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ANTHROPOGENICALLY-INDUCED EROSION IN ARID AND SEMIARID AUSTRALIA

Erosión en zonas áridas y semiáridas inducida antrópicamente: el ejemplo de Australia

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Resumen: Aproximadamente un tercio del continente australiano es árido y un tercio semiárido. Estas areas se localizan de manera dispersa aunque todas ellas se ven afectadas por las actividades humanas. Extensas áreas se usan para el pastoreo, otras tiene un uso agrícola y algunas otras tienen un uso mixto para labradío. Se han encontrado importantes depósitos minerales en las zonas desérticas y la investigación continua. El turismo es progresivamente mas importante. La cubierta vegetal ha sido eliminada accidentalmente o por la construcción de sendas, caminos, carreteras o líneas férreas. Se han introducido plantas o animales exóticos. Las tierras han sido labradas y el freático ha sido rebajado aquí y elevado allí, en este último caso resultando en una generalizada salinización del suelo. Estas actividades han convertido la superficie de la tierra en más vulnerable a la erosión. La erosión acelerada del suelo, expresado de manera más evidente en el acarcavamiento, pero de manera más importante en la erosión por arroyada difusa ha ocasionado la pérdida del horizonte A de manera generalizada. En el momento actual está en marcha un genuino epiciclo de erosión (y deposición).

Palabras clave: Tierras áridas y semiáridas; Erosión acelerado; Impactos antrópicos; Restauración; Australia Central.

Abstract: Roughly one third of the Australian continent is arid and one third semiarid. These areas are sparsely settled, yet all are affected by human activities. Large areas are under pastoral lease, some are agricultural, and some are in mixed farming. Important ore deposits have been found in the desert and the search continues. Tourism is increasingly important. Vegetation has been cleared by accident or by design and paths, tracks, roads and railways constructed. Exotic plants and animals have been introduced. The land has been ploughed, the water table lowered here, but raised there, in the latter case resulting in widespread soil salinisation. These activities have rendered the land surface vulnerable to erosion. Accelerated soil erosion, most obviously in the form of gullying but more importantly sheet erosion, involving the stripping of the A-horizon, is widespread. A veritable epicycle of erosion (and deposition) is in train.

Key words: Arid and semiarid lands; Accelerated erosion; Human impacts; Restoration; Central Australia

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1. Introduction

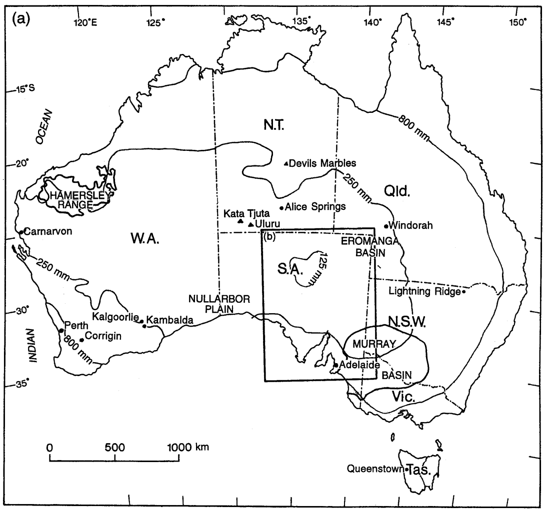
Forensic scientists believe devoutly in Locard's Principle. Locard (1877-1966) was a distinguished French detective who realised that humans cannot go anywhere without leaving evidence of their presence. As a corollary, they themselves are contaminated by the site environment, for when moving on they inevitably take with them some elements of the site visited. The same sort of principle applies also to the landscape. Wherever they go humans have changed their environments, most commonly to the longer-term detriment of both. Moreover the results of their activities eventually come back to haunt humans for they cannot escape the legacy of an impoverished and damaged environment. Human impacts on the landscape are, however, even more pervasive than Locard's Principle suggests, for people do not need to be physically present for their activities to modify, or even destroy, an environment. Airborne toxic wastes generated by smelters has affected entire districts, as for example the vegetational desert around Queenstown, western Tasmania, the acid rain emanating from industrial regions of western Europe extends downwind and damages forests far beyond the sites where the poison is generated, and the CFC (chlorofluorocarbon)-induced polar ozone holes are far removed from their areas of origin.

Here various forms of soil erosion induced by human activities in arid and semiarid Australia are reviewed (Fig. 1).

2. Accelerated soil erosion

Any activity which increases susceptibility to runoff causes erosion either where none would have occurred or at an increased rate: hence *accel - erated* erosion. Deforestation diminishes the protection afforded the land surface against both water and wind erosion by reducing or eliminating the umbrella effect, as also does the removal of any surficial stone layer, such as that widely developed in areas of *reg*, like Sturts Stony Desert of central Australia (Fig. 2; Twidale & Bourne, 2002). The surface is made vulnerable to raindrop impact, which sets soil particles in motion downslope. Root binding, which enhances soil cohesion and decreases the possibility of both mass movements and particulate erosion, is diminished or destroyed by clearance. Compression of clay soils (and few soils are devoid of clays) decreases permeability just beneath the surface affected by the vertical stress, produces a zone of depletion alongside the compressed area (Fig. 3), and frequently produces a surface depression which funnels runoff (Webb, 1983). The compressed zone in particular is susceptible to runoff erosion. Such changes in soil properties have been effected in various ways.

Although Australia is the driest of the inhabited continents almost all the land is formally in use. The arid lands are natural pastoral regions and in



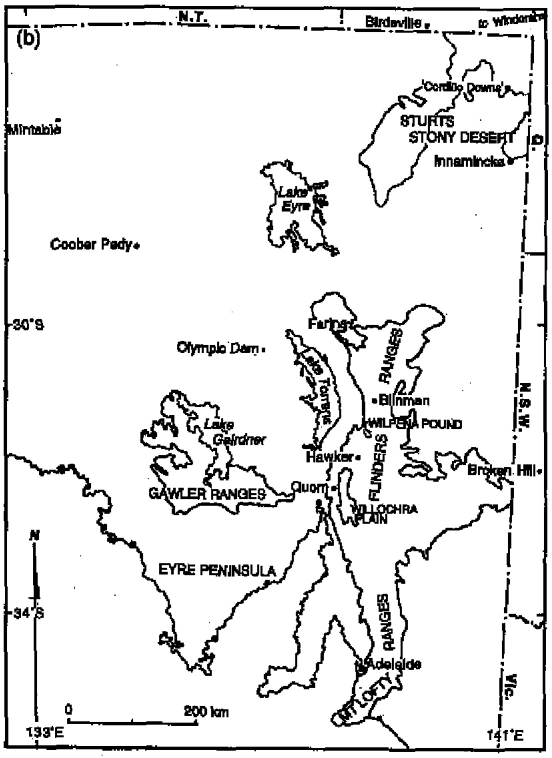


Figure 1. Location diagrams (a) Australia. Arid, semiarid, and hyperarid zones indicated by isohyets. (b) Part of eastern South Australia.

