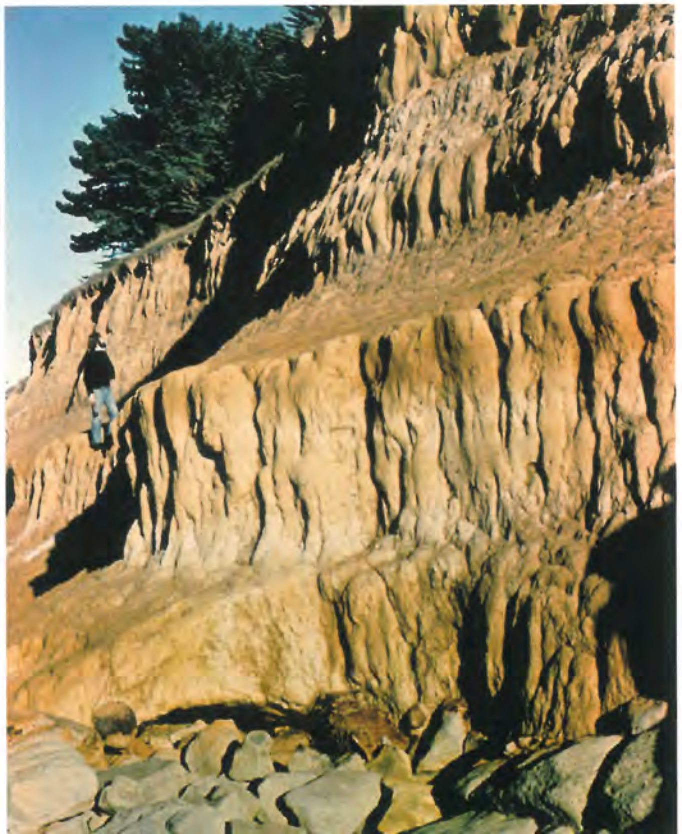
Dusty Horizons

Dust whipped up and deposited by wind forms sheets of loess, which drape over the land. These loess deposits and the soils formed within them yield insights into past climatic and environmental change.

David J Lowe
Philip Tonkin
Julie Palmer
Kerri Lanigan
Alan Palmer

Loess deposits are layers of wind-blown dust. They form the most widespread on-land cover deposits in Zealandia, and are especially common in eastern, western, and southern South Island and southern North Island. Loess deposits greater than a metre thick, blanket at least 10 percent of the land surface. The term loess (meaning 'loose') was first applied in the early 19th century in Germany to yellowish wind-blown sediment formed of silt-sized particles 0.002–0.06 mm in diameter. In China, loess is called *Hwang tu* ('yellow earth'); some deposits there are hundreds of metres thick. Thinner deposits occur in North America and southern South America.

Julius von Haast was the first to identify loess deposits in New Zealand, on Banks Peninsula, in 1878. In 1889, John Hardcastle confirmed their wind-blown origin and recognised buried soils in the loess deposits of South Canterbury. Hardcastle argued that the loess "... accumulated not only slowly, but intermittently, with prolonged periods of pause; and that its growth was dependent upon a set of climatic conditions that no longer prevail in the neighbourhood". He wrote that during cold glacial times "... great ice fields and glaciers in the highlands ... sent down floods of sludgy water, inundating the lowlands, and creating fields of dust, from which the winds picked up and deposited ... a bed of loess". He inferred that in warm interglacial times the supply of dust diminished and soils formed within the loess deposits. Hardcastle recognised several distinct buried soils within the loess, implying that climate had changed repeatedly in the past. Recent research, however, shows that soils form during, as well as after, each episode of loess deposition.



Dust Engines

The major 'dust engines' creating loess deposits in New Zealand are riverbeds. Loess is thickest immediately downwind of rivers, and thins with distance away from them. Loess deposition is usually linked to the climatically controlled infilling of valleys and the formation of plains by the build-up of sediment (aggradation). During glacial periods, over tens of thousands of years, large amounts of sediment are supplied to rivers by erosion. The rivers aggrade and widen. The sparsely vegetated flood plains and fans accumulate fine sediments along with coarse gravels. These fines are the source of loess.

