1

Introduction

1.1 The Periglacial Concept

The term ‘periglacial’ was first used by a Polish geologist, Walery von Łozinski, when referring to the mechanical disintegration of sandstones in the Gorgany Range of the southern Carpathian Mountains, a region now part of central Roumania. Łozinski described the angular rock rubble surfaces that characterize the mountain summits as ‘periglacial facies’ formed by the previous action of intense frost (von Łozinski, 1909). Following the XI Geological Congress in Stockholm in 1910 and the subsequent field excursion to Svalbard in 1911 (von Łozinski, 1912), the concept of a ‘periglacial zone’ was introduced to refer to the climatic and geomorphic conditions peripheral to Pleistocene ice sheets and glaciers. Theoretically, this was a tundra zone that extended as far south as the tree line. In the mountains, it was a zone between the timberline and the snow line (Figure 1.1).

Almost certainly, Łozinski was influenced by a Swedish geologist, J.G. Andersson, who had summarized, a few years earlier, his observations on mass-wasting on Bear Island (latitude 74°N), a cold, wet and windy island in the northern North Atlantic (Andersson, 1906, pp. 94–97; 104–110). It was Andersson who introduced the term ‘solifluction’ to the scientific literature. He also described the ‘stone runs’, or quartzite blockfields, that characterize the gentle slopes of the equally cold and damp Falkland Islands, located in the South Atlantic. On hearsay alone, the latter phenomena had already been compared to the ‘rubble-drift’ and ‘head’ deposits of southern England by the English geologist James Geikie (1874, pp. 722–723) who attributed them to a ‘cold climate more severe than the present’.

Łozinski referred to his rock-rubble accumulations as *periglacial facies* (Figure 1.2). In subsequent years, angular rock-rubble accumulations on upland slopes and summits were widely reported in the scientific literature. Today, they are usually referred to as ‘blockfields’ or ‘mountain-top detritus’ (see Table 15.1).

Over a hundred years later, Łozinski’s definition is regarded as unnecessarily restricting. Few, if any, modern analogs exist (French, 2000). There are two main reasons. First, frost-action phenomena are known to occur at great distances from both present-day and Pleistocene ice margins. In fact, frost-action phenomena can be completely unrelated to ice-marginal conditions. Second, although Łozinski used the term to refer primarily to areas rather than processes, the term has increasingly been understood to refer to a complex of cold-dominated geomorphic processes. These include not only frost-action and permafrost-related processes but also the range of azonal processes associated with snow, running water and wind. These demand neither a peripheral ice-marginal location
nor excessive cold. Instead, they assume distinctive or extreme characteristics under cold, non-glacial conditions.

1.2 Diagnostic Criteria

Periglacial environments are relatively simple to define. They are characterized by intense frost and restricted to areas that experience cold, but essentially non-glacial, climates (French, 2007).

Two criteria are regarded as diagnostic. First, there is ground freezing and thawing. According to J. Tricart (1968, p. 830), ‘...the periglacial morphogenetic milieu is that where the influence of freeze-thaw oscillations is dominant’. Second, all periglacial environments experience either seasonally-frozen or perennially-frozen ground. The latter, if it persists for more than two years, is termed *permafrost* (Muller, 1943). According to T. L. Péwé (1969, p. 4), ‘...permafrost is the common denominator of the periglacial environment, and is practically ubiquitous in the active periglacial zone’.
1 Introduction

Figure 1.2 Typical ‘periglacial facies’ developed on granite in the Carpathian Mountains, southern Poland. Note that the periglacial facies described by Łozinski were in sandstone and further to the east in the Gorgany Range, now in Roumania. The photograph was supplied courtesy of Dr R. Zurawek. See also ‘mountain-top detritus’, Chapter 15.

Periglacial environments should not be confused with either proglacial or paraglacial environments, although both may be regarded as being periglacial in nature. Whereas ‘periglacial’ is essentially a function of process, ‘proglacial’ is a function of location and ‘paraglacial’ is a function of the degree and mode of recovery from a previous geomorphic system (Ballantyne, 2002; Slaymaker, 2009). It follows that periglacial and proglacial environments are largely adjusted to contemporary processes while paraglacial environments are explicitly transitional and transient in nature. Thus, periglacial landscapes that existed during the cold periods of the Quaternary in areas that no longer experience periglacial conditions are largely paraglacial in nature. The term ‘periglaciation’ is used to describe the degree of cold-climate landscape adjustment (Ballantyne and Harris, 1994). This is discussed in Chapter 15.