Figura 1. Diagramas de localización (a) Australia. Zonas ári - das, semiáridas e hiperáridas indicadas por isoyetas. (b). Parte del Este de Australia Sur.

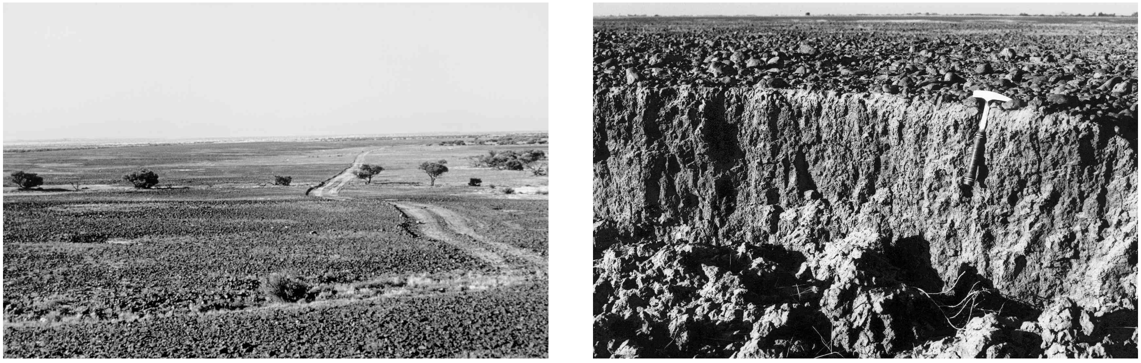


Figure 2. Sturts Stony Desert (a) general view, (b) roadside section showing stone or gibber layer only one stone thick.
Figura 2. Desierto de piedras de Sturt (a) vista general, (b) corte en la carretera mostrando un lecho de piedras o gibber con un espesor de una sola piedra.

Australia the desert regions, which constitute one third of the whole, most of the land is under pastoral lease. Grazing is also allowed in some arid zone National Parks. No desert is rainless and the Australian arid lands, whether consisting of dunefields, gibber or stony desert, alluvial plains or salinas, receive occasional rains, after which the desert briefly blooms. Much of the Australian arid zone is underlain by artesian or subartesian basins, so that stock can be fairly readily watered (and grapes are grown under irrigation near Alice Springs, and wines produced). The pastoral stations are large (up to 50 years ago one holding was larger than Belgium and several others were almost as extensive, but they have all now been subdivided) with low carrying capacity (*n* – some small number - square kilometres per beast) and

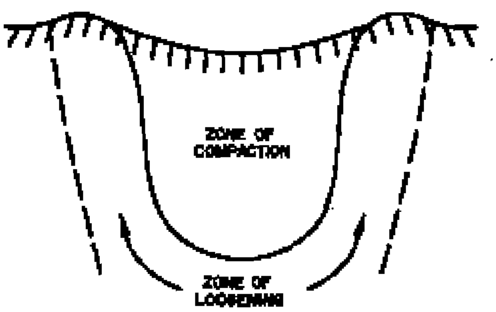


Figure 3. Section showing strain in soil underneath a vertical load, e.g. vehicle tyre. (Webb, 1983).
Figura 3. Corte mostrando la deformación del suelo por debajo de una carga vertical, por ejemplo la rueda de un vehículo. (Webb, 1983).

not uncommonly they are administratively linked with other stations in better-watered and pastured areas so that cattle can be moved to where feed is available.

In Australia, the arid lands are used for stock rearing: beef cattle in the north, sheep in the south. This distribution reflects not only climate, vegetation and current economics (demand) but also the location of the dingo-proof fence. Sheep are vulnerable to attack by wild dogs, and for this reason cattle are preferred in some central and northern areas which are otherwise well suited to wool and lamb production. The early years of European settlement in the second half of the Twentieth Century coincided with unusually high rainfall in some parts of the southern arid zone, encouraging the belief that 'rain follows the plough' (e.g. Meinig, 1962). In the Flinders Ranges, agriculture based on cereal (mainly wheat) farming was attempted in many parts of what were later realised to be natural pastoral areas (Fig. 4). In northern South Australia, a rail siding officially known as 'Government Gums' was renamed (and remains) Farina (Latin, flour). It averages less than 160 mm of rain per annum. The same ephemeral, atypical and misleading high rainfalls also encouraged stocking on some pastoral stations at a carrying capacity later appreciated as being far too high.

Native animals such as the kangaroo, and feral animals, in particular the rabbit and goat, but also camels, horses (brumbies) and donkeys, are well known for their capacity to multiply and for the depredations they have wrought on the vegetation

