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Glacier lake outburst flood on James Ross Island, Antarctic Peninsula region

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Abstract: A glacier lake outburst flood occurred on James Ross Island, Antarctic Peninsula region, during the 2004–2005 austral summer season. The source lake was located on the Lachman II ice-cored rock glacier, and formed prior to 1980. The size of the lake has been increasing gradually since the 1990s. The lake basin extended to approximately 220 m in length and 160 m in width by the end of February 2005. We observed that the lake had drained by February 2005, and found a deep gully on the south side of the lake rim. It appears that the lake level rose and water overflowed the lake rim here. James Ross Island contains a large number of debris-covered glaciers, ice-cored moraines, and rock glaciers with glacier lakes which are dammed by these features or which form upon them. As climatic warming has recently been reported for this region, further glacier lake outburst floods seem likely to occur.

Key words: Antarctic Peninsula, James Ross Island, glacier lake outburst flood, climatic warming.

Introduction

Rapid recent regional warming has been reported for the Antarctic Peninsula. For example, the mean annual air temperature at Esperanza station (Fig. 1) is calculated to have increased by 3.4° C over the past century (Vaughan *et al*. 2003). This is a significant increase compared to the global mean increase of 0.6° C over the same period. The climatic warming has resulted in many environmental

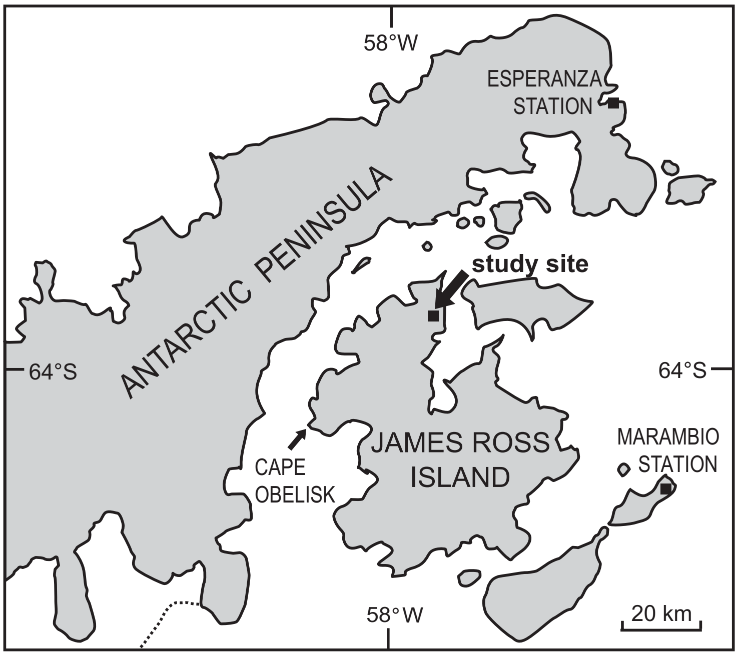

Fig. 1. Location of the study site at Lachman Crags.

changes in this region, including the retreat of glacier fronts, lowering of glacier surfaces, collapse of ice shelves, and changes in sea ice patterns (*e.g.* Skvarca *et al.* 1998; Scambos *et al.* 2000; Parkinson 2002; Cook *et al.* 2005). Despite such changes, glacier lake outburst floods (GLOFs) which are generally recognized as a symptom of climatic warming (O'Connor and Costa 1993; Evans and Clague 1994), have yet to be described in this region. Recent GLOFs have been documented in the Himalayas, Andes, European Alps, Iceland, and in the mountains of North America and central Asia (*e.g.* Haeberli 1983; O'Connor and Costa 1993; Evans and Clague 1994; Yamada 1998; Sakai *et al.* 2000; Kershaw *et al.* 2005).

In February 2005, the joint Argentine-Japanese research group "Criología" visited Lachman Crags to extend an ongoing permafrost research project (Fig. 1). During the fieldwork, we found evidence of the outburst of a supra-glacier lake on a rock glacier.