1.3 Periglacial Environments

Periglacial environments occur not only as tundra zones in either the high latitudes or adjacent to glaciers and ice sheets, as defined by Łozinski’s concept, but also as forested areas south of tree line and at high elevation in the mountains of the mid and low latitudes. These complicate any simple delineation of periglacial environments. So-called ‘periglacial’ conditions often extend south of the latitudinal tree line and below the
Part I The Periglacial Domain

altitudinal timberline. This is partly because many areas of the northern boreal forest are underlain by relict permafrost while, in alpine regions, glaciers may extend below timberline and into the forest zone. Finally, the tree line is a zone rather than a line and may extend over a latitudinal distance of 100–150 km.

In specific terms, periglacial environments include (a) the polar deserts and polar semi-deserts of the High Arctic; (b) the extensive tundra zones of the high northern latitudes; (c) the northern parts of the boreal forests of North America and Eurasia; and (d) the alpine zones that lie above timberline and below snow-line in mid-and low-latitude mountains (Figure 1.3). To these must be added (i) the ice-free areas of Antarctica and the southern tip of South America; (ii) the extensive high-elevation (montane) environments of central Asia, the largest of which is the Qinghai-Xizang (Tibet) Plateau of China; and (iii) small oceanic islands in the higher latitudes of both Polar Regions.

The most extensive periglacial environments are either arctic or subarctic in nature. The boundary between the two approximates the northern limit of trees, the so-called tree line. This is a zone, 30–150 km wide in extent, north of which trees are no longer able to survive. North of the tree line, the terrain is perennially frozen and the surface thaws for periods of only 2–3 months each summer. Ecologists refer to the vegetated but treeless arctic as tundra. Where Precambrian basement rocks occur, as in the tablelands of northern Canada and northern Siberia, the tundra is barren. Near the tree line the tundra is often referred to as shrub-tundra. At higher latitudes, the tundra progressively changes into semi-desert and, ultimately, into polar desert terrain (a ‘frost-rubble’ zone). The latter occurs in the High Arctic of Canada, northeast Greenland, Svalbard and Novaya Zemblya. In Antarctica, the relatively small ice-free areas are also true polar deserts. Here, the landscape consists of rock-rubble surfaces that are kept free of snow and ice by sublimation from strong katabatic winds that flow outwards from the Antarctic ice sheet.

South of the tree line, the environment is subarctic in nature. Near the tree line there is a transition zone from tundra to forest consisting of either open woodland or forest-tundra. Here, the trees are stunted and deformed, often being less than 3–4 m high. This zone grades into the boreal forest, or taiga, an immense zone of almost continuous coniferous forest extending across both North America and Eurasia. The southern boundary of the sub-arctic is less clearly defined than its northern boundary; typically, coniferous species begin to be replaced by others of either local or temperate distribution, such as oak, hemlock and beech, or by steppe, grassland and semi-arid woodland in more continental areas. These cool-climate ecosystems, which experience deep seasonal frost, represent the outer limits of the periglacial environment.

The mid-latitude alpine periglacial environments are spatially less extensive than those of high latitude. They are dominated by both diurnal and seasonal temperature effects and by much higher solar radiation. In such environments, the timberline constitutes the boundary between the alpine and sub-alpine. The alpine environments are dominated by steep slopes, tundra (alpine) plants, rocky outcrops, and snow and ice. The montane environments of central Asia differ from alpine environments in that they are more extensive, far more arid, and consist of steppe grasslands and intervening desert-like uplands.

1.4 The Periglacial Domain

The periglacial domain refers to the global extent of periglacial environments. Using the diagnostic criteria presented earlier, a conservative estimate is that approximately 25% of the earth’s land surface currently experiences periglacial conditions. There are
Figure 1.3 The global extent of the periglacial domain in the northern hemisphere after J. Karte, 1979, and J. Karte and H. Liedtke, 1981.
all gradations between environments in which frost processes dominate, and where a whole or a major part of the landscape is the result of such processes, and those in which frost action processes are subservient to others. Having said this, there are two complicating factors. First, certain lithologies are more prone to frost action than others, and hence more susceptible to periglacial landscape modification. Second, many periglacial landscapes show the imprint of previous glacial or non-glacial (i.e. temperate or tropical) conditions.