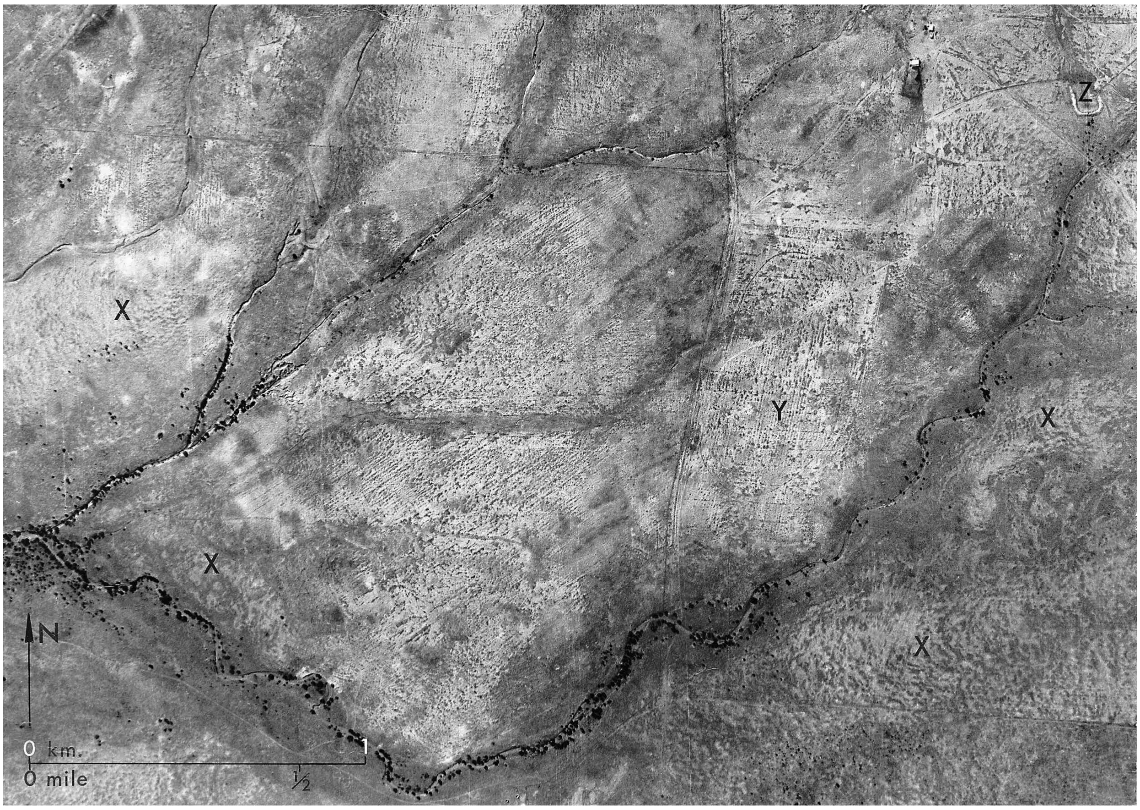


Figure 4. Air photo of part of the Willochra Plain showing plough furrows (Y). The pattern has been disturbed by soil churning (gilgai formation - X). (S.A. Department of Lands).

Figura 4. Foto aérea de la Llanura de Willochra mostrando los surcos de arado (Y). El patrón del trazado se ha visto modificado por la agitación del suelo (formación de gilgai - X). (S.A. Department of Lands).

cover in arid and semiarid Australia (e.g. Ratcliffe, 1936, 1937, 1938; McKnight, 1976). The pads they make going to and from water, and along fence lines, also contribute to the soil erosion hazard.

Road construction in the Australian desert poses insoluble problems. In Sturts Stony Desert, for example, grading the roads strips the surficial stone layer. This is desirable because the angular, hard, silcrete fragments not only give a rough ride which is hard on vehicle suspension but also tear and shred tyres. Such grading also exposes the clays beneath the stone layer to water erosion, particularly as the roads are cambered. Also, some graded material is left in ridges on each side of the graded track, resulting in the funnelling and concentration of runoff. The grader operators leave regularly spaced openings that allow runoff to escape to the offroad areas. In heavy rain, however, this can lead to ponds which form temporary watering points for animals but the water may overtop the roadside ridges and flood the road surface. Sealing the road would be expensive, for the clays are expansive, so that unless the foundation was very thick the bituminised surface would be disturbed (the clays are evocatively known as 'Bay of Biscay' soils in South Australia). Moreover, a sealed surface would be impermeable and runoff from the cambered surface correspondingly rapid and heavy. The risk of roadside erosion and undermining of the road would be high.

Sand drift can be a hazard where (as on the Birdsville-Windorah road, and also around Minilya, north of Carnarvon, in the northwest of Western Australia) the sealed road is directed through trenched dunes. Furthermore, if the dunes are not cut to the same level as the road to either side, blowing sand reduces visibility on already blind crests.

All this has increased the exposure of an already vulnerable landscape to accelerated erosion by water and by wind. That wind is particularly effective as an agent of transportation and deposition is attested by the many dunefields, past and present, typical of arid and semiarid lands. Transport and deposition imply erosion, and though there are few specific forms due to wind erosion, a general lowering of the surface is widely in evidence. That running water is an effective erosional agent in deserts, and even especially effective, is also not surprising (Peel, 1941). It is not that desert rains are especially intense – though, as elsewhere, heavy falls do occur (Russell, 1936) – but rather that the surface on which the rain falls is poorly protected against water erosion in its various forms. The surface tends in an immediate and surficial sense at any rate to be dried and baked. It is impermeable and thus conducive to rapid and high runoff.

In addition to these generalities, particular activities invite particular types and causes of accelerated erosion.

3. Land use and erosion

3.1. Pastoral activity

Rearing cattle or sheep requires fences to keep the stock in paddocks where there is feed, and to control breeding and watering points. These in turn imply tracks for maintenance and access. Fences and watering points also mean the funnelling of stock (as well as native animals like kangaroos) along certain lines, the making of pads (or narrow tracks) and the formation of a compressed surface soil layer which is of low permeability, and is flanked by narrow zones of tension or spatial depletion. Despite the increasing use of light aircraft and helicopters for mustering and other purposes, the making and maintenance of tracks are still inevitable. Tracks mean vehicles, whether with four or two wheels, and again, compaction, depression and low permeability, and erosion (Fig. 5).

Stock also eat grasses and if necessary, in drought, the low branches of shrubs and trees. Both with intent and as a matter of course, the land is more-or-less cleared, though pastoralists have customarily left some trees to provide shelter against sun

Figure 5. Washed-out tracks (a) on Cordillo Downs station, northeastern South Australia, (b) in the western piedmont of Flinders Ranges, near Wilpena Pound, South Australia; the track runs essentially along rather than across, the contour of the land, and (c) alongside the abandoned railway line west of Wilpena Pound, eastern Lake Torrens plain, South Australia. The track was used to service the rail bed. Note the evidence of sheet wash (S).

Figura 5. Sendas sujetas a lavado de finos (a) en la Estación de Cordillo Downs, al noreste de Australia del Sur, (b) en el piedemonte occidental de los Flinders Ranges, cerca de Wilpena Pound, Australia del Sur; la senda discurre mas bien a lo largo que a través del contorno de la tierra, y (c) por el borde de la línea de ferrocarril abandonada cerca de Wilpena Pound, en el Este de la llanura del Lago Torrens, Australia del Sur. La senda se usó para el servicio del trazado del ferrocarril. Nótense las pruebas de lavado en lámina (S).

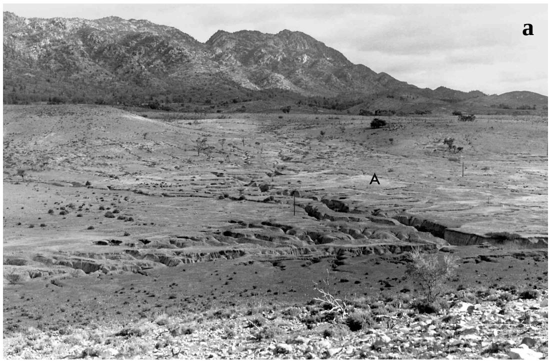
Figure 6. Gullies formed on the conical shale hill known locally as 'Fuji Yama', between Hawker and Wilpena Pound, central Flinders Ranges, following a heavy (about 280 mm in 24 hours) late summer rainstorm in February, 1955.

