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Periglaciation and the Primary Economy – An Uneasy Alliance in Contemporary Alaska

The US state of Alaska is enormous, spanning 20 degrees of latitude and 60 degrees of longitude (Figure 1). Divided by mountain ranges into markedly contrasting coastal and interior regions, it demonstrates some remarkable periglacial processes and landforms (Box 1), and experiences extreme climatic variability. Conditions range from mild, wet maritime in the south, to extreme cold, arid, polar in the north. Natural resources, in the broadest sense, mirror this environmental diversity – Alaska contains the world's fourth-largest glaciated area, 40% of the USA's surface water, and its largest fisheries, wilderness areas and land designated as parks, reserves and wildlife refuges (Figure 2). Add to this Alaska's dependency on primary economic activities, including exploitation of vast oil reserves (20% of the USA's total production), gold (Box 2) and other minerals, and, not least, a large Native population still practising traditional subsistence ways of life, then the variety and scope of this remarkable, tectonically active, resource-dependent territory can start to be appreciated.

This **Geofile** aims to outline the practical geographical significance of **periglaciation** and climate change, to key primary economic issues in Alaska – namely oil exploitation, and existing and future infrastructure developments.

Climate trends over more than 30 years have shown significant warming (up to 1 degree Celsius mean per decade recorded), most notably in interior and arctic regions, resulting in extensive melting of glaciers and thawing of **permafrost**. Furthermore, climate-modelling predictions project a continuation of these trends, leading towards a warmer, wetter climate, most notable in the southeast and interior. Further widespread thawing of permafrost and glacial retreat, a shorter snow season, and reduced sea ice are believed widely now to be inevitable. All this has already resulted in major environmental and socio-economic impacts – impacts which will be exacerbated in future and which present long-term planning challenges. The **sustainability** of existing settlements and lifestyles, fishing in the Bering Sea and off the south coast, forestry and agriculture in the interior, tourism and mineral (most notably oil) exploitation will all be affected.

Figure 1: Alaska

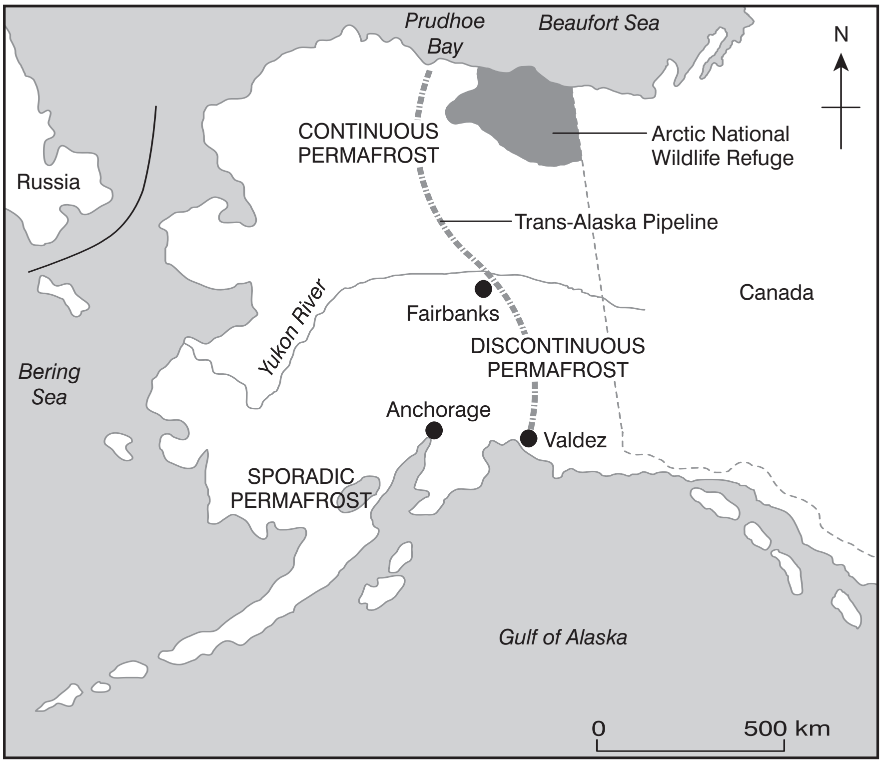

Figure 2: Alaskan landscape

Alaska has few cities and many rural communities. However, its infrastructure is nonetheless wide-spread and diverse – understandably, given the extraordinary demands of the oil industry.