Study area

James Ross Island is located on the east side of the northernmost tip of the Antarctic Peninsula (Fig. 1). The island extends approximately 80 km from north to south and 70 km from east to west. Approximately 80% of the island is covered by glaciers. Ice-free ground is concentrated on the northwest of the island where per-

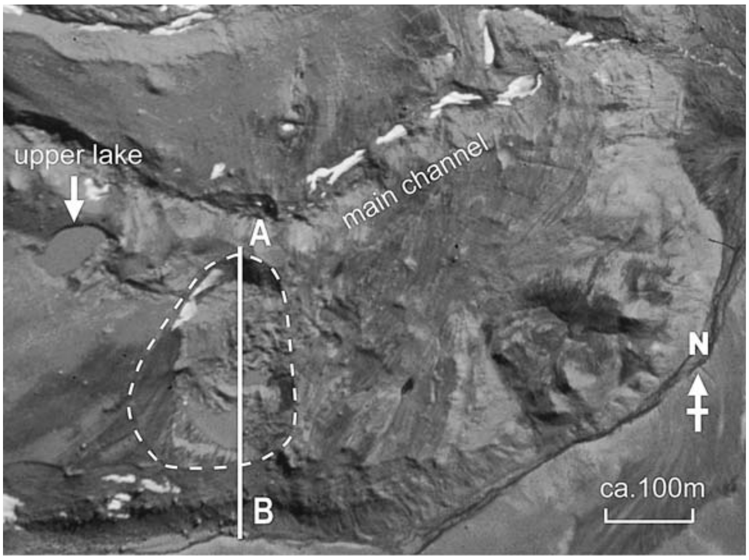

Fig. 2. Aerial photograph of the Lachman II Rock Glacier Line A-B shows the line of cross section in the lake basin, marked by the dashed line. (Photograph taken in February 2004).

mafrost occurs (Fukuda *et al*. 1992; Strelin and Malagnino 1992; Borzotta and Trombotto 2004). Periglacial landforms such as rock glaciers, stone-banked terraces, and patterned ground have developed in this area (Strelin and Malagnino 1992; Sone and Strelin 1997; Mori *et al.* 2006; Strelin *et al*. 2006).

The study site comprises the eastern flank of Lachman Crags on the NW tip of James Ross Island, where the Lachman II ice-cored rock glacier (Strelin and Sone 1998) is located at 63°53', 57°48' (Fig. 2). A small lake located on the right-hand side of this 500 m wide rock glacier was drained rapidly sometime between February 2004 and February 2005. We recorded the 1999–2004 mean annual air temperature at a coastal site close to the rock glacier as –5.0° C.

Description of the glacier lake outburst

During the authors' first visit to the Lachman II rock glacier area in 1992, the lake was approximately 160 m long and 80 m wide. Foliated glacier ice was exposed on the NE-facing wall of the lake basin. During the period 1995–98 lake water discharged through an intra-glacier channel. By the end of February 2004, lowering of the water level led to the formation of two separate lakes within the lake basin (Fig. 2).

However, when we visited the area in February 2005, the lake basin was empty of water. A deep and narrow gully with vertical walls had formed on the south side of the rim of the former lake basin, *i.e.* on the right-hand side of the

Fig. 3. The alluvial cone downstream the breach.

rock glacier and an alluvial cone was observed immediately downstream of the breach (Fig. 3). At maximum the cone was 60 m wide and its surface was inclined at 16° to the south. Downstream, the riverbed had been widened by river bank erosion (Fig. 4). The dry lake basin was 220 m long, 160 m wide and 20–30 m deep relative to the original surface of the rock glacier (Fig. 5). The upper slope of the rock glacier is inclined at 18–19° and consists of glacier ice covered by a thin layer of debris; the lower, inclined at 28°, consists of ice and frozen debris. The bottom of the former lake was covered by debris (Fig. 6). In places there were lake sediments with horizontal laminations. The highest level of the lake, as denoted by the distribution of the lake sediments, corresponded exactly with the level of the lowest rim of the lake where the outburst occurred. When full, the lake would have been 120 m long and 90 m wide, and had a surface area of 7,500 m^2; the mean depth was 5 m.

Until the summer of 2004, the main water channel occupied the centre of the rock glacier; it then changed course via the breach in the lake rim.