Figura 6. Cárcavas formadas sobre una colina cónica de pizarras localmente conocida como 'Fuji Yama', entre Hawker y Wilpena Pound, en la zona central de los Flinders Ranges, formadas des - pués de una lluvia intensa, (aproximadamente de 280 mm en 24 horas) en una tomenta la final del verano en Febrero de 1955.

and weather. The soil surface is significantly deprived of protection. Using tracks in the stony desert has the same effect for the stone cover is only one layer thick (Fig. 2b). The introduction of rabbits and goats added to the depredations of kangaroos and the occasional swarms of locusts, plus the occasional impacts of bushfires, add to the problems introduced by vegetational clearance. Also, exotic grasses have been introduced, either intentionally or by accident. They have spread at the expense of native species but they do not withstand drought and heat, so that by late summer vegetation is depleted and in many areas the soil is bare and vulnerable (Fig. 6). The problem is exacerbated when there is overstocking, as in the early days of settlement, or occasionally at present, based in false expectations, greed, miscalculation or ignorance (Fig. 7). The thrust of the Lincolnshire farmer's saying that 'one should live every day as if it were your last, but farm as if you will live for ever', is either unknown or ignored.

Added to localised factors like those cited are the impacts of regional services such as arterial roads and railways. Both in the construction phase, and subsequently, factors conducive to accelerated erosion are introduced. Railways are accompanied by access and service tracks (Fig. 5c). Main roads are either graded regularly or are sealed. If graded, vegetational protection is prevented from taking hold. If sealed, camber concentrates runoff. In both cases, vehicle fumes inhibit or kill roadside vegetation (Fig. 8). Cuttings expose rock or regolith, the latter readily eroded until stabilised by vegetation.

Drought causes lowering of the water table, reduces vegetation cover and so facilitates soil erosion. Long-term drought and deliberate clearance



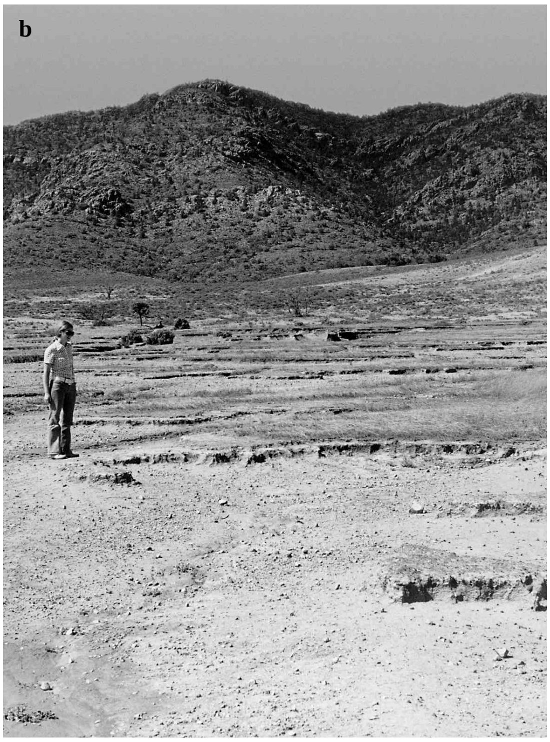


Figure 7. (a) Sheet erosion (A) within gullied area, Chace Range, central Flinders Ranges, South Australia. (b) Detail of A.

Figura 7. (a) Erosión en lámina (A) en una zona acarcavada, en la Chace Range, zona central de los Flinders Ranges, Australia del Sur. (b) Detalle de A.

Figure 8. Gullying in roadside area alongside the Quorn-Hawker road sealed in the mid nineteen ‘sixties. The gully was soon filled by natural runoff, deposition and vegetational colonisation.
Figura 8. Acarcavamiento en una zona adyacente a la carrete - ra a lo largo de la ruta Quorn-Hawler, carretera asfaltada a mediados de los años 1960. El acarcavamiento se selló por la escorrentía natural, por deposición y por colonización vegetal.

cause a decrease in organic matter in the soil, and a loss of soil structure. This also is conducive to soil erosion and accounts for the observed delay between clearance and the onset of erosion noted in some areas (Waksman, 1938; Twidale, 1997). Local but significant losses of vegetation cover can also be induced by boring and heavy use (mining) of shallow groundwaters around small towns and even large pastoral stations.

Whatever their causation, that many gullies postdate European settlement is demonstrated in a variety of ways. Comparison of time-lapse plans, maps, air photographs and photographs are useful, as is oral history. Physical evidence points in the same direction. Partly buried fence posts, exposed tree roots in commercial forests, the establishment of which can be dated, and wells sited adjacent to deep gullies (Fig. 9) provide physical evidence, as

Figure 9. (a) Buried fence posts in the southern Mt Lofty Ranges. (b) Tree roots exposed in shallow gully, a washed-out track in the Wanilla Forest, a commercial enterprise on southern Eyre Peninsula planted in 1911 or 1913. (c) Well (W) dug in the alluvial fan fronting the Willunga Scarp, some 50 km south of Adelaide, in about 1854. The gully surely postdates the well which would not have been built at the site had the gully already existed.
Figura 9. (a) Postes de valla enterrados en el Sur de los Mt Lofty Ranges. (b) Raices de árbol expuestas en una cárcava superficial, una senda sujeta a lavado de finos en Wanilla Forest, una empresa comercial del Sur de la Península de Eyre que lo plantó en 1911 o 1913. (c) Pozo (W) en el abanico aluvial frente al escarpe Willunga unos 50 km al sur de Adelaide (Australia del Sur) aproximadamente en 1854. La cárcava posiblemente es posterior al pozo que no habría sido construido en este lugar si existiera la cárcava.

do gullies developed along plough furrows (Fig. 4, and see below), for they all clearly postdate human occupation.

3.2. Arable and mixed farming

Many semiarid areas have been cleared and are utilised for agriculture. Huge areas of semiarid southern Australia are utilised for mixed farming. In particular, the huge wheat-sheep belt extends from the Indian Ocean in the west to central New South Wales and northwestern Victoria in the east, though interrupted by a sheep-only zone on the Nullarbor Plain. The same factors as those which apply in pastoral conditions are important also here. Clearance tends to be severe, for whereas pastoralists tend to leave some trees to provide shade for stock, such vegetational 'islands' interrupt the pattern and ease of cultivation. Deforestation is essentially complete except where special conditions and regulations apply. For instance, in many parts of South Australia agriculture has extended into low and unreliable rainfall areas such as northern Eyre Peninsula and the northwestern Murray Basin, which border the arid zone and which in the Late Quaternary were desert dunefields. Though government regulations now require that the larger dunes remain in vegetation, paths, tracks or roads driven across such obstacles, as well as local excavations for building sand, are exploited by wind. It is not uncommon for a crop to be 'beheaded' by blowing sand. In addition, most dust storms experienced in the southeast of Australia involve soil exposed by ill-timed ploughing, for ploughing renders the soil especially vulnerable both to water and wind erosion (Fig. 10). As to prevention or protection against wind scouring, as the Chinese have shown in the northwest of their vast country, planting of suitable vegetation can retard wind erosion by binding the sand and impeding airflow near the land surface.