Construction of all infrastructure and oil exploitation in Alaska requires working knowledge of periglacial processes and particularly of permafrost. This is because the construction of buildings, roads and pipelines interferes locally with the **active layer,** causing great problems for the stability of these structures. For example, centrally heated buildings warm the ground beneath, which causes subsidence into the active layer. Surfacing roads with dark tarmac, which has a low albedo, again encourages subsidence, which may cause the surface to crack and break up. Similarly, oil, sewerage and water pipelines heat the ground around them and they may then subside, distort and even fracture, causing spillages. Furthermore, drilling for oil generates frictional heat around the bore hole, which also melts the permafrost. The enlarged hole resulting produces drill vibration, leading to reduced drilling efficiency and vulnerability to breakage.

Solutions to such problems are well-established and documented, most notably involving elevation of houses and other small buildings on pile-driven (predominantly wooden) stilts in order to allow freezing air to circulate beneath the construction. Larger unheated buildings and airstrips can be constructed safely on thick gravel pads (up to 2 metres deep) in order to maintain the integrity of the permafrost. All pipelines must be insulated, and, better still, elevated on stilts (illustrated by the Trans-Alaska oil pipeline from Prudhoe Bay to Valdez – see Box 3). Established construction techniques, such as those outlined above, requires continual review because of both contemporary and projected climate change – even if only to the extent of increasing pile driving and gravel pad depths.

Oil exploitation

The story of oil in Alaska

Following the boom of the gold rushes in the late 19th and early 20th centuries (Box 2), interior Alaska suffered an economic downturn. However, after the Japanese attack on Pearl Harbor in 1942, precipitating America's entry to the Second World War, construction began on airfields, roads and communication systems; most significant was the construction of the 2,450-km Alaska Highway connecting the state with adjacent Canada. Defence spending remained significant throughout the Cold War, yet in 1959 interior Alaska remained an economically depressed and dependent area - two-thirds of the labour force was employed by government in one form or another.

The fortunes of Alaska changed when the largest oil fields in North America were discovered on the shores of the Arctic Ocean in Prudhoe Bay in 1968 (Figure 1). Production from the 19 producing North Slope fields did not start, however, until 1977 and the completion of the Trans-Alaska pipeline (Box 3). Since 1977, over 12.8

BOX 1: Key periglacial processes and landforms

Processes

1. Weathering - frost shattering, congelifraction, frost heave and nivation

Frost shattering depends upon the lithology and degree of jointing in rocks to create distinctive scree (talus) deposits. It is most effective with widely fluctuating temperatures, especially a large diurnal range, at high altitudes. Frost shattering applied specifically to periglaciated areas is known as **congelifraction**. Water seeps in and expands on freezing, so widening the joints or fissures. Repeated freeze-thaw cycles will lead, eventually, to the rocks splitting – often leading to large, relatively flat areas of frost-shattered rocks and boulders known as blockfields (or felsenmeer).

Frost heave is a similar process to congelifraction, occurring when water freezes in the soil, pushing material to the surface and leaving distinctively patterned ground.

Nivation (altiplanation or cryoplanation) is a process familiar from the explanation of corrie glacier formation. Periglacial areas have discontinuous snow cover. However, should perennial snow banks build up, then the very slow process of nivation can occur. **Permafrost** beneath the snow bank is important because it prevents day-time meltwater from draining through the rocks beneath, so allowing it to take part in freeze-thaw weathering. This breaks up the rocks, which eventually slide off with the melting snow in spring and summer - leaving an enlarged hollow for fresh snow next winter to settle in, so allowing the sequence to continue.