Sometime between 2002 and 2004 an upper lake formed about 80 m upstream of the main lake (Fig. 2); this also drained prior to February 2005. The remnant gully of the upper lake outlet channel had vertical ice walls, and was less than 1 m wide. The bottom of this lake was also covered by debris, and, in places, there were

Fig. 4. The riverbed widened by river bank erosion.

lake sediments with horizontal laminations. The distribution of the lake sediments indicates that the highest level of the upper lake corresponded to the lowest level of the rim, where the outlet was situated. When full, the upper lake would have been 100 m long, 50 m wide, and maximum 5 m deep.

Discussion

Trigger of the outburst. — Overtopping waves induced by rock, snow and ice avalanches can cause the failure of moraine-dams (Kershaw *et al.* 2005); however, as no evidence of rapid failure of the lake wall has been detected, this is unlikely to have been the trigger of the outburst in the lower lake. The highest water level of the lake, as determined from the level of sediments deposited close to the shoreline, corresponds with the level of the lowest section of the lake rim. A cross-section of the lower lake basin shows that the water channel was of approximately constant slope (Fig. 5). We suggest that the lake level simply rose gradually and that water overflowed the rim of the lake. In turn, the overflowing water then initiated a breach of the ice rim, followed by progressive deepening of the channel while retaining the course of meander. We suggest that the draining of the lake oc-

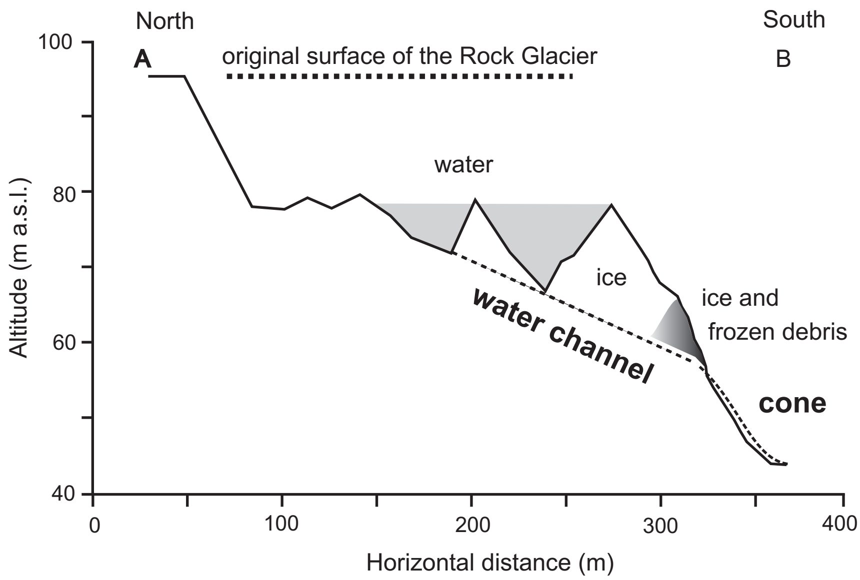

Fig. 5. Cross section of the lake and profile of the water channel. See Fig. 2 for location.