Arable farming has led to soil salinisation in many areas. Clearing land of trees causes the water table to rise. The shallow groundwaters are saline and this quality is imposed on soils, rendering them useless for cereal cultivation and inhibiting natural vegetation growth. Though especially widespread in the wheatlands of the southwest of Western Australia, where the problem is known as the 'White Death', it has long been developing and is spreading in other states (Figs. 11a & 11b).

In the early years of settlement in South Australia, transport and communications were poor. If only for subsistence purposes, land was ploughed and wheat was grown in areas that later, and appropriately, were adjudged more suitable for sheep. The early farmers used single share ploughs, and ploughed in strips or 'lands' (Twidale & Bourne, 1978). An especially deep furrow marked the junction of such lands. They persisted after the return to pasture and were in many areas sufficient to concentrate runoff and induce gullying. Piping has caused such erosion to be discontinuous in places (Fig. 12a; also Fig. 4). Furrows and associ-

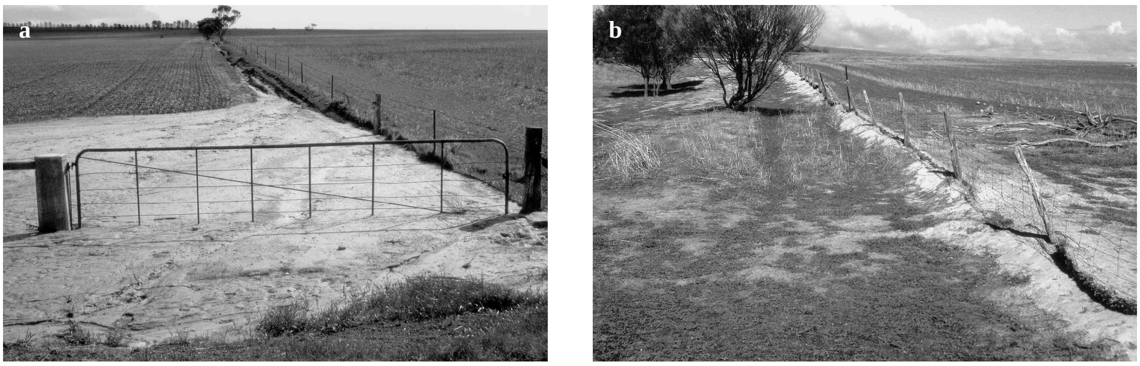


Figure 10. (a) Gate partly buried by sediment washed from ploughed field, west of Port Lincoln, southern Eyre Peninsula, 1960. (b) Wind-blown sand accumulated along a fence line, Corrigin area, Western Australia, 2001.

Figura 10. (a) Puerta enterrada parcialmente por el sedimento lavado desde el campo de labranza, al Oeste de Port Lincoln, al Sur de la Península de Eyre, 1960. (b) Acumulación de arena transportada por el viento acumulada a lo largo de una alambrada divisoria en la zona de Corrigin, Australia Oeste, 2001.

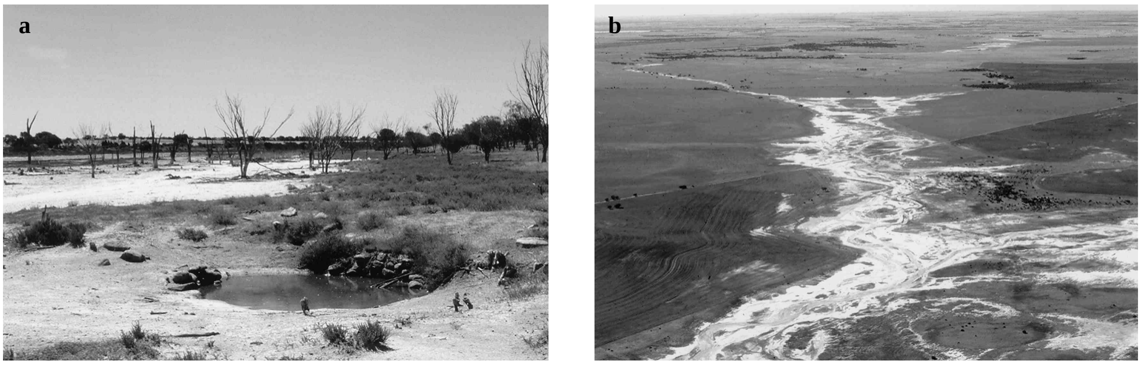


Figure 11. The ‘White Death’, salt affected soils, (a) in the Wilkerson Well area, Dowerin Shire, some 150 km northeast of Perth, Western Australia, and (b) in cleared land in Moora Shire about 150 km north of Perth. (Both courtesy Dr B.M.J. Hussey, Land for Wildlife, CALM, WA).

Figura 11. La ‘Muerte Blanca’, suelos salinizados, (a) en la zona del Pozo Wilkerson, Dowerin Shire, unos 150 km al noroeste de Perth, Australia Oeste, y (b) en una zona roturada en Moora Shire unos 150 km al Norte de Perth. (ambas fotos gentileza del Dr B.M.J. Hussey, Land for Wildlife, CALM, WA).

ated gullies are common in the Mt Lofty Ranges (Fig. 12b), but have been noted on southern Eyre Peninsula, in western Victoria and in the Flinders Ranges, on the Willochra and Lake Torrens plains, in Wilpena Pound (Fig. 12c) and as far north as Blinman (average precipitation 283 mm/year).

3.3. Mineral search

Economic mineral deposits have been discovered at several sites in the Australian arid zone. Broken Hill, Kambalda, the Hamersley Range and Olympic Dam, readily come to mind. The search

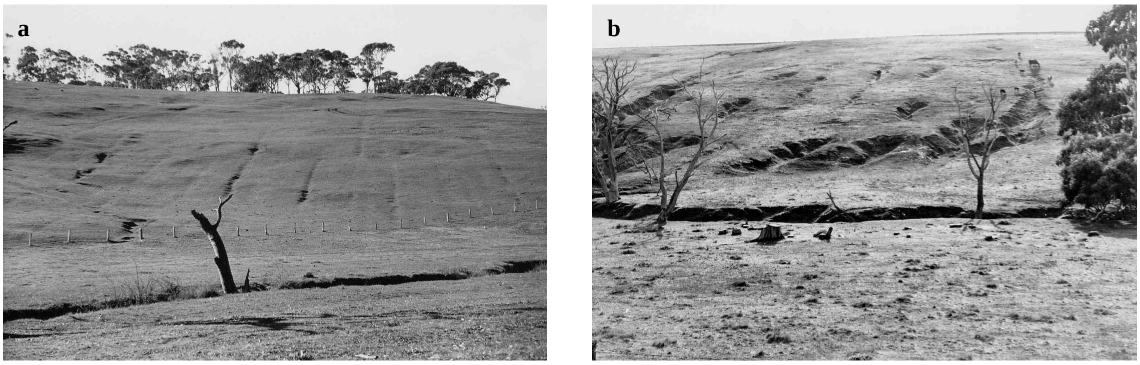


Figure 12. (a) Lands near Yankalilla, southern Mt Lofty Ranges, with some suffering piping and sapping, while others remain essentially unaffected by erosion. (b) Gullies developed along furrows in the same area of the southern Mt Lofty Ranges. (c) Furrows delineating lands within Wilpena Pound, central Flinders Ranges. The farm was abandoned in 1914, after a drought -breaking flood washed away the only access track into and out of this natural enclosed basin.