During the cold periods of the Pleistocene, large areas of now-temperate middle latitudes experienced reduced temperatures because of their proximity to ice sheets. They would have experienced intense frost action and frozen ground (permafrost) would have formed, only to have degraded during later climatic ameliorations. In all probability, an additional 20–25% of the earth’s land surface experienced frost action and permafrost conditions at some time in the past.

It should be emphasized that there is no perfect spatial correlation between areas of intense frost and areas underlain by permafrost. For example, a number of subarctic, maritime, and alpine locations experience frequent freeze–thaw oscillations but lack permafrost. Furthermore, the fact that relict permafrost underlies extensive areas of the boreal forest in Siberia and North America makes any simple delimitation of periglacial environments difficult. In practice, the relict permafrost of Siberia and North America extends the periglacial domain beyond its normal (i.e. frost action) limits.

Figure 1.4 Components of the cryosphere with relevant time scales. Source: Lemke et al., 2007, Figure 4.1.
1.5 The Periglacial Domain and the Cryosphere

The cryosphere is the scientific term which collectively describes those portions of the Earth’s surface that are seasonally or perennially frozen. In these areas water exists for much of the year in its frozen state. The main components of the cryosphere are snow, river and lake ice, sea ice, glaciers and ice caps, ice shelves and ice sheets, and frozen ground (Figure 1.4).

The spatial extent and global volume of the different cryospheric components are summarized in Table 1.1. Collectively, seasonally-frozen ground and permafrost have the largest areal extent. As an approximation, the maximum extent of seasonally-frozen ground is about 51% of the land area of the northern hemisphere. The extent of snow cover approximates 49% of the northern hemisphere land surface in mid-winter. These facts make it clear that the periglacial domain contains important components of the cryosphere.

The cryosphere plays a critical role in the global climate system (Barry, 2002; Barry and Gan, 2011). For several reasons, it is highly relevant to current global warming concerns. First, an ice-albedo feedback mechanism results from the high surface reflectivity of ice and snow surfaces. If these surfaces decrease in extent, albedo is reduced and the increased absorption of solar radiation increases temperature. Central to this concern is the recent shrinkage in extent and duration of Arctic sea ice because this may amplify climate sensitivity by about 25–40%. Second, the carbon storage contained within the boreal forest and in near-surface permafrost assumes great importance if long-term

Table 1.1 Area, volume and sea-level equivalents of the cryospheric components.

<table>
<thead>
<tr>
<th>Cryospheric component</th>
<th>Area ($10^{-6}$ km$^{-2}$)</th>
<th>Ice volume ($10^{-6}$ km$^{-3}$)</th>
<th>Potential sea-level rise (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow on land, Northern Hemisphere</td>
<td>1.9–45.2</td>
<td>0.0005–0.005</td>
<td>0.001–0.001</td>
</tr>
<tr>
<td>Sea ice</td>
<td>19–27</td>
<td>0.019–0.025</td>
<td>~0</td>
</tr>
<tr>
<td>Glaciers and ice caps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smallest estimate</td>
<td>0.51</td>
<td>0.05</td>
<td>0.15</td>
</tr>
<tr>
<td>Largest estimate</td>
<td>0.54</td>
<td>0.13</td>
<td>0.37</td>
</tr>
<tr>
<td>Ice shelves</td>
<td>1.5</td>
<td>0.7</td>
<td>~0</td>
</tr>
<tr>
<td>Ice sheets</td>
<td>14.0</td>
<td>27.6</td>
<td>63.9</td>
</tr>
<tr>
<td>Greenland</td>
<td>1.7</td>
<td>2.9</td>
<td>7.3</td>
</tr>
<tr>
<td>Antarctica</td>
<td>12.3</td>
<td>24.7</td>
<td>56.6</td>
</tr>
<tr>
<td>Seasonally-frozen ground, Northern Hemisphere</td>
<td>5.9–28.1</td>
<td>0.006–0.065</td>
<td>~0</td>
</tr>
<tr>
<td>Permafrost, Northern Hemisphere</td>
<td>22.8</td>
<td>0.011–0.037</td>
<td>0.03–0.10</td>
</tr>
</tbody>
</table>

Notes:
1. Permafrost extent excludes permafrost under oceans, ice sheets and glaciers.
2. Calculations of areas of glaciers and ice caps, both large and small estimates, exclude Greenland and Antarctica.
3. Calculation of potential sea level rise assumes oceanic area of $3.62 \times 10^{-8}$ km$^{-2}$, ice density of 917 kg m$^{-3}$ and seawater density of 1028 kg m$^{-3}$.