Most of the fine material is derived by abrasion and breakdown of rocks as they are transported in rivers, especially during glaciations. Smaller amounts of fines are contributed by glacial grinding and by freeze-thaw processes. The dust engines that deposited the loess were driven by the belt of strong westerly winds that blew during glacial

◀The Dashing Rocks sequence at Timaru, recognised by John Hardcastle more than 100 years ago, contains four loess sheets. Coastal erosion has formed a stepped cliff face, highlighting the soil morphological features.

Reading the Signs

After time as a school teacher, John Hardcastle (1847–1927) worked at the *Timaru Herald* newspaper for nearly four decades, including a stint as editor. An amateur scientist, his two brilliant papers on loess at Timaru, published in 1889 and 1890, were the first to make the connection between loess and glacial climate, many years before such interpretations were made in other countries.

▲ Dust blowing from the exposed bed of the Rakaia River creates a haze in inland Central Canterbury.

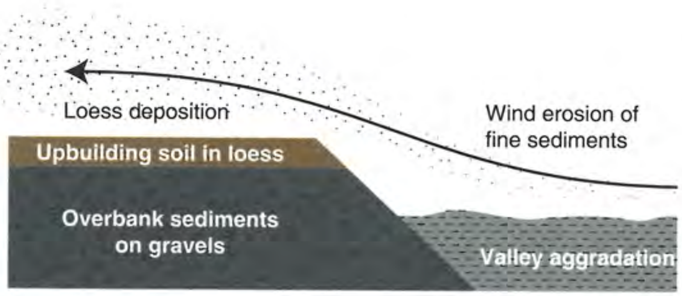
periods. Additional small amounts of dust were blown from Australia to New Zealand by these winds—aeolian dust deposits are recognised in drill cores from the Tasman Sea and southwestern Pacific Ocean and in montane peat bogs on land. Such foreign dust was swamped, however, by the much more voluminous locally derived fines.

Mean air temperatures during past glacials were c. 6°C colder on average than today, and the Southern Alps were covered by an extensive ice cap [see p.285]. Changed vegetation on land surfaces, especially hillsides and mountain slopes, made them prone to erosion. In places this susceptibility was further exacerbated by ongoing tectonic deformation and by changes in sea level. In central North Island, continuing volcanic activity generated large volumes of volcanic-derived sediment.