Figura 12. (a) Tierras cerca de Yankalilla, al sur de los Mt Lofty Ranges, donde algunas de ellas han sufrido zapamientos y sufu - sión mientras que otras no han sido afectadas sustancialmente por la erosión. (b) Cárcavas desarrolladas a lo largo de surcos en la misma zona al Sur de los Mt Lofty Ranges. (c) Surcos que limitan fincas en Wilpena Pound, zona central de los Flinders Ranges. La granja se abandonó en 1914, después de una sequía una avenida se llevó por delante el único camino de acceso al interior del recinto de Wilpena Pound.

Figure 13. (a) Gully erosion in the gibber plain where the stone layer has been compressed beneath the wheels of heavy vehicles involved in seismic survey in the Innamincka area of northeastern South Australia. F – alluvial fan. (b) Two parallel tracks on slope in Sturts Stony Desert near Innamincka. Note that erosion has either ceased or been retarded in the left-hand track where bedrock - shale - has been exposed. (R. Langley, PIRSA).

Figura 13. (a) Erosión por acarcavamienmto en la llanura de gibber donde el nivel de piedras ha sido comprimido entre las ruedas de los vehículos pesados destinados a la investigación sísmica en la zona de Innamincka en el noreste de Australia del Sur. F - abanico aluvial. (b) Dos senderos paralelos sobre una ladera en el Desierto de Piedra de Sturt cerca de Innamincka. Nótese como la erosión se ha detenido o ha sido retardada en el borde izquierdo del sendero donde aflora el sustrato rocoso de pizarra. (R. Langley, PIRSA).

for minerals has taken geologists and geological surveys into various parts of the arid lands, with the corollary of tracks and the transport of heavy machinery, and inevitably leads to accelerated erosion. Abandonment of such sites, even with regulation clean-up, frequently allows ongoing erosion. The search for oil and gas in the Eromanga Basin of northeastern South Australia and adjacent parts of Queensland, all in Sturts Stony Desert, called for the survey of geophysical lines and the use of heavy machinery. This disturbed the stone or gibber cover and has induced severe and ongoing gullying (Fig. 13), comparable to that inherent in the development and maintenance of pastoral stations in the same area (Twidale & Bourne, 2002).

3.4. Tourism

The Australian desert boasts several well-known tourist destinations. In general terms the Centre, based in Alice Springs, but with Uluru and Kata Tjuta the 'jewels in the crown', are perhaps the best known, but the Devils Marbles and such opal centres as Coober Pedy, Mintabie and Lightning Ridge are also prominent, and more and more tourists are spending time 'going bush', i.e. camping and exploring 'off the bitumen', or sealed roads. The impacts of tourism can be considered under two headings: that in controlled Parks and other. National Park administrators encourage and insist upon vehicles staying on selected tracks and their occupants camping at approved sites. Even so, frequent use of tracks inevitably leads to erosion: the more popular the Park, the greater is the chance of track erosion.

The coming of the 4WD vehicle as a desirable and safe family vehicle – seemingly safe, that is, for the occupants, though not for any pedestrian, cyclist or driver of a conventional motor vehicle for whom the height and the various bullbars and other allegedly protective 'armaments'pose unnecessary hazards - has introduced road tourism to many parts of the arid zone, so that a vacation in 'the bush', away from sealed roads, has become fashionable. Convoys of more than a score of vehicles are not uncommon. If caught by rain they cannot afford to wait until an unsealed track or road dried out, as locals do, because tourists are on a limited time schedule, and with 4WD they are able to move even on muddy tracks; but at dreadful cost to the state of the track which is left a churned quagmire which dries and hardens to a veritable obstacle course. But this is of no concern to the 4WD tourists: it is only the locals who have to face a rough journey to school or to town until the grader can come around and clean up the mess.

Off-track use of 4WD vehicles is, however, much worse, for drivers tend to take their vehicles wherever the whim takes them, without regard to long-term or even short-term impacts; and a single impression is enough to induce erosion, particularly as in arid and semiarid lands such random tracks, used only once, are known to last several years. (For example, tracks made in the Gawler Ranges by the explorers Eyre and Darke were noted up to almost 20 years later by Hack and Warburton). Travelling over the stony desert later named after him, Sturt (1849, vol. I, p. 375) observed that his horses and cart left a track that was visible only here and there; nevertheless the impression they made would have been enough to induce erosion.

Offroad and offtrack driving is encouraged by disgraceful advertising which frequently depicts 4WD vehicles, with implicitly 'macho' drivers, splashing through rocky creeks, or speeding over unsealed tracks and dunes, and along beaches, throwing plumes of dust and sand in their wake. One international manufacturer, whose cold weather experience should tell him how stupid it is, depicts the alleged fun and excitement to be had taking the vehicle in and out of the edge of the sea while racing along a beach. Another advertises sedans standing on the bed of a salina (Lake Gairdner) omitting to mention the effects of salt on bodywork and the fact that the salt crust can fail, as at least one owner of a partly submerged and necessarily abandoned 4WD knows to his cost! Or perhaps 'salt-rusting' and submerging vehicles in saline mud encourages sales?! Suffice it to say that erosion by wind and water will still be effecting erosion and hence provide an enduring memento of fun drives long after the perpetrators have gone home.

4. Impacts

These various factors have led to extensive gullying and sheet erosion in the pastoral areas. Of these gullying is the more obvious and is difficult to counter in the short term, though only the unconsolidated regolith is affected, for erosion ceases once lithified bedrock is exposed (Fig. 13b). There being plenty of space, the usual solution for a washed-out track, which is eroded and reduced to a quagmire in the 'wet', is to move the track laterally, and this has in places been done several times – up to seven on a slope near Innamincka. Even so, it is easy to understand how the sunken roads of western Europe, where lateral diversion was restricted by hedges and other field boundaries, were formed over the centuries. Sheet erosion is widespread but not so obvious to the casual observer. Nevertheless it is the more important of the two types of accelerated erosion, for it involves the loss of the organically richer few centimetres of surface soil – the A-horizon (Figs. 5c & 7).