Source: IPCC, 2007, Table 4.1., Lemke et al., 2007.
global climate warming occurs. The thaw of near-surface permafrost will release large reservoirs of terrestrial CO\textsubscript{2} (carbon dioxide) and CH\textsubscript{4} (methane) to the atmosphere. These are greenhouse gases that represent a positive feedback mechanism. Third, there is the actual snow-cover effect itself; snow cover insulates and modifies the temperature of the underlying ground. A reduction in snow cover can mean not only warmer mean annual ground surface temperatures but also more severe winter cooling. The former could thaw frozen ground, the latter could increase the extent of frozen ground.

1.6 Disciplinary Considerations

The 21st century sees several emergent issues that are relevant to periglacial environments. The first is the relationship between periglacial geomorphology and Quaternary science, a relationship implicit in Łozinski’s original definition of a ‘periglacial zone’. A second, more fundamental, issue is the relationship between the traditional disciplines of geology, physics, mathematics, chemistry and engineering and the growing discipline of geocryology, here defined simply as permafrost science. Third, the cryosphere is assuming an ever-increasing importance in view of its potential roles in global climate change. Following French and Thorn (2006), these disciplinary overlaps are illustrated schematically in Figure 1.5.

1.6.1 The Growth of Geocryology

Geocryology (permafrost science) is the study of earth material having a temperature below 0°C. It is one of the cryospheric sciences. Clearly, both the cryolithosphere (i.e., perennially-frozen and seasonally-frozen ground) and the cryohydrosphere (i.e., snow cover, glaciers, and river, lake and sea ice) are important components of the periglacial environment.

The early development of geocryology occurred in Russia where, as early as 1924, an Institute of Permafrost was established at Yakutsk, central Siberia, by the Soviet Academy of Sciences. By 1940, the first edition of what was to become a standard text in the Soviet Union, *Obshcheye Merzlotovedeniya* (*General Permafrostology*) had been published (Sumgin *et al*., 1940) and by the mid-1960s the first of many undergraduate textbooks had emerged. By comparison, North American geocryology is of relatively recent origin. Permafrost became important only during and immediately after the Second World War (Muller, 1943). In China, geocryology developed even more recently but in a Soviet-style context (Academia Sinica, 1975). The expansion of permafrost studies into alpine regions is also relatively new and initially focused upon rock glaciers in the mid-latitude mountains of Europe (Haeberli, 1985) and central Asia. More recently, attention in alpine permafrost has begun to focus upon the creep and stability of frozen rock masses (Gruber and Haeberli, 2007; Harris *et al*., 2009).

For several reasons, the relations between geocryology and periglacial geomorphology are complex. For many years, permafrost studies in North America and the Soviet Union were conducted not only in relative isolation to each other but also in isolation from mainstream (geographical) geomorphology. Moreover, both Russian and Chinese geocryology adopt a holistic, all-encompassing approach whereas North American permafrost studies are usually characterized as being either ‘science’ or ‘engineering’ in nature. Thus, there is currently no North American text that equals the breadth and depth presented by the most recent Russian and Chinese texts, *General Geocryology* (Yershov, 1990) and *Geocryology in China*. 
1.6.2 The Challenge of Quaternary Science

In the second half of the 20th century, Łozinski’s concept of Pleistocene periglacial geomorphology was questioned by the rapid growth of Quaternary science. This was fuelled by the expansion and proliferation of sophisticated dating techniques. For example, traditional Pleistocene studies involving paleo-environmental reconstruction based upon morphological evidence (Edelman and Tavernier, 1940; Edelman et al., 1936; Budel, 1944; 1951; 1953; Poser, 1948; Smith, 1949; Dylik, 1956; Sharp, 1942b) started to be replaced by studies that relied upon a broad range of evidence. This included biological phenomena such as fauna and flora, arboreal and non-arboreal pollen, temperature-sensitive insects such as beetles (coleopteran species) and geochemical indicators such as isotopes. In North America, S. Taber (1943) was one of the earliest to infer earth history from the investigation of cold-climate conditions in Alaska. Together with S.W. Muller (see section 1.6.1, above), these two geologists represent the founders of modern North American studies in periglacial geomorphology and permafrost. In 1954, in Łódź, Poland, a journal *Biuletyn Peryglacjany* had been founded that focused largely on cold-climate paleo-environmental reconstruction.