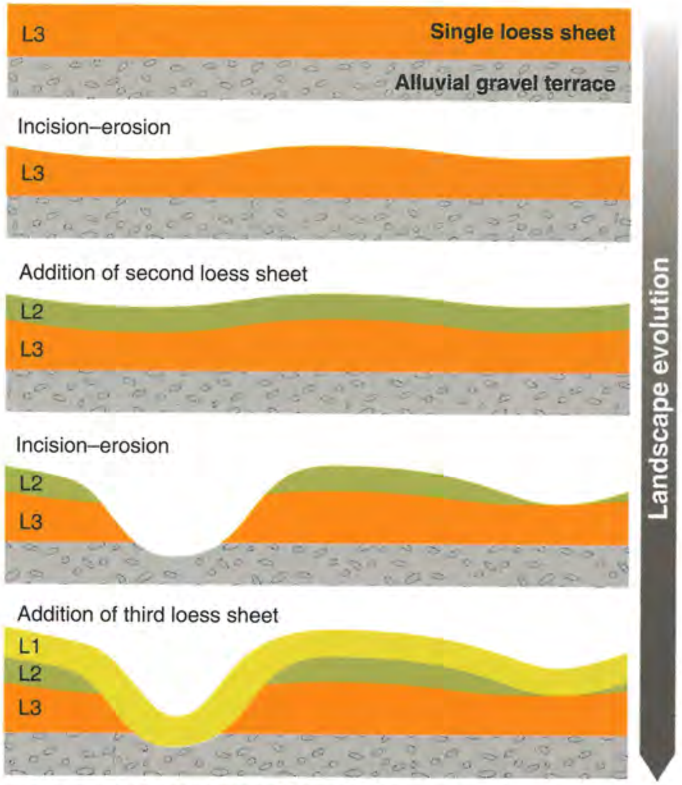
A Variety of Sources

Most New Zealand loess consists of the minerals quartz, feldspar, and mica; these are derived from schist and siltstone, rocks that are readily broken down to fine sediment. In central North Island, a major source of loess is the sediment eroded from the andesitic volcanoes of the Taupo Volcanic Zone and Taranaki, as well as andesitic and rhyolitic tephras, which give rise to tephric loess deposits.

In the South Island, loess is derived mainly from



▶ A model for loess deposition shows rivers aggrading during glacial periods, and fine sediment being blown onto nearby terraces to accumulate as loess. The maximum rates of accumulation of loess coincide with major periods of river aggradation.



▲ Evolution of a loess landscape may involve several loess sheets (here labelled L1–L3 from youngest to oldest, in the order they would be encountered during drilling). With each additional loess sheet, ridges grow higher while the valley floors remain at about the same relative level or are lower. The result is a smooth, undulating 'downland' landscape, such as those seen in South Canterbury, Manawatu, and Whanganui regions.

aggrading flood plains and fans within and beyond the main mountain ranges. During lowered sea level in glacial times, flood plains extended onto the exposed continental shelf to the east of the South Island and the west of the North Island, providing additional sources of dust. In eastern and southern South Island, where the mean annual rainfall is less than 1200 mm, the thickest loess deposits occur below c. 300 m altitude. For example, in South Canterbury six loess sheets total 20 m in thickness, and in Southland five loess sheets total 6 m in thickness. In West Coast, where mean annual rainfall is greater than 2000 mm, five loess sheets total just 3 m in thickness, draping terraces and moraines. Nevertheless, research has shown that the loess fluxes, although relatively slow, have effectively retarded the rate at which soils have evolved despite the super-humid West Coast environment.

In the Manawatu and Whanganui regions, a set of loess-draped terraces shows the relationship between periods of river aggradation and increased loess production. Each loess sheet is named after the aggradational episode from which it was derived. The four youngest loess deposits and associated terraces are Ohakea (sparse cover), Rata (one sheet), Porewa (two sheets), and Marton (three sheets). At Rangitatau East, northwest of Whanganui city, there are 11 loess sheets with a total thickness of 17 m. To the southeast, in the Ruamahanga River catchment in Wairarapa where it was drier, there are three sheets with a total thickness of 20 m. In central North Island, c. 3 m of unstratified tephric loess deposits were derived from rhyolitic tephra-fall and ignimbrite deposits, which were eroded during glacial periods to form valley fill and fan deposits, supplemented by glassy dust blown from existing tephra deposits.

▲ At Rangitatau East a sequence of 11 loess sheets is inter-layered with tephras, including Rangitawa Tephra. The dark bands represent strongly developed buried soils that formed during interglacial periods—marine oxygen isotope stages (MIS) 5, 7, 9 and 11 [see p.270]—when loess accumulation was minimal or zero.