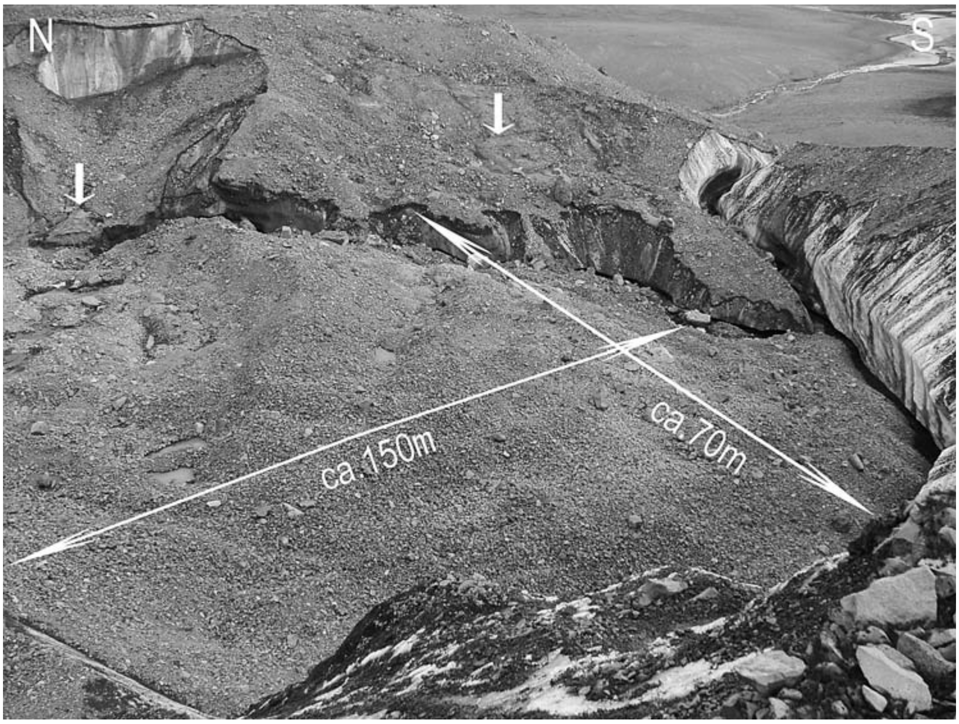

Fig. 6. The bottom of the former lake covered by debris. The arrows show the position of the lake sediments.

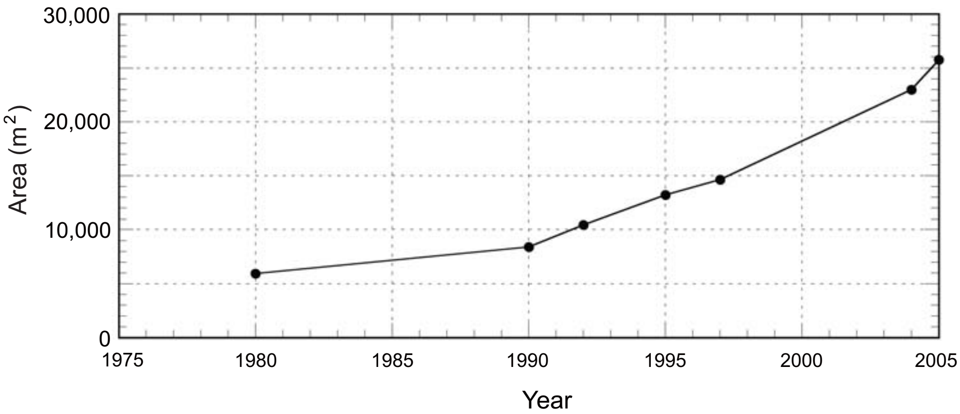

Fig. 7. Changes in the area of the lake depression after aerial photographs and field observations.

curred over a relatively short time period and caused a flood that resulted in the formation of an alluvial cone and widening the riverbed downstream. There is no evidence that the lake water was discharged via an intra-glacial channel.

The volume of the lake water immediately prior to the outburst was approximately 37,500 m^3, whereas the volume of ice melted by the water channel is estimated to be 1,000 m^3. If we assume that the ice temperature is at freezing point, and that the lake water temperature is 2° C, the heat capacity of the lake water corresponds to that of the melting of the ice wall. As the lake bottom was covered with debris and the summer mean air temperature in this area is approximately 2° C, the lake water would have been warmer than the freezing point. Thus once the lake water had overflowed the lake rim, the ice rim would have readily melted. We consider that the upper lake is also an example of glacier lake outburst caused by an overflow of lake water.

Areal changes in the lake and summer air temperature. — Figure 7 shows changes in the area of the lake depression based on aerial photographs taken in 1980, 1990, 1992, 1995, 1998, 2004 and our field survey in 2005. The lake formed prior to 1980, and the area of the lake basin gradually increased from 6000 m^2 in 1980 to 8500 m^2 in 1990. The lake grew in area more rapidly after 1990. As the lake was located in the ablation zone of the glacier, both exposed ice and thin layers of debris-covered ice melted widely in the lake basin (Strelin and Sone 1998). As the lake expanded, the right-hand rim of the rock glacier was lowered. The lake drained prior to February 2005.