2. **Mass movement - solifluction and cambering**

Solifluction (gelifluction or congelifluction) under gravity can act upon slopes as low as 2 degrees because the waterlogged summer surface slides easily over permafrost and tundra vegetation is often absent, or at least so shallow-rooted as to be useless as an anchor.

Cambering is the dislodging of rocks on sloping ground (particularly rock faces). Again, it is related to freeze-thaw action, with consequences very similar to **dilatation**.

3. **Removal – wind saltation and deflation, and fluvial action**

Saltation and **deflation**, exacerbated by limited vegetation cover, may blanket existing relief with sand or fertile, stone-free **loess**.

Fluvial action is particularly effective seasonally owing to the potentially large volumes of high velocity late spring, early summer meltwater eroding, transporting and depositing large amounts of material.

Landforms

1. Thermokarst features are associated with subsidence caused most notably by an increase in the depth of the **active layer**. This is particularly relevant nowadays, given both climatic change and economic development. Irregular mounds and hollows are caused by the formation and melting of ground ice. Poor drainage, with many marshes and lakes, results.

2. Pingos are dome-shaped ice-cored hillocks, interrupting characteristically flat tundra plains, occasionally exceeding 50m in height. Whether caused by inward-freezing of lake-saturated sediment (so-called closed system pingos) or by the upward flow of groundwater (open system), these symmetrical landforms may be found isolated, or in groups, or even collapsed on melting into a form of crater lake.

3. **Ice wedges** form in unconsolidated material which has frozen and expanded in winter, only to contract and crack on thawing in summer. Water subsequently filling the cracks will freeze and expand the following winter as ice wedges, which may grow over the years to enormous proportions.

4. Polygonal stone patterns and stone stripes (**garlands**) also form by alternate freezing and thawing. The centres of the polygons are domed during expansion, due to frost heave, causing stones and other debris to move through gravity to the sides. The steeper the slope angle, the more elongated the polygons - ultimately leading to garlands.

5. Nivation hollows are rounded depressions in hillsides caused by nivation. The largest of these may develop into nivation cirques (corries).

BOX 2: All that glisters is not 'gold'

In 1876, when US Secretary of State William Seward purchased Alaska from Russia for $7.2m, few would have foretold of the riches locked in the landscape of ice, permafrost and water.

However, long before the discovery of oil, gold was the first natural resource to shape the landscape. Gold had been discovered by a Russian mining engineer on the Kenai Peninsula in 1849, but the first big gold strike did not happen until 1880, in Juneau.

The Klondike gold rush (1897) in adjacent Yukon Territory, Canada, resulted in the largest mobilisation of gold seekers in history. Alaskan ports such as Nome and Skagway were used to ferry prospectors into the region. This influx of prospectors led to smaller gold rushes in the far north and the establishment of formal settlements such as Fairbanks (Figure 1). Gold revenue brought wealth and prosperity to pockets of Alaska and allowed for the construction of a modern infrastructure. For example, in Fairbanks alone in 1905, gold production had risen to $6,000,000 a year and revenue had enabled construction of sewerage and a power plant, a three-storey 'skyscraper', saloons, stores, police and fire protection, and a thriving 'red light' district! The White Pass and Yukon railway was completed in 1900 to transport miners to the gold fields of the Klondike, and the history of the famous Alaska Railroad can also be traced to the opportunities presented by the gold industry.

Today, gold mining continues to impact upon the landscape and people of Alaska. A huge gold and copper deposit has been found near Lake Iliamna, about 380km southwest of Anchorage (Figure 1). It is estimated to contain 31.3 million ounces of gold and 18.8 billion pounds of copper, making it the largest deposit of gold and second largest deposit of copper in North America. In 2007 the Pebble Mine Corporation was established with the intention of constructing a mining complex at an estimated cost of US$1.425 billion. The so-called 'Pebble Claim Block' covers 140 sq km, but is just one small part of a much larger 870 sq km contiguous claim block near Lake Iliamna.