---

**Figure 1.5** Diagram illustrating the disciplinary interactions and overlap of periglacial geomorphology. (a) The relations between physical geography, geomorphology and periglacial geomorphology. (b) The relation between periglacial geomorphology and geocryology and the interactions of these disciplines with Quaternary science and other natural sciences. (c) Periglacial geomorphology and its overlap with the cryospheric sciences. Note: all the disciplinary boundaries are porous and those marked by broken lines are particularly so. *Source: French and Thorn, 2006.*
In the second half of the 20th century, the traditional stratigraphic approach became supplemented by ground ice studies, or what is now termed cryostratigraphy. Thaw unconformities, truncated ice bodies and cryostructures began to be used to infer Quaternary freezing-and-thawing events and more recent Holocene climatic changes. By the end of the 20th century, it was apparent that traditional Pleistocene periglacial geomorphology has been largely replaced by Quaternary science and cryostratigraphy.

1.6.3 Periglacial Geomorphology or Cold-Region Geomorphology?

Geomorphology is no longer the preserve of geographers and geologists. Others with different science backgrounds are increasingly involved. This trend, ongoing since the 1960s, came first as the result of quantification, then of increasingly rigorous process studies founded on Newtonian principles, and finally, as the inevitable product of the all-embracing theory of plate tectonics which ultimately led geophysicists to be interested in topics previously held to be largely geomorphic.

In the last 75 years, this approach has produced a sub-discipline of periglacial geomorphology that is focused largely upon quantitative process studies. The central role played by the Canadian geomorphologist and physical geographer, J. Ross Mackay, in this change cannot be overestimated (French, 2015; Church, 2015; 2016). His seminal contribution was summarized in a series of papers presented at a special symposium in his honor at the 7th Canadian Permafrost Conference, held in Quebec City, Canada, in 2015 (Burn, 2015).

From the 1960s onwards, and largely due to the wide international influence of Ross Mackay, opportunistic descriptions of patterned ground and other frost-action phenomena, the so-called ‘smokescreen of the periglacial scenery’ (André, 1999), lost their attraction. By the early 1990s process measurements had clearly demonstrated not only serious shortcomings inherent in understanding traditional frost-action processes but also that azonal processes, such as running water, wind, waves, and gravity-controlled mass movements differ little in cold environments, if at all in some instances, from similar processes operating in other climatic environments. A summary of these contemporary shifts is provided by M.-F. André (2009). One solution has been to emphasize the role of snow as a unifying concept within periglacial geomorphology. Accordingly, the discipline was defined largely in purely process terms (Thorn, 1992) and periglacial geomorphology was increasingly viewed as a cryospheric science that included ice-marginal (proglacial) environments and associated paraglacial transitions.

Other trends cast doubt upon the widely-assumed rapidity of periglacial landscape modification; for example, it is suggested that the complete footprint of periglacion is rarely achieved (André, 2003; French 2015; see Chapters 9, 15). At the same time, paraglaciation (Ballantyne, 2002) appears increasingly relevant in the context of current climate warming. On a more general level, the importance of polar and alpine regions as critical observatories of ongoing climate change means that periglacial geomorphologists are increasingly involved in the detection, monitoring and prediction of environmental changes. In summary, the challenge for periglacial geomorphology is to maintain a bridging position between the changing nature of geomorphology, the emerging discipline of geocryology and the increasing sophistication of Quaternary science.

1.7 Societal Considerations

Although periglacial environments occupy approximately one quarter of the Earth’s land surface, their human population, most of who live in Russia and China, is less than 1–3%
of the world’s population. Thus, the larger importance of periglacial environments lies in their spatial extent and their natural resources. For example, the Precambrian-age basement rocks that outcrop as huge tablelands in both Canada and Siberia contain precious minerals such as gold and diamonds and sizable deposits of lead, zinc and copper. Equally important are the sedimentary basins of western Siberia, northern Alaska, and the Canadian High Arctic that contain hydrocarbon reserves.