Figure 8 provides summer mean air temperatures (December, January and February) for Lachman, *Marambio* Station and *Esperanza* Station. *Marambio* and *Esperanza* stations are situated approximately 70 km SE and 80 km NE from the study site, respectively (Fig. 1). The summer mean air temperatures at the *Mara-*

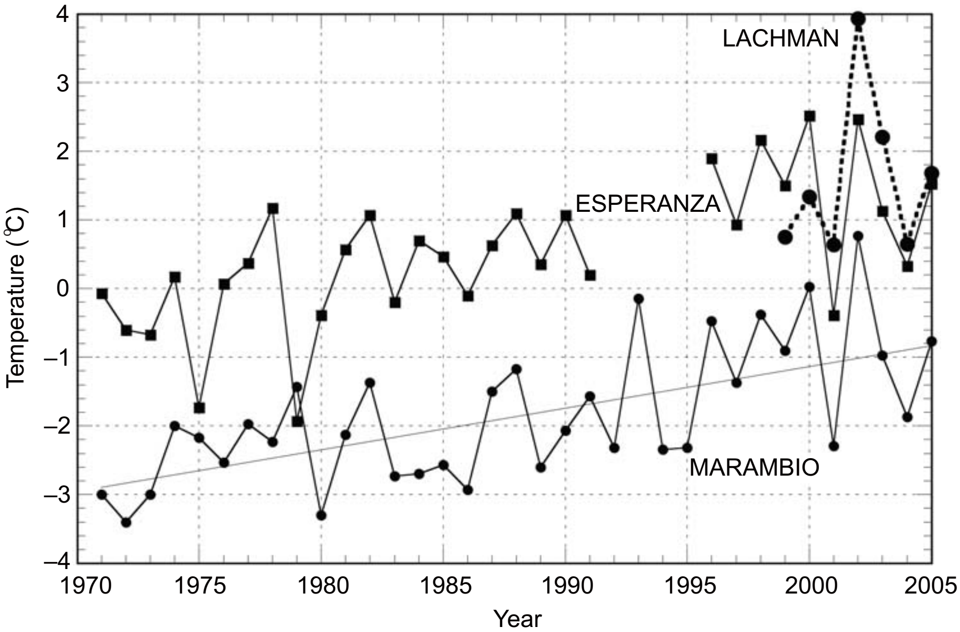

Fig. 8. Summer mean air temperatures (December, January, February) in Lachman, *Esperanza* Station and *Marambio* Station.

mbio and *Esperanza* stations are steadily increasing and the trend of summer mean temperatures at Lachman changed during 2001. Prior to 2001, Lachman was colder than *Esperanza* Station by about 1° C, but this trend has been subsequently reversed since 2001. The summer mean temperatures on James Ross Island are also rising, and as determined from the temperature trend prior to 2001, increased above the freezing point around 1990. The area of the studied lake basin increased commensurably with the increase in the summer mean temperature. The highest summer mean temperature was recorded in 2002, although relatively high temperatures were also recorded in 2005.

Future glacier lake outburst floods. — James Ross Island contains numerous glaciers and many supra- and pro-glacier lakes, and has undergone dramatic recent climatic warming. Thus further glacier lake outburst floods seem likely in this region. In this paper, we described a supra-glacier lake outburst flood of only modest size. However, there exists a strong possibility of large-scale outburst floods on this island and in the wider Antarctic Peninsula region. For example, an ice-cored moraine-dammed lake, typical of glacier lakes, is located near Cape Obelisk, west of James Ross Island; GLOF from this lake and others like it would cause relatively important geomorphological changes in this region.

Conclusions

- A glacier lake outburst flood occurred on James Ross Island during the 2004–2005 austral summer. The trigger of the outburst was overflow of lake water over the right bank.
- The lake outburst was located on an ice-cored rock glacier. The area of the supra-glacier lake had increased rapidly since 1990. Summer mean air temperature on the island is increasing markedly and increased to above freezing point about 1990.
- Given the recent rapid warming of the climate in this region, we predict that further glacier lake outburst floods are likely on James Ross Island and in the wider Antarctic Peninsula region.

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