Issues that must be addressed before completion of the Pebble mining project include the construction of a 160km access road, disposal of mine waste so it does not threaten the headwaters of major salmon-spawning rivers, and provision of power to the site. Barring any delays, mining would begin in 2010. Whilst the mine would bring short-term economic prosperity to the region, locals and conservationists are concerned of the longer-term environmental impacts, in an area widely considered 'the last great salmon fishery'.

billion barrels of oil have been transported along the 1300km-long pipeline to the northernmost ice-free port in the Western hemisphere - the terminal at Valdez.

Production from the Prudhoe Bay region peaked in 1988 at about 2 million barrels a day. Between 1980 and 1986, Alaska's 500,000 population enjoyed $26 billion oil revenues! However, as the 'gold dust settled' once more over the state, the vulnerabilities of a **single-product economy** were again highlighted.

Following the global oil crisis of the late 1970s, oil production in Alaska crashed – one quarter in 1979 showed unemployment in Fairbanks at 20%. Despite a recovery in the mid-1980s, production from Prudhoe Bay continued to decline. By May 2005 production had fallen below 1 million barrels a day and current estimates suggest that only around 3 billion barrels of oil remain recoverable in the region. At current rates of production this would see reserves depleted within a decade. It should be of little surprise therefore, that politicians, oil companies and environmentalists hold mixed views as to the future viability and sustainability of oil exploitation in Alaska.

The future

Somewhat perversely, the future of periglacial Alaska is inextricably linked with defence spending.
During the first Gulf War (1990-91), when world oil prices soared and defence spending threatened to spiral out of budget, considerable pressure was applied to open the Arctic National Wildlife Refuge to drilling. The argument over whether to exploit one of Alaska's last great untouched wildernesses continues today – coincidentally at a time when the federal budget is again under strain from foreign defence commitments in Iraq.

The Arctic National Wildlife Refuge (ANWR) is a fragile buffer in an increasingly desperate political and economic tug of war. The 7.7 million ha refuge in remote north-eastern Alaska runs from the mountains of the Brooks Range north to the Arctic Ocean, and includes habitats such as tundra, boreal forest, barrier islands, and coastal lagoons.

Controversially established in 1973 by President Richard Nixon, the ANWR has been a political 'ping-pong ball' ever since. Repeatedly under threat by Republicans, its fate was almost sealed in December 2005, when a Republican plan to tack the opening up of the ANWR on to a major defence spending bill was only narrowly defeated in the Senate.

Republican President George W. Bush believes that it is possible to exploit the vast oil reserves (estimated in excess of 10 billion barrels) whilst simultaneously protecting the fragile environment. Anxious environmentalists are not convinced by the President's optimism.

Likened to the Serengeti nature reserve of East Africa, the ANWR contains an abundance of wildlife, including polar bears, oxen, caribou and millions of migratory birds. The ANWR is also the home of Alaska's Gwich'in Indians, whose hunting grounds are protected by the 1973 law. Fragile tundra soils and vegetation, argue environmentalists, would never recover if oil exploration were to begin. They argue that a proportion of the oil is recoverable using advanced, albeit costly drilling techniques such as **directional drilling**, without opening up the reserve. Economists, however, point to the USA's increasing dependence on oil imports, particularly from the Middle East, and the threat that this poses to national security. Furthermore, oil exploitation in the ANWR, argue economists and Republicans, would create many jobs, reduce the price of oil for consumers, increase federal, state and local tax revenues (every Alaskan receives an 'oil bonus' of around $1,000 per annum from Alaska's government)

BOX 3: **The Trans-Alaska Pipeline**

The construction of the Trans-Alaskan pipeline remains one of the world's greatest engineering feats. Construction began on March 27, 1975 and the pipeline was completed on May 31, 1977 at a cost of $8 billion. The Alyeska Pipeline Service Company had to negotiate the unique challenge of building on permafrost, climbing the Brooks and Alaska Ranges of mountains and crossing over 800 rivers and streams, including the Yukon River (see Figure 1). Furthermore, the continued threat of natural hazards (southern Alaska was devastated by an earthquake in 1964) and the fragility of the tundra flora and fauna complicated the 22-month-long construction programme.

Oil is pumped through the pipeline at 80°C, because of temperatures that drop to as low as minus 50°C, including wind-chill. Wherever the warm oil would cause thawing of the underlying permafrost, the pipeline sits on top of insulated supports. The pipeline is built up to 3m above ground to span rivers and to allow the migration of caribou and other wildlife below. To counter the effect of tectonic activity, the pipeline is built on sleepers that allow up to 6m of horizontal movement and 1.5m vertical movement. In addition, a network of 12 pumping stations control the flow of oil and close down sections of pipeline in the event of spillage.

and reduce the US trade deficit. In an era of dwindling oil reserves and increasing awareness of climate change, the arguments on both sides are likely to remain passionate.

Conclusion

Alaskan climate change-related thawing has already resulted in a northward retreat of the continuous permafrost zone, and sea ice reduction. Indeed, not all consequences of this are negative, with benefits to sea transport, tourism and off-shore oil exploration being notable considerations. However, changing ecological balances, coastal erosion, increased slope instabilities, and road, building, airfield and pipeline subsidence already necessitate costly monitoring, maintenance and replacement. Furthermore, engineers continue constructing roads, buildings and other infrastructure on the reducing permanent, discontinuous and even sporadic permafrost – with high potential future repair costs inevitable.

Over the 21st century, increases in the thickness of the active layer and the virtual disappearance of discontinuous and sporadic permafrost are projected to be inevitable. This will lead to increased coastal erosion, widespread subsidence, further slope instability and landslides – all threatening existing buildings, pipelines and communication links. The ramifications for oil exploitation (both production and distribution) are clear. Recent projections (June 2007) of infrastructure repair and replacement costs – covering roads, railways, airstrips, water and sewerage – are estimated to reach $40 billion by 2030. Furthermore, these projections do not include 'major' costs such as protecting the Trans-Alaska Pipeline, moving villages, or protecting private property! The uneasy alliance between Alaska's periglacial environment and predominantly primary economy looks increasingly precarious.

Glossary

Active layer: The highly mobile, often saturated surface layer of permafrost which melts during the summer and freezes in the winter. It can vary in depth from a few cm to over 5m.

Dilatation: The mechanical weathering process of pressure release, whereby rocks formed under considerable pressure, such as granite, are eventually exposed to the atmosphere by the erosion of overlying rocks. Stress is thus allowed to be released in the form of expansion, causing cracks parallel to the surface to result in sheeting.

Directional drilling: This is where the drill bit can be manoeuvred or directed at an angle; in contrast to the vertical-only movement of traditional drilling methods.

Loess: Deposits of silt laid down by wind action.

Periglaciation: The processes of periglacial areas - literally 'round about the ice sheet' or 'near to or at the fringe of an ice sheet.' Contemporary periglacial areas are commonly referred to as cold regions with permafrost - and tundra climate, soils and vegetation. Arctic Alaska, Canada and the Russian Federation dominate.

Permafrost: Permanently frozen subsoil associated with one-fifth of the Earth's surface and classified into continuous, discontinuous and sporadic.

Single-product economy: An economy almost entirely dependent on the export of one commodity.

Sustainability: To continue to use the environment without any long-term damage.

Further Resources

http://arcticcircle.uconn.edu/ANWR/anwrindex.html - Arctic National Wildlife Refuge Special Report. Includes overviews of both sides of the argument.
http://www.anwr.org - Arctic National Wildlife home page.
http://www.pbs.org/wgbh/amex/pipeline/sfeature/flyover.html - Alaska Pipeline flyover videos and teacher's guide.

Focus Questions

1. Using an annotated diagram only:
a) explain the process of frost shattering
b) describe the formation of pingos.

2. In no more than 100 words, explain why a working knowledge of periglacial processes is needed for the construction of an infrastructure in Alaska.

3. As a two-column table, list the physical and human dangers that threaten the long term sustainability of the Alaskan environment.

4. 'There is an uneasy alliance between periglaciation and the primary economy in Alaska'. Discuss.