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MANAGEMENT OF THERMOKARST LANDFORMS AND PROCESSES AT MARINE PLAIN, EAST ANTARCTICA

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INTRODUCTION

Thermokarst, a cold-climate form of pseudokarst, comprises irregular, hummocky terrain with closed depressions that appear similar to sinkholes. This topography forms in periglacial (cold climate) environments and results from differential melting of permafrost ice in the ground and settlement of the sediments in which the ice occurs. Some forms of human activity in thermokarst terrain have the potential to cause accelerated melting of the frozen sediments and trigger increased land-surface instability (Washburn 1979). Periglacial thermokarst is well developed in high northern latitudes but it is rare in the southern hemisphere due to such factors as the limited extent of land at subpolar latitudes, the burial of most of Antarctica beneath glaciers, and the extreme aridity of Antarctica where there is little ground ice despite very cold temperatures (Bockheim and Hall 2002).

The Marine Plain area in the Vestfold Hills, Princess Elizabeth Land, hosts the largest occurrence in East Antarctica of thermokarst landforms resulting from degradation of permafrost. This area was designated as a Site of Special Scientific Significance in 1987, primarily in response to the discovery of Pliocene (4.2-3.5 million years old) dolphin and mollusc fossils. Its significance as a thermokarst was not recognised at that time. This paper briefly describes the thermokarst and considers some issues entailed in management of the area.

THERMOKARST IN THE MARINE PLAIN AREA

Marine Plain (67^{o}37’S, 78^{o}9’E) comprises a small basin of 4 km^2 at 15-20m altitude which, together with neighbouring Poseiden Plain, is filled with Pliocene marine diatomite sediments ~9m thick (Quilty 1993). These sediments include some very minor limestone lenses, but dissolution of these does not appear to have contributed significantly to development of the pseudokarst landforms. The Pliocene material is overlain by ~100-150cm of bouldery glacial sediments that were deposited during a lateral expansion of the adjacent Sørsdal Glacier that constructed low but distinct northward-curving moraine ridges.

These sediments are permanently frozen apart from the uppermost 100-150cm which thaws in summer. The mean annual temperature at Davis Station, 6 km to the northwest, is -10.3^{o}C, the mean monthly maximum being 0.9^{o}C in January and minimum -17.4^{o}C in July and August. There is little surface melting before late November and refreezing commences in late February.

The development of ground ice and evolution of the thermokarst has potentially occurred over a relatively long time. The precise age of the glacial sediments is unknown but they appear to predate 6.5 thousand years BP (before present) (Quilty 1991) and may date to the last part of the main Vestfold Glaciation which predates 12 ka BP (Adamson and Pickard 1986, Fabel et al 1995). The Sørsdal Glacier was at or south-east of its present margin by 8.6 thousand years BP (Fitzsimons and Domack 1993). The maximum height of flooding by the sea following deglaciation is less than 10m above present sea level, hence most of the thermokarst area was unaffected.

The thermokarst landforms formed by thawing of fozen ground include thaw pits, thaw lakes, ground ice slumps, linear depressions and very small-scale beaded drainage systems involving small channels that link thaw lakes and ponds (Kiernan et al 1999).

NATURAL THERMOKARST LANDFORMS

The thaw pits are shallow (0.5-2m deep) depressions arranged in arcs across Marine Plain and scattered more randomly on Poseiden Plain. The pits on Marine Plain emphasise the visible curvature of the moraine ridges between which they occur. These pits appear to be forming only very slowly as a result of minor surface drainage into the low points between the moraine ridges, causing deeper melting of the permafrost in the depressions than occurs on the adjacent moraine ridges.

Retreating scarps and thaw lakes occur at both Marine Plain and Poseiden Plain. The scarps are up to 10m high and are formed primarily in the diatomite peripheral to the boundaries of the two plains; surrounding thaw lakes; parallel to moraine ridges; and orthogonal to cols and gullies formed along structural lineaments in the surrounding Precambrian bedrock hills from which seasonal snow meltwater discharges. The thaw lakes vary in size from small thaw pits that contain little water to lakes up to 250m long. They have been incised up to 10m into the sediments but the water is generally very shallow and some are frequently dry. Degradation of the permafrost with scarp and lake development appears to be very slow (over thousands of years) and the main process appears to involve re-radiation of heat from the surrounding rocks on which very high temperatures can be generated by summer insolation. The long-wave radiation penetrates the permafrost causing peripheral thawing with scarp and lake development, but leaving the central part of the Marine Plain basin less affected. The permafrost at Poseiden Basin has been degraded more, partly because of closer juxtaposition of the bedrock with the permafrosted sediments and possibly also due to greater duration of exposure.

Ground ice slumps have resulted from the liberation of water by melting ice in retreating scarps. These features are similar to slumps formed in conventional fluvial environments but in permafrost situations sediments in the seasonally-thawed surface layer becomes saturated by meltwater that cannot penetrate the underlying permafrost. The best developed slumps are broad (±10 m) semicircular depressions with evidence of axial flowage, development of small (<20-30 cm-high) pressure ridges towards their toe, and minor fluvial channels with associated sediments downslope. However, most slumps are much smaller.