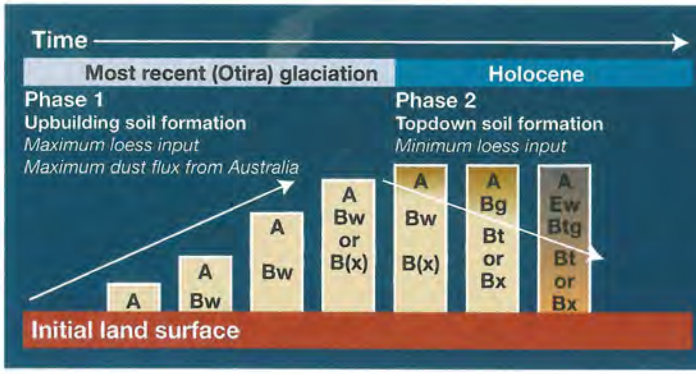
Dating Loess

Determining the age of loess directly is not straightforward. Radiocarbon dating is limited in its application to the past c. 60,000 years [see p.64–66], and dateable organic material is scarce in loess and often contaminated by younger carbon. Luminescence dating produces inconsistent results for deposits older than c. 200,000 years, but has provided some credible dates for North Island loess deposits of younger age. [see p.73]

The oldest known loess deposits are of Early Pleistocene age in Waikato (c. 1.7–1.1 Ma) and Wairarapa (c. 1.0–0.9 Ma). The Rangitatau East section comprises the longest, continuous, loess sequence, ranging in age from c. 500,000 years ago to the present. At Bidwill Hill (Wairarapa) the oldest loess was deposited c. 70,000 years ago. In the Mohaka River catchment of central Hawke's Bay and the Waipaoa River catchments of the Gisborne region, the oldest loess was deposited c. 150,000 years ago, and at Tapapa near Tirau (Waikato), the basal loess is c. 200,000 years old.

In the North Island, many loess sequences have been correlated using well-dated tephras from the Taupo Volcanic Zone. Several of these tephras have been identified also in South Island loess deposits, including the c. 25,400 year-old Kawakawa Tephra. This tephra occurs as a thin layer in loess sequences to about half way down the eastern and western coasts of the South Island, and beyond that as glass shards incorporated in the loess as a cryptotephra deposit. The loess sheet containing Kawakawa Tephra, Ohakea Loess, began forming c. 30,000 years ago, and has been found widely throughout the Manawatu, Whanganui, Wairarapa, Hawke's Bay and Gisborne regions, and as far north as the Waikato and Bay of Plenty regions. Other widely distributed tephras used to correlate loess include Rangitawa Tephra (erupted c. 340,000 years ago), which has been identified as a cryptotephra in Marlborough, Rotoehu Ash (erupted c. 50,000 years ago), Omataroa Tephra (erupted c. 32,500 years ago), and Okareka Tephra (erupted c. 21,900 years ago). Rerewhakaaitu Tephra was erupted c. 17,600 years ago, close to the time when rivers began to cut into their sediments and dust-fall into the ocean east of the North Island decreased sharply. This tephra thus marks the slow-down or cessation of loess deposition over much, but not all, of the North Island.

Contrary to general belief, loess deposits formed in New Zealand throughout the past 11,700 years (the Holocene), albeit at a much reduced scale. Deposition took place continuously along the margins of South Island braided rivers such as the Waitaki, Rangitata, Rakaia, and Waimakariri in Canterbury, and the Awatere in Marlborough. The Holocene loess sheets are probably variable in age, with the age being dependent on proximity to the source of the loess. In West Coast, dust continues to rise today from rivers such as the Haast and Waiho, but generally it is not accumulating fast enough to form recognisable loess deposits. Minor amounts of loess were deposited throughout the Holocene in the North Island, mainly at inland or elevated sites close to sources, such as the Tukituki River in central Hawke's Bay, where dust is accumulating today. The influx of airborne



A model of loess accumulation and soil development illustrates the gradation from upbuilding to topdown soil formation as environmental conditions changed from glacial (Otira Glaciation) to interglacial (Holocene) over the past c. 30,000 years. The letters represent various soil horizon types. Phase 1: Upbuilding soil formation during maximum but slow loess accretion under cold climatic conditions as the land surface gently rises. Topdown soil formation occurs, but its footprint is weak. Phase 2: Topdown soil formation with minimal or no loess accretion during warm climatic conditions, with land elevation essentially constant. The maximum development of subsurface soil horizons occurs when soil formation has a greater impact, in phase 2.