In North America, the geotechnical and environmental problems associated with human settlement and resource development in periglacial environments were first described in a 1943 U.S. Army Field Manual (Muller, 1943) that was subsequently updated to include research during the period 1945–1960 (French and Nelson, 2008). In the last 40 years, the growth of cold regions geotechnical and environmental engineering has addressed many of these problems. The annual proceedings of engineering conferences in North America, Russia and Scandinavia record the preventive and/or adaptive measures that are used. These issues are discussed in more detail in Part V.

1.8 The Growth of Periglacial Knowledge

Even before Łozinski proposed his periglacial concept, a scattered body of knowledge was available concerning the cold non-glacial regions of the world.

As might be expected, many of the first observations were made by the early European explorers of the vast sub-arctic regions of North America and Eurasia. These observations were casual, opportunistic and non-scientific. For example, in Russian Alaska, the peculiarities of frozen ground were observed in 1816 by members of the Otto von Kotzebue expedition (von Kotzbue, 1821) as they travelled through the Bering Strait region (Figure 1.6). The presence of massive ground ice bodies was to subsequently become

Figure 1.6 Members of the privately-financed Russian expedition led by Otto von Kotzebue examine exposed ground ice on Kotzebue Sound in 1816. ‘Vue des Glaces dans le Paris’, 1822, plate IX. Painting from the Rasmuson Library Collection, University of Fairbanks-Alaska, donated by the National Bank of Alaska.
an important component of periglacial study in the latter part of the twentieth century. Elsewhere in Russia, Karl Ernst von Baer, an Estonian-German naturalist who had travelled to Novaya Zemlya and Lapland in 1837, was the first to report (Baer, 1838) upon the excavation of a well in perennally-frozen ground at Yakutsk, central Siberia. Von Baer suggested that regular observations should be made in the shaft (Fritzsche and Tammiksaar, 2016). Subsequently, Alexander von Middendorff, von Baer’s younger travelling companion from an earlier expedition to Lapland, descended the shaft (Tammiksaar, 2016; Tammiksaar and Stone, 2007) that is known today as Shergin’s Well. The temperatures that he measured (Middendorff, 1861) are the earliest published information on the thermal regime of what is now termed permafrost. Middendorff correctly interpreted the ground temperature variations with depth and recognized what is now referred to as the ‘depth of zero annual amplitude’ (see Chapter 5).

In North America, the 18th century employees of the Hudson Bay Company occasionally made observations related to the terrain over which they had travelled. Later, in 1839, Dr John Richardson, the physician who accompanied the explorer John Franklin on his expeditions of 1819–1822 and 1825–1827, presented observations upon frozen ground in North America (Richardson, 1839; 1841). He sketched one of the distinctive pingos of the Mackenzie Delta region, known locally today as Aklisuktuk (‘the little one that is growing’) (Richardson, 1851, p. 234). Following upon the disappearance of John Franklin’s 1848–1849 expedition to the arctic and the numerous Franklin searches and other expeditions in the subsequent decades, data on the depth of frost penetration at various latitudes on the North American continent were published in a series of reports by The Royal Geographical Society in Great Britain (Lefroy, 1887; 1889a; 1889b).

The beginning of the twentieth century saw a sharp increase in knowledge concerning the cold non-glacial regions of the world. This was the time of the 1898 Klondike Gold Rush in north-western Canada and the subsequent migration of many miners to Alaska in 1901–1903. It was also the time of heroic exploration in Antarctica, culminating in the race to reach the South Pole between Scott and Amundsen in 1910–1911. Many of the individuals involved in these historic activities made observations upon the frozen ground, and the harsh, cold-climate conditions that they experienced. For example, there is considerable anecdotal evidence concerning the exceptional strength of the katabatic winds blowing off the Antarctic ice sheet. C. E. Borchgrevink (1901, p. 128, p. 140) was one of the first to comment on the ability of strong and persistent wind to transport sediment particles, small boulders, and even objects such as heavy boots, over considerable distances. Observations by members of Scott’s Northern Party (Priestley, 1914, p. 139), who spent a winter of incredible hardship in Northern Victoria Land in 1910–1911, confirm this: ‘pebbles were flying about the beach like small bullets…’ and ‘…the sea ice was strewn with pebbles up to half an inch in diameter’. Almost certainly, comments like these contributed to general acceptance of the importance of wind in periglacial environments. J. B. Priestley was also the first to record, in popular writing (Priestley, 1914, p. 290), the audible sound of thermal-contraction-cracking, a process that, the following year, was to be corrected inferred as the cause of ice-wedge formation in northern Alaska (Leffingwell, 1915). Griffith Taylor, another member of the 1910–1913 British Antarctic Expedition, was the first to describe the large sand-wedge polygons (‘tesselations’) of the McMurdo Sound region (Taylor, 1916).