Linear depressions and small-scale beaded drainage systems are locally prominent. The best developed linear depression is Big Ditch on Marine Plain, which extends 700m east-west across northern Marine Plain and is up to 100m wide. The best developed beaded drainage systems occur in central and southern Marine Plain. The linear depressions have formed due to permafrost degradation along lines of thaw pits, by scarp retreat, and by erosion due to heat transport from adjacent rock surfaces that are warmed by the sun in summer.

Overall, strong thermal conductivity adjacent to bedrock hills on the margin of the plain is an important process that has promoted permafrost degradation. The existence of only small thaw pits away from the bedrock margins of the plain suggests that the permafrost is probably closely in equilibrium with the present day climate and is undergoing only very slow natural degradation over a long time.

THERMOKARST PROCESS ACCELERATION BY HUMAN ACIVITY

Understanding the permafrost, and minimising unnatural instability within it, are important considerations in management of this area. In addition to the intrinsic value of this unusual environment, natural thermokarst processes are the means by which the celebrated cetacean fossils have become exposed at the surface for study. Unnaturally accelerated permafrost melting has the potential to expose important fossil material to degradation by the elements, and there is limited capacity for the managing agency to respond effectively to any requirement for conservation of material so exposed (Kiernan and McConnell 2001a).

Permafrost melting and thermokarstic processes in high northern latitudes is being stimulated by global warming that is increasingly attributed to the release of atmospheric pollutants that are contributing to the enhanced Greenhouse Effect (Osterkamp et al, 2000). However, the more immediately recognisable changes in the Marine Plain area relate to on-site human activities. One research project undertaken in the 1980s involved excavation over several square metres in extent into a natural thermokarst scarp on the edge of Big Ditch. Slumping, outflow of fine sediments and surface salinisation were observed when we visited the site in 1997. This appears to have resulted from artificial thinning of the seasonally-thawed layer over the permafrost, allowing deeper penetration of thawing processes into the permafrost (Kiernan and McConnell 2001a). Damage is only localised at present, but it highlights the sensitivity of this environment and the need to develop appropriate management protocols.

RECENT MANAGEMENT RESPONSES

Rehabilitation research

Further research undertaken at the Big Ditch site in 1997 involved minor clearing-back of one face of the depression excavated in the 1980s, after which an attempt was made to rehabilitate the entire excavation. However, the potential to rehabilitate effectively was by now limited because much of the material removed originally had since been dispersed by the wind and meltwater. Quarrying to win more material to properly fill the excavation was considered likely to extend the same instability problem to a new location. Notwithstanding the efforts made in 1997, continued bleeding of permafrost meltwater and fine sediment was revealed during monitoring in December 2000, perhaps due to this inability to fully restore an adequate insulating cover (Kiernan and McConnell 2001b).

A more successful outcome was achieved following the excavation of a 9m long trench down another thermokarst scarp in 1997. In this case, rehabilitation was undertaken immediately upon conclusion of the research. The strategies adopted included subsurface reconstruction that was designed to prevent surface settling and slumping, and reconsolidation of the fill to minimise long-term thermal disturbance of the permafrost and the potential for slope instability which it might have instigated. Measures were also taken to remediate visual impacts (Kiernan and McConnell 2001b). Monitoring in December 2000 suggested these efforts had been successful, but longer term observation is required. However, the initially encouraging result from this site, compared to the disappointing results from the attempted rehabilitation of the Big Ditch site well after the original disturbance, suggests that where terrain of this kind is disturbed, remedial measures need to be taken immediately if long term damage is to be minimised. Moreover, rehabilitation in such an environment needs to carefully planned and budgeted for — merely kicking a few rocks back into an excavated hole is unlikely to be adequate.

Management planning

Aspects of the thermokarst landscape were first recognised by researchers more than two decades ago (Adamson and Pickard 1986, Zhang and Peterson 1984), but the extent and significance of the thermokarst were not taken into account in designation of the area as a Site of Special Scientific Significance for its palaeontological values. Hence, no management guidelines designed to minimise disturbance of this special value were incorporated in the original management plan or taken into account in determining permit requirements for researchers visiting the area.

More recent research focused on the thermokarst itself has allowed deficiencies in the information available to the managing authority to be redressed. Marine Plain has recently been re-designated as Antarctic Specially Protected Area No 143. A new management plan now recognises the significance of the thermokarst and provides a basis for improved guidelines for field parties operating in the area.

CONCLUSIONS

Thermokarst environments pose particular challenges to land managers wherever they exist. The facts that the Marine Plain area contains the largest area of true periglacial thermokarst in East Antarctica, that thermokarst is scarce in the southern hemisphere, and that important palaeontological values also exist in this area, highlight the need for effective management based on sound knowledge. Recent advances in knowledge of the thermokarst in the Marine Plain area include improved understanding of its significance, the potential for on-site human impacts, and some of the requirements if these are to be minimised. Such advances become all the more important in the context of global warming that is having profound ramifications in some northern hemisphere thermokarsts and may yet impact on Antarctic thermokarst.

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