▼This 4 m-thick grey loess deposit on Oturoa Road near Ngongataha was deposited in the last glacial coldest period between c. 31,500 and c. 15,600 years ago. Named tephra layers provide ages (in thousands of years ago) for New Zealand climatic events (NZce) 10, 8, and 6, the coldest periods or stadials.

quartz to western North Island dropped sharply to low or zero c. 15,000 years ago, as westerly winds weakened and the continental shelf was inundated by rising sea level.

Variable Rates

The rates at which loess has accumulated have differed from place to place and through time. In general, the fastest rates of accretion were during the cold glacial periods, and especially during marine oxygen isotope stage 2, when rivers aggraded very rapidly. Based on calculations from 18 sites throughout New Zealand, and assuming minimal loss through erosion or dissolution, net accretion rates of loess since the eruption of Kawakawa Tephra c. 25,400 years ago, and prior to the Holocene, have been mostly c. 3–10 mm per century. The fastest rates are 15–25 mm per century where deposition was enhanced by turbulence, and the slowest is less than one millimetre per century. Accretion rates for loess in southern West Coast, where weathering and dissolution probably affected preservation, are 2–7 mm per century, similar to those for tephric loess in the Waikato, 3–8 mm per century. Holocene loess accumulation rates vary with proximity to rivers, and range from 60 mm per century within 5 m of the flood plain to 3 mm per century 2 km away from it. The average rates of loess accumulation in New Zealand are slow compared with those of China, where loess builds up at c. 20 mm per century, and Europe, where it ranges from 20 to 100 mm per century. The most extreme rates known are at Bignell Hill in Nebraska, USA, where more than 50 m of loess was deposited at up to 1200 mm per century (12 mm per year) between 22,000 and 18,000 years ago.

Soil Formation

As recognised by John Hardcastle, loess deposits commonly consist of multiple sheets, with distinct buried soil horizons formed during phases of very slow or no loess deposition marking the boundaries between them. In some places, the loess–soil sequences represent cold and warm climates, respectively. For example, in the Manawatu and Whanganui regions, cold climatic conditions correspond to maximum loess accumulation and relatively slow soil formation, and warm conditions to relatively fast soil formation and no loess accumulation. Where little loess is accumulating, 'topdown' soil processes alter the underlying material in a downward-moving front, forming distinctive subsoil features. These same features identify buried soils in loess. They include fragipans, very dense, non-cemented, silt-rich (Bx) horizons that commonly form vertical prisms, the edges of which are typically highlighted by greyish zones depleted in iron and manganese. In other sequences, clay-enriched (Bt) horizons form.

During periods when loess is accumulating, topdown soil formation does not stop, but its effects are lessened because any one position in the loess deposit is not exposed to soil processes for long before it is buried too deeply for these processes to be effective. Nonetheless, this 'upbuilding' history leaves the loess deposit with a soil fabric of root traces and worm burrows throughout, inherited from when the loess was part of the ground surface (A) horizon. The burrows and traces are sometimes filled by secondary calcium carbonate. The fabric allows loess to be distinguished from other silty sedimentary rocks such as siltstone. In an upbuilding phase, soil formation thus occurs simultaneously with slow loess accumulation, forming a 'soil-sediment'. This model of alternate developmental upbuilding and topdown soil forming phases applies widely to loess sequences in the South Island and to most of southern North Island where there has been limited tephra deposition.

Citation:

Lowe, D.J., Tonkin, P.J., Palmer, J., Lanigan, K., Palmer, A.S. 2015. Dusty horizons. *In*: Graham, I.J. (editor) "A Continent on the Move: New Zealand Geoscience Revealed, Second Edition". *Geoscience Society of New Zealand in association with GNS Science*, Wellington, pp. 286-289.