Scalding is a type of erosion involving the removal of all vegetation and all topsoil – again, the A-horizon. These bare crusted areas are commonly found on saline soils which inhibit or kill many types of vegetation. They are formed by either wind scouring or sheetwash. Sheetwash can be detected on surfaces lacking drainage lines by indirect evidence. Surviving remnants of the A-horizon of soils are commonly bounded by distinct low cliffs, but miniature flared slopes developed on surficial blocky cobbles, as for example on the Brachina pediment, in the western piedmont of the Flinders Ranges, point to a recent lowering of soil level of some 7-8 cm. Exposed tree roots tell a similar story (Fig. 14).

Soil creep (or wash) is spectacularly evidenced at some sites (Figs. 15a & 15b) and though only infrequently obvious is nevertheless commonplace. Mostly induced by earth movements and heavy rains, mass movements of material are developed in all climatic zones, including midlatitude arid and semiarid lands (e.g. Shreve, 1968; Watson & Wright, 1969). Some lithologies are especially vul-

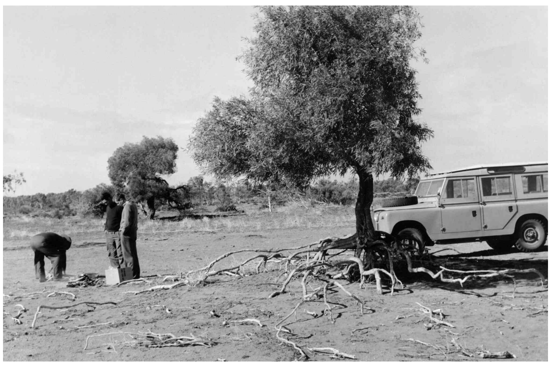


Figure 14. Evidence of lowering of soil level by almost a metre, Lake Torrens plains west of Hawker, South Australia.
Figura 14. Pruebas de un rebajamiento del nivel del suelo de casi un metro en las llanauras del Lago Torrens al Oeste de Hawker, Australia del Sur.

nerable. The Permian glacigene clay and sand exposed in the Inman Valley, in the southern Mt Lofty Ranges, some 70 km south of Adelaide, for example, have been extensively gullied and are also prone to mass movements. Tracks induce landslides both by undercutting the slope above and by concentrating runoff on to the slope below (Figure 15c). The Lochiel Landslip (Fig. 15d) formed during the night of 9-10 August 1974 on Bumbunga Hill, about 170 km north of Adelaide, South Australia (Twidale, 1986), where the land was cleared for mixed farming during the last half of the Nineteenth Century. The Landslip extends some 200 m along the slope and 100 m downslope, is at least 11 m deep at the tension scar, and involved some 250,000 tonnes of quartzitic country rock. The strata dip gently (about 12º) eastwards and downslope. The Landslip was due to heavy winter rains which lubricated thin lenses and beds of interbedded smectitic clay. Cracks continue to form and extend along the slope: the Landslip will eventually be enlarged (Twidale, 1986).

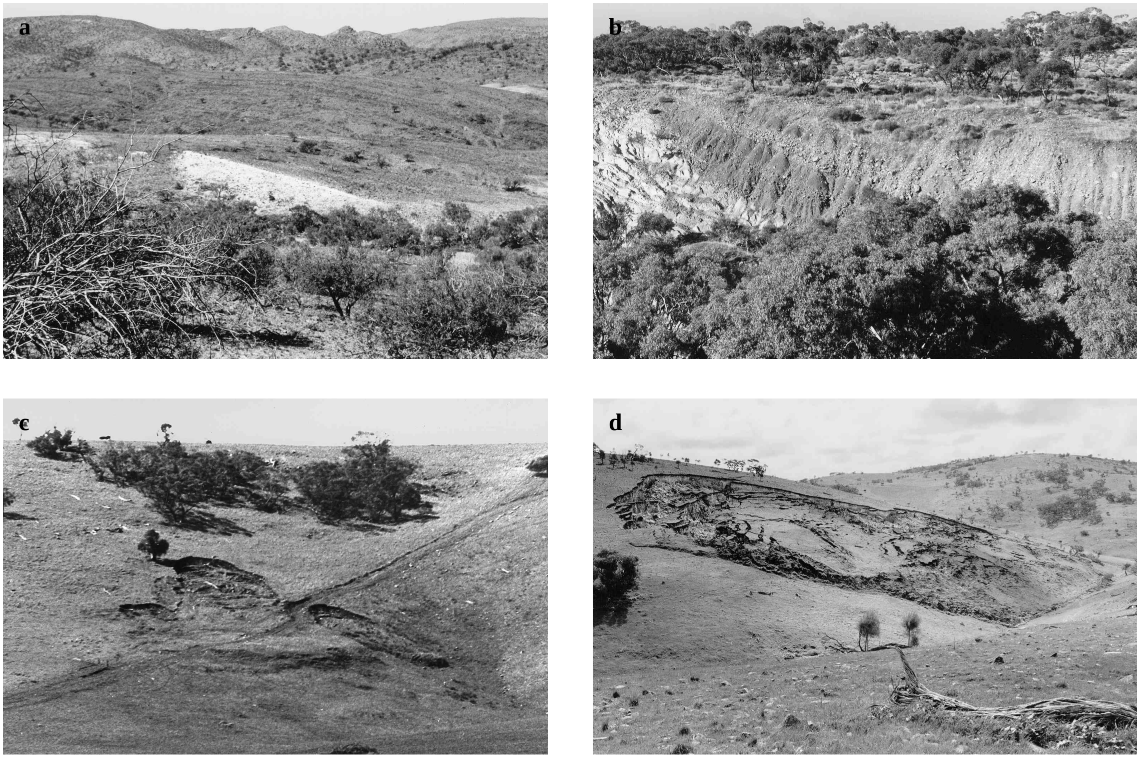


Figure 15. (a) Fragments of milky quartz shed from a vein and creeping or being washed downslope, near Mt Babbage, northern Flinders Ranges, South Australia. (b) Depositional slope exposed in railway cutting in the Pichi Richi Pass, southern Flinders Ranges. Its character is not obvious in its pristine state, but excavation reveals that it is underlain by ten or more metres of colluvium. The coarse strata presumably imply rainstorms and heavy runoff, the fines the more usual wash. (c) Landslides formed adjacent to track on western slope of the Bumbunga Range about 175 km north of Adelaide. The mass movement above the track was induced in the nineteen ‘seventies by the undercutting of the slope, whereas the slide below is due to saturation by runoff from the track. (d) The Lochiel Landslip formed overnight 9-10 August 1974.