Given this context, it is not surprising that the periglacial concept was enthusiastically embraced by European geologists in the years following Łozinski’s presentation
at Stockholm in 1910. Several influential benchmark papers quickly followed. For example, cold-climate patterned ground was described by W. Meinardus (1912) and the importance of frost-shattering was highlighted by B. Hogbom (1914). Because of the inaccessibility of most northern regions at that time, it was perhaps inevitable that periglacial geomorphology subsequently developed as a branch of a European-dominated climatic geomorphology. The primary aims were paleo-geographic reconstruction and global regionalization.

The real development of periglacial geomorphology occurred in Europe in the decades following the end of World War Two. A specialized journal, the *Biuletyn Peryglacjalny*, was started in Poland in 1954 under the editorship of J. Dylik. Although ‘cryo’ terminology (Bryan, 1946; 1949) was initially proposed to describe the cold-climate (cryogenic) processes involved, the Pleistocene orientation of periglacial geomorphology led to acceptance of the word ‘periglacial’ (Dylik, 1964). This raised criticism because the word was being used to refer to both processes and areas and led some to suggest that it be replaced by more specific terms such as permafrost, ground-ice, or soil-ice environment (Linton, 1969).

Two widely-held assumptions fuelled this disciplinary growth. First, there was uncritical acceptance of the importance of mechanical (frost) weathering and, second, of rapid cold-climate landscape modification. A sequence of influential texts by J. Tricart (1950; 1963; Tricart and Cailleux, 1967) and A. Cailleux (1948; Cailleux and Taylor, 1954) promoted these ideas. However, by the early 1960s these assumptions were being seriously challenged. Observations in both the high latitudes and at high elevation failed to record the numerous freeze–thaw cycles thought responsible, a shortcoming compounded by a lack of moisture in certain regions. Air climates were shown to be poor indicators of the relevant ground climates.

Fuller accounts of the development of periglacial geomorphology in the 20th century are now available (French, 2005; 2008; Shiklomanov, 2005). From the privileged viewpoint of history, it is now easy to see how the concept of a ‘periglacial environment’ and a ‘morpho-climatic zone’ (Budel, 1963; 1977) became popular and why a so-called ‘periglacial fever’ prevailed in the three decades after 1945 (André, 2003). It is now clear that the process assumptions underpinning traditional Pleistocene periglacial geomorphology were erroneous. Other weaknesses were that insufficient consideration was given to the influence of lithological and structural control over so-called ‘periglacial’ landscapes and the variability, duration and efficacy of cold-climatic conditions, both today and during the Quaternary, was neglected.

The 1970s witnessed a dramatic increase in awareness of the high northern latitudes, partly for geopolitical reasons but also in response to the search for natural resources, notably oil and gas. An upsurge in cold regions geotechnical engineering associated with hydrocarbon exploration and pipeline construction prompted an increase in the study of permafrost-related processes. Permafrost science (geocryology) became a priority research discipline in the United States, Canada, Scandinavia, and the USSR, often with substantial government involvement. As a result, traditional Quaternary-oriented cold-climate studies became overshadowed.

A series of international permafrost conferences held first in 1963 and then at regular intervals since 1973, progressively record increasing international collaboration in cold regions science and engineering. Of special significance was the formation of the International Permafrost Association (IPA) in 1983. The last 35 years has seen a proliferation
of peer-reviewed journals. *Permafrost and Periglacial Processes* was launched in 1990. A Chinese journal, *Bingchuan Dongtu (Journal of Glaciology and Geocryology)*, first published in 1978, has now been transformed into a bimonthly journal, *Sciences in Cold and Arid Regions*, published by the Chinese Academy of Sciences. In Russia, an international journal, *Earth Cryosphere*, was launched in 1997 by the Institute of Earth's Cryosphere (Tyumen), Siberian Branch, Russian Academy of Sciences. Other international journals that record advances in periglacial knowledge include the various AGU journals, *Cold Regions Science and Technology, Journal of Quaternary Science, Geografiska Annaler, Geomorphology, Progress in Physical Geography, Polar Geography, Arctic, and Arctic, Antarctic and Alpine Research.*