada*. 2005. Barrick Gold faces determined opposition at Pascual-Lama and Veladero. *MiningWatch Canada Newsletter* 20. http://www.miningwatch.ca/ (accessed December 23, 2005).

Moussa, N. 1999. *El desarrollo de la minería del cobre en la segunda mitad del siglo XX*. Serie Recursos Naturales e Infraestructura 4. Santiago: United Nations.

Padilla, A. 1996. Participación ciudadana en el Proyecto Gasoducto GasAndes: Poniendo a prueba el desarrollo sustentable. *Ambiente y Desarrollo* 12:7–16.

Pizarro, R., and P. Vasconi. 2004. *Una nueva institucionalidad ambiental para Chile*. Análisis de Políticas Públicas 26.

Ripley, E. A., R. E. Redman, and A. A. Crowder. 1995. *Environmental effects of mining*. Delray Beach, FL: St. Lucie Press.

Roer, I. 2003. Rock glacier kinematics in the Turtmanntal, Valais, Switzerland: Observational concept, first results, and research perspectives. In *Permafrost: Proceedings of the Eighth International Conference on Permafrost, July 2003, Zürich, Switzerland*, ed. M. Phillips, S. Springman, and L. Arenson, 971–75. Lisse: Balkema.

Sabatini, F., and C. Sepúlveda. 1996. Lecciones del conflicto del gasoducto en el Cajón del Maipo: Negociación ambiental, participación y sustentabilidad. *Ambiente y Desarrollo* 12:19–24.

Schrott, L. 1996. Some geomorphological–hydrological aspects of rock glaciers in the Andes (San Juan, Argentina). *Zeitschrift für Geomorphologie* 104, suppl.:161–73.

Schwegler, D. 2004. Weltnaturerbe unter Beschuss. *Der Schweizerische Beobachter* 21/2004:33–35.

Whalley, W. B., C. F. Palmer, S. J. Hamilton, and J. E. Gordon. 1994. Ice exposures in rock glaciers. *Journal of Glaciology* 40:427.