Figura 15. (a) Fragmentos de cuarzo lechoso procedentes de una vena movilizados por reptación o por arroyada hacia la parte baja de la vertiente cerca de Mt Babbage, al norte de los Flinders Ranges, Australia del Sur. (b) Ladera deposicional expuesta en un corte del Ferrocarril en el Paso de Pichi Richi, al sur de los Flinders Ranges. Sus características no son tan evidentes en su estado natural pero la excavación revela que recubre 10 o más metros de coluvión. El estrato más grueso presumiblemente implica chaparrones y lluvia muy intensa, los finos corresponden al lavado mas frecuente. (c) Deslizamientos formados en una zona adyacente a la senda en la ladera oeste de la Bumbunga Range aproximadamente a 175 km al Norte de Adelaide (Australia del Sur). El movimiento de masa por encima del sendero fue inducido en los años sesenta del siglo XX por la socavación del talud, mientras que el deslizamiento situado por debajo se debe a la saturación por el agua de escorrentía procedente del sendero. (d) El deslizamiento de Lochiel se formó durante la noche del 9-10 agosto de 1974.

5. Repair and restoration

Turning to possible ameliorative practices, contour ploughing, introduced to prevent rapid runoff, can fail and cause deep gullying. On the other hand, there is some evidence that if left alone, gullies will fill themselves. They are depressions and thus attract water and sediment. This process has filled roadside gullies developed after the sealing of the Quorn-Hawker road across the Willochra Plain (Fig. 8) in the southern Flinders Ranges in the mid ‘sixties, and is true also of some of the gullies related to land clearance by whatever means in both the Flinders and Mt Lofty ranges (e.g. Fig. 6). But unless stabilised by vegetation, the unconsolidated fill is more susceptible to subsequent erosion during and following heavy rains.

In the context of gullies, self-sealing is helped if, as has frequently happened, coarse debris (concrete blocks, large rocks, old refrigerators, etc) is dumped in the gullies. Whatever the motive, such obstacles achieve the same end. Channel roughness is increased and stream velocity and erosional potential are lowered (Rubey, 1952). Given no further catastrophic rains and runoff, such gullies tend to build their floors and vegetation binds the sediment. But this takes time and calls for good luck in the timing of heavy rains.

Figure 16. Drain excavated to evacuate saline groundwater and lower the water table, near Corrigin, southwest of Western Australia.
Figura 16. Drenaje excavado para evacuar el agua subterránea salada y así deprimir el nivel freático, cerca de Corrigin, al sudoeste de Australia Oeste.

Soil salinisation, or White Death, can be combated in the short term by excavating deep drains which take away the saline groundwaters (Fig. 16). In the longer term planting of trees (initially salt-tolerant varieties) lowers the water table. The problem with this solution is that plant growth and lowering of the water table take time, and the farmers who formerly harvested cereals from the paddocks have to earn a living in the meantime.

6. Concluding remarks

Human interference in the ecosystem commonly results in accelerated soil erosion. Viewed globally, such soil erosion is of catastrophic proportions, with immense volumes of soil lost and huge areas diminished or rendered useless for agriculture or for pastoral purposes. This applies equally to technologically-advanced societies, as to the more elementary (or ‘primitive’ or subsistence) types based in intense labour inputs. The arid and semiarid lands are particularly vulnerable (see e.g. Whyte, 1961), for all desert biota, including the living soil, survive precariously. The environmental balance is delicate and is easily disturbed, resulting in catastrophic soil erosion. An anthropogenically-induced epicycle of erosion and deposition is in train. In terms of geological time and events it is minor, but for humans is disastrous. Whatever the environment, the pressure on soil is exacerbated by the ever-increasing use of land suitable for food production, for various construction purposes. Humans are arguably in process of self destructing. The problem is not new, for Virgil (70-19 BC) asked, “What region of the Earth is not full of our calamities?” It is merely now more urgent as human populations increase and their demands on space, soil and water multiply.

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References

McKnight, T.L. (1976). *Friendly Vermin: a Survey of Feral Livestock in Australia*. California University Press, Berkeley, 104 pp.

Meinig, D.W. (1962). *On the Margins of the Good Earth*. Rand McNally, Chicago, 231 pp.

Peel, R.F. (1941). Denudation landforms of the central Libyan Desert. *Journal of Geomorphology*, 4, 3-23.

Ratcliffe, F.N. (1936). Soil drift in the pastoral areas of South Australia. *CSIR Pamphlet,* 64, 84 pp.

Ratcliffe, F.N. (1937). Further observations on soil erosion and sand drift, with special reference to southwest Queensland. *CSIR Pamphlet,* 70, 28 pp.

Ratcliffe, F.N. (1938). *Flying Fox and Drifting Sand*. Chatto & Windus, London, 341 pp.

Rubey, W.W. (1952). Geology and mineral resources of the Hardin and Brussels quadrangles, Illinois. *United States Geological Survey Professional Paper,* 218, 170 pp.

Russell, R.J. (1936). The desert rainfall factor in denudation. *Report of the 15th International Geological Congress,* Part 2, 337-372.

Shreve, R.L. (1968). The Blackhawk Landslide. *Geological Society of America Special Paper*, 108, 47 pp.

Sturt, C. (1849). *Narrative of an Expedition into Central Australia performed under the Authority of Her Majesty's Government during the years 1844, 5, and 6.* 2 volumes, Boone, London.

Twidale, C.R. (1986). The Lochiel Landslip. *Australian Geographer,* 17, 35-39.

Twidale, C.R. (1997). Some recently developed landforms: climatic implications. *Geomorphology,* 19, 349-365

Twidale, C.R. & Bourne, J.A. (1978). Distribution of relic 'lands' or strip fields in South Australia. *Australian Geographer,* 14, 22-29.

Twidale, C.R. & Bourne, J.A. (2002). Sturts Stony Desert, central Australia. *Erdkunde,* 56, 401-418.

Waksman, S.A. (1938). *Humus: Origin, Chemical Composition, and Importance in Nature*. Williams & Wilkens, Baltimore, 526 pp.

Watson, R.A. & Wright, H.E. (1969). The Saidmarreh landslide. *Geological Society ofAmerica Special Paper,* 123, 115-139.

Webb, R.H. (1983). Compaction of desert soils by off-road vehicles. *In: Environmental Effects of Off-Road Vehicles. Impacts and Management in Arid Regions.* (R.H. Webb and H.G. Wilshire, eds.). Springer, New York, 51-79.

Whyte, R.O. (1961). Evolution of land use in south-western Asia. *In: A History of Land Use in Arid Regions.* (L.D. Stamp, ed.). UNESCO, Paris, 57-